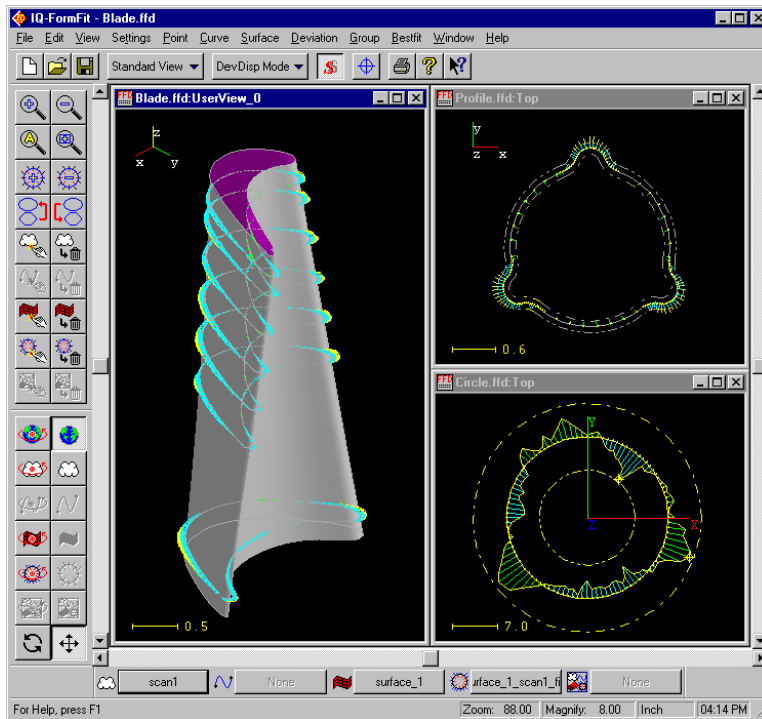

IQ-FormFit™

Version 2.0

User's Guide

Integrated Quality, Inc.

(www.iq-metrology.com)



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Web <http://www.iq-metrology.com>

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Chapter 1 Introduction

1.1 Introduction

IQ-FormFit is a powerful bestfit analysis package that utilizes measurement data and nominal CAD model to analyze the dimensional quality of manufactured parts. It is most powerful in analyzing the accuracy of physical parts having sophisticated composite geometries or irregular surfaces. Such parts can be often found in die/mold industry, automotive industry, aerospace industry, and so on. If you are engaged in manufacturing such complex parts and want to check whether your parts conform to the accuracy requirements of the original CAD design, this program is best suited for you.

IQ-FormFit has a Microsoft Windows based graphics user interface and a powerful graphics engine for manipulating and visualizing inspection data, CAD model, and analysis results. It provides an intuitive mouse-based interactive graphics environment that is easy-to-use. With your CAD model and measurement data, you can quickly start to use the program to perform your analysis tasks.

The major functionality in IQ-FormFit can be divided into the following categories:

- CAD translator for importing CAD files;
- Graphics engine for viewing CAD model, measurement data and analysis results;
- Tolerance evaluation functions for calculating size, position/orientation and form tolerance of standard features from measurement data;
- Best-fit algorithms for matching measurement data to 2D and 3D CAD model.

The CAD translators can interpret CAD data exported in IGES, DXF and VDA file format from major CAD systems such as Pro/Engineer, AutoCAD, CATIA, Unigraphics, I-DEAS and so on.

The graphics engine and the associated viewing tools allow you to get the best visualization result of your CAD model, measurement data and analysis results. You can also use these tools to visually align your measurement data with your CAD model.

The tolerance evaluation functions enable you to calculate the size, position/orientation and form tolerance of both 2D and 3D features including: line, arc/circle, ellipse, parabola, NURBS curve, plane, sphere, cylinder, cone and NURBS surface.

The best-fit algorithm of IQ-FormFit provides a powerful tool to mathematically eliminate the misalignment between the measurement data and your CAD model so that you can obtain the best tolerance evaluation results for your inspection tasks. IQ-FormFit can perform both 2D and 3D bestfit operations depending on your inspection requirements. In 2D best-fit operation, measurement data are optimally matched to 2D curves such as hole-patterns and profile contours. In 3D best-fit operation, measurement data are optimally matched to 3D surfaces such as the CAD model of a die.

1.2 Organization of This User's Guide

This User's Guide explains how to use IQ-FormFit. It contains information describing the functions of IQ-FormFit and examples showing the user how to use each function step by step. The documentation consists of ten chapters and they are organized as follows:

Chapter 1	"Introduction" is an introduction to the IQ-FormFit program. It also provides information about the organization of this documentation, system requirements for running the program, and installation instructions.
Chapter 2	"Graphics User Interface" is an overview of the graphics user interface of IQ-FormFit. It introduces the graphics tools used to interact with the program.
Chapter 3	"Document, View and Related Operations" discusses the document/view structure of the program and the relationship between a document and its views. It also covers document and view related operations such as file input/output and methods for view manipulations.
Chapter 4	"Entity and Common Entity Operations" summarizes the entity classes and entity types handled by IQ-FormFit and the basic operations common to various entities.
Chapter 5	"Operations for Vectors and Transformations" discusses how to create vectors and transformations.
Chapter 6	"Operations for Point Clouds" covers special operations for point cloud entities.
Chapter 7	"Operations for Curves" covers special operations for curve entities.
Chapter 8	"Operations for Surfaces" covers special operations for surface entities.
Chapter 9	"Operations for Deviation Clouds" covers special operations for deviation cloud entities.
Chapter 10	"Bestfit Analysis" describes the issues and procedures related to calculating normal deviation from measurement points to CAD model and bestfitting measurement points to CAD model.
Appendix A	ASCII data file format and sample data files
Appendix B	ASCII deviation file format and sample files
Appendix C	IQ feature list file format and sample files

1.3 Conventions

To clarify the discussion of various topics, the following conventions are used in this documentation:

"Text"	Text in quotation marks are used to separate special text and terms from other text (for example, "Introduction")
Boldface	Boldfaced text are used for menu, submenu and menu options. A slash(/) will appear in front of the main menu or the root menu. A parent menu and its submenu are separated by a slash(/) (for example, /File/Open)
" Boldface "	Boldfaced text in quotation marks are used for disk labels (for example, " Installation Disk #1 ")
[Boldface]	Boldfaced text in square brackets are used for push button names (for example, the [OK] button).
< Boldface >	Boldfaced text in angle brackets are used for key names of the keyboard (for example, < Shift > key, < ESC > key)
<i>Italic</i>	Italic text are used for title of dialog boxes (for example, the <i>Set New Zoom Factor</i> dialog box)
" <i>Italic</i> "	Italic text in quotation marks are used for particular areas or fields of dialog boxes (for example, the " <i>New Zoom Factor</i> " box on the <i>Set New Zoom Factor</i> dialog box)
<i>Italic</i>	Boldfaced italic text are used for important notes and file names (for example, <i>readme.txt</i>).
<u><i>Italic</i></u>	Underscored boldfaced italic text are used for new definitions (for example, <u><i>Working Plane</i></u>)
"A:Setup"	Information the user enters from the key board appears "between two quotation marks in courier font like this". Type everything between the two quotation marks exactly as shown.

Screen shots will also be used throughout the documentation to illustrate the operations and functionalities of the program.

1.4 System Requirements

Currently, IQ-FormFit is only available for IBM PC-compatible computers running Microsoft Windows 95/98, Windows NT 4.0 or Windows 2000.

For better performance, it is recommended that the system should have sufficient memory and graphics resources.

1.5 Installation Guide.

IQ-FormFit comes with a hardware protection key which should be attached to the parallel port of the computer. If a printer cable is connected to the parallel port, you can first attach the key to the parallel port and then attach the printer cable to the key. The hardware key will be transparent to the printer.

If you install IQ-FormFit on Windows NT 4.0 system, you must log on as administrator in order for the installation program to install device drivers for the hardware protection key.

Installation Procedure:

- a. Insert the diskette labeled "**IQ-FormFit Installation Disk #1**" into A drive of your computer;
- b. Select **Run** from the **Start** menu, a *Run* dialog box will pop up;
- c. In the "*Open*" box on the *Run* dialog box, type "A:SETUP", then click the **[OK]** button to start installation.
- d. Reboot your computer to let the installed device drivers to take effect.

Chapter 2 Graphics User Interface

2.1 Introduction

IQ-FormFit has a Microsoft Windows based intuitive graphics environment that is easy-to-use. The figure below shows the outline of the graphics user interface of IQ-FormFit. It has a main frame window which holds view windows, a main menu bar, a tool bar, a tool box, a control box, three scroll bars and an active entity bar.

All operations of the program can be executed through the menu. Some of the commonly used functions are implemented on the tool bar, the tool box, the control box and the active entity bar so that they can be accessed quickly by a single click on the corresponding buttons.

The scroll bars are used for view manipulation as well as entity transformation.

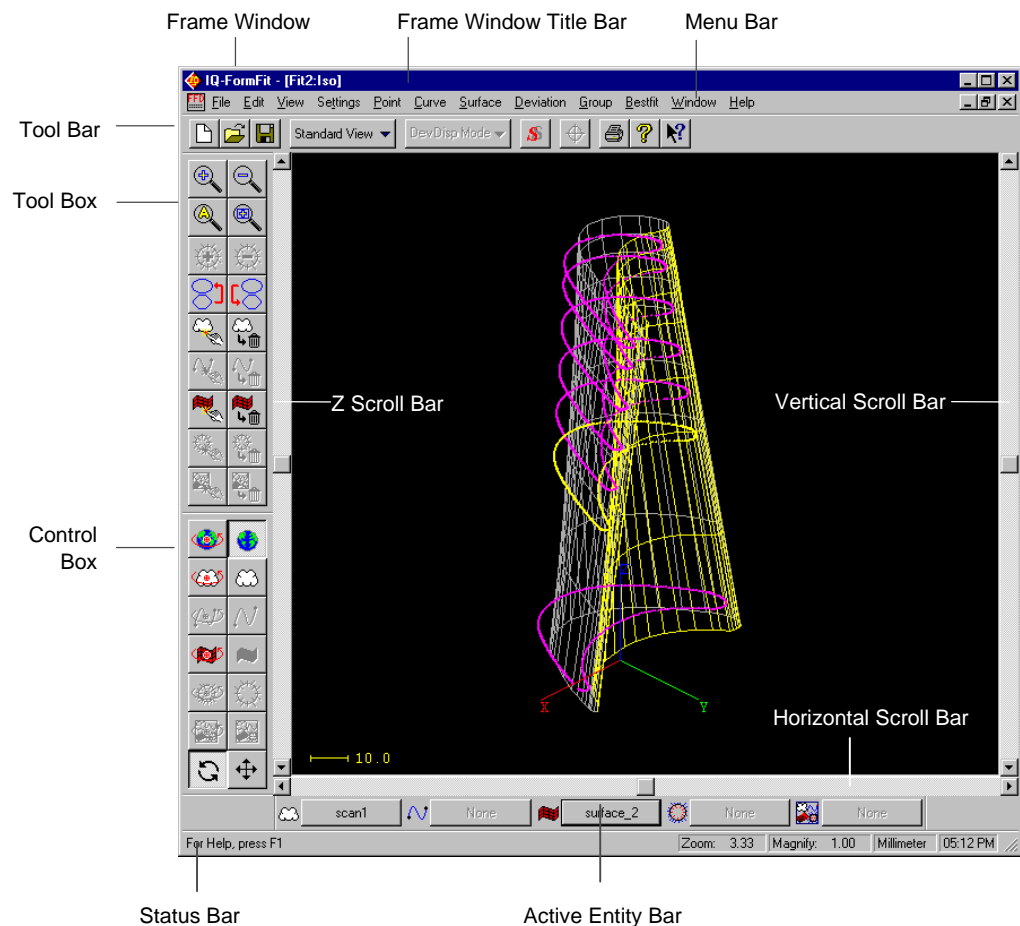


Figure 2.1 Graphics User Interface Overview

2.2 The Menus

The main menu appears under the title bar of the frame window (Figure 2.1). All functional and commands of IQ-FormFit can be accessed through the menus. A menu can be activated by pointing the mouse cursor to the menu name and clicking the left mouse button. It can also be activated by holding down the **<Alt>** key and pressing the underscored letter of the menu name. Submenus of a popup menu can be selected by clicking the left mouse button on the submenu item, or typing the underscored letter of the submenu, or using the arrow keys to select the submenu item and then pressing the **<Enter>** key to activate the selected submenu.

2.3 The Tool Bar

The horizontal window appearing under the main menu bar is the tool bar (Figures 2.1, 2.2). It contains several buttons as shown in Figure 2.2. The user can click a button on the tool bar to carry out the associated command. The commands associated with the tool bar buttons will be discussed in the subsequent chapters.

When the mouse cursor is pointed to a button on the tool bar, a yellow message box will appear to briefly describe the function associated with the button. The yellow message box is called tool tip box.

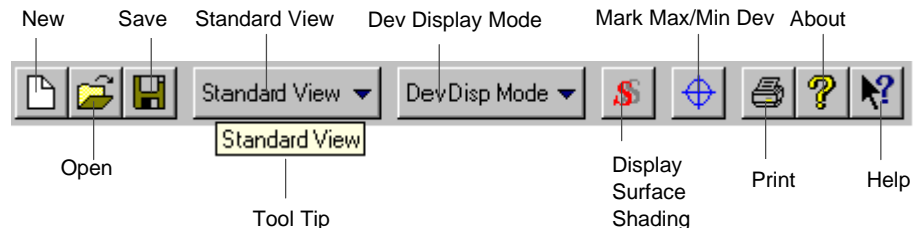


Figure 2.2 The Tool Bar

2.4 The Tool Box

The tool box is the vertical window on the left of the view window and under the tool bar (Figures 2.1, 2.3). It contains 18 buttons which implement the most commonly used commands of IQ-FormFit. Although these commands can be accessed through the menu, the tool box provides a more efficient way to access these commands with a single mouse click on the corresponding buttons. When pointing the mouse cursor to a button, a tool tip box will remind the user of the commands associated with the button. The commands associated with the tool box buttons will be discussed in the subsequent chapters.

In Figure 2.1, the tool box is docked to the left of the view window. The user can make the tool box float. To make the tool box float, point the mouse cursor to the marginal region of the tool box, then hold down the left mouse button and drag the tool box out of its docked position. When the tool box is floating, it will have a thin title bar with a caption of "Tool Box" as shown in Figure 2.4. By moving the thin title bar of the floating tool box, the tool box can be docked back to the left of the view window. It can also be docked to the right of the view window.

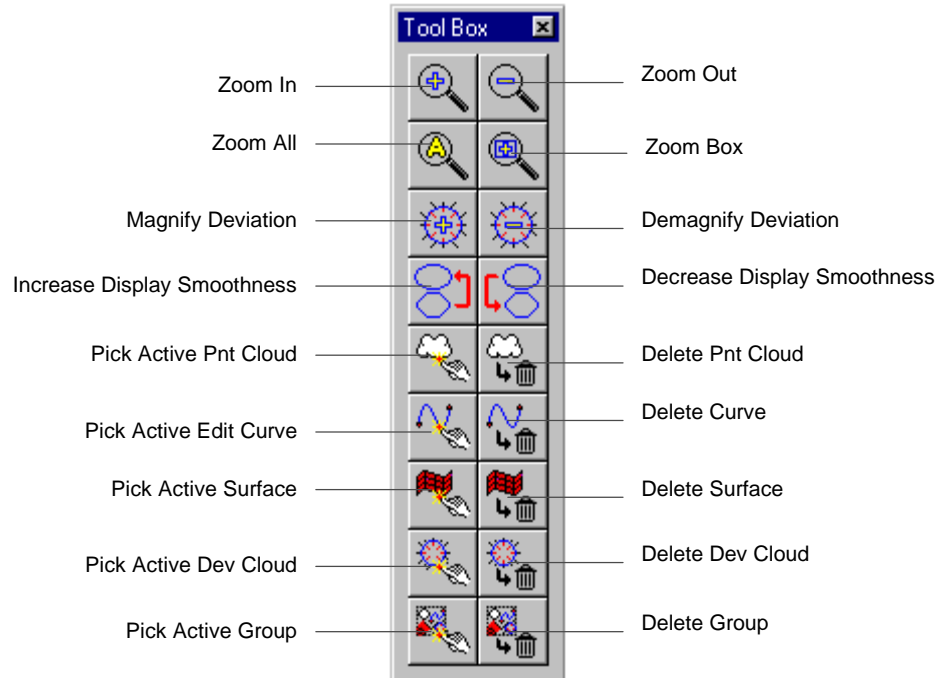


Figure 2.3 The Tool Box

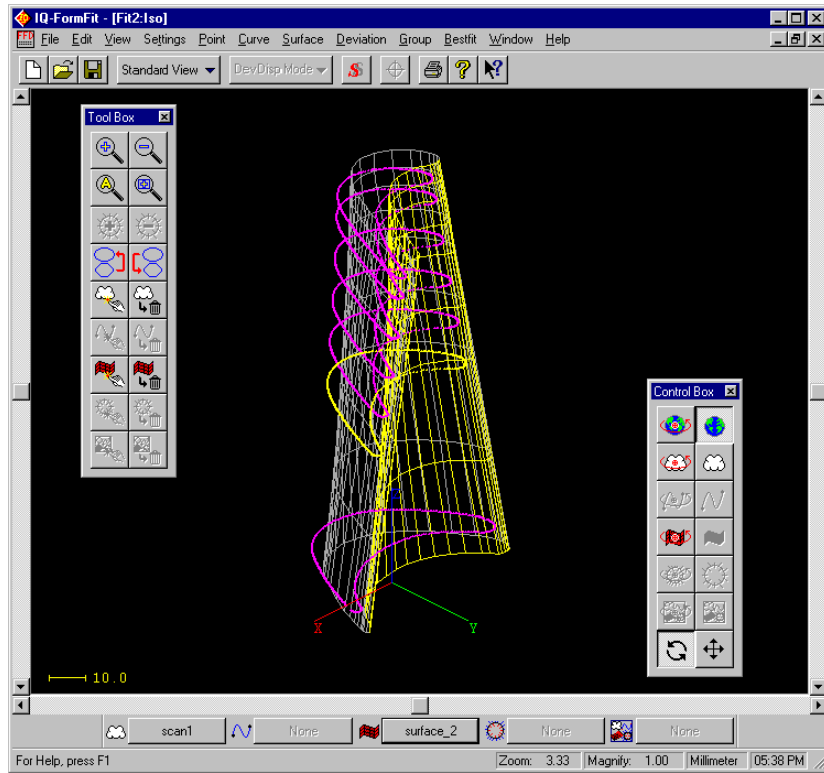


Figure 2.4 Floating Tool Box and Control Box

2.5 The Control Box

See section 3.3.3 on Pivot Point of Rotation

The control box is shown in Figure 2.5. It has six buttons which are used to set the pivot point of rotation operation. Another eight buttons are used to change the operation mode of the three scroll bars. The commands associated with the control box buttons will be discussed in the subsequent chapters. The control box can also be floating as shown in Figure 2.4 or docked to the left or right of the view window.

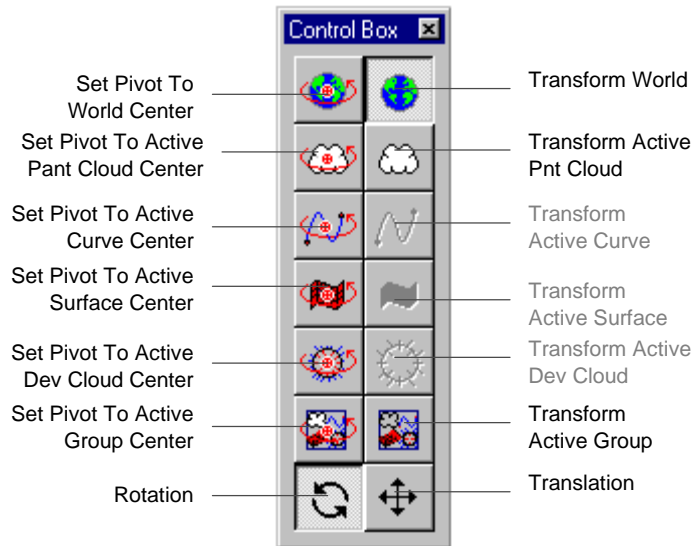


Figure 2.5 The Control Box

2.6 The Active Entity Bar

The active entity bar is shown in Figure 2.6. It displays the names of the active point cloud, the active curve, the active surface, the active deviation cloud and the active group. The commands associated with the active entity bar buttons will be discussed in chapter 4 of this documentation. The active entity bar can be either floating or docked under the view window.

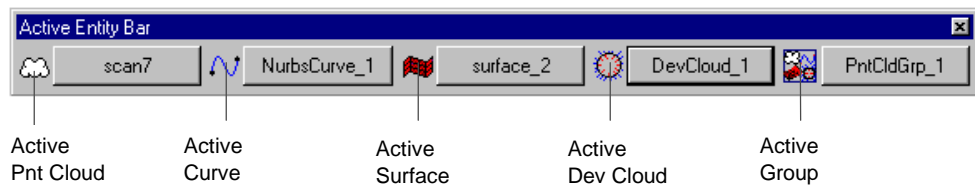


Figure 2.6 The Active Entity Bar

2.7 The Scroll Bars

See chapters 3 & 4 for the details about view manipulation and active entity transformation using scroll bars

As shown in Figure 2.1, IQ-FormFit has three scrollbars. They are called the “Horizontal Scroll Bar”, the “Vertical Scroll Bar” and the “Z Scroll Bar”. These scroll bars are used for view manipulation as well as active entity transformation, depending on the mode under which they are working.

2.8 The Status Bar

See Chapter 3 about active database and active view

The status bar is the horizontal window that appears at the bottom of the frame window (Figures 2.1, 2.7). The status bar has five panes. The left pane is called the message pane and is used to display system messages. When a tool tip of a command appears on the screen, a more detailed description of the command will be displayed in the message pane. The zoom factor pane shows the zoom factor of the current active view. The magnification factor pane shows the magnification factor used to magnify the geometric deviation vectors in the active view. The working unit pane shows the current working unit of the active database. The time pane shows the current time.



Figure 2.7 The Status Bar

2.9 Configuring Graphics Tools

The user can change the configuration of the graphics tools by selecting menu **View/Tool Configuration** to bring up the *Tool Configuration* dialog box as shown in Figure 2.8. Using this dialog box, the user can toggle the show/hide status for the tool bar, the tool box, the control box, the active entity bar and the status bar. The user can also change the layout style of the tool box and the control box.

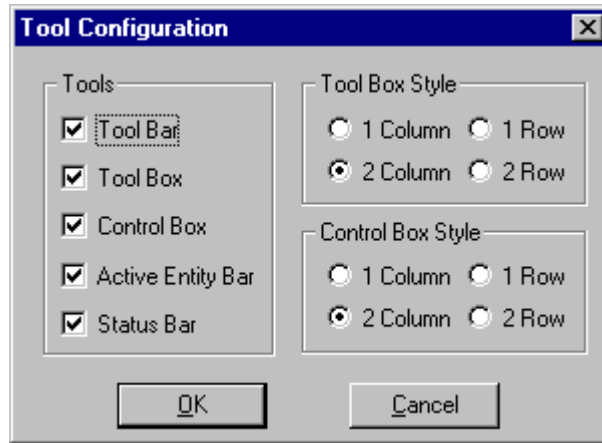


Figure 2.8 The *Tool Configuration* Dialog Box

Chapter 3 Database, View and Related Operations

3.1 Introduction

The database of IQ-FormFit is like a storage room that stores the user data. A view of a database is like a window opened on the wall of the storage room. A database can be saved to or loaded from a disk file. Through the view window, the user can see the contents of the database and apply operation tools to manipulate the data in the database.

3.1.1 Multiple Database Support

See section 3.2.2 on how to open database files

IQ-FormFit can open more than one database at the same time. For example, as shown in figure 3.1, the program can have one database file named "PROFILE.FFD". At the same time, the program can have another database file called "BLADE.FFD", and so on. However, only one database is active at a time, and all operations are exerted on the active database. The title bar of the active database's window is highlighted, and the name of the active database is displayed on the title bar of the program's frame window. By pointing the mouse cursor to the desired window and clicking the left mouse button, the user can switch the active database to work on. The active database can also be switched by selecting the database name listed under the **Window** menu.

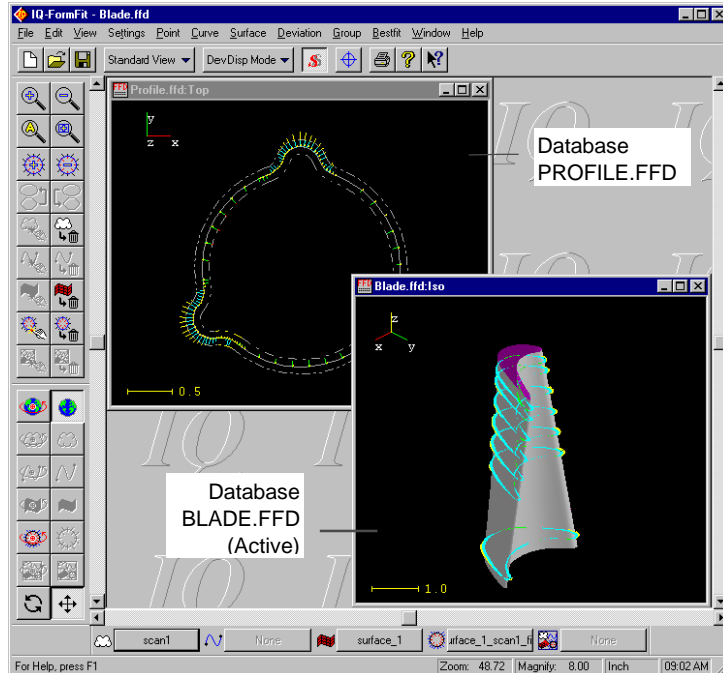


Figure 3.1 Multiple Database Support(MDI)

3.1.2 Multiple Views of a Database

For each database, it can have multiple views, as shown in Figure 3.2. However, at any time only one view can be active. The title bar of the active view is highlighted. All view operations are directed toward the current active view. To select a view to work on, the user can click the left mouse button while the mouse cursor is over the view window. Each view can have different view perspectives such as view angle, zoom factor and deviation magnification factor. This multiple view feature can be used to view different side of a part at the same time. It can also be used to zoom in a particular region to get more detailed view of that region. The names of each view window will be listed under the **Window** menu, so the user can also switch the active view by selecting the view window name listed under the **Window** menu.

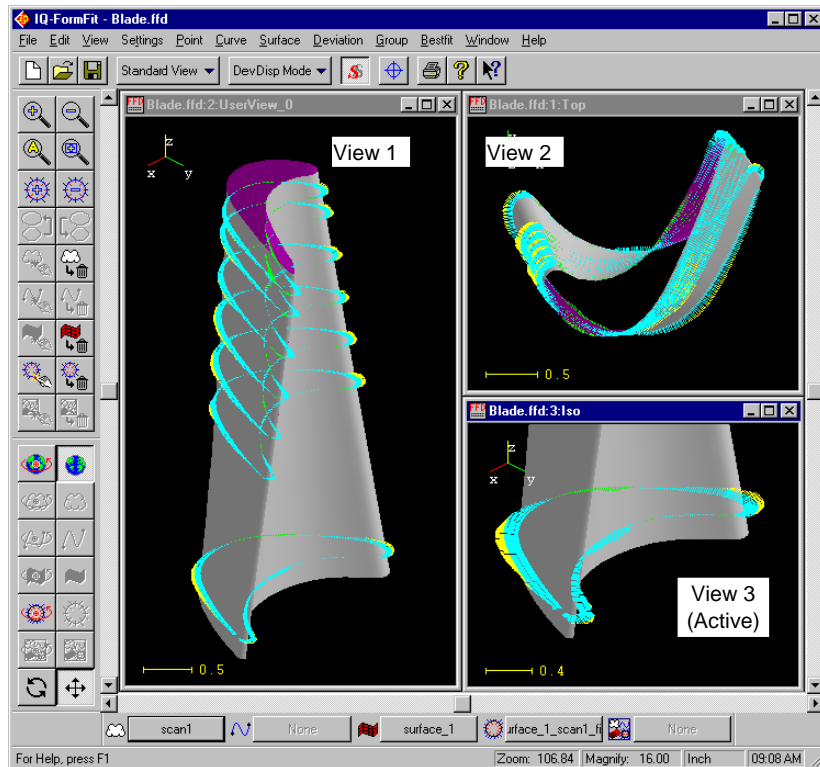


Figure 3.2 Multiple Views of a Database

3.1.3 Database Content

Entity is the basic data unit of an IQ-FormFit database. The entities handled by IQ-FormFit include both geometric entities and non-geometric entities. The classes and types of geometric entities supported by IQ-FormFit are listed in Table 3.1. The two non-geometric entities supported by IQ-FormFit are vector entity and transformation entity.

The group entity of IQ-FormFit can be a group of point clouds, a group of curves, a group of surfaces, or a group of deviation clouds. A group entity is formed by grouping geometric entities together through the grouping operation described chapter 4 of this User's Guide.

Table 3.1 Geometric Entity Classes and Types

Entity Class	Entity Type
Point Cloud	2D and 3D Point Cloud
Curve	Line, Arc, Circle, Ellipse, Parabola, Hyperbola, Parametric Spline Curve, NURBS Curve, Composite Curve
Surface	Plane, Sphere, Cylinder, Cone, Parametric Spline Surface, NURBS Surface, Surface of Revolution, Tabulated Surface, Ruled Surface
Deviation Cloud	Deviation Cloud
Group	Point Cloud Group, Curve Group, Surface Group, Deviation Cloud Group

3.1.4 Database Working Unit

Each database has a working unit shown on the working unit pane of the status bar (Figure 2.7). IQ-FormFit supports 11 different working units: “Inch”, “Millimeter”, “Foot”, “Mile”, “Meter”, “Kilometer”, “Mil”(i.e. 0.001 inch), “Micron”, “Centimeter”, “Microinch” and “Yard”. When a new empty database is created, the default working unit is millimeter. The user can change the working unit of a database to any of the supported units by selecting menu **/Settings/System Unit /Inch....Yard**.

See section 3.2.2 on how to open a new database

When an IGES file is read into a database, the program will automatically determine the unit of the CAD data in the IGES file. When reading other supported data files into a database, a *Specify Data Unit* dialog box will pop up to let the user specify the unit of the data file, and the input data will be converted to the working unit of the database. For example, if the input data is measured in millimeter, the user should select millimeter from the *Specify Data Unit* dialog box. If the working unit of the database is inch, then the input data will be converted into inch when it is read into the database.

See section 3.2.1 for supported file types

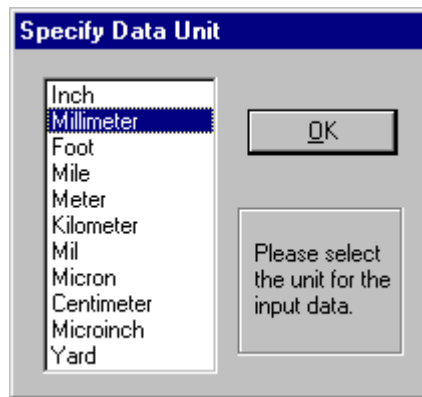





Figure 3.3 The *Specify Data Unit* Dialog Box

3.2 File Types and Operations

File operations are executed by selecting the **/File** menu and its submenus or using the first three buttons(the **[New]** button , the **[Open]** button , and the **[Save]** button ) on the tool bar. All data files are read in and written out through the **/File** menu or the three file operation buttons.

3.2.1 File Types

IQ-FormFit supports various data file formats. These data file formats include “FormFit Database File”, “ASCII Data File”, “IGES File”, “DXF File”, “VDA Data File”, “Hymarc Data File”, “IQ Deviation File”, and “IQ Feature List File”. IQ-FormFit will also support any user specific file format based on requirement. Please contact the development team for further information.

3.2.1.1 FormFit Database File

The FormFit database file is a proprietary binary data file format. When a database is saved into a file, this file format is used. The default extension for this file format is “ffd” or “FFD”.

3.2.1.2 ASCII Data File

See Appendix A for the complete description of this file format and sample data files

The ASCII data file format is a text based file format. The default extension for this file format is “dat” or “DAT”. This file format supports comment lines, 2D and 3D data points, multiple point clouds in one file, and different delimiting characters. IQ-FormFit can read ASCII data files exported from most other measuring systems without modification. The simplest example of an ASCII data file is a list of xyz-triplets as follows:

$$\begin{array}{ccc} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \dots\dots\dots & & \\ x_n & y_n & z_n \end{array}$$

where x , y , and z are the coordinates of each data point. Please refer to Appendix A for more information on the ASCII data file format supported by IQ-FormFit.

3.2.1.3 IGES File

The IGES file format is used to import CAD data generated from CAD systems such as Pro/E, CATIA, etc. The default extension of this file format is “igs” or “IGS”. IQ-FormFit supports all commonly used geometric entities specified in IGES specification Version 5.0. These commonly used geometric entities are listed in the following table.

Table 3.2 IGES Entity Types Supported by IQ-FormFit

IGES Entity Type #	Entity Type	IGES Entity Type #	Entity Type
100	Circular Arc	122	Tabulated Cylinder
102	Composite Curve	124	Transformation Matrix
104	Conic Arc	126	Rational B-Spline Curve
106	Copious Data	128	Rational B-Spline Surface
108	Plane	130	Offset Curve
110	Line	140	Offset Surface
112	Parametric Spline Curve	141	Boundary
114	Parametric Spline Surface	142	Curve on a Parametric Surface
116	Point	143	Bounded Surface
118	Ruled Surface	144	Trimmed Parametric Surface
120	Surface of Revolution		

3.2.1.4 DXF File

The DXF file format is used to import CAD data generated from CAD systems such as AutoCAD. The default extension of this file format is "dxf" or "DXF". IQ-FormFit supports the commonly used geometric entities such as line, arc and circle specified in AutoDesk's DXF specification..

3.2.1.5 VDA Data File

The VDA file format is used by IQ-FormFit to import measurement data exported by measurement systems such as Zeiss's CMM. The default extension of this file format is "vda" or "VDA". VDA entities supported by IQ-FormFit include POINT, PSET(point set), MDI(point vector set).

3.2.1.6 Hymarc Data File

The Hymarc data file format is used by IQ-FormFit to import scanning data from Hymarc's laser scanning systems. The Hymarc data file is a compressed proprietary binary file format. The default extension of this file format is "dat" or "DAT".

3.2.1.7 IQ Deviation File

See Appendix B for the complete description of this file format and sample data files

The IQ deviation file format is a text based file format. The default extension for this file format is "dev" or "DEV". This file format supports comment lines, multiple deviation clouds in one file, and different delimiting characters. A simple example of this file format is show below:

$$\begin{array}{cccccc}
 x_1 & y_1 & z_1 & i_1 & j_1 & k_1 & m_1 \\
 x_2 & y_2 & z_2 & i_2 & j_2 & k_2 & m_2 \\
 \dots & \dots & \dots & \dots & \dots & \dots & \dots \\
 x_n & y_n & z_n & i_n & j_n & k_n & m_n
 \end{array}$$

where x , y , and z are the coordinates of the starting point of a deviation vector. i , j , and k are the direction numbers of the deviation vector, and m is the magnitude of the deviation vector. Please refer to Appendix B for more information.


3.2.1.8 IQ Feature List File

See Appendix C for the complete description of this file format and sample data files


The IQ feature list file is a text based file format for user to create and import 2D and 3D standard features as well as NURBS curves and surfaces. This file format can also be used as a simple interface between IQ-FormFit and other systems which does not have IGES exporting capability.

3.2.2 Creating New Database

See section 3.2.5 on how to change database file name

To create a new empty database, select menu **/File/New** or simply click the **[New]** button  on the tool bar. When a new empty database is created, a default database file name is given. The default database file name can be changed when the file is saved to a disk.

3.2.3 Opening Previously Saved FormFit Database File

If you have saved a database into a file, you can open the saved database file by selecting menu **/File/Open** or simply click the **[Open]** button  on the tool bar. An *Open File* dialog box as shown in Figure 3.4 will pop up. This *Open File* dialog box is almost the same as the default Windows' *Open File* dialog box except that it has an "Open As" drop-down list which is used to specify the format of the file to be opened. When the *Open File* dialog box pops up, the default file type is "FormFit Database Files (*.FFD)" and all files with "FFD" extension in the current directory will be listed. The default selection of the "Open As" drop-down list is "FormFit Database File". To open a previously saved FormFit Database File, point the mouse cursor to the file to be opened, then click the file name and the **[Open]** button.

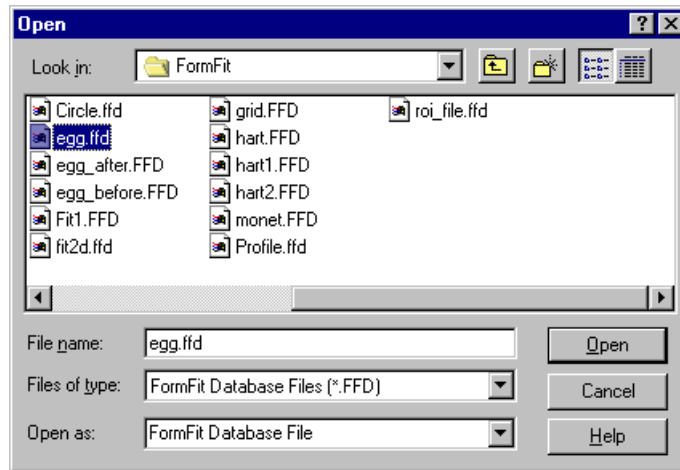



Figure 3.4 The *Open File* Dialog Box

3.2.4 Reading Other Data Files

Other data files with any of the supported file formats can be read into the current active database. To read a file which is in one of the supported file formats, select menu **/File/Open** or click the **[Open]** button  on the tool bar to bring up the *Open*

File dialog box as shown in Figure 3.4. Once the *Open File* dialog box pops up, you can select the appropriate file extension from the “Files of Type” drop-down list. When a file type is selected, the “Open As” drop-down list will change to the corresponding file format. If the “Open As” drop-down list shows a different file format than the one you want, you should select the correct file format from the “Open As” drop-down list to read a desired data file into the current active database for analysis and operations. Figure 3.5 shows how to read an IGES file.

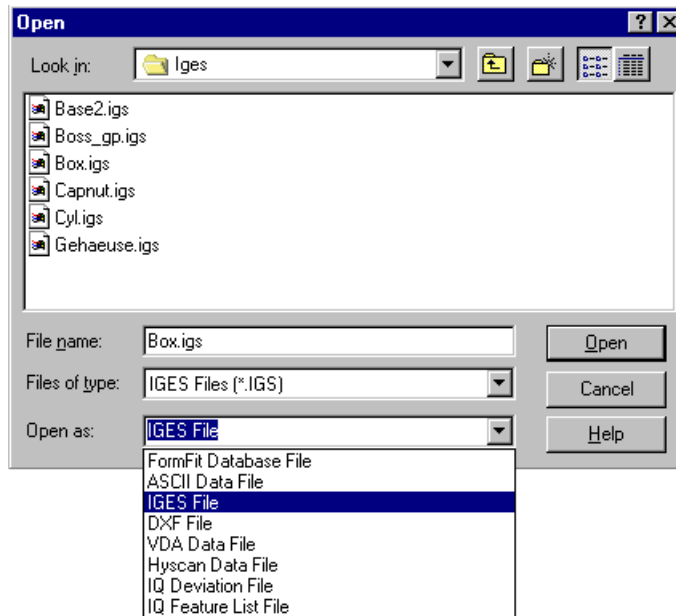



Figure 3.5 Reading IGES File

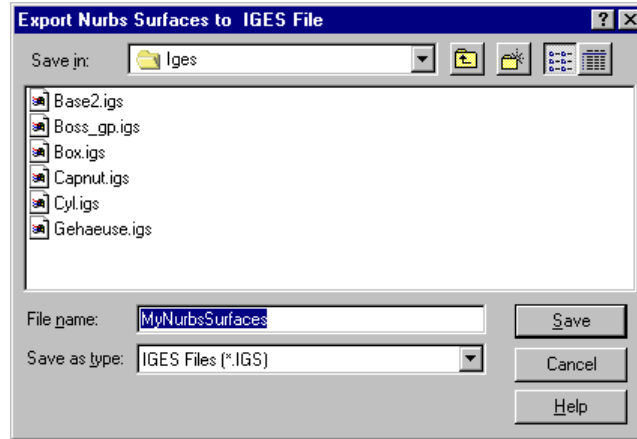
3.2.5 Saving FormFit Database File

To save the content of the current active database into a file, select menu **/File/Save** or simply click the **[Save]** button  on the tool bar. To save the current database into a different file name, select menu **/File/Save As** to bring up the *Save As* dialog box. The user can type a new file name in the “File Name” box and click the **[Save]** button to save the file into the desired file name. You will notice that the caption of the database window being saved will also be changed. Therefore, using the **Save As** option of the **/File** menu, you can also change the name of a database. The default extension for FormFit Database File is “FFD” or “ffd”.

3.2.6 Exporting NURBS Surface to IGES File

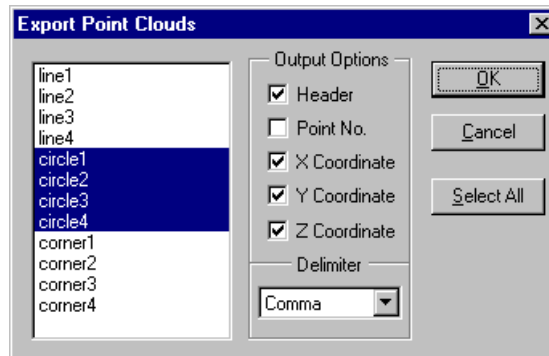
See section 8.2.5 on fitting NURBS surface from measurement data

NURBS surfaces fitted from measurement points can be exported to an IGES file for other uses. To export NURBS surfaces in a database to an IGES file, the user can select menu **/File/Export/Nurbs Surface** to bring up the *Export Nurbs Surface to IGES File* dialog box as shown in Figure 3.6. When the user type a name for the export file, IQ-FormFit will convert all NURBS surfaces in the database to IGES format and export them to the IGES file. The default file extension for IGES file is “IGS”. IQ-FormFit does not export boundary information when exporting NURBS surfaces to IGES file.

Figure 3.6 The *Export Nurbs Surfaces to IGES File* Dialog Box

3.2.7 Exporting Point Cloud to ASCII File

Point clouds that are either imported into IQ-FormFit or generated from curves/surfaces inside IQ-FormFit can be exported to an ASCII text file for other uses. To export the point clouds to an ASCII text file, the user can select menu **/File/Export/Pnt Cloud** to bring up the *Export Point Clouds* dialog box, as shown in Figure 3.7.

Figure 3.7 The *Export Point Clouds* Dialog Box

See Appendix A for a complete description of IQ-FormFit ASCII data file format

From this dialog box, the user can select point clouds to export and check the exporting options. The exporting options include information to export and the delimiting character. To make the exported text based data file to be readable by IQ-FormFit, the user should uncheck the “*Point No.*” check box, and check all three of the “*X Coordinate*”, “*Y Coordinate*” and “*Z Coordinate*” check boxes. IQ-FormFit can read the exported data file with or without the header. When it reads the header of a data file, it just treats the header lines as comment lines.

When the **[OK]** button on the *Export Point Clouds* dialog box is clicked, the *Export ASCII Data File* dialog box, similar to the *Export Nurbs Surfaces to IGES File* dialog box shown in Figure 3.6, will pop up. The user can use this dialog box to specify a name for the output file. The default file extension for the exported data file is “*DAT*” or “*dat*”.

3.2.8 Exporting Deviation Cloud to ASCII File

See section 9.6.5 on Deviation Information View

Deviation clouds that are obtained from bestfit analysis operations can be exported into an ASCII text file for other uses. To export deviation clouds to an ASCII deviation file, the user can select menu **/File/Export/Dev Cloud** when the active view is the graphics view, or menu **/File/Export** when the active view is the deviation information view. When either one is selected, the *Export Deviation Clouds* dialog box, as shown in Figure 3.8, will pop up.

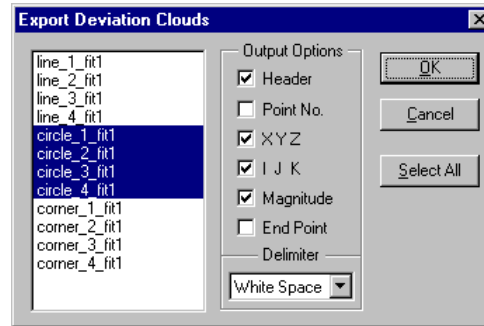


Figure 3.8 The *Export Deviation Clouds* Dialog Box

See Appendix B for a complete description of IQ-FormFit ASCII deviation file format

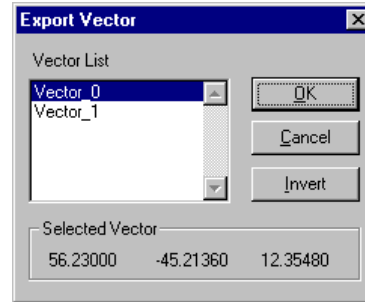
From this dialog box, the user can select the deviation clouds to export and check the exporting options. The exporting options include information to export and the delimiting character. The “Header” option is for comment lines. The “Point No.” option is for exporting sequence number. The “XYZ” option is for exporting the starting point of deviation. The “IJK” option is for exporting direction vector. The “Magnitude” option is for exporting magnitude. The “End Point” option is for exporting end point of deviation.

To make the exported text based deviation file to be readable by IQ-FormFit, the “Point No.” check box and the “End Point” check box should not be checked, and the “XYZ”, “IJK” and “Magnitude” check boxes should be checked. IQ-FormFit can read the exported deviation file with or without the header. When it reads the header of a deviation file, the header lines are treated as comment lines.

When the **[OK]** button on the *Export Deviation Clouds* dialog box is clicked, the *Export ASCII Deviation File* dialog box, similar to the *Export Nurbs Surfaces to IGES File* dialog box shown in Figure 3.6, will pop up. The user can use this dialog box to specify the name for the output file. The default file extension for exported deviation file is “DEV”.

3.2.9 Exporting Vector to ASCII File

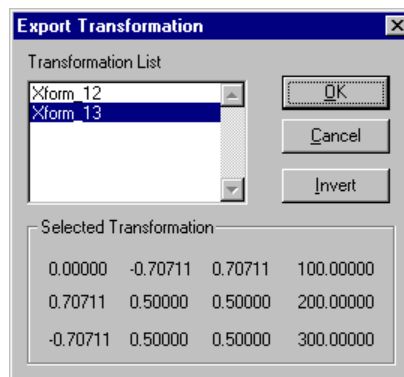
Vectors that are created by the user or recorded from the results of bestfit analysis operations can be exported into a text file for other uses. To export a vector to a text file, select menu **/File/Export/Vector** to bring up the *Export Vector* dialog box as shown in Figure 3.9. From this dialog box, the user can select one vector to export to a file. The components of the selected vector will be displayed in the “Selected Vector” box. The user can click the **[Invert]** button to flip the signs of the exported vector components. However, the actual sign of the vector in the database will not be altered.

Figure 3.9 The *Export Vector* Dialog Box

When the **[OK]** button on the *Export Vector* dialog box is clicked, the *Export Vector To File* dialog box, similar to the *Export Nurbs Surfaces to IGES File* dialog box shown in Figure 3.6, will pop up. The user can use this dialog box to specify the name for the output file. The default extension for the exported vector file is “txt”.

3.2.10 Exporting Transformation to ASCII File

Transformations that are created by the user or recorded from the results of bestfit analysis operations can be exported into a text file for other uses such as to re-adjust the alignment of an inspection part on a CMM. To export a transformation to a file, select menu **/File/Export/Xform** to bring up the *Export Transformation* dialog box as shown in Figure 3.10. From this dialog box, the user can select one transformation to export to a file. The selected transformation is displayed in the “*Selected Transformation*” box. The user can click the **[Invert]** button to get the inverse of the transformation to be exported.

Figure 3.10 The *Export Transformation* Dialog Box


When the **[OK]** button on the *Export Transformation* dialog box is clicked, the *Export Transformation To File* dialog box, similar to the *Export Nurbs Surfaces to IGES File* dialog box shown in Figure 3.6, will pop up. The user can use this dialog box to specify the name for the output file. The default extension for the exported transformation file is “txt”.


3.3 View Operations


View operations are used to change the aspects of a view. View operations include zooming, translation/rotation of view, setting pivot point for view rotation, selecting preprogrammed standard views, and save/recall user views.

3.3.1 Zooming


Zooming functions enable the user to get a more detailed view of a particular region or to make all visible geometric entities in a database fit into a view window. There are five zooming functions available. These functions and their access methods are summarized as follows.

- Zoom In
 - ⇒ Menu access: **/View/Zoom/Zoom In**
 - ⇒ Button access: **[Zoom In]** button  on the tool box
 - ⇒ Function: Changing the zoom factor of the current active view window by a factor of 2

- Zoom Out
 - ⇒ Menu access: **/View/Zoom/Zoom Out**
 - ⇒ Button access: **[Zoom Out]** button  on the tool box
 - ⇒ Function: Changing the zoom factor of the current active view window by a factor of 1/2

- Zoom Box
 - ⇒ Menu access: **/View/Zoom/Zoom Box**
 - ⇒ Button access: **[Zoom Box]** button  on the tool box
 - ⇒ Function: Setting the mouse to “Zoom Box Mode”

Under this mode, the user can point the mouse cursor to the top left corner of the region of interest, then hold down the left mouse button and move the mouse toward the bottom right corner of the region of interest. A rubber band rectangle will appear on the current active view window. When the mouse button is released, the region inside the rubber band rectangle will be zoomed in to fit into the view window. When zoom box mode is set, the **[Zoom Box]** button on the tool box will be depressed until the zoom box operation is finished or any key is pressed.

- Zoom All
 - ⇒ Menu access: **/View/Zoom/Zoom All**
 - ⇒ Button access: **[Zoom All]** button  on the tool box
 - ⇒ Function: Calculating a zoom factor such that all the geometric entities of the database fit into the current active view window

- Zoom Factor
 - ⇒ Menu access: **/View/Zoom/Zoom Factor**
 - ⇒ Button access: None
 - ⇒ Function: Bringing up the *Set View Zoom Factor* dialog box as shown in Figure 3.11 for the user to change the zoom factor

Initially, the current zoom factor is shown in the “*New Factor*” box. To change the zoom factor, type the desired zoom factor in the “*New Factor*” box and then hit the <Enter> key or click the [OK] button. If the [Cancel] button is clicked, the new zoom factor is discarded and the current zoom factor will remain unchanged.

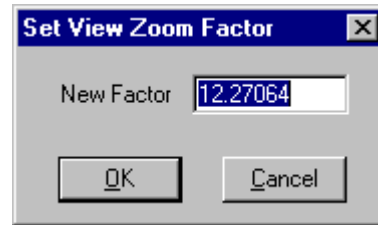


Figure 3.11 The *Set View Zoom Factor* Dialog Box

3.3.2 View Manipulation Using Scroll Bars

The user can use the three scroll bars in combination with the scroll bar mode control buttons on the control box to change the view angles of the current active view. To understand operations that change the view angles, it is necessary to introduce the view coordinate system and the world coordinate system.

As shown in Figure 3.12, the ***View Coordinate System*** is a Cartesian coordinate system defined at the center of the view window with its x-axis pointing to the right, the y-axis pointing upward, and the z-axis perpendicular to the screen and pointing out from the screen plane toward the user. When the view window is re-sized or moved, the origin of the view coordinate system is always attached to the center of the view window, and the orientation of the view coordinate system is always fixed as shown in Figure 3.12. View coordinate system is not displayed in the view window.

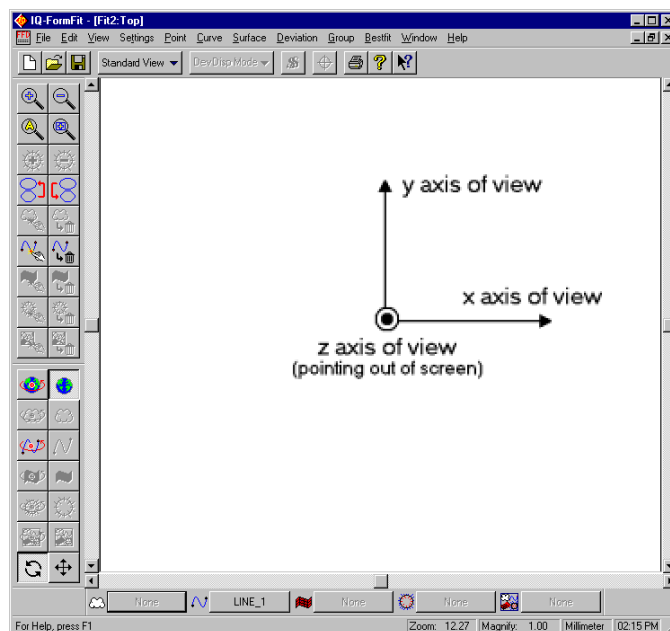


Figure 3.12 Definition of View Coordinate System

The **World Coordinate System** is the reference coordinate system for all the geometric entities contained in a database. The world coordinate system can be displayed or hidden by selecting menu **/View/Axes/World Axes**. The user can also show/hide the orientation axes of the world coordinate system by selecting menu **/View/Axes/Orient Axes**. When a new database is opened, the world coordinate system initially coincides with the view coordinate system. By applying translation and rotation operations, the relative position and orientation between the world coordinate system and the view coordinate system can be changed, thus the different aspects of the data in a database can be viewed.

On the other hand, if we take the view coordinate as the reference coordinate system, we can think that the view manipulations change the position and orientation of the world coordinate system with respect to the view coordinate system. In the analogy of storage room and the window on the wall, this relation is similar to fixing the window on the wall and moving and/or rotating everything inside the room together so that we can see them from different view angles. For ease of explanation, we choose the later approach, i.e. view operations transform the world coordinate system with respect to the view coordinate system.

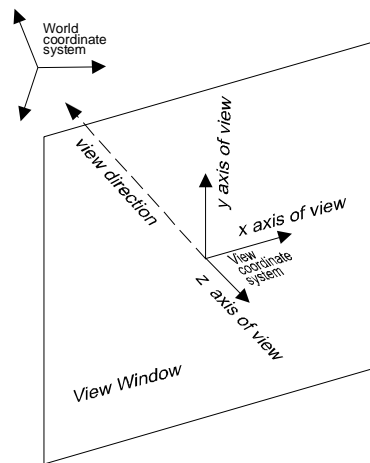




Figure 3.13 Relationship between World Coordinate System and View Coordinate System

The transformation of the world coordinate system with respect to the view coordinate system is achieved by using the three scroll bars. The operation procedures are summarized as follows:

- Setting Transformation Mode to “Transform World”
 - ⇒ To use the scroll bars to transform the world coordinate system with respect to the view coordinate system, the scroll bar operation mode must be set to the “Transform World” mode. To set this mode, click the **[Transform World]** button  on the control box to make it depressed. You can also select menu **/View/Set Xform Mode To/Transform World** to set this mode.
- Translating World
 - ⇒ Make sure that the **[Translation]** button  on the control box is depressed. If it is not, click the button or select menu **/View/Set Scroll Bar To/Translation** to set the scroll bar operation mode to the “Translation” mode.

⇒ Move the horizontal scroll bar to translate the world coordinate system along the x axis of the view coordinate system; move the vertical scroll bar to translate the world coordinate system along the y axis of the view coordinate system. In translation mode, the z scroll bar is disabled.

- Rotating World



⇒ Make sure that the **[Rotation]** button on the control box is depressed. If it is not, click the button or select menu **/View/Set Scroll Bar To/Rotation** to set the scroll bar operation model to the “Rotation” mode.

⇒ Move the horizontal scroll bar to rotate the world coordinate system around a rotation axis parallel to the y axis of the view coordinate system; or move the vertical scroll bar to rotate the world coordinate system around a rotation axis parallel to the x axis of the view coordinate system; or move the z scroll bar to rotate the world coordinate system around a rotation axis parallel to the z axis of the view coordinate system.

3.3.3 Setting Pivot Point of Rotation

When performing a rotational transformation, the rotation is carried out with respect to a rotation center. This center of rotation is called the **Pivot Point of Rotation**. When using the three scroll bars to rotate the world coordinate system, the three rotation axes for the three scroll bars all pass the pivot point of rotation, as shown in Figure 3.14. Since the rotation of world coordinate system is carried out around the pivot point, the position of the pivot point itself with respect to the view coordinate system will not change during a rotation operation.

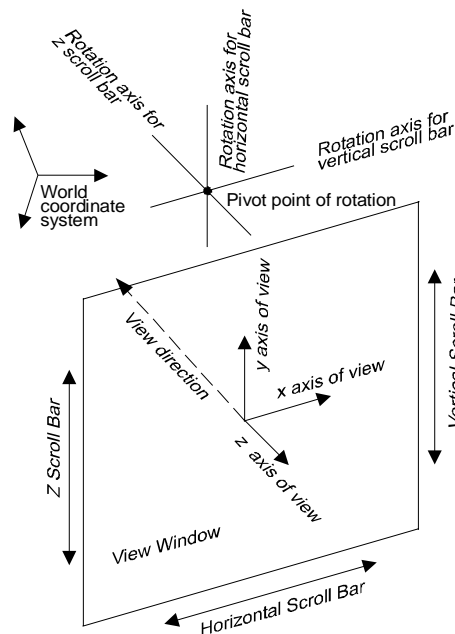








Figure 3.14 Rotation Axes for Scroll Bar and Pivot Point of Rotation

When a new database file is opened, the pivot point is initially set to the origin of the world coordinate system. Therefore, when rotating the world coordinate system, the origin of the world coordinate system will remain at the same point on the screen.

However, it is often desirable to set the pivot point to points other than the origin of the world coordinate system. Considering the case where a geometric entity such as a surface is quite distant from the origin of the world coordinate system, if the pivot point is at the origin of the world coordinate system, then it is very easy that the surface will be rotated out of the range of the view window. In this case, if the user is interested in viewing the surface from different angles, then it is desirable to set the pivot point of rotation to the center of the surface so that the rotation is around the center of the surface.

In IQ-FormFit, the user can set the pivot point to the center of different entities by a single click of the corresponding button on the control box or by selecting the corresponding menu items. The operation for setting pivot point is summarized as follows:

- Setting Pivot Point to World Center
 - ⇒ Menu access: **/View/Set Pivot To/World Center**
 - ⇒ Button access: **[Set Pivot To World Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to world center which is the center of the total bounding box of all the geometric entities contained in the database.
- Setting Pivot Point to Center of Active Point Cloud
 - ⇒ Menu access: **/View/Set Pivot To/Active Pnt Cloud Center**
 - ⇒ Button access: **[Set Pivot To Active Pnt Cloud Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to the center of the active point cloud entity
- Setting Pivot Point to Center of Active Curve
 - ⇒ Menu access: **/View/Set Pivot To/Active Curve Center**
 - ⇒ Button access: **[Set Pivot To Active Curve Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to the center of the current active curve entity
- Setting Pivot Point to Center of Active Surface
 - ⇒ Menu access: **/View/Set Pivot To/Active Surface Center**
 - ⇒ Button access: **[Set Pivot To Active Surface Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to the center of the active surface entity
- Setting Pivot Point to Center of Active Deviation Cloud
 - ⇒ Menu access: **/View/Set Pivot To/Active Dev Cloud Center**
 - ⇒ Button access: **[Set Pivot To Active Dev Cloud Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to the center of the active deviation cloud entity
- Setting Pivot Point to Center of Active Group
 - ⇒ Menu access: **/View/Set Pivot To/Active Group Center**
 - ⇒ Button access: **[Set Pivot To Active Group Center]** button 
 - ⇒ Function: Setting the pivot point of rotation to the center of the active group entity

See section 4.3
about active entity

3.3.4 Mouse-based View Manipulation

In stead of using the scroll bars, the user can drag the mouse in a view window to continuously translate or rotate the world coordinate system with respect to the view coordinate system. To use the mouse for view manipulation, you must first press the **<Shift>** key and then drag the mouse in the view window. Whether the view is rotated or translated depends on the status of the **[Translation]** button and the **[Rotation]** button on the control box. After one mouse drag is finished, you must press the **<Shift>** key again in order to perform another mouse-based view manipulation.

3.3.5 Standard Views

IQ-FormFit has eight pre-programmed standard view angles available to the user. The standard views are defined in Table 3.3 and they can be accessed by either selecting the options of menu **/View/Standard View/Top...Axonometric** or by clicking the standard view button on the tool bar as shown in Figure 3.15. The pre-programmed standard views can also be accessed through the standard view popup menu by clicking the right mouse button while the cursor is inside a graphics view.

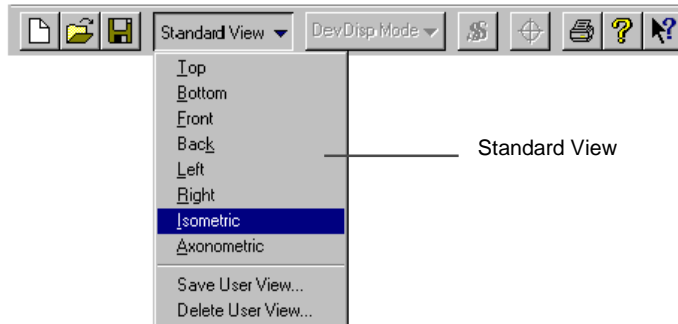


Figure 3.15 Select Standard View

Table 3.3 Definition of Standard Views

Top View	Viewing database data from +z axis of the world coordinate system
Bottom View	Viewing database data from -z axis of the world coordinate system
Front View	Viewing database data from -y axis of the world coordinate system
Back View	Viewing database data from +y axis of the world coordinate system
Left View	Viewing database data from -x axis of the world coordinate system
Right View	Viewing database data from +x axis of the world coordinate system
Isometric View	Viewing database data from the first quadrant of the world coordinate system
Axonometric View	Viewing database data from the seventh quadrant of the world coordinate system

3.3.6 User Defined Views

IQ-FormFit supports up to 30 user defined views. To define a user view, the user should first adjust the view to the desired view aspects including view angles, zoom factor and view window layout. Then the user can select menu **/View/Save User View** or click the standard view button on the tool bar as shown in Figure 3.15 and select the **Save User View** option. When the Save User View menu is selected, the *Save User View* dialog box as shown in Figure 3.16 pops up to let the user type a name for the view to be saved.

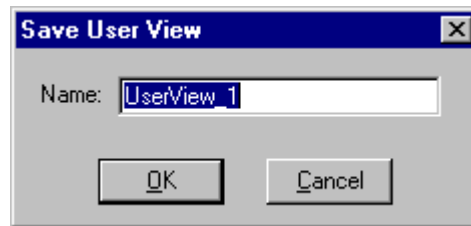


Figure 3.16 Save User View

When a user defined view is saved, all aspects of the view including view angle, zoom factor, deviation magnification factor and view window position and size are all saved. To recall a user defined view, select the desired view listed under menu **/View/User View**. If the right mouse button is clicked while the mouse cursor is inside a graphics view, the saved user views are also listed under the User View option of the standard view pop up menu.

To delete a saved view, select menu **/View/Delete User View...** to invoke the *Delete User View* dialog box as shown in Figure 3.17. Select the view you want to delete and click the **[Delete]** button. When you finish deleting the view, click the **[Close]** dialog button to close the *Delete User View* dialog box.

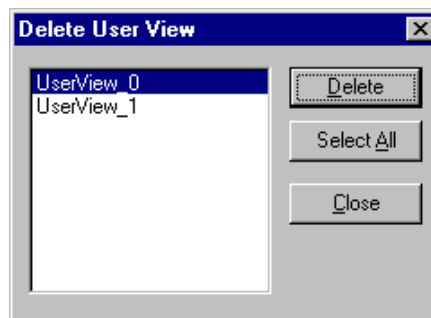


Figure 3.17 Delete User View

3.4 View Options

View options supported by IQ-FormFit will be discussed in this section. In IQ-FormFit, two major groups of view options are supported: display of coordinate system and display of scale.

3.4.1 Displaying Coordinate System Axes

Coordinate systems involved in view operations are discussed in section 3.3.2. IQ-FormFit will not graphically display the three axes of the view coordinate system on the screen. However, the user can display axes of the world coordinate system, the axes of world orientation, and the axes of the entity coordinate system on the screen by turning on the appropriate view option switch. The following menu items toggle the view option switch for displaying coordinate systems:

- Displaying World Coordinate System Axes
 - ⇒ Menu access: **/View/Axes/World Axes**
 - ⇒ Function: Toggle display option for world coordinate system axes
- Displaying World Orientation Axes
 - ⇒ Menu access: **/View/Axes/Orient Axes**
 - ⇒ Function: Toggle display option for world orientation axes
- Displaying Entity Coordinate System Axes
 - ⇒ Menu access: **/View/Axes/Entity Axes**
 - ⇒ Function: Toggle display option for entity coordinate system axes for all geometric entities

When it is displayed, the world orientation axes is always displayed at the upper left corner of the view window.

3.4.2 Displaying Scale

It is often very useful to display a scale in the view window so that the user can estimate the dimension of the geometry displayed in the view window. IQ-FormFit supports two different types of scales: dimension scale and deviation scale. The dimension scale can be used to estimate the dimension of the displayed geometry, and the deviation scale can be used to estimate the magnitude of the deviation vectors displayed in the view window. The two scales are especially helpful in dealing with 2D geometry and 2D deviations. The dimension scale is displayed by default and the deviation scale is not displayed initially. However, the user can use the following menu items to toggle the display option for these two scales.

- Displaying Dimension Scale
 - ⇒ Menu access: **/View/Scale/Dimension**
 - ⇒ Function: Toggle display option for dimension scale
- Displaying Deviation Scale
 - ⇒ Menu access: **/View/Scale/Deviation**
 - ⇒ Function: Toggle display option for deviation scale

When they are displayed, the dimension scale is displayed at the lower left corner of each view window in yellow color, and the deviation scale is displayed at the lower right corner of each view window in cyan color.

Chapter 4 Entity and Common Entity Operations

4.1 Introduction

See section 3.1.3 for supported entity types in each class

Entity is the basic data unit in an IQ-FormFit database. IQ-FormFit supports five geometric entity classes and two non-geometric entity classes. The geometric entity classes are point cloud, curve, surface, deviation cloud and group. The non-geometric entity classes are vector and transformation. For each of the five supported geometric entity classes, there are some common operations among them. These common operations include setting active entity, transforming active entity, local standard view of active entity, setting display thickness, setting default display options, changing display smoothness, changing entity display properties, editing entity display properties, showing/hiding entities, displaying entity labels, grouping/ungrouping entities, extracting entity coordinate system, deleting entities, and re-ordering entity list for each entity class. These common entity operations will be discussed in this chapter.

4.2 Setting Active Entity

See section 2.6 for discussion about active entity bar

In an IQ-FormFit database, each geometric entity class will have one active entity if at least one entity exists in that geometric entity class. This means that a database can have an active point cloud, an active curve, an active surface, an active deviation cloud and an active group. The name of the active entity of each entity class is shown on the corresponding active entity buttons on the active entity bar (Figure 2.6). If no entity exists in a specific geometric entity class, the corresponding active entity button of that entity class will be grayed out with "None" on the button face.

If a geometric entity class has more than one entity, the user can set any of the entities in that entity class to be the active entity of that class. IQ-FormFit supports two ways for the user to set an active entity: selecting the active entity from a dialog box and picking the active entity on screen using the mouse. The first method is convenient when the user knows the name of the entity that is to be set to the active entity, and the second method is convenient when the user knows the graphics display of the entity that is to be set to the active entity.

4.2.1 Selecting Active Entity

To select the active entity for an entity class, the user can either select the appropriate menu or click the active entity button on the active entity bar to invoke the corresponding select active entity dialog box. The access methods for selecting the active entity for each geometric entity class are summarized as follows:

- Selecting Active Point Cloud
 - ⇒ Menu access: **/Point/Select Active Pnt Cloud**
 - ⇒ Button access: **[Select Active Pnt Cloud]** button
- Selecting Active Curve
 - ⇒ Menu access: **/Curve/ Select Active Curve**
 - ⇒ Button access: **[Select Active Curve]** button

- Selecting Active Surface
 - ⇒ Menu access: **/Surface/ Select Active Surface**
 - ⇒ Button access: **[Select Active Surface]** button
- Selecting Active Deviation Cloud
 - ⇒ Menu access: **/Deviation/ Select Active Dev Cloud**
 - ⇒ Button access: **[Select Active Dev Cloud]** button
- Selecting Active Group
 - ⇒ Menu access: **/Group/ Select Active Group**
 - ⇒ Button access: **[Select Active Group]** button

Selecting the menu or clicking the active entity button will invoke a dialog box. Figure 4.1 shows the *Select Active Point Cloud* dialog box. When the dialog box pops up, it lists all entities in the entity class with the name of the current active entity being highlighted. The user can select the new entity to be set to the active entity and click the **[OK]** button to close the dialog box. When a new entity is set to the active entity, it will be displayed in highlight yellow color, and the previous active entity will be set back to its original color. This color change feature can be used to check the name of an entity. For example, when a database has many point clouds, each point cloud will have a name. To check the correspondence between the point clouds and their names, the user can use the up and down arrow keys to go through the point cloud list on the *Select Active Point Cloud* dialog box. By observing the change of display color, the correspondence can be identified.

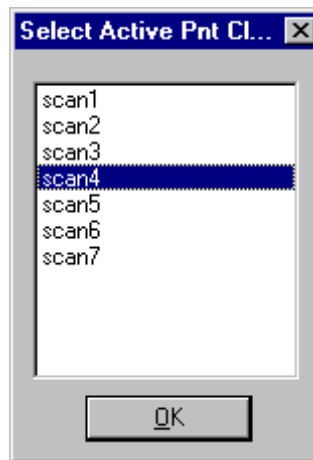






Figure 4.1 The *Select Active Point Cloud* Dialog Box

4.2.2 Picking Active Entity

To use the mouse to pick the active entity on the screen, the user needs to activate the appropriate menu or click the pick active entity button on the tool box to set the mouse into pick active entity mode. When this mode is set, the mouse cursor will change to the hand-shaped picking cursor and the corresponding pick active entity button will be depressed until the picking operation is finished. The access methods for setting the mouse to pick active entity mode are summarized as follows:

- Picking Active Point Cloud
 - ⇒ Menu access: **/Point/Pick Active Pnt Cloud**
 - ⇒ Button access: **[Pick Active Pnt Cloud]** button 

- Picking Active Curve
 - ⇒ Menu access: **/Curve/Pick Active Curve**
 - ⇒ Button access: **[Pick Active Curve]** button 
- Picking Active Surface
 - ⇒ Menu access: **/Surface/Pick Active Surface**
 - ⇒ Button access: **[Pick Active Surface]** button 
- Picking Active Deviation Cloud
 - ⇒ Menu access: **/Deviation/Pick Active Dev Cloud**
 - ⇒ Button access: **[Pick Active Dev Cloud]** button 
- Picking Active Group
 - ⇒ Menu access: **/Group/Pick Active Group**
 - ⇒ Button access: **[Pick Active Group]** button 

When the mouse is set to pick active entity mode, the user can use the mouse to pick the entity of interest. If no entity of the interested entity class is hit by the mouse, you will hear a beep sound and a prompt message will also appear on the status bar. If this happens, you can keep trying until you hit an entity of that class. You can abort the picking active entity operation by pressing the **<ESC>**. When the mouse hits at least one entity of the interested entity class, a confirmation dialog box will pop up. Figure 4.2 shows the *Pick Active Surface* dialog box. When this dialog box pops up, it displays the name of the first entity among a list of entities that are hit by the mouse. You can use the **[Prev]** and **[Next]** buttons to go through the picked entities. When you switch between the picked entities, the name of the currently selected entity will be displayed on the dialog box. At the same time, the currently selected entity will be displayed in bright yellow color on the screen. When it comes to the right entity that you want to set to the active entity, you can click the **[Accept]** button and this will set the currently selected entity to be the active entity. It is straightforward that this picking active entity function can also be used to identify the name of a particular entity on the screen.



Figure 4.2 The *Pick Active Surface* Dialog Box

4.3 Transforming Active Entity

A geometric entity is completely determined by its shape, its position and orientation. In IQ-FormFit, the position and orientation of a geometric entity is represented by a coordinate system that is called the ***Entity coordinate system*** as shown in Figure 4.3. In contrast to the world coordinate system that is sometimes called the global

coordinate system, entity coordinate system is also called **Local coordinate system**. The shape of each geometric entity is defined in its entity coordinate system by its shape parameter(s). When a transformation operation is applied to a geometric entity, the entity coordinate system is transformed with respect to the world coordinate system while the entity remained the same with respect to its entity coordinate system. It is possible that the local coordinate system of a geometric entity coincides with the world coordinate system.

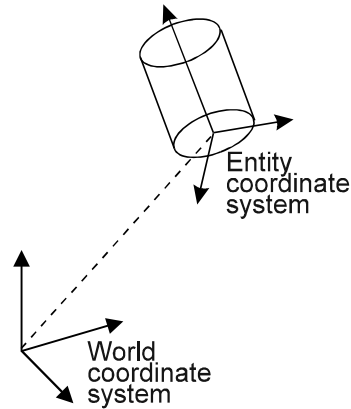


Figure 4.3 Entity Coordinate System

IQ-FormFit provides tools for the user to manipulate the position and orientation of each active entity relative to the world coordinate system. In this section, we will discuss these transformation operations in detail.

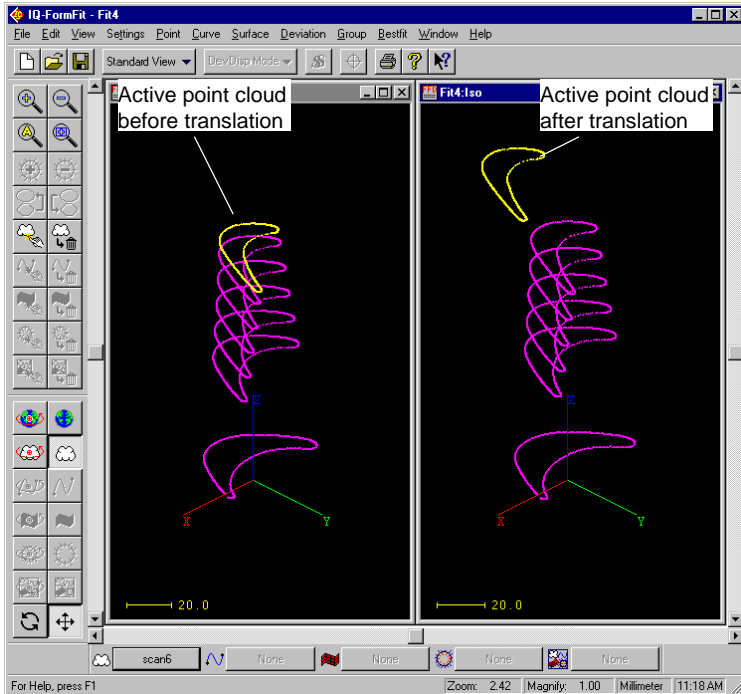






Figure 4.4 Translation of Active Point Cloud

As discussed in section 3.3.2, the transformation of world coordinate system changes the position and orientation of the world coordinate system with respect to

the view coordinate system while the position and orientation of each entity relative to the world coordinate system remains the same. However, when we transform an active entity, only the position and orientation of the active entity with respect to the view coordinate system will be changed. Since the world coordinate system remains unchanged with respect to the view coordinate system, the position and orientation of the active entity relative to the world coordinate system will be changed when the active entity is transformed. Figure 4.4 shows the translation of the active point cloud. On the left is the position of the active point cloud before translation, and on the right is the position of the active point cloud after translation.

4.3.1 Translating/Rotating Active Point Cloud/Active Point Cloud Group Using Scroll Bars

IQ-FormFit has three scroll bars. They can be used to change the aspects of a view window as discussed in chapter 3. They can also serve as unique graphical tools for translating/rotating active entities. It is designed that the scroll bars can be used for translating/rotating the active entity of every supported geometric entity class. However, the user usually only needs to use the scrollbars to manipulate the measurement data to align the data with the nominal model. Therefore, the program only allows the scrollbars to be used to translate/rotate the active point cloud and the active point cloud group. The procedures for translating/rotating the active point cloud or the active point cloud group are summarized as follows:

- Setting Transformation Mode
 - ⇒ To transform the active point cloud, make sure that the **[Transform Active Pnt Cloud]** button  on the control box is depressed. If it is not, click the button or select menu **/View/Set Xform Mode To/Pnt Cloud** to set the transformation mode to the “Transform Active Point Cloud” mode.
 - ⇒ To transform the active point cloud group, make sure that the **[Transform Active Group]** button  on the control box is depressed. If it is not, click the button or select menu **/View/Set Xform Mode To/Group** to set the transformation mode to the “Transform Active Group” mode.
- Translating Active Point Cloud/Active Point Cloud Group
 - ⇒ Make sure that the **[Translation]** button  on the control box is depressed. If it is not, click the button or select menu **/View/Set Scroll Bar To/Translation** to set the scroll bar operation mode to the “Translation” mode.
 - ⇒ Move the horizontal scrollbar to translate the active point cloud or active point cloud group along the x axis direction of the view coordinate system; or move the vertical scrollbar to translate the active point cloud or the active point cloud group along the y axis direction of the view coordinate system. In translation mode, the z scroll bar is disabled.
- Rotating Active Point Cloud/Active Point Cloud Group
 - ⇒ Make sure that the **[Rotation]** button  on the control box is depressed. If it is not, click the button or select menu **/View/Set Scroll Bar To/Rotation** to set the scroll bar operation model to the “Rotation” mode.
 - ⇒ Move the horizontal scrollbar to rotate the active point cloud or the active point cloud group around the rotation axis for the horizontal scrollbar; or move the vertical scrollbar to rotate the active point cloud or the active point

See 3.3.2 and Figure 3.9 for illustration of rotation axes for the three scrollbars and pivot point of rotation

cloud group around the rotation axis for the vertical scrollbar; or move the z scrollbar to rotate the active point cloud or the active point cloud group around the rotation axis for the Z scroll bar.

4.3.2 Translating Active Entity by a Vector

To translate the active entity of a geometric entity class by a vector, select the appropriate menu to invoke the translate active entity dialog box. Figure 4.5 shows the *Translate Active Point Cloud* dialog box. The user can type the three components of translation directly. If any vectors are available in the database, the **[Browse]** button will be enabled. By clicking this button, the user can bring up the *Select Vector* dialog box, as shown in Figure 4.6. On the left of the *Select Vector* dialog box is a list of available vectors. When the user selects a vector from the vector list, the three components of the selected vector are shown in the “*Selected Vector*” box. The user can click the **[Invert]** button to flip the signs of the vector components, or click the **[OK]** button to confirm the selection, or click the **[Cancel]** button to cancel the selection. After the user types the three components of translation or selects a translation vector, the **[OK]** button on the translate active entity dialog box should be clicked to execute the translation operation on the active entity.

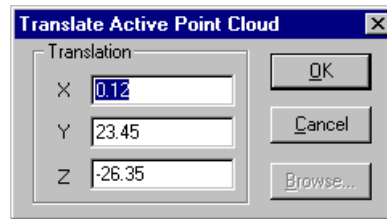


Figure 4.5 The *Translate Active Point Cloud* Dialog Box

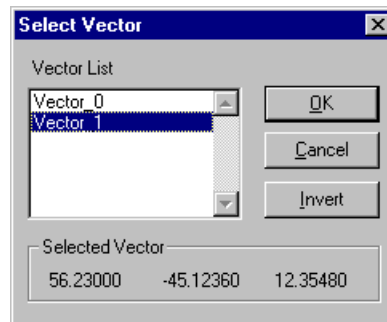


Figure 4.6 The *Select Vector* Dialog Box

The following summarizes the menu access for translating the active entity of each entity class by a translation vector:

- Translating Active Point Cloud by a Vector
⇒ Menu access: **/Point/Xform Active Pnt Cloud/Translate**
- Translating Active Curve by a Vector
⇒ Menu access: **/Curve/Xform Active Curve/Translate**
- Translating Active Surface by a Vector
⇒ Menu access: **/Surface/Xform Active Surface/Translate**

- Translating Active Deviation Cloud by a Vector
⇒ Menu access: **/Deviation/Xform Active Dev Cloud/Translate**
- Translating Active Group by a Vector
⇒ Menu access: **/Group/Xform Active Group/Rotate**

4.3.3 Rotating Active Entity around an Axis by an Angle

To rotate the active entity of a geometric entity class around an axis by an angle, select the appropriate menu to invoke the rotate active entity dialog box. Figure 4.7 shows the *Rotate Active Point Cloud* dialog box. The user can type the three components of rotation axis direction and the rotation angle. The rotation axis always passes through the origin of the world coordinate system. If the rotation angle is given in degree, then the “Degree” box should be checked. When the [OK] button on the rotate active entity dialog box is clicked, the rotation operation on the active entity will be executed.

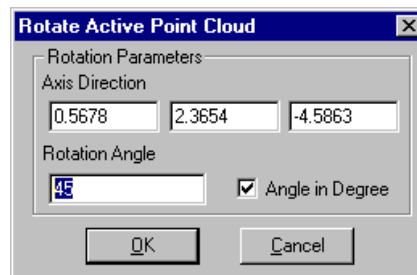


Figure 4.7 The *Rotate Active Point Cloud* Dialog Box

The following summarizes the menu access for rotating the active entity of each entity class around an axis by an angle:

- Rotating Active Point Cloud around an Axis by an Angle
⇒ Menu access: **/Point/Xform Active Pnt Cloud/Rotate**
- Rotating Active Curve around an Axis by an Angle
⇒ Menu access: **/Curve/Xform Active Curve/Rotate**
- Rotating Active Surface around an Axis by an Angle
⇒ Menu access: **/Surface/Xform Active Surface/Rotate**
- Rotating Active Deviation Cloud around an Axis by an Angle
⇒ Menu access: **/Deviation/Xform Active Dev Cloud/Rotate**
- Rotating Active Group around an Axis by an Angle
⇒ Menu access: **/Group/Xform Active Group/Rotate**

4.3.4 Transforming Active Entity by a Transformation Matrix

To transform the active entity of a geometric entity class by a 3x4 transformation matrix, select the appropriate menu to invoke the transform active entity dialog box. Figure 4.8 shows the *Transform Active Point Cloud* dialog box. On the left of the dialog box is a list of available transformations. When the user selects a transformation from the list, the selected transformation is shown in the “*Selected Transformation*” box. The user can click the **[Invert]** button to get the inverse of the selected transformation, or click the **[OK]** button to execute the transformation operation on the active entity, or click the **[Cancel]** button to cancel the operation.

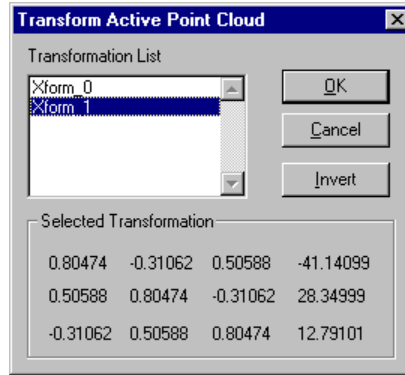


Figure 4.8 The *Transform Active Point Cloud* Dialog Box

The following summarizes the menu access for transforming the active entity of each entity class by a transformation matrix:

- Transforming Active Point Cloud by a Transformation Matrix
⇒ Menu access: **/Point/Xform Active Pnt Cloud/Transform**
- Transforming Active Curve by a Transformation Matrix
⇒ Menu access: **/Curve/Xform Active Curve/Transform**
- Transforming Active Surface by a Transformation Matrix
⇒ Menu access: **/Surface/Xform Active Surface/Transform**
- Transforming Active Deviation Cloud by a Transformation Matrix
⇒ Menu access: **/Deviation/Xform Active Dev Cloud/Transform**
- Transforming Active Group by a Transformation Matrix
⇒ Menu access: **/Group/Xform Active Group/Transform**

4.3.5 Sending Active Entity Back to Home Position

Each entity has its home position. Initially, the home position of an entity is its position in the world coordinate system when it is read into a database. Each entity remembers its home position so that after a translation / rotation / transformation operation is applied to the entity, its home position can still be restored. To send the active entity back to its home position, just select the corresponding menu item as summarized below:

- Sending Active Point Cloud Back to Home Position
⇒ Menu access: **/Point/Xform Active Pnt Cloud/Send Home**
- Sending Active Curve Back to Home Position
⇒ Menu access: **/Curve/Xform Active Curve/Send Home**
- Sending Active Surface Back to Home Position
⇒ Menu access: **/Surface/Xform Active Surface/Send Home**
- Sending Active Deviation Cloud Back to Home Position
⇒ Menu access: **/Deviation/Xform Active Dev Cloud/Send Home**
- Sending Active Group Back to Home Position
⇒ Menu access: **/Group/Xform Active Group/Send Home**

4.3.6 Resetting Active Entity Home Position

You can reset the home position of the active entity in each entity class to its current position. To reset the home position of the active entity, just select the corresponding menu item as summarized below:

- Resetting Home Position of Active Point Cloud
⇒ Menu access: **/Point/Xform Active Pnt Cloud/Reset Home**
- Resetting Home Position of Active Curve
⇒ Menu access: **/Curve/Xform Active Curve/Reset Home**
- Resetting Home Position of Active Surface
⇒ Menu access: **/Surface/Xform Active Surface/Reset Home**
- Resetting Home Position of Active Deviation Cloud
⇒ Menu access: **/Deviation/Xform Active Dev Cloud/Reset Home**
- Resetting Home Position of Active Group
⇒ Menu access: **/Group/Xform Active Group/Reset Home**

4.4 Local Standard Views of Active Entity

Like the standard views of the world coordinate system described in section 3.3.5, IQ-FormFit also provides the interface for the user to get the eight pre-programmed standard view angles of the active entity of each entity class. Unlike the standard view of world coordinate system which is defined in world coordinate system, the standard view of an active entity is defined with respect to the local coordinate system of the active entity (Table 4.1).

Local standard view of active entity is very convenient for viewing standard 3D entities such as plane and cylinder from special view angles. It is especially convenient for viewing 2D entities such as line and circle from the direction perpendicular to the plane of the 2D feature. Without the local standard view function, it would be difficult to use the scrollbars to manipulate the view to get the standard view of a 2D entity.

Table 4.1 Definition of Active Entity Local Standard Views

Local Top View	Viewing from +z axis of the local coordinate system of the active entity
Local Bottom View	Viewing from -z axis of the local coordinate system of the active entity
Local Front View	Viewing from -y axis of the local coordinate system of the active entity
Local Back View	Viewing from +y axis of the local coordinate system of the active entity
Local Left View	Viewing from -x axis of the local coordinate system of the active entity
Local Right View	Viewing from +x axis of the local coordinate system of the active entity
Local Isometric View	Viewing from the first quadrant of the local coordinate system of the active entity
Local Axonometric View	Viewing from the seventh quadrant of the local coordinate system of the active entity

To view an entity from a standard view angle with respect to its local coordinate system, the user first needs to set that entity to be the active entity of its class, then select the corresponding menu items for the desired local standard view. The following summarizes the menu access for the local standard view of the active entity of each entity class:

- Local Standard View of Active Point Cloud
 - ⇒ Menu access: **/Point/Active Pnt Cloud Std View/Top**
/Point/Active Pnt Cloud Std View/Bottom

/Point/Active Pnt Cloud Std View/Axonometric
- Local Standard View of Active Curve
 - ⇒ Menu access: **/Curve/Active Curve Std View/Top**
/Curve/Active Curve Std View/Bottom

/Curve/Active Curve Std View/Axonometric
- Local Standard View of Active Surface
 - ⇒ Menu access: **/Surface/Active Surface Std View/Top**
/Surface/Active Surface Std View/Bottom

/Surface/Active Surface Std View/Axonometric
- Local Standard View of Active Deviation Cloud
 - ⇒ Menu access: **/Deviation/Active Dev Cloud Std View/Top**
/Deviation/Active Dev Cloud Std View/Bottom

/Deviation/Active Dev Cloud Std View/Axonometric
- Local Standard View of Active Group
 - ⇒ Menu access: **/Group/Active Group Std View/Top**
/Group/Active Group Std View/Bottom

/Group/Active Group Std View/Axonometric

4.5 Entity Display Options

The display of each entity in the graphics window is controlled by a set of parameters called entity display options. This section discusses the display options of each entity class. Some of the options are global which is used to control the display of all entities of an entity class, some of the options can be adjusted for each individual entity.

4.5.1 Display Options of Point Cloud Class

Display options of point cloud class include display thickness, visible status, display color, display mode and sample rate.

- **Display Thickness**
This parameter controls the display weight of a point displayed on the screen when the point cloud is displayed in POINT or POLYLINE mode. It is a global option and all point clouds are displayed using the same display thickness.
- **Visible Status**
This parameter controls whether a point cloud is displayed in the graphics window. This flag can be controlled for each individual point cloud.
- **Display Color**
This parameter controls the display color of a point cloud. Each individual point cloud can be displayed in different colors.
- **Display Mode**
Each point of a point cloud can be displayed in one of the four display modes: POINT, CROSS, CIRCLE, POLYLINE. In POINT mode, each point is displayed as a dot. In CROSS mode, each point is displayed as a cross. In CIRCLE mode, each point is displayed as a small circle. In POLYLINE mode, a point cloud is displayed as a polyline that connects the points of the point cloud. This parameter can be controlled for each individual point cloud.
- **Sample Rate**
This parameter controls the display density for each point cloud. When the sample rate is 1, every point in a point cloud will be displayed. If the sample rate is 2, every other point will be displayed. A sample rate of 5 means the 1st, 6th, 11th, ..., and the last point will be displayed. IQ-FormFit treats any points that are not displayed as inactive points. Inactive points will not participate in analytical computations such as bestfit.

4.5.2 Display Options of Curve Class

Curves are always displayed using connected line segments. Display options of curve class include display thickness, visible status, display color, segment control, segment number and chord height tolerance.

- **Display Thickness**
This parameter controls the display weight of the line segments that represent a curve on the screen. This is a global option and all curves are displayed using the same display thickness.

- **Visible Status**
This parameter controls whether a curve is displayed in the graphics window. This flag can be controlled for each individual curve.
- **Display Color**
This parameter controls the display color of a curve. Each individual curve can be displayed in different colors.
- **Segment Control Mode**
Connected line segments are used to approximate a curve in the graphics display as illustrated in Figure 4.9. It is obvious the smoothness of a displayed curve depends on the number of line segments that represent the curve. The number of segments can be decided either uniformly or adaptively. If it is decided uniformly, a given number of segments will be created evenly over the parameter range of a curve. If it is decided adaptively, the curve will be adaptively subdivided into segments until the chord height deviation is smaller than a given chord height tolerance, as shown in Figure 4.9. IQ-FormFit supports both segment control methods and each curve can have either UNIFORM segment control or ADAPTIVE segment control.

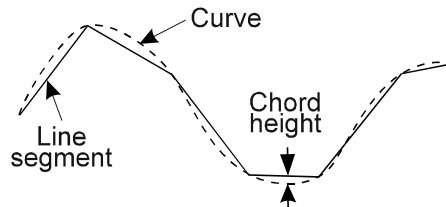


Figure 4.9 Curve Display and Chord Height

- **Segment Number**
This option controls the display smoothness when a curve is in UNIFORM segment control mode.
- **Chord Height Tolerance**
This option controls the display smoothness when a curve is in ADAPTIVE segment control mode.

4.5.3 Display Options of Surface Class

Surfaces are displayed by connected line segments representing its boundary curves or by polygon meshes which are in turn displayed by connected line segments. Display options of surface class include display thickness, visible status, display color, display mode, display density control, wire density, mesh density and chord height tolerance.

- **Display Thickness**
This parameter controls the display weight of the line segments that represents the surface boundary curves or the surface meshes on the screen. This is a global option and all surfaces are displayed using the same display thickness.
- **Visible Status**
This parameter controls whether a surface is displayed in the graphics window. This flag can be controlled for each individual surface.

- **Display Color**
This parameter controls the display color of a surface. Each individual surface can be displayed in different colors.
- **Display Mode**
This parameter controls how a surface will be displayed on the screen. It can be WIRE, MESH or TRIM. In WIRE mode, the wire frame which are the boundary curves of the surface are displayed. In MESH mode, the untrimmed surface meshes are displayed. In TRIM mode, the trimmed surface meshes that are the surface meshes trimmed by the surface boundary curves are displayed. Each individual surface can have different display mode.
- **Display Density Control Mode**
Similar to segment control mode of curves, the display density control mode for a surface can be either UNIFORM or ADAPTIVE. In UNIFORM density control, the display density (or smoothness) is determined by the number of line segments representing each boundary curve if the surface is displayed in WIRE frame, or is determined by the number of meshes representing the surface if the surface is displayed in MESH or TRIM mode. In ADAPTIVE density control, the display smoothness is controlled by a given chord height tolerance and the surface will be subdivided until the chord height deviation is smaller than the given chord height tolerance. Each surface can have either UNIFORM display density control or ADAPTIVE display density control.

Table 4.2 Surface Display Density Control

Display Mode	Mesh Control	Display Density (smoothness) controlled by
WIRE	UNIFORM	Wire Density
	ADAPTIVE	Chord Height Tolerance
MESH	UNIFORM	Mesh Density (in u, v parameter direction)
	ADAPTIVE	Chord Height Tolerance
TRIM	UNIFORM	Mesh Density (in u, v parameter direction)
	ADAPTIVE	Chord Height Tolerance

- **Wire Density**
This option controls the display smoothness of the boundary curves of a surface when the surface is displayed in WIRE frame mode and when the display density control mode is UNIFORM mode.
- **Mesh Density**
This option controls the mesh density of a surface when the surface is displayed in MESH or TRIM mode and when the display density control mode is UNIFORM mode.
- **Chord Height Tolerance**
This option controls the display smoothness when the display density control is in ADAPTIVE mode regardless of the surface display mode.

4.5.4 Display Options of Deviation Cloud Class

Display options of point cloud class include display thickness, visible status, display colors, display mode and sample rate.

- **Display Thickness**
This parameter controls the display weight of each deviation vector in a deviation cloud. It is a global option and all deviation clouds are displayed using the same display thickness.
- **Visible Status**
This parameter controls whether a deviation cloud is displayed in the graphics window. This flag can be controlled for each individual deviation cloud.
- **Display Colors**
A deviation cloud has five colors that, in conjunction with the display mode of a deviation cloud, controls the graphical appearance of a deviation cloud. The five colors are “Display Color”, “Spike Color(+, Out Tol)”, “Spike Color(-, Out Tol)”, “Spike Color(+, In Tol)” and “Spike Color(-, In Tol)”. The “Display Color” is used to display the end points and the connecting line segments in the POINT, CONNECT and SPK&CONN display modes. When a deviation cloud is displayed in SPIKE or SPK&CONN mode, the out-of-tolerance portion of each plus deviation vector will be displayed using “Spike Color(+,Out Tol)”, the out-of-tolerance portion of each minus deviation vector will be displayed using “Spike Color(-,Out Tol)”, the in-tolerance portion of each plus deviation vector will be displayed with “Spike Color(+,In Tol)”, and the in-tolerance portion of each minus deviation vector will be displayed using “Spike Color(-, In Tol)”.
- **Display Mode**
Each deviation of a deviation cloud can be displayed in one of the four display modes: POINT, SPIKE, CONNECT, SPK&CONN. In POINT mode, only the end point of each deviation vector is displayed. In SPIKE mode, spikes (whiskers) are drawn for each deviation vector. In CONNECT mode, the end points of deviation vectors are connected with line segments to illustrate profile. In SPK&CONN mode, both the spikes and the connecting line segments are displayed.
- **Sample Rate**
This parameter controls the display density for each deviation cloud. When the sample rate is 1, every deviation vector in a deviation cloud will be displayed. If the sample rate is 2, every other deviation cloud will be displayed, and so on.

4.5.5 Display Options of Group Class

In IQ-FormFit, there are four different types of groups: point cloud groups, curve groups, surface groups and deviation groups. Display options of group class include visible status and display colors. Grouped entities will be displayed with the same display weight of their original class.

- **Visible Status**
This parameter controls whether a group is displayed in the graphics window. This flag can be controlled for each individual group.
- **Display Colors**
This parameter controls the display color for a group and all entities in a group will be displayed in the same “Display Color”. Colors for displaying deviation spikes have the same meaning as that of a deviation cloud.

4.6 Setting Display Thickness

See section 4.5 for more information on display options of each entity class

As discussed in section 4.5, all geometric entities are displayed in line segments or pixel. The weight for displaying a geometric entity on the screen is controlled by the display thickness parameter for each entity class. The default display thickness for each entity class are 2 pixels for point clouds and 1 pixel for curves, surfaces and deviation clouds. The user can change the display thickness for displaying geometric entities in each class. To set the display thickness, select menu **/Settings/Display Thickness** to bring up the *Set Display Thickness* dialog box as shown in Figure 4.10. When the dialog box pops up, the current values for the display thickness of each entity class are displayed. The user can change them to the proper values for desired display or print out effect.

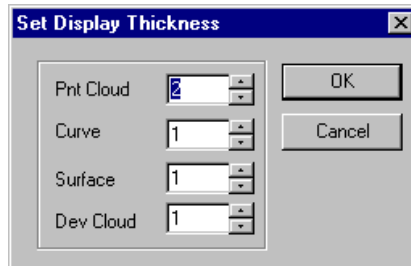


Figure 4.10 The *Set Display Thickness* Dialog Box

4.7 Setting Default Display Options

See section 4.5 for more information on display options of each entity class

Default display options such as display color are used to display new geometric entities created in IQ-FormFit. IQ-FormFit allows the user to change the default display options. To set the default display options, select menu **/Settings/Display Options** to bring up the *Display Options* dialog box as shown in Figure 4.11. When the dialog box pops up, the current values for the display options for each entity class are displayed in respective pages. By switching the pages, the user can change the default options to the proper values for each entity class.

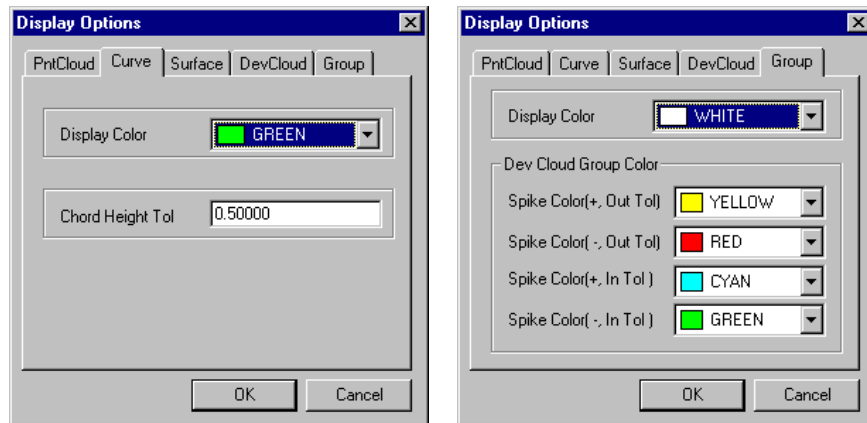




Figure 4.11 The *Display Options* Dialog Box

4.8 Increasing/Decreasing Display Smoothness for All Curves and Surfaces

See section 4.5 for more information on display options of each entity class

As explained in section 4.5, all curves are displayed with connected line segments and all surfaces are displayed either with line segments representing its boundary curves or meshes representing the surface. Since curves and surfaces are approximated by line segments or meshes in graphics display, how smooth the curves and surfaces are displayed in graphics depends on how many line segments or meshes are used to approximate the curves or surfaces in graphics display. IQ-FormFit provides different operations to adjust the display smoothness for curves and surface. Here is how to increase and decrease display smoothness for all curves and surfaces with a single mouse click.

- To increase the display smoothness for all curves and surfaces in a database, select menu **/View/Display Smoothness/Increase** or click the **[Increase Display Smoothness]** button  on the tool box.
- To decrease the display smoothness for all curves and surfaces in a database, select menu **/View/Display Smoothness/Decrease** or click the **[Decrease Display Smoothness]** button  on the tool box.

The effects of these two operations to the curves and surfaces depend on the display density control mode of each individual curve and surface. For curves and surfaces that are in UNIFORM display density control mode, the number of segments or meshes will be doubled by the increase display smoothness operation and reduced by half by the decrease display smoothness operation. For curves and surfaces that are in ADAPTIVE display density control mode, the chord height tolerance of them will be reduced by half by the increase display smoothness operation and doubled by the decrease display smoothness operation.

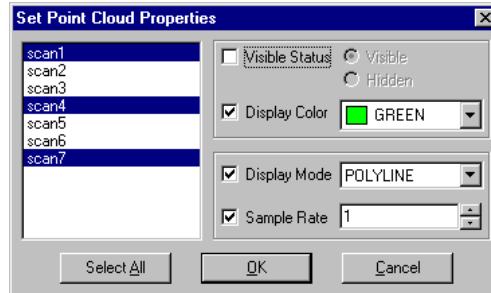
4.9 Setting Entity Display Properties

When a new entity is created in IQ-FormFit, its display related properties such as display color, display mode and display density are controlled by the default display options. As discussed in section 4.7, the default display options can be customized. However, changing the default display options will not affect the display properties of entities that already exist in the database. In this section we discuss how to set the display properties for existing entities.

4.9.1 Setting Display Properties for Point Clouds

See section 4.5 for more information on display options of point cloud class

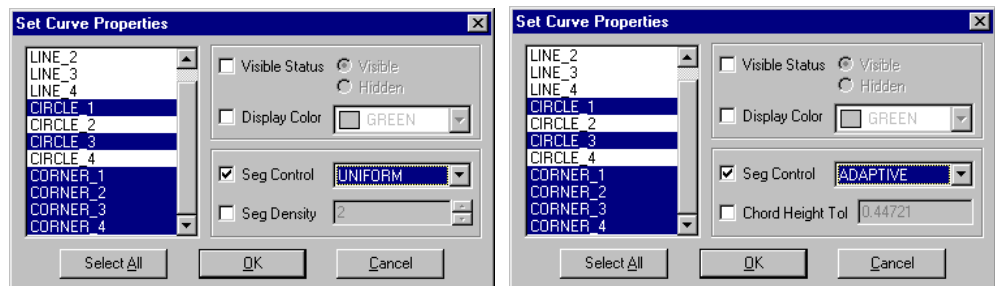
To set the display properties for existing point clouds, select menu **/Point/Set Properties** to bring up the *Set Point Cloud Properties* dialog box as shown in Figure 4.12. On the left of the dialog box is the list of all point clouds. From the point cloud list, the user can select the point clouds whose display options are to be changed. On the right half of the dialog box, all display options for point cloud entities are laid out. When the dialog box pops up, all options are grayed out. In order to change a display option, the check box on the left of that option must be checked. Only after the check box for an option is checked can the user change that option. When the **[OK]** button is clicked, the display options will be changed to the user specified options for the selected point clouds.

Figure 4.12 The *Set Point Cloud Properties* Dialog Box

4.9.2 Setting Display Properties for Curves

See section 4.5 for more information on display options of curve class

To set the display properties for existing curves, select menu **/Curve/Set Properties** to bring up the *Set Curve Properties* dialog box as shown in Figure 4.13. On the left of the dialog box is the list of all curves. From the curve list, the user can select the curves whose display options are to be changed. On the right half of the dialog box, all display options for curve entities are laid out. When the dialog box pops up, all options are grayed out. In order to change a display option, the check box on the left of that option must be checked. Only after the check box for an option is checked can the user change that option. The dialog box changes its layout according to the selected segment control mode. When the **[OK]** button is clicked, the display options will be changed to the user specified options for all the selected curves.

Figure 4.21 The *Set Curve Properties* Dialog Box

4.9.3 Setting Display Properties for Surfaces

See section 4.5 for more information on display options of surface class

To set the display properties for existing surfaces, select menu **/Surface/Set Properties** to invoke the *Set Surface Properties* dialog box as shown in Figure 4.22. On the left of the dialog box is the list of all surfaces. From the surface list, the user can select the surfaces whose display options are to be changed. On the right half of the dialog box, all display options for surface entities are laid out. The *Set Surface Properties* dialog box changes its layout according to the selected display mode and density control mode. When the dialog box pops up, all options are grayed out. In order to change a display option, the check box on the left of that option must be checked. Only after the check box for an option is checked can the user change that option. When the **[OK]** button is clicked, the display options will be changed to the user specified options for all the selected surfaces.

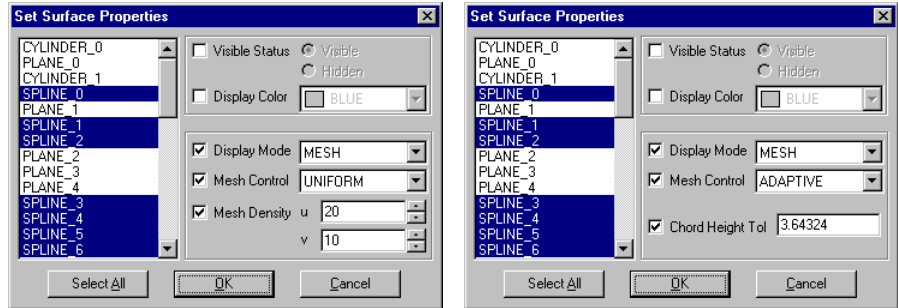


Figure 4.22 The *Set Surface Properties* Dialog Box

4.9.4 Setting Display Properties for Deviation Clouds

See section 4.5 for more information on display options of deviation cloud class

To set the display properties for existing deviation clouds, select menu **/Deviation/Set Properties** to bring up the *Set Deviation Cloud Properties* dialog box as shown in Figure 4.23. On the left of the dialog box is the list of all deviation clouds. From the deviation cloud list, the user can select the deviation clouds whose display options are to be changed. When the dialog box pops up, all options are grayed out. In order to change a display option, the check box on the left of that option must be checked. Only after the check box for an option is checked can the user change that option. When the **[OK]** button is clicked, the display options will be changed to the user specified options for all the selected deviation clouds.

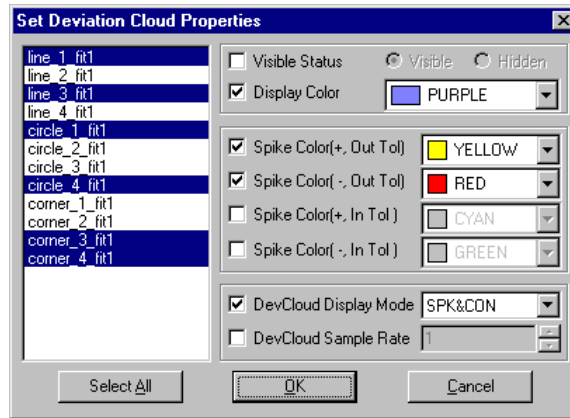


Figure 4.23 The *Set Deviation Cloud Properties* Dialog Box

4.9.5 Setting Display Properties for Groups

See section 4.5 for more information on display options of group class

To set the display properties for groups, select menu **/Group/Set Properties** to bring up the *Set Group Properties* dialog box as shown in Figure 4.24. On the left of the dialog box is the list of all groups. From the group list, the user can select the groups whose display options are to be changed. On the right half of the dialog box, all display options for group entities are laid out. When the dialog box pops up, all options are grayed out. In order to change a display option, the check box on the left of that option must be checked. Only after the check box for an option is checked can the user change that option. The check boxes for the spike colors will be enabled only when at least one deviation cloud group is selected. When the **[OK]**

button is clicked, the display options will be changed to the user specified options for all the selected groups.

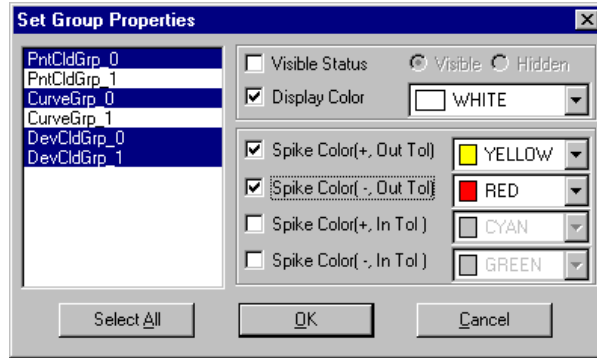


Figure 4.24 The *Set Group Properties* Dialog Box

4.10 Editing Entity Properties

In section 4.9, operations of setting display properties for selected entities of each entity class are discussed. The properties of an entity, such as its name, display color, visible status and so on, can also be changed through editing entity properties operations. The editing entity properties functions are implemented using two dialog boxes. The first dialog box displays the properties of each entity in a list box. When the user selects an entity and click the **[Edit]** button or by double-clicks the entity to be edited, a second dialog box will pop up. The user can use the second dialog box to modify the properties of the selected entity.

4.10.1 Editing Point Cloud Properties

See section 4.5 for more information on display options of point cloud class

To edit the properties of point clouds, select menu **/Point/Edit Properties** to bring up the *Point Cloud Properties* dialog box as shown in Figure 4.25. This dialog box displays the properties of all point clouds in the database.

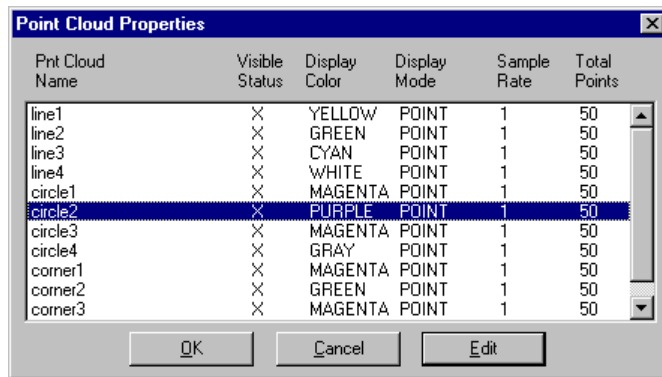


Figure 4.25 The *Point Cloud Properties* Dialog Box

To edit the properties of a point cloud, select the point cloud and click the **[Edit]** button or double click the point cloud in the list box to invoke the *Edit Point Cloud Properties* dialog box, as shown in Figure 4.26. Using this second dialog box, the user can edit the point cloud name by typing in the “Cloud Name” box, or select a

different color from the “*Display Color*” list, or hide the point cloud by checking the “*Hidden*” radio button, or select the desired display mode from the “*Display Mode*” list. The user can change the sample rate by either typing in the “*Sample Rate*” box or clicking on the up/down arrows attached to the right of the “*Sample Rate*” box. Hit the <Enter> key or click the [OK] button will close the *Edit Point Cloud Properties* dialog box and the information in the *Point Cloud Properties* dialog box will be updated. Click the [Cancel] button will close the *Edit Point Cloud Properties* dialog box but all selections will be discarded.

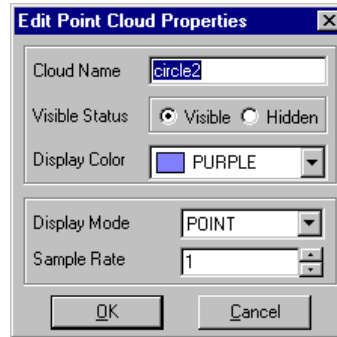


Figure 4.26 The *Edit Point Cloud Properties* Dialog Box

4.10.2 Editing Curve Properties

See section 4.5 for more information on display options of curve class

To edit the properties of curves, select menu /Curve/Edit Properties to bring up the *Curve Properties* dialog box as shown in Figure 4.27. This dialog box displays the properties of all curves in the database.

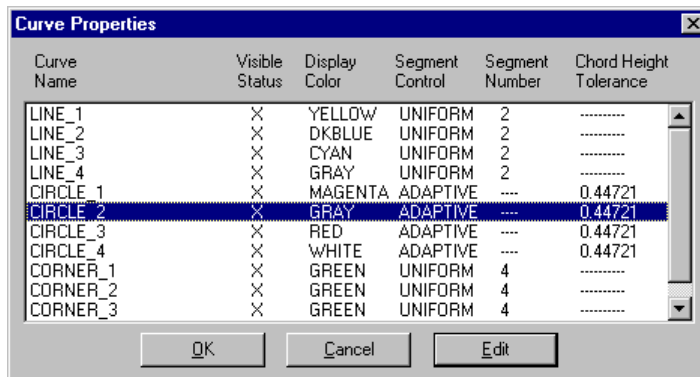


Figure 4.27 The *Curve Properties* Dialog Box

To modify the properties of a curve, select the curve and click the [Edit] button to invoke the *Edit Curve Properties* dialog box as shown in Figure 4.28. The layout of the *Edit Curve Properties* dialog box will change according to the selected segment control mode. When the segment control is in UNIFORM mode, the number of segments will be shown so that the user can change the number of segments. If the segment control is in ADAPTIVE mode, the chord height tolerance will be shown so that the user can change the chord height tolerance.

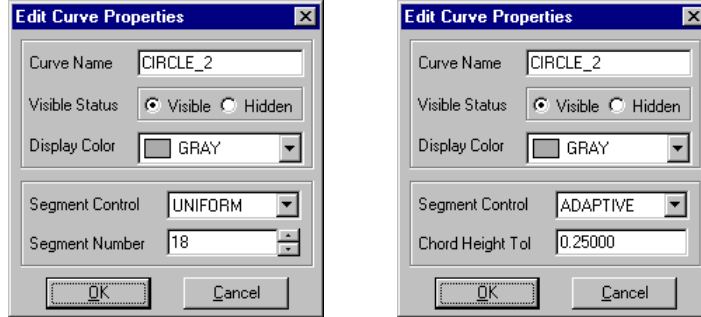


Figure 4.28 The *Edit Curve Properties* Dialog Boxes

4.10.3 Editing Surface Properties

See section 4.5 for more information on display options of surface class

To edit the properties of surfaces, select menu **/Surface/Edit Properties** to bring up the *Surface Properties* dialog box as shown in Figure 4.29. This dialog box displays the properties of all surfaces in the database.

Surface Name	Visible Status	Display Color	Display Mode	Density Control	Uniform Density u v	Chord Height Tolerance
CYLINDER_0	X	YELLOW	MESH	ADAPTIVE	----	3.64324
PLANE_0	X	GRAY	WIRE	UNIFORM	2	-----
CYLINDER_1	X	RED	MESH	UNIFORM	2 2	-----
SPLINE_0	X	GRAY	TRIM	ADAPTIVE	----	3.64324
PLANE_1	X	GREEN	MESH	UNIFORM	2 2	-----
SPLINE_1	X	GRAY	TRIM	ADAPTIVE	----	3.64324
SPLINE_2	X	BLUE	WIRE	ADAPTIVE	----	3.64324
PLANE_2	X	GRAY	MESH	UNIFORM	2 2	-----
PLANE_3	X	CYAN	MESH	UNIFORM	2 2	-----
PLANE_4	X	GRAY	MESH	UNIFORM	2 2	-----
SPLINE_3	X	GRAY	TRIM	ADAPTIVE	----	3.64324

Figure 4.29 The *Surface Properties* Dialog Box

The last three columns of this dialog box show the surface display density control parameters. When the display density control mode is ADAPTIVE, the display density of a surface is controlled by the chord height tolerance which is shown in the chord height tolerance column. When the display density control mode is UNIFORM, the segment number for wireframe or the mesh density for surface mesh will be shown in the uniform density column. If the surface is displayed in wireframe mode, the surface display density is the same as the display density of its boundary curves, and the segment number for each boundary curve will be shown in the “u” column. If the surface is displayed in mesh or trimmed mesh, the surface mesh density is controlled by the number of grids in u and v parameter directions which are shown in the “u” and “v” columns.

To modify the properties of a surface, select the surface and click the **[Edit]** button to invoke the *Edit Surface Properties* dialog box as shown in Figure 4.30. The layout of the *Edit Surface Properties* dialog box will change according to the selected surface display mode and the selected display density control mode. Figure 4.30 shows two different layouts of the *Edit Surface Properties* dialog box for ADAPTIVE WIRE (frame) mode and UNIFORM WIRE (frame) mode.

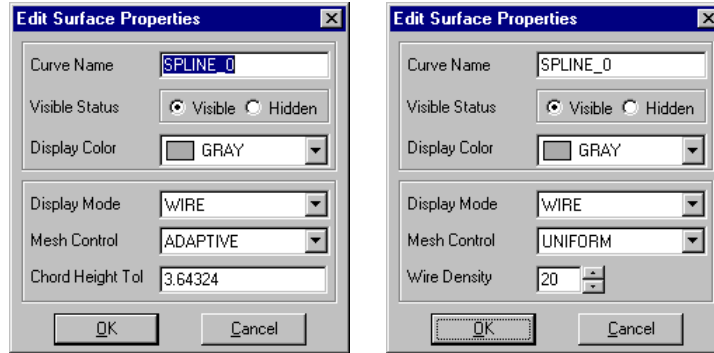


Figure 4.30 The *Edit Surface Properties* Dialog Boxes

4.10.4 Editing Deviation Cloud Properties

See section 4.5 for more information on display options of deviation cloud class

To edit the properties of deviation clouds, select menu **/Deviation/Edit Properties** to bring up the *Deviation Cloud Properties* dialog box as shown in Figure 4.31. This dialog box displays the properties of all deviation cloud entities in the database.

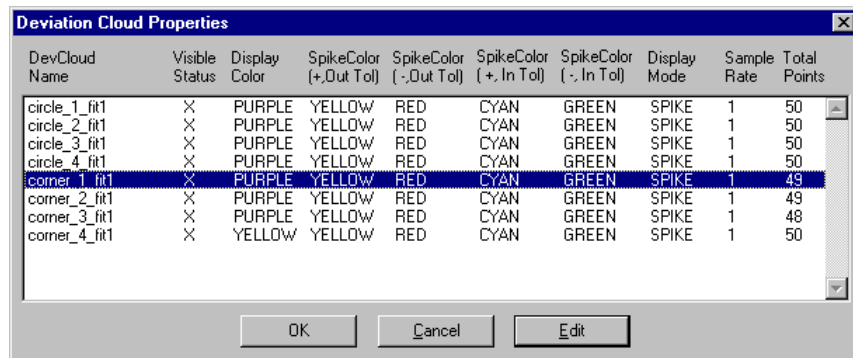


Figure 4.31 The *Deviation Cloud Properties* Dialog Box

To modify the properties of a deviation cloud, select the deviation cloud and click the **[Edit]** button to invoke the *Edit Deviation Cloud Properties* dialog box as shown in Figure 4.32.

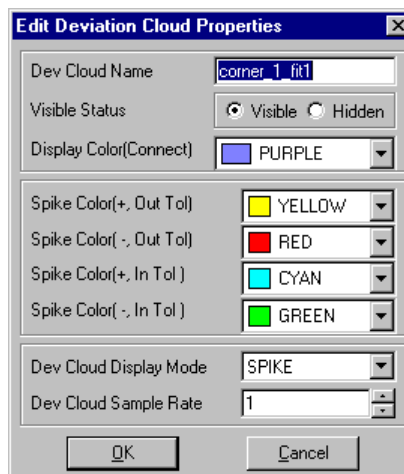


Figure 4.32 The *Edit Deviation Cloud Properties* Dialog Box

4.10.5 Editing Group Properties

See section 4.5 for more information on display options of group class

To edit the properties of groups, select menu **/Group/Edit Properties** to bring up the *Group Properties* dialog box as shown in Figure 4.33. This dialog box displays the properties of all group entities. The name of each group is shown in the first column. In the second column, the type of the group is displayed. There are four different group types: PNTCLOUD group, CURVE group, SURFACE group, and DEVCLOUD group. Most groups have only one display color except the deviation cloud groups which have five display colors. The display colors of a deviation cloud group are the same as the display colors of a deviation cloud.

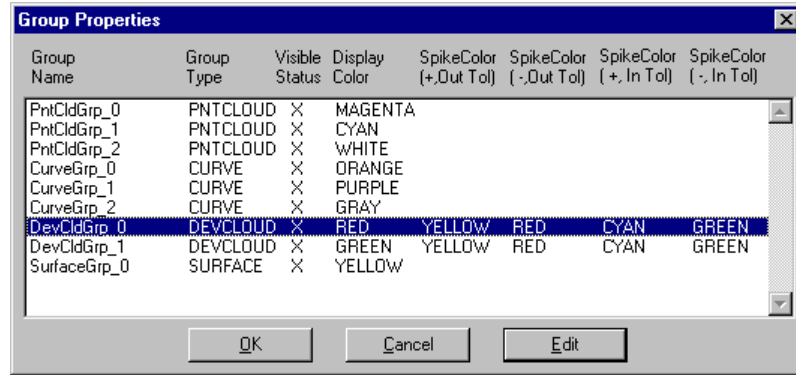


Figure 4.33 The *Group Cloud Properties* Dialog Box

To modify the properties of a group, double click the group or select the group and click the **[Edit]** button to invoke the *Edit Group Properties* dialog box shown in Figure 4.34. The layouts of the *Edit Group Properties* dialog box are different for deviation cloud groups and non-deviation cloud groups.

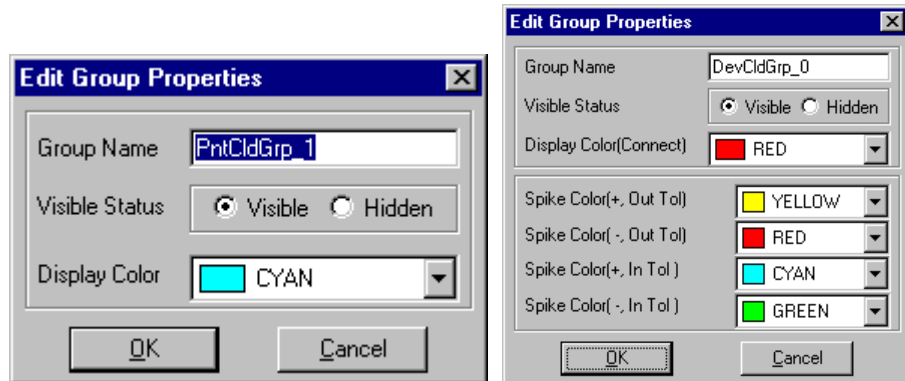


Figure 4.34 The *Edit Group Properties* Dialog Box

4.11 Showing/Hiding Entities

When a database contains a lot of geometric entities and the display becomes very crowded, it is very helpful to hide some entities so that the user can get a better look at the entities of interest. IQ-FormFit provides several ways to change the visible status of geometric entities. In section 4.7, we discussed how to change the visible status of entities using the setting display properties operation. In section 4.8, we discussed how to change the visible status of entities using the editing entity

properties function. Here we introduce a new set of commands that toggle the visible status of the entities of a given entity class. This set of commands include **Show All**, **Hide All**, **Show Active Only**, **Hide Picked**, **Hide Boxed** and **Switch Show/Hide**. The functions and operations of this set of commands are explained as follows:

- **Show All**
This command will show all entities of an entity class.
- **Hide All**
This command will hide all entities of an entity class.
- **Show Active Only**
This command will hide all entities in a class except the active entity of that class which will be made visible
- **Hide Picked**
When this command is invoked, the mouse will enter the picking operation mode and the mouse cursor will change to a hand. Under this operation mode, the user can start to pick any entities of a particular entity class and hide them. After finishing picking, the user should press the **<ESC>** key to end this operation.
- **Hide Boxed**
When this command is invoked, the mouse cursor will change to cross to allow the user to draw a rectangular rubber band on the screen. Any entities of a particular entity class that completely fall inside the user drawn rubber band will be hidden.
- **Switch Show/Hide**
This command will toggle the visible status flag for each entity in a particular entity class, i.e. visible entities of that class will become hidden and hidden entities will become visible. This command is particularly useful when you want to hide all entities of an entity class except a few. In this case, you can first hide the entities that you want to be visible and then use this command to make the visible entities of that class become hidden and bring those entities of your interest visible.

The menu access for these commands are summarized as follows:

- Commands for Showing/Hiding Point Clouds
⇒ Menu access: **/Point"Show/Hide"/Show All**
/Point"Show/Hide"/Hide All
/Point"Show/Hide"/Show Active Only
/Point"Show/Hide"/Hide Picked
/Point"Show/Hide"/Hide Boxed
/Point"Show/Hide"/Switch "Show/Hide"
- Commands for Showing/Hiding Curves
⇒ Menu access: **/Curve"Show/Hide"/Show All**
/Curve"Show/Hide"/Hide All
/Curve"Show/Hide"/Show Active Only
/Curve"Show/Hide"/Hide Picked
/Curve"Show/Hide"/Hide Boxed
/Curve"Show/Hide"/Switch "Show/Hide"

- Commands for Showing/Hiding Surfaces
 - ⇒ Menu access: **/Surface”Show/Hide”/Show All**
/Surface”Show/Hide”/Hide All
/Surface”Show/Hide”/Show Active Only
/Surface”Show/Hide”/Hide Picked
/Surface”Show/Hide”/Hide Boxed
/Surface”Show/Hide”/Switch “Show/Hide”
- Commands for Showing/Hiding Deviation Clouds
 - ⇒ Menu access: **/Deviation”Show/Hide”/Show All**
/Deviation”Show/Hide”/Hide All
/Deviation”Show/Hide”/Show Active Only
/Deviation”Show/Hide”/Hide Picked
/Deviation”Show/Hide”/Hide Boxed
/Deviation”Show/Hide”/Switch “Show/Hide”
- Commands for Showing/Hiding Groups
 - ⇒ Menu access: **/Group”Show/Hide”/Show All**
/Group”Show/Hide”/Hide All
/Group”Show/Hide”/Show Active Only
/Group”Show/Hide”/Hide Picked
/Group”Show/Hide”/Hide Boxed
/Group”Show/Hide”/Switch “Show/Hide”

4.12 Displaying Entity Label

As described in section 4.2, the user can use the color changing feature in selecting or picking active entity to identify the correspondence between a particular entity and its name. However, it is sometimes more convenient to display the labels of all the entities of an entity class on the screen so that the user can quickly identify the correspondence between entities and their names. To display the labels of all the entities of an entity class, the user should select the menu items as summarized below. Selecting the same menu item again will turn off the entity labels. The label of each entity and the entity itself will be displayed in the same color.

- Displaying Labels for All Point Clouds
 - ⇒ Menu access: **/View/Label/Pnt Cloud**
 - ⇒ Function: Toggle label display for all point clouds
- Displaying Labels for All Curves
 - ⇒ Menu access: **/View/Label/Curve**
 - ⇒ Function: Toggle label display for all curves
- Displaying Labels for All Surfaces
 - ⇒ Menu access: **/View/Label/Surface**
 - ⇒ Function: Toggle label display for all surfaces
- Displaying Labels for All Deviation Clouds
 - ⇒ Menu access: **/View/Label/Dev Cloud**
 - ⇒ Function: Toggle label display for all deviation clouds
- Displaying Labels for All Groups
 - ⇒ Menu access: **/View/Label/Group**
 - ⇒ Function: Toggle label display for all groups

4.13 Grouping and Ungrouping Entities

Entities can be grouped together to form a group entity. To group entities, select the appropriate submenu of the **/Group** menu. This will invoke a group entity dialog box. Figure 4.35 shows the *Group Curves* dialog box.

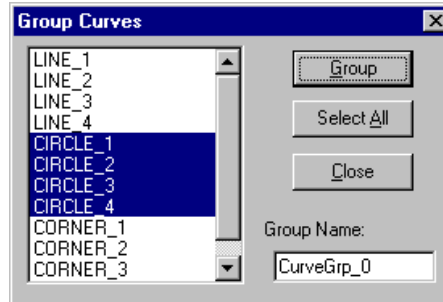


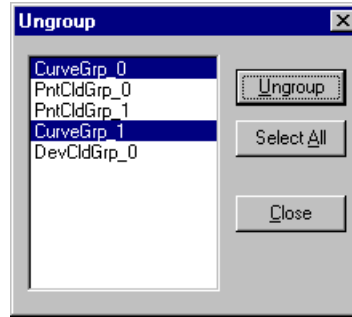
Figure 4.35 The *Group Curves* Dialog Box

In the dialog box, the entities available for grouping are listed in the entity list box. The user can select the entities to be grouped and then click the **[Group]** button. A default group name will be given in the “*Group Name*” box. The user can change the default group name by either editing the default group name or typing a new group name. Once an entity is grouped, it is no longer accessible through its original entity class. For example, if the active point cloud is grouped, the system does not treat it as an individual point cloud any more but as a member of a group entity. Therefore, it can no longer be set to the active point cloud. When the active entity of a given entity class is grouped, the system automatically select another entity in that class as the active entity.

The menu access for grouping operations are summarized as follows:

- Grouping Point Clouds
 - ⇒ Menu access: **/Group/Group Point Clouds**
 - ⇒ Function: Grouping point clouds to form a PNTCLOUD group
- Grouping Curves
 - ⇒ Menu access: **/Group/Group Curves**
 - ⇒ Function: Grouping curves to form a CURVE group
- Grouping Surfaces
 - ⇒ Menu access: **/Group/Group Surfaces**
 - ⇒ Function: Grouping surfaces to form a SURFACE group
- Grouping Deviation Clouds
 - ⇒ Menu access: **/Group/Group Dev Clouds**
 - ⇒ Function: Grouping deviation clouds to form a DEVCLOUD group

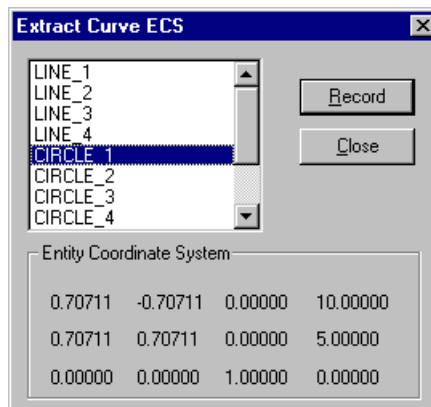
Grouped entities can be ungrouped. To ungroup the grouped entities, select the menu **/Group/Ungroup** to invoke the *Ungroup* dialog box as shown in Figure 4.36. The user can select the groups to be ungrouped and click the **[Ungroup]** button to ungroup the selected groups. The ungrouped entities will be treated as individual entities of their original entity class.

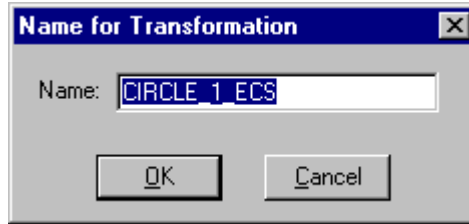
Figure 4.36 The *Ungroup Dialog Box*

4.14 Extracting Entity Coordinate System

As discussed in section 4.3, the position and orientation of each geometric entity is represented by its entity coordinate system. Mathematically the entity coordinate system is expressed as a 3x4 transformation matrix. The first three column of the transformation matrix defines the axis direction for the entity coordinate system with respect to the world coordinate system and the fourth column defines the origin of the entity coordinate system in the world coordinate system. When an entity is transformed, its entity coordinate system is changed and the transformation matrix is updated. IQ-FormFit provides a set of commands for the user to extract the transformation matrix representing the entity coordinate system and save the transformation matrix for other uses such for alignment.

To extract the entity coordinate system, select the corresponding sub menu item of **/Edit/Extract Ent Coord Sys** to invoke the extract ECS dialog box. Figure 4-37 shows the *Extract Curve ECS* dialog box. When an entity is selected from the entity list, the transformation matrix of the entity coordinate system will be shown in the “Entity Coordinate System” box. The user can click the **[Record]** button to record the transformation matrix for later use or the **[Close]** button to close the dialog box. When the **[Record]** button is clicked, the *Name for Transformation* dialog box as shown in Figure 4.38 will pop up to let to the user to specify a name for the transformation matrix to be recorded. The user can either accept the default name or type a new name.

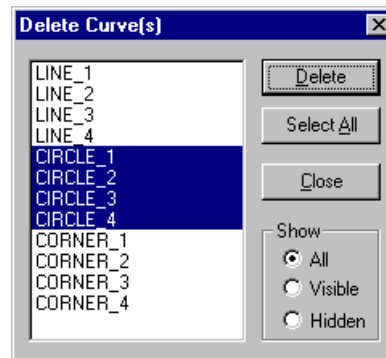
Figure 4.37 The *Extract Curve ECS Dialog Box*

Figure 4.38 The *Name for Transformation* Dialog Box




4.15 Deleting Entities



4.15.1 Delete Selected Entities

To delete entities of an entity class, select the appropriate menu item or use the delete entity buttons on the tool box to invoke the delete entity dialog box. Figure 4.39 shows the *Delete Curve(s)* dialog box. When the dialog box pops up, all entities of that particular entity class are listed in the list box. If the “Visible” option is selected, then only visible entities of that class will be listed. If the “Hidden” option is selected, then only the hidden entities of that class will be listed. From the list box, the user can select the entity or entities to be deleted and click the **[Delete]** button to delete the selected items. The **[Select All]** button will select all the entities in the entity list.

Figure 4.39 The *Delete Curve(s)* Dialog Box

Access methods for deleting entities of each entity class are summarized as follows:

- Deleting Point Cloud
 - ⇒ Menu access: **/Edit/Delete/Pnt Cloud**
 - ⇒ Button access: **[Delete Pnt Cloud]** button 
- Deleting Curve
 - ⇒ Menu access: **/Edit/Delete/Curve**
 - ⇒ Button access: **[Delete Curve]** button 
- Deleting Surface
 - ⇒ Menu access: **/Edit/Delete/Surface**
 - ⇒ Button access: **[Delete Surface]** button 

- Deleting Deviation Cloud
 - ⇒ Menu access: **/Edit/Delete/Dev Cloud**
 - ⇒ Button access: **[Delete Dev Cloud]** button 
- Deleting Group
 - ⇒ Menu access: **/Edit/Delete/Group**
 - ⇒ Button access: **[Delete Group]** button 
- Deleting Vector
 - ⇒ Menu access: **/Edit/Delete/Vector**
- Deleting Transformation
 - ⇒ Menu access: **/Edit/Delete/Transformation**

By selecting menu **/Edit/Clear All**, the user can delete the content of an entire database including all geometric and non-geometric entities.

4.15.2 Delete Picked Entities

IQ-FormFit also allows the user to delete any visible geometric entities by mouse picking. To delete an entity, using mouse picking, the user should select the appropriate menu to enter the corresponding mouse operation mode and then use the mouse to pick the entity to be deleted. For example, the user can select menu **/Edit/Pick to Delete/Curve** to enter the pick to delete curve operation mode. In this mode, the mouse cursor will change to a hand cursor and a message will be displayed on the status bar to prompt the user to pick to delete any visible curves. To exit this mouse operation mode, the user can hit the **<ESC>** key. Otherwise this operation mode will remain in effect until there are no visible curves to pick or another mouse operation mode is invoked.

Menu selections for deleting entities using mouse pick are summarized as follows:

- Pick to delete point cloud
 - ⇒ Menu access: **/Edit/Pick to Delete/Pnt Cloud**
- Pick to delete curve
 - ⇒ Menu access: **/Edit/Pick to Delete/Curve**
- Pick to delete surface
 - ⇒ Menu access: **/Edit/Pick to Delete/Surface**
- Pick to delete deviation cloud
 - ⇒ Menu access: **/Edit/Pick to Delete/Dev Cloud**
- Pick to delete group
 - ⇒ Menu access: **/Edit/Pick to Delete/Group**

4.16 Re-ordering Entity List

In IQ-FormFit database, there is an entity list for each entity class and all entities in the entity class are put into the entity list in the order that the entity is registered to the entity list. However, the user can change the order of an entity list using the re-ordering entity list function. To use this function to re-order an entity list, select the appropriate menu to bring up the change order dialog box. Figure 4.40 shows the *Change Curve Order* dialog box. When an entity is selected from the list box, the selected entity will be set to the active entity of its class and displayed in yellow color on the screen so that the user can easily identify which entity she/he is working on. When the up-arrow button or the down-arrow button is clicked, the position of the selected entity in the entity list will be moved up or down accordingly.

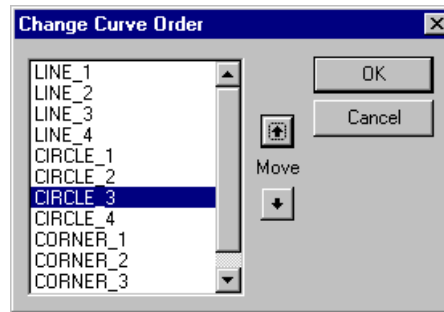


Figure 4.40 The *Change Curve Order* Dialog Box

Menu selections for re-ordering entity list operations are summarized as follows:

- Re-ordering Point Cloud List
⇒ Menu access: **/Point/Re-ordering Pnt Cloud List**
- Re-ordering Curve List
⇒ Menu access: **/Curve/Re-ordering Curve List**
- Re-ordering Surface List
⇒ Menu access: **/Surface/Re-ordering Surface List**
- Re-ordering Deviation Cloud List
⇒ Menu access: **/Deviation/Re-ordering Dev Cloud List**

Chapter 5 Operations for Vectors and Transformations

5.1 Introduction

See section 4.3 on how to transform an active entity

Vector and transformation are two non-geometric entity types supported by IQ-FormFit. Vectors are often used for the translation of an active entity and transformations are used for the transformation of an active entity. In sections 3.2.9 and 3.2.10, we discussed how to export vector and transformation to a file. In section 4.15 we discussed how to delete vector and transformation entities. In this chapter, we will discuss how to create vectors and transformations, and.

5.2 Creating Vector

See section 4.3.2 on how to translate an active entity by a vector

Vectors can be used to translate an active entity. The user can create vectors and save them for later use in translation operations.

To create a vector, select menu **/Edit/Create/Vector** to bring up the *Create Vector* dialog box as shown in Figure 5.1. The user can input the three components of the vector. When the dialog box pops up, a default name will be displayed in the "Name" box for the new vector. The user can accept the default name or type a new name for the vector in the "Name" box.

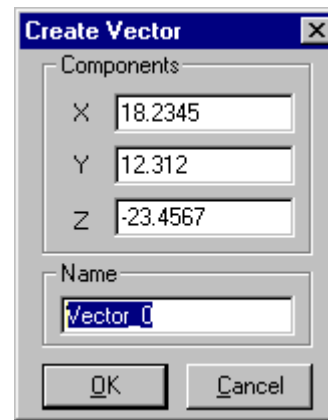


Figure 5.1 The *Create Vector* Dialog Box

5.3 Creating Transformation

See section 4.3.4 on how to transform an active entity by a transformation

Transformations can be used to transform an active entity. The user can create transformations and save them for later use in transformation operations.

To create a transformation, select menu **/Edit /Create /Xform** to bring up the *Create Transformation* dialog box as shown in Figure 5.2. A transformation can be created in many ways. Here the *Create Transformation* dialog box provides an interface for the user to create a transformation by specifying rotation plus translation. The rotation is determined by the rotation axis direction and the rotation angle. Notice that the rotation axis always passes through the origin of the world coordinate

system. The translation is the amount of movement after the rotation. When the dialog box pops up, a default name will be displayed in the “Name” box for the new transformation. The user can accept the default name for the transformation or type a new one in the “Name” box. If the rotation angle is given in degree, then the “Degree” check box should be checked. For rotation angle in radian, the “Degree” check box should be unchecked.

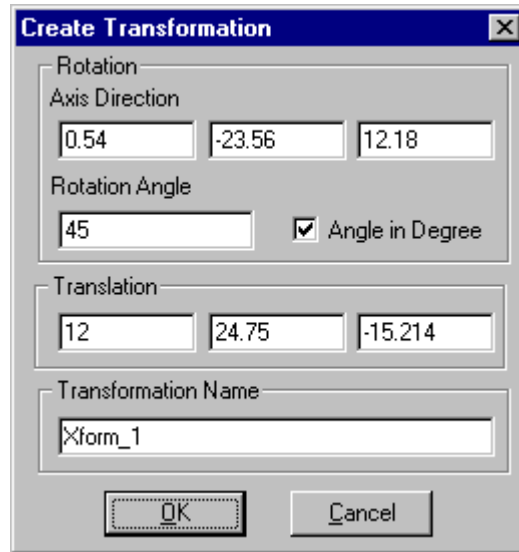


Figure 5.2 The *Create Transformation* Dialog Box

Chapter 6 Operations for Point Clouds

6.1 Introduction

Common operations for point clouds are discussed in chapter 4. The most frequently used common operations for point clouds include selecting/picking active point cloud, transforming active point cloud, local standard view of the active point cloud, setting point cloud display properties, editing point cloud properties, and deleting point clouds. In this chapter, operations that are specific to point cloud will be discussed. These operations include creating point clouds, modifying point clouds and supporting probe radius for point clouds.

6.2 Creating Point Clouds

As discussed in Chapter 3, measurement data points can be read into IQ-FormFit. IQ-FormFit also provides the interface for the user to create a point cloud either from a curve or from a surface.

6.2.1 Creating Point Clouds From Curves

To create point clouds from curves, select menu **/Point/Create From Curve** to bring up the *Create Point Cloud From Curve* dialog box as shown in Figure 6.1. The user can specify the number of points to generate from each of the selected curves and the offset amount of the generated points from the curves along curve normal direction. When the curves are selected from the curve list and the **[OK]** button is clicked, a point cloud will be created from each of the selected curves with uniform equal parameter spacing. The name of each generated point cloud is the prefix "From_" plus the curve name from which the point cloud is generated. For example, the name for the point cloud generated from "CIRCLE_1" will be "From_CIRCLE_1".

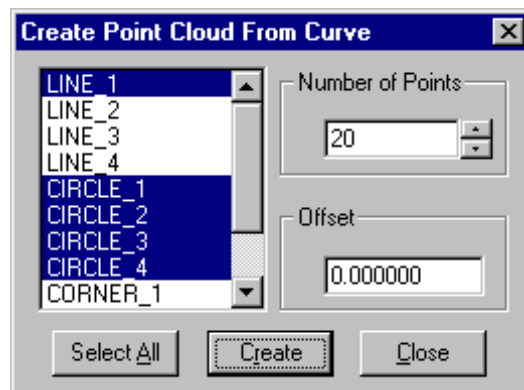


Figure 6.1 The *Create Point Cloud From Curve* Dialog Box

6.2.2 Creating Point Clouds From Surfaces

To create point clouds from surfaces, select menu **/Point/Create From Surface** to bring up the *Create Point Cloud From Surface* dialog box as shown in Figure 6.2. The user can specify the number of points to generate from each of the selected surfaces and the offset amount of the generated points from the surfaces along surface normal direction. If the “*Check Boundary*” box is checked, only points within the surface boundary will be kept. When the surfaces are selected from the surface list and the **[OK]** button is clicked, a point cloud will be created from each of the selected surfaces with uniform equal parameter spacing in u and v direction of the surface parameter space. The name of each generated point cloud is the prefix “From_” plus the surface name from which it is generated. For example, the name for the point cloud generated from “PLANE_3” will be “From_PLANE_3”.

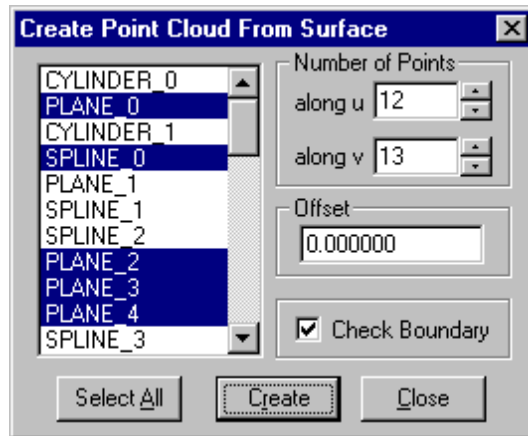


Figure 6.2 The *Create Point Cloud From Surface* Dialog Box

6.3 Modifying Point Clouds

In order to perform tolerance evaluation and bestfit analysis operations, it is often necessary to modify point clouds. This section will introduce the tools provided for the user to modify point clouds. Point cloud modification includes projecting to working plane, projecting to bestfit plane, circle-selecting point clouds and merging point clouds.

6.3.1 Working Plane and 2D Point Cloud

We know that curve features such as arc, circle, ellipse and parabola are planar curves. When fitting a planar curve from a point cloud, all data points of the point cloud must be co-planar. However, measurement data points are usually not strictly co-planar. Therefore, we need to select a reference plane and project all data points of the point cloud onto the reference plane. The reference plane is called the **Working Plane**. Since a plane is defined by the xy-plane of the plane’s entity coordinate system, the entity coordinate system of the working plane is called the **Working Coordinate System**. Figure 6.3 illustrates the working plane and working coordinate system for a point cloud.

When a general point cloud is projected to a selected working plane, the entity coordinate system of the point cloud will be set to the working coordinate system and all data points will be on the xy-plane of the working coordinate system. A point

cloud is called a **2D Point Cloud** when all data points of the point cloud are on the xy-plane of the point cloud's entity coordinate system. Otherwise, it is called a **3D Point Cloud**

In IQ-FormFit, the user can project an existing point cloud to any existing plane or to the bestfit plane of the point cloud itself. When the point cloud is projected to an existing plane, the working plane is explicitly selected. When the point cloud is projected to its bestfit plane, the bestfit plane of the point cloud is implicitly selected as the working plane. It is important to point out that if all points of a point cloud are very close to a line(co-linear point cloud), the bestfit plane of the point cloud be either non-existing or very ill-conditioned. Therefore, a co-linear point cloud should not be projected to its own bestfit plane.

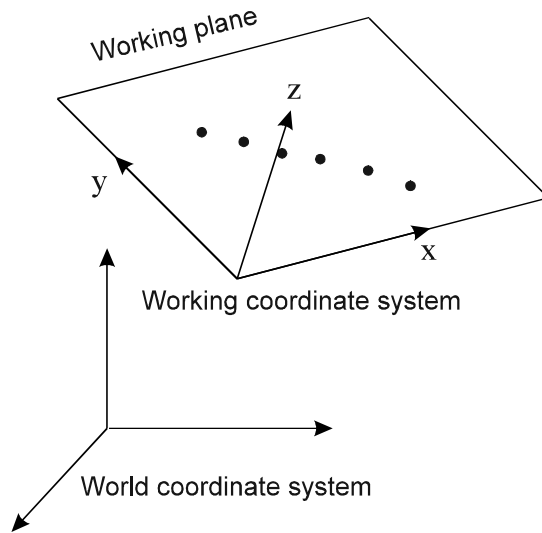


Figure 6.3 Working Plane and Working Coordinate System

6.3.2 Projecting Point Clouds to Working Plane

To project point clouds to a working plane, select menu **/Point/ Project To Working Plane** to invoke the *Project Cloud To Working Plane* dialog box as shown in Figure 6.4.

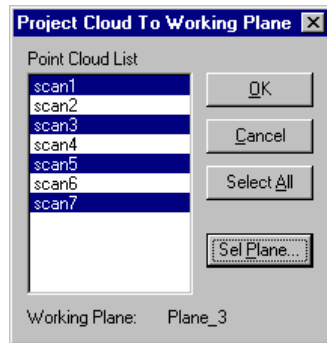


Figure 6.4 The *Project Cloud To Working Plane* Dialog Box



Figure 6.5 The *Select Plane* Dialog Box

In order to carry out the projection, a projection plane must be selected. When the *Project Cloud To Working Plane* dialog box pops up, the default projection plane is the XY_PLANE of the world coordinate system. The user can click the **[Sel Plane]** button to bring up the *Select Plane* dialog box to select a different working plane. Figure 6.5 shows the *Select Plane* dialog box which lists the three coordinate planes (XY_PLANE, YZ_PLANE and ZX_PLANE) of the world coordinate system and all plane entities in the database. When a working plane is selected, the name of the selected working plane will be displayed at the bottom of the *Project Cloud To Working Plane* dialog box as shown in Figure 6.4.

Once a projection plane is selected, the user can select one or more point clouds to project them to the selected working plane. Clicking the **[OK]** button will execute the projection and convert the selected point clouds to 2D point clouds.

6.3.3 Projecting Point Clouds to Bestfit Plane

To project point clouds to their own bestfit planes, select menu **/Point/Project To Bestfit Plane** to bring up the *Project Cloud To Bestfit Plane* dialog box as shown in Figure 6.6. Selecting the point clouds from the point cloud list and clicking the **[OK]** button will carry out the projection and convert the selected point clouds to 2D point clouds. After projecting a point cloud to its bestfit plane, the local coordinate system of each converted 2D point cloud is set to the coordinate system of its bestfit plane.

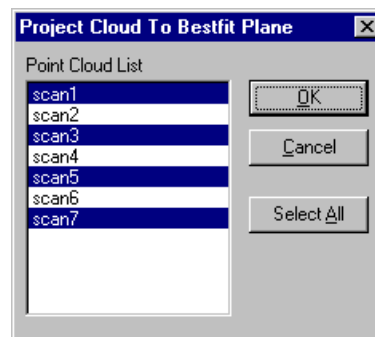


Figure 6.6 The *Project Cloud to Bestfit Plane* Dialog Box

6.3.4 Circle-Selecting Point Clouds

It is sometimes necessary to delete some “bad” points from a point cloud or combine some points from different point clouds to create a new point cloud. These tasks can be performed through the circle-selecting point clouds operation. To carry out this operation, first select menu **/Point/Circle-Select Points** to set the mouse operation mode to DRAW POLYGON mode. In this mode, the cursor will change to the pencil-shaped cursor, and the user can use the mouse to draw a circling polygon on the screen, as shown in Figure 6.7. The circling polygon is drawn through a sequence of click-release of the left mouse button. A final double click of the left mouse button will close the circling polygon and end the drawing.

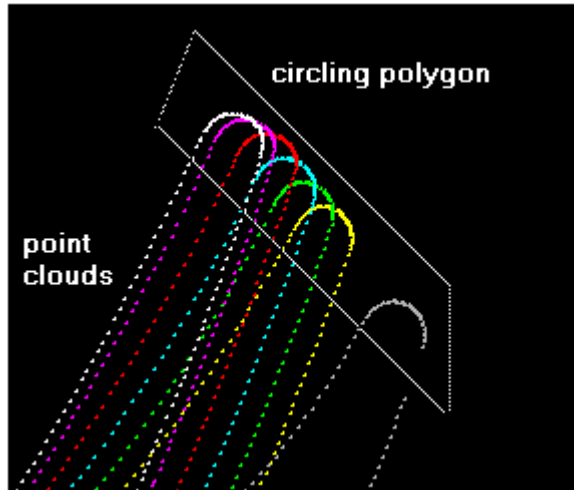
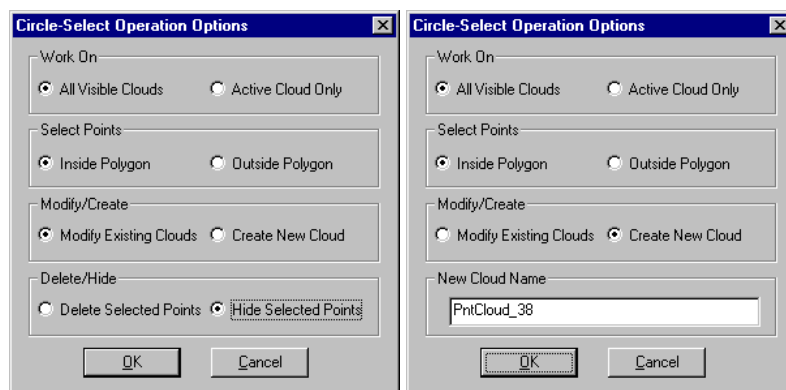


Figure 6.7 Circle-Selecting Points

After finishing drawing the circling polygon, the *Circle-Select Operation Options* dialog box, as shown in Figure 6.8, will pop up. The four pairs of radio buttons are used to specify what to do in the operation. The first pair of radio buttons specify if you want the operation only applies to the active point cloud or all visible point clouds. The second pair of radio buttons specify if you want to select the points inside the circling polygon or the points outside the circling polygon. The third pair of radio buttons specify if you want to use the selected points to create a new point cloud or modify the existing point clouds. When the “*Modifying Existing Clouds*” radio button is selected, you can choose either to hide the selected points in the existing point clouds or delete the selected points from the existing point clouds. When the “*Create New Cloud*” radio button is selected, the “*New Cloud Name*” box will be enabled. The user can accept the default cloud name or type a new name for the new point cloud. After checking the appropriate radio buttons, click the [OK] button to complete the operation. The contents of the existing point clouds will not be altered if the “*Create New Cloud*” radio button is selected.

Figure 6.8 The *Circle-Select Operation Options* Dialog Box

6.3.5 Merging Point Clouds to Create New Point Cloud

The user can select menu **/Point/Merge Point Clouds** to merge existing point clouds together to create a new point cloud. When the menu is selected, the *Merge Point Clouds* dialog box, as shown in Figure 6.9, will pop up.

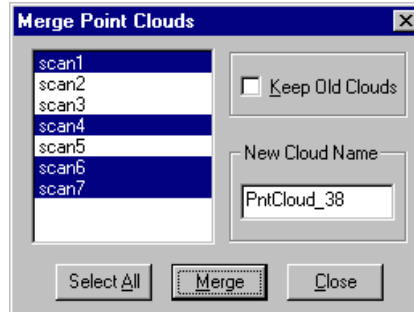


Figure 6.9 The *Merge Point Clouds* Dialog Box

Select the point clouds to be merged together from the available point clouds and click the **[Merge]** button, a new point cloud will be created. This operation will keep the selected existing point clouds if the “*Keep Old Clouds*” box is checked. The user can accept the default new point cloud name or type a different name for the new point cloud.

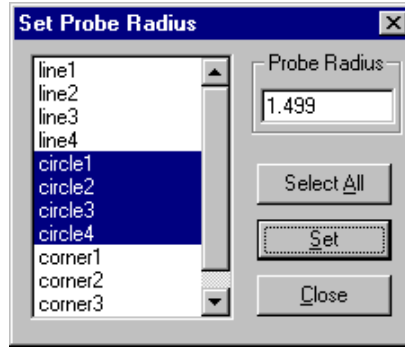
The local coordinate system of the newly created point cloud coincides with the world coordinate system, and it is a 3D point cloud even if it is created from 2D point clouds. If necessary, the user can convert it to a 2D point cloud by either projecting it to a working plane or to its own bestfit plane.

6.4 Supporting Probe Radius for Point Clouds

In IQ-FormFit, each point cloud can be associated with a probe radius. This probe radius will be used for automatic probe radius compensation in feature evaluation operation and bestfit analysis operation. The user can embed the probe radius information in an ASCII data file using the format specified in Appendix A. When the ASCII data file is imported into IQ-FormFit, the probe radius information will be correctly associated with each point cloud. The user can change the probe radius using the set probe radius function or the edit probe radius function. The set probe radius function can be used to associate a probe radius value to multiple point clouds while the edit probe radius function is designed to change the probe radius value one point cloud at a time.

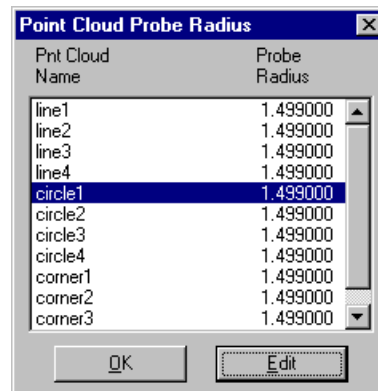
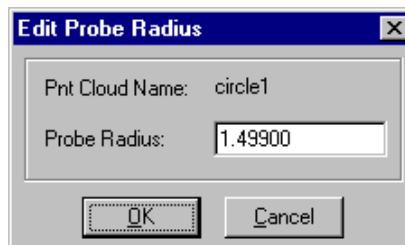
6.4.1 Setting Probe Radius for Point Clouds

To set probe radius for multiple point clouds, select menu **/Point/Set Probe Radius** to bring up the *Set Probe Radius* dialog box as shown in Figure 6.10. The user can select the point clouds from the point cloud list and specify the probe radius value in the “*Probe Radius*” box. When the **[Set]** button is clicked, the specified probe radius value will be associated to the selected point clouds. The user can continue to set the probe radius for other point clouds until the probe radius information is set for all point clouds.

Figure 6.10 The *Set Probe Radius* Dialog Box

6.4.2 Editing Probe Radius for Point Clouds

To edit probe radius for point clouds, select menu **/Point/Edit Probe Radius** to bring up the *Point Cloud Probe Radius* dialog box as shown in Figure 6.11. This dialog box lists all point clouds and displays the probe radius for each point cloud in the “*Probe Radius*” column. When the user select a point cloud from the point cloud list and clicks the **[Edit]** button, the *Edit Probe Radius* dialog box as shown in Figure 6.12 will pop up to let the user change the probe radius value for the selected point cloud. The user can continue to edit the probe radius for other point clouds until the probe radius information is correct for all point clouds.

Figure 6.11 The *Point Cloud Probe Radius* Dialog BoxFigure 6.12 The *Edit Probe Radius* Dialog Box

6.5 Interrogate Point

This operation is designed to help the user to easily identify the coordinates of a point in a point cloud on the screen with a mouse pick. To use this function, first select menu **/Point/Interrogate Point** to set the mouse operation mode to INTERROGATE POINT mode. In this operation mode, the mouse cursor will change to hand shaped cursor to prompt the user to pick a point on the screen. Once the point is picked, the picked point will be marked and a small yellow window, as shown in Figure 6.13, will popup to display the xyz coordinates of the picked point. The user can continue to pick other points to query their coordinates until the **<ESC>** key is hit to end this operation mode. The yellow window that displays the coordinates will automatically disappear when a time interval elapses or when the mouse cursor is moved.

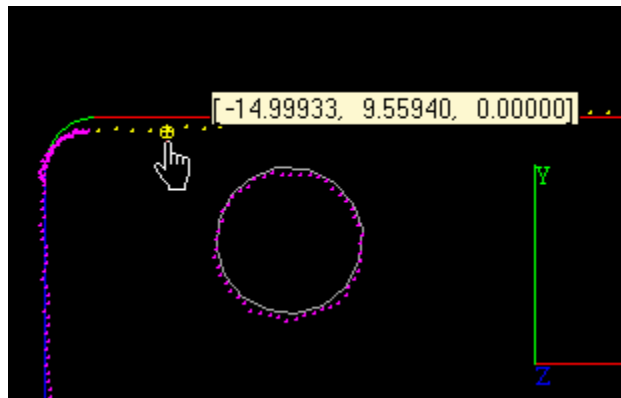


Figure 6.13 Interrogate Point

Chapter 7 Operation for Curves

7.1 Introduction

Common operations for curves are discussed in chapter 4. The most frequently used common operations for curves include selecting/picking active curve, transforming active curve, local standard view of the active curve, setting curve display properties, editing curve properties, and deleting curves. In this chapter, operations that are specific to curves will be discussed. These operations include fitting 2D and 3D curves from point clouds, constructing curves, modifying curves, form tolerance support for curves, position tolerance support for circles, and testing curve normal direction.

7.2 2D Curve and 3D Curve

For feature calculation and bestfit analysis operations, it is necessary to distinguish 2D and 3D curves. A curve is called a **2D Curve** if it satisfies the following three conditions:

- It is a planar curve;
- The curve lies on the xy-plane of its entity coordinate system;
- Its normal vector at any point of the curve also lies on the xy-plane of the curve's local coordinate system.

In contrast, a **3D Curve** is either a non-planar curve, or the curve does not lie on the xy-plane of the curve's local coordinate system, or some or all of the curve's normal vectors do not lie on the xy-plane of the curve's local coordinate system.

In IQ-FormFit, arcs, circles, ellipses and parabolas are 2D curves by nature. For a NURBS curve or a parametric spline curve, if the curve lies on the xy-plane of its local coordinate system, it is a 2D curve. Otherwise, it is a 3D curve even if it is a planar curve. For example, two curves shown in Figure 7.1 have exactly the same shape and they are both planar curves. However, due to the differences in their entity coordinate system, the curve shown on the left is a 2D curve while the one shown on the right is a 3D curve.

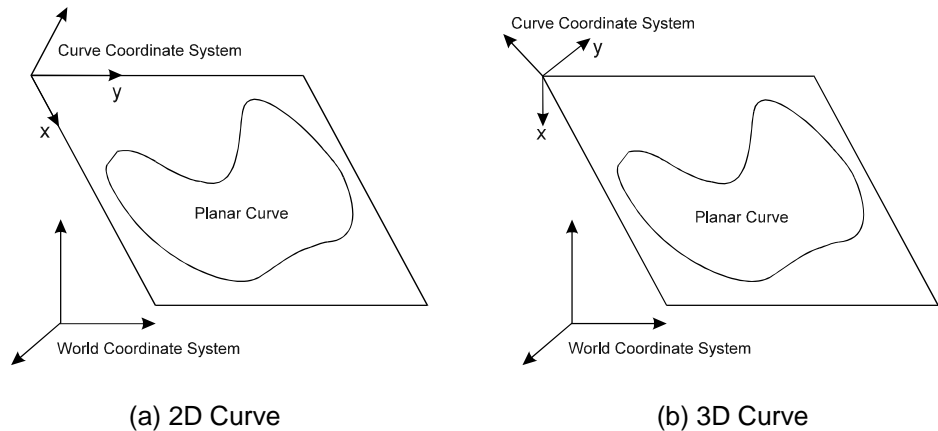


Figure 7.1 Definition of 2D and 3D Curves

Line entity is a special case, it can be a 2D line or a 3D line. IQ-FormFit defines a line along the x-axis of the line entity coordinate system. Therefore a line always lies on the xy-plane of its local coordinate system. However, for a 2D line, its normal vectors also lie on the xy-plane of the line coordinate system. For a 3D line, its normal vectors are not confined to the xy-plane of its entity coordinate system.

7.3 Fitting 2D Curves from Point Clouds

See section 6.3 on how to modify a general point cloud to a 2D point cloud

In metrology, it is often necessary to evaluate position/orientation, size and form errors of standard 2D curve features from measurement data. To meet these needs, IQ-FormFit provides a full set of evaluation functions for fitting standard 2D curves from point clouds. By using this set of functions, the user can calculate the position/orientation, size and form errors of these standard 2D curve features. This set of functions include fitting 2D line, arc, circle, ellipse, and parabola. In order to fit a 2D curve from a point cloud, the point cloud must be a 2D point cloud.

As described in section 6.3, when a point cloud is projected to a working plane, the local coordinate system of the converted 2D point cloud is set to the local coordinate system of the working plane (Figure 6.3). Therefore, by setting a 2D point cloud to be the active point cloud and switch to the local top view of the active point cloud, we can view the 2D point cloud in its working coordinate system (Figure 7.1). This special view is very convenient in viewing fitted 2D curves and deviations. In later discussion, we will see that this view is also very important in fitting 2D lines since it is necessary to specify line normal vector with respect to the x- or y-axis of the working coordinate system in 2D line fitting.

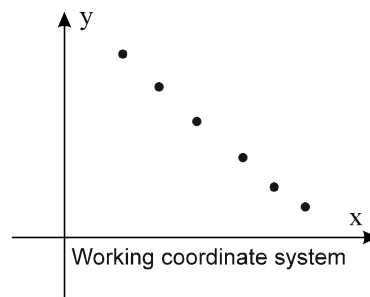


Figure 7.1 Local Top View of 2D Point Cloud

7.3.1 Fitting 2D Line from Point Cloud

See section 6.3 for definition of 2D point cloud

For fitting a 2D line from a point cloud, the point cloud must be a 2D point cloud. Before starting the fitting process, the user should set the 2D point cloud to be the active point cloud and change the view to the local top view of the active point cloud as shown in Figure 7.1. This step is necessary because the user must specify the normal direction of the line with respect to the working coordinate system of the 2D point cloud for probe compensation purpose when the user sets the options for 2D line fitting.

To fit a 2D line from a 2D point cloud, select menu **/Curve/Fit From Pnt Cloud/Fit 2D Line** to bring up the *Fit 2D Line* dialog box as shown in Figure 7.2. The dialog box lists all visible point clouds in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a 2D line from the

selected point cloud. If the selected point cloud is not a 2D point cloud, an error message will prompt the user to first convert the selected point cloud to a 2D point cloud. When the *Fit 2D Line* dialog box pops up, the default selection is the active point cloud.

The user can change the fitting options by clicking the **[Options]** button on the *Fit 2D Line* dialog box to bring up the *Options* dialog box as shown in Figure 7.3. From the *Options* dialog box, the user can select the desired accuracy level, specify the option for the normal vector direction of the line, specify the probe radius for probe compensation, and input form tolerance values for the fitted 2D line and the generated deviation cloud.

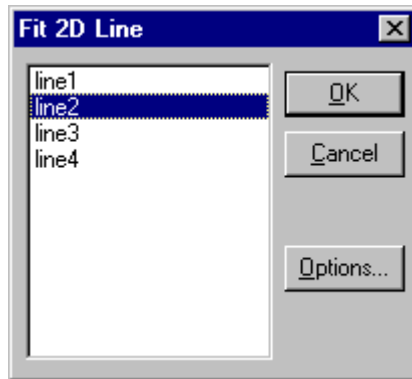


Figure 7.2 The *Fit 2D Line* Dialog Box

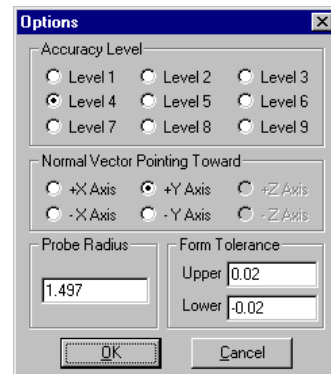


Figure 7.3 The *Options* Dialog Box

Selection of accuracy level for feature evaluation

The fitting process is an optimization process. During the fitting process, the program tries to find a set of feature parameters that minimize the RMS residual. IQ-FormFit lets the user select the accuracy level to control the termination condition for the optimization process. There are nine selectable accuracy levels. The relationship between each accuracy level and the accuracy of the fitting results can be approximately described as “for accuracy level n , the final RMS residual will be accurate to the n -th digit after the decimal point”. The default accuracy level is “Level 4” which means the RMS residual will be approximately accurate to the fourth digit after the decimal point.

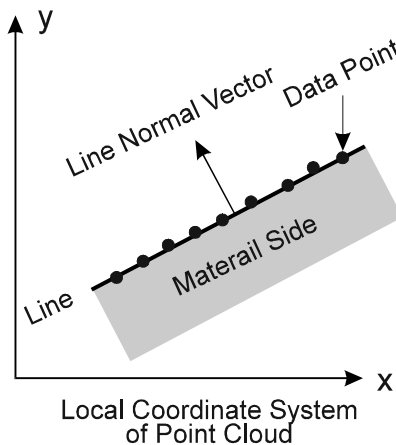


Figure 7.4 2D Line Normal Vector

The normal vector of a 2D line is defined as the unit vector perpendicular to the line and pointing away from the material side, as shown in Figure 7.4. The program uses this information to decide the material side of the line and the direction for probe radius compensation. The user should set the option for line normal vector according to the normal vector of the line relative to the working coordinate system of the 2D point cloud from which the line is to be fitted. For the example in Figure 7.4, the line normal vector option should be set to either “-X” or “+Y” since the line normal vector is pointing towards “-X” axis direction and “+Y” axis direction.

The probe radius is used for probe compensation. When the *Options* dialog box pops up, the probe radius associated with the selected point cloud will be displayed in the “*Probe Radius*” box. The user can type a different value in the “*Probe Radius*” box for probe radius compensation. However the probe radius value associated with the selected point cloud will not be updated.

The user can specify the form tolerance zone for the 2D line to be fitted from the point cloud. This form tolerance zone will be passed to the fitted 2D line and the generated deviation cloud. After selecting all the options, the user should click the **[OK]** button on the *Options* dialog box to return to the *Fit 2D Line* dialog box.

The operation of fitting a 2D line from a point cloud will create a line that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted 2D line. Since the data points are on the xy-plane of the local coordinate system of the point cloud, the deviation vectors resulted from the 2D line fitting are also co-planar. Figure 7.5 is the *2D Line Fitting Results* dialog box which displays the line parameters, deviation and form error information, as well as residual RMS value. The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard. Once the fitting results are copied to the clipboard, the user can paste the results to a text editor such as Windows’ Notepad or a word processor such as Microsoft Word to edit the results into desired format or insert the results into a report.

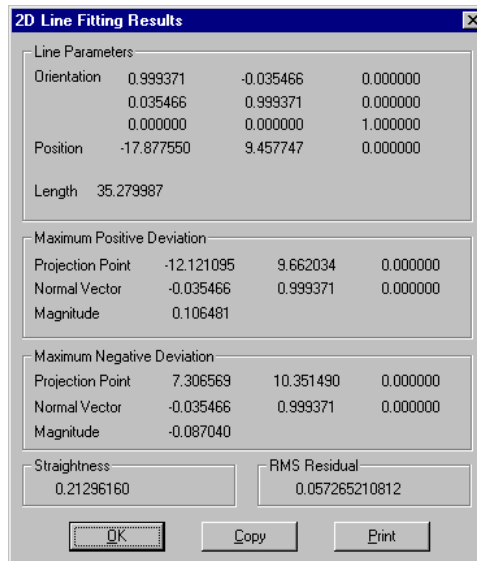


Figure 7.5 The 2D Line Fitting Results Dialog Box

IQ-FormFit defines a line along the positive x-axis of the line coordinate system (Figure 7.6). The orientation matrix shown in the *2D Line Fitting Results* dialog box is the orientation of the line coordinate system relative to the world coordinate system. The first column is the line direction vector and the second column is the line normal vector in world coordinate system. The position shown in the dialog box is the coordinate origin of the line coordinate system. The position is also the line starting point in the world coordinate system. The “*Maximum Positive Deviation*” and the “*Maximum Negative Deviation*” are the deviations from the two extreme points away from the fitted 2D line. The straightness of the fitted line is shown in the “*Straightness*” box. Finally, the residual RMS value for the 2D line fitting is displayed in the “*RMS Residual*” box.

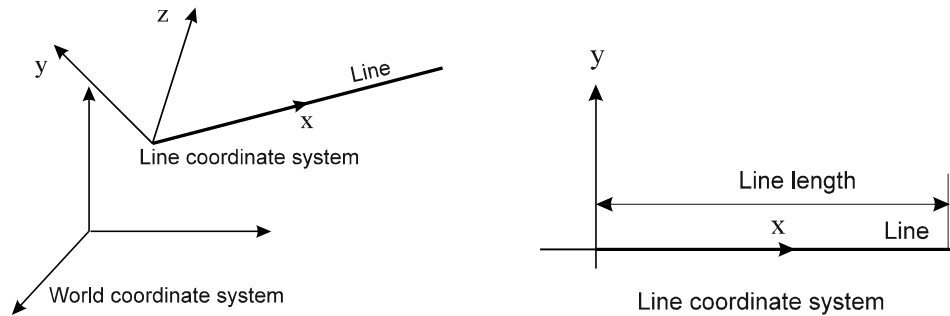


Figure 7.6 Line and Line Coordinate System

When a line is fitted from a point cloud, the newly fitted line will be automatically set as the active curve. By changing the view to the local top view of the active curve, the user can view the deviations as shown in Figure 7.7.

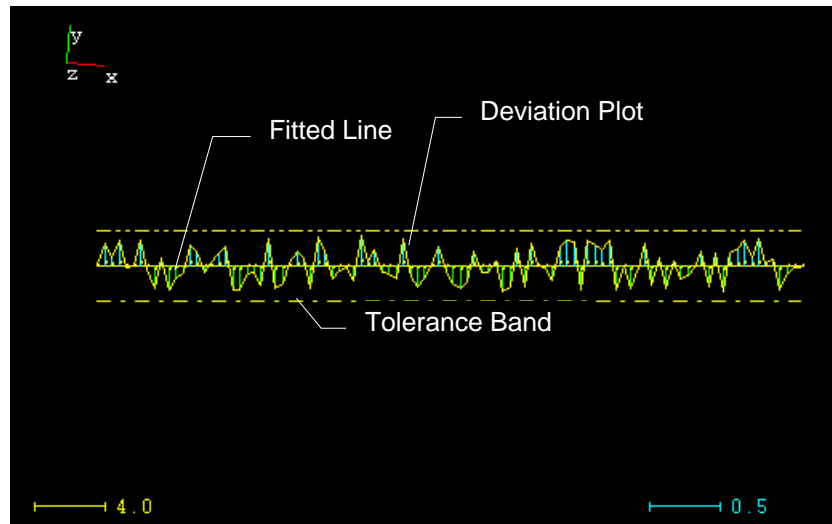


Figure 7.7 Viewing 2D Line Fitting Results from Line Local Top View

7.3.2 Fitting Arc from Point Cloud

See section 6.3 for definition of 2D point cloud

To fit an arc from a point cloud, select menu **/Curve/Fit From Pnt Cloud/Fit Arc** to bring up the *Fit Arc* dialog box as shown in Figure 7.8. The dialog box lists all visible point clouds in the point cloud list. An arc is a 2D curve entity by nature and it can only be fitted from a 2D point cloud. It is recommend that the user convert a point cloud to 2D point cloud using the methods described in section 6.3 before fitting an arc from the point cloud. However, if a 3D point cloud is selected for fitting an arc, the program will display a prompt message box. When the user confirms the continuation of the operation, the program will automatically project the 3D point cloud to its bestfit plane to convert it to a 2D point cloud before fitting an arc from the converted 2D point cloud.

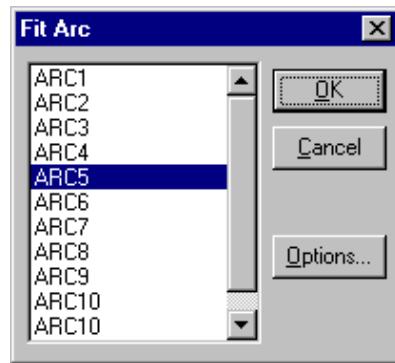


Figure 7.8 The *Fit Arc* Dialog box

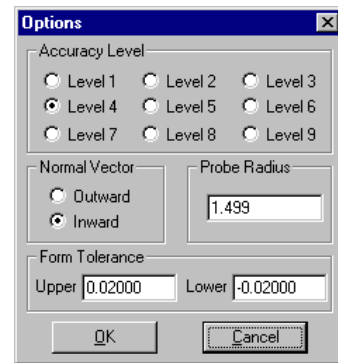


Figure 7.9 The *Options* Dialog Box

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can set the options for arc fitting if necessary. The *Options* dialog box can be invoked by clicking the **[Options]** button on the *Fit Arc* dialog box. From the *Options* dialog box, the user can select the desired accuracy level, specify the option for the normal vector direction of the arc, specify the probe radius for probe compensation, and input form tolerance values for the fitted arc and the generated deviation cloud. For an arc entity, its normal vector direction is “Outward” when it is part of a pin or “Inward” when it is part of a hole.

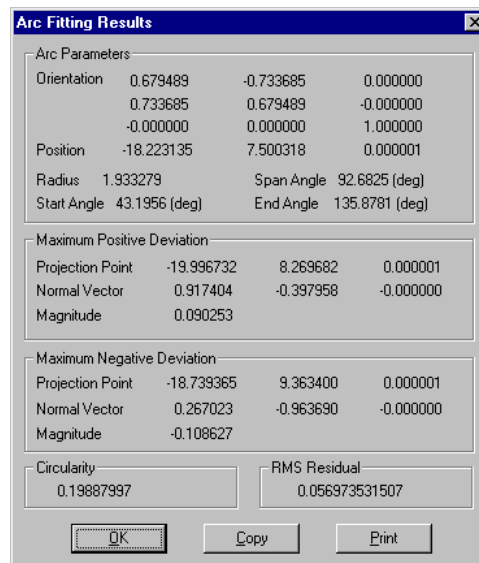


Figure 7.10 The *Arc Fitting Results* Dialog Box

The operation of fitting arc from a point cloud will create an arc that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted arc. Figure 7.10 shows the *Arc Fitting Results* dialog box. In the “*Arc Parameters*” box, the orientation matrix represents the orientation of the local coordinate system of the fitted arc with respect to world coordinate system, and the position is the coordinate origin of the arc coordinate system which is also the center of the arc in world coordinate system. Both the start angle and the end angle are CCW angles starting at the positive x axis of the arc coordinate system (Figure 7.11). The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

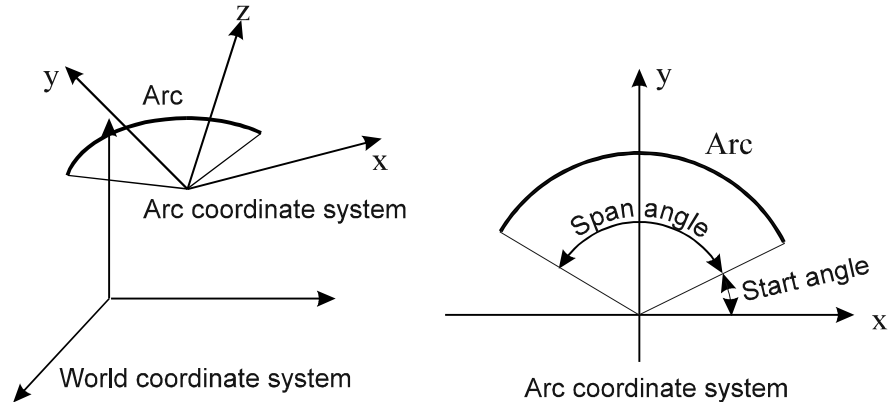


Figure 7.11 Arc and Arc Coordinate System

7.3.3 Fitting Circle from Point Cloud

The user can select menu **/Curve/Fit From Pnt Cloud/Fit Circle** to perform the operation of fitting a circle from a point cloud. The procedure for circle fitting operation is almost identical to that of arc fitting. A circle is only a special case of an arc with zero start angle and 2π span angle.

7.3.4 Fitting Ellipse from Point Cloud

To fit an ellipse from a point cloud, select menu **/Curve/Fit Curve From Pnt Cloud/Fit Ellipse** to invoke the *Fit Ellipse* dialog box as shown in Figure 7.12. The dialog box lists all visible point clouds in the point cloud list. An ellipse is a 2D curve entity by nature and it can only be fitted from a 2D point cloud. It is recommend that the user convert a point cloud to 2D point cloud using the methods described in section 6.3 before fitting an ellipse from the point cloud. However, if a 3D point cloud is selected for fitting an ellipse, the program will display a prompt message box. When the user confirms the continuation of the operation, the program will automatically project the 3D point cloud to its bestfit plane to convert it to a 2D point cloud before fitting an ellipse from the converted 2D point cloud.

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can set the options for ellipse fitting if necessary. The *Options* dialog box for fitting ellipse is the same as shown in Figure 7.9. It can be invoked by clicking the **[Options]** button on the *Fit Ellipse* dialog box. From the *Options* dialog box, the user can select the desired accuracy level, specify the option for the normal vector direction of the ellipse, specify the probe radius for probe compensation, and input

the form tolerance information for the fitted ellipse and the generated deviation cloud. For an ellipse entity, its normal vector direction is “Outward” when the material side is the inside of the ellipse or “Inward” when the material side is the outside of the ellipse.

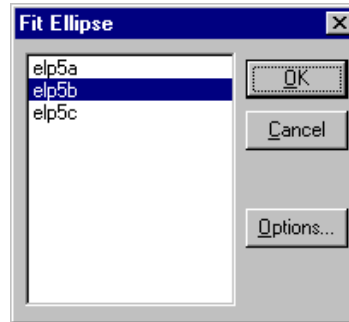


Figure 7.12 The *Fit Ellipse* Dialog box

The operation of fitting ellipse from a point cloud will create an ellipse that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted ellipse. Figure 7.13 is the *Ellipse Fitting Results* dialog box. In the “*Ellipse Parameters*” box, the orientation matrix represents the orientation of the local coordinate system of the fitted ellipse. The first column is the x-axis of the ellipse local coordinate system which is also the major axis direction of the fitted ellipse. The second column is the y-axis of the ellipse coordinate system which is also the minor axis direction of the fitted ellipse. The position shown in the “*Ellipse Parameters*” box is the center of the ellipse in the world coordinate system. Both the start angle and the end angle are CCW angles starting at the positive x axis of the local coordinate system of the fitted ellipse (Figure 7.14). The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

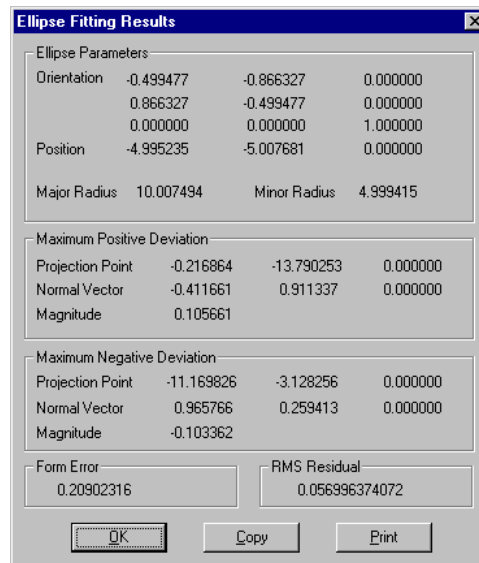


Figure 7.13 The *Ellipse Fitting Results* Dialog Box

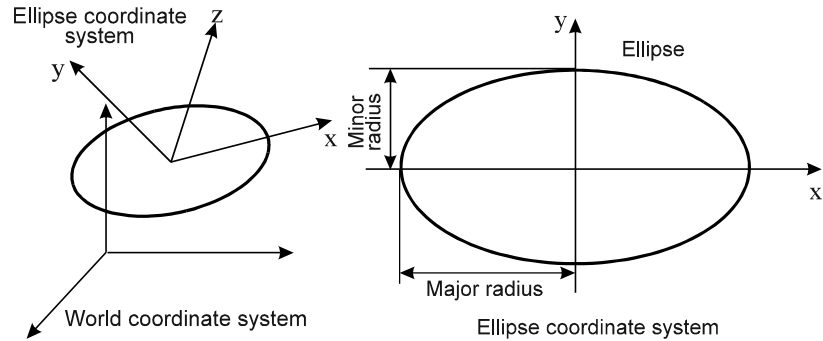
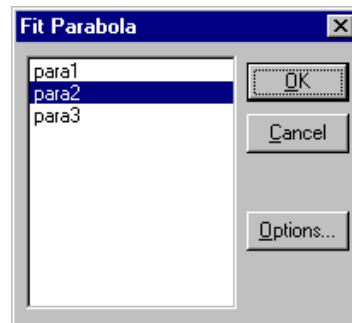


Figure 7.14 Ellipse and Ellipse Coordinate System

7.3.5 Fitting Parabola from Point Cloud

See section 6.3 for discussion on definition of 2D point cloud

To fit a parabola from a point cloud, select menu **/Curve/Fit From Pnt Cloud/ Fit Parabola** to invoke the *Fit Parabola* dialog box as shown in Figure 7.15. The dialog box lists all visible point clouds in the point cloud list. A parabola is a 2D curve entity by nature and it can only be fitted from a 2D point cloud. It is recommended that the user convert a point cloud to 2D point cloud using the methods described in section 6.3 before fitting a parabola from the point cloud. However, if a 3D point cloud is selected for fitting a parabola, the program will display a prompt message box. When the user confirms the continuation of the operation, the program will automatically project the 3D point cloud to its bestfit plane to convert it to a 2D point cloud before fitting a parabola from the converted 2D point cloud.

Figure 7.15 The *Fit Parabola* Dialog box

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can set the options for parabola fitting if necessary. The *Options* dialog box for fitting ellipse is the same as shown in Figure 7.9. It can be invoked by clicking the **[Options]** button on the *Fit Parabola* dialog box. From the *Options* dialog box, the user can select the desired accuracy level, specify the option for the normal vector direction of the parabola, specify the probe radius for probe compensation, and input form tolerance information for the fitted parabola and the generated deviation cloud.

The operation of fitting parabola from a point cloud will create a parabola that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted parabola. Figure 7.16 is the *Parabola Fitting Results* dialog box. In the "Parabola Parameters" box, the orientation matrix represents the orientation of the local coordinate system of the fitted parabola. The first column of the orientation matrix is the x-axis of the parabola local coordinate system which is also the symmetric axis of the fitted parabola. The position shown in the "Parabola

Parameters box is the focal point of the parabola in the world coordinate system. Both the start angle and the end angle are CCW angles starting at the positive x axis of the local coordinate system of the fitted parabola (Figure 7.17). The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

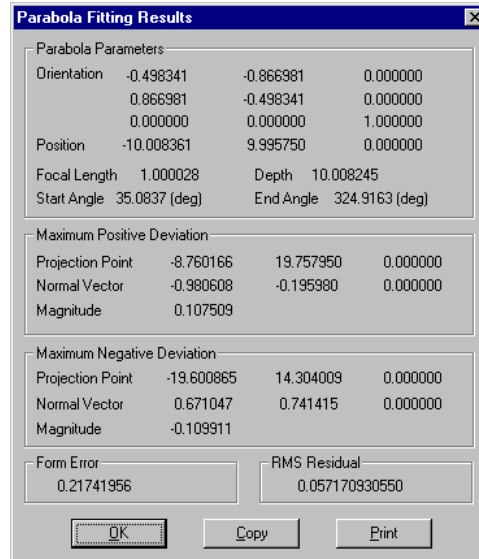


Figure 7.16 The *Parabola Fitting Results* Dialog Box

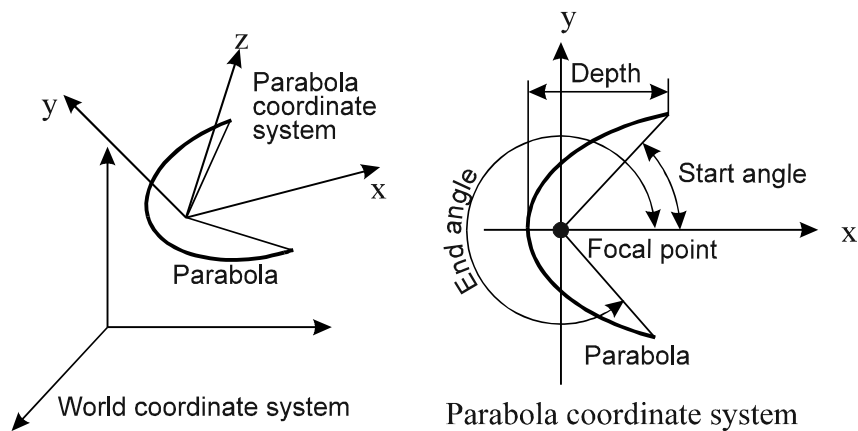


Figure 7.17 Parabola and Parabola Coordinate System

7.4 Fitting 3D Curves from Point Clouds

In IQ-FormFit, 3D lines, NURBS curves, spline curves are possible 3D curves. For a 3D line, its normal vectors are perpendicular to the line but not confined to the xy-plane of its local coordinate system. For a NURBS curve or a spline curve, it may not necessarily be a planar curve, or the curve may not be on the xy plane of its entity coordinate system.

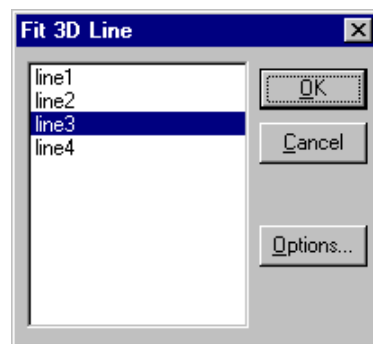
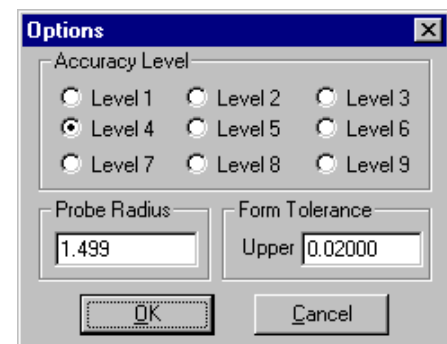
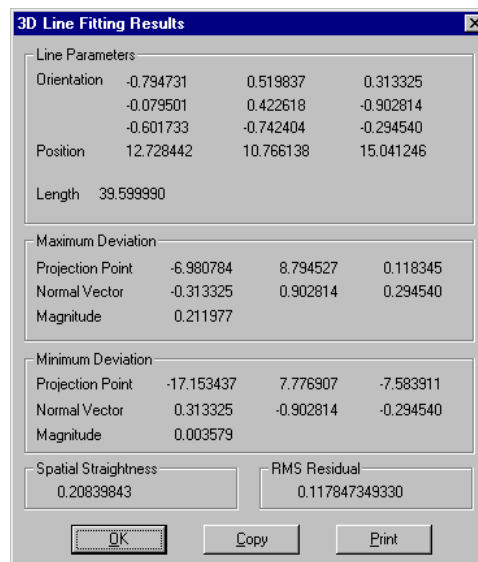
IQ-FormFit allows the user to fit a 3D curve directly from a general 3D point cloud without having to convert the 3D point cloud to a 2D point cloud as required in 2D curve fitting.

7.4. 1 Fitting 3D Line from Point Cloud

To fit a 3D line from a point cloud, select menu **/Curve/Fit From Pnt Cloud/Fit 3D Line** to bring up the *Fit 3D Line* dialog box as shown in Figure 7.18. The dialog box lists all visible point cloud in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a 3D line from the selected point cloud. When the *Fit 3D Line* dialog box pops up, the default selection is the active point cloud.

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can change the fitting options by clicking the **[Options]** button on the *Fit 3D Line* dialog box to bring up the *Options* dialog box as shown in Figure 7.19. From the *Options* dialog box, the user can select the desired fitting accuracy level, specify the probe radius for probe compensation, and input upper bound of form tolerance zone for the fitted 3D line and the generated deviation cloud. The lower bound of form tolerance zone for a 3D line is always zero.

Figure 7.18 The *Fit 3D Line* Dialog BoxFigure 7.19 The *Options* Dialog BoxFigure 7.20 The *3D Line Fitting Results* Dialog Box

The operation of fitting a 3D line from a point cloud will create a 3D line that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted 3D line. Figure 7.20 shows the *3D Line Fitting Results* dialog box. The first column of the orientation matrix is the line direction vector and the position

vector is the line starting point in the world coordinate system. Since 3D lines are only abstract lines such as axis of cylinder, cone, etc., they do not have material side. Therefore, normal vector is meaningless for 3D lines and the second column of the line orientation matrix, which is the y-axis of line coordinate system, does not represent the normal vector of the line. 3D lines can be converted to 2D lines when they are projected to a working plane. The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

When fitting a 3D line from a point cloud, the deviation of each point is always non-negative and equal to the normal distance from the point to the fitted 3D line. The deviation vector of each point is perpendicular to the 3D line and points away from the 3D line. It is obvious that the deviation vectors resulted from 3D line fitting are not co-planar. Spatial straightness of the fitted 3D line equals to twice the maximum deviation.

7.4.2 Fitting NURBS Curve from Point Cloud

To fit a NURBS curve from a point cloud, select menu **/Curve/Fit From Pnt Cloud/ Fit NURBS Curve** to bring up the *Fit NURBS Curve* dialog box as shown in Figure 7.21. The dialog box lists all visible point clouds in the point cloud list. When the *Fit NURBS Curve* dialog box pops up, the default selection is the active point cloud. However, the user can select any point cloud from the point cloud list to fit a NURBS curve. To fit a closed curve through the points of the selected point cloud, the “*Curve Closed*” box should be checked. To force the fitted curve to pass through all the data points, the “*Interpolation*” box should be checked. When fitting a non-interpolated curve, the user can specify the degree and the number of segments of the curve. These two parameters will affect how close the fitted curve to the data points. By default, a degree of 3 (cubic curve) is recommended. Number of segments will depend on the complexity of the curve.

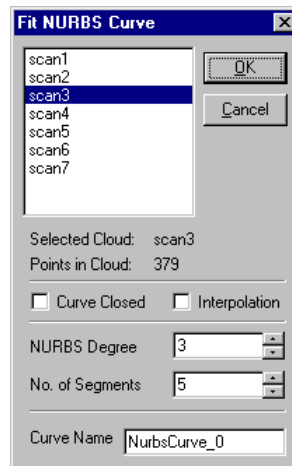


Figure 7.21 The *Fit NURBS Curve* Dialog Box

The operation of fitting a NURBS curve from a point cloud will create a NURBS curve that bestfits the point cloud. The fitted NURBS curve has its local coordinate system coincide with the world coordinate system. The curve usually does not lie on the xy-plane of its coordinate system, i.e. it is usually not a 2D curve, unless that all the points are on the xy-plane of the world coordinate system. However, it can be

converted to a 2D curve by projecting it to a working plane. The NURBS curve fitting operation will not automatically generate a deviation cloud. The deviations from the data points to the fitted NURBS curve can be obtained through the operation of calculating normal deviations from point clouds to curves discussed in Chapter 10.

7.5 Constructing Curves

IQ-FormFit provides some simple user interfaces for the construction of commonly used curves such as lines and circles(including arcs). By using these curve construction functions, the user can create a simple 2D CAD model inside IQ-FormFit.

7.5.1 Constructing Line

To construct a line, select menu **/Curve/Construct Curve/ Construct Line** to bring up the *Construct Line* dialog box as shown in Figure 7.22.

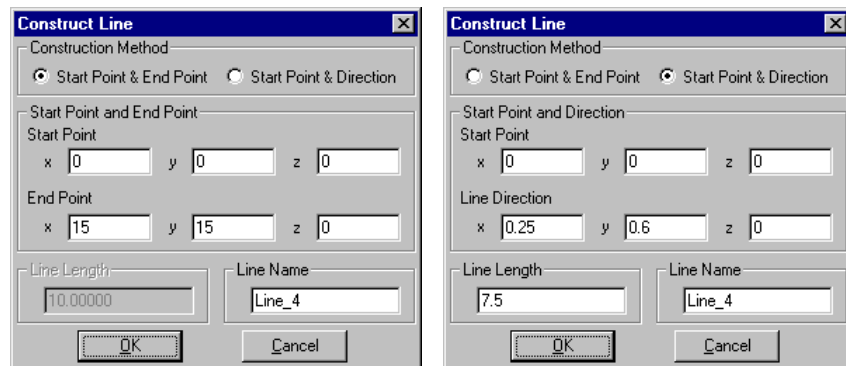


Figure 7.22 The *Construct Line* Dialog Box

On the upper portion of the dialog box is the construction method. Two construction methods are supported. The user can use either the start and end points or the start point plus line direction to construct a line. The layout of the dialog box will change according to the selected line construction method. When using the start and end points, the user needs to type the coordinates of the start and end. In this construction method, if the z coordinate of the start point equals to the z coordinate of the end point, the constructed line will be a 2D line. Otherwise, the constructed line will be a 3D line. When using the start point plus line direction, the user needs to input the coordinates of the start point, the three components of the line direction vector and the length of the line. In this method, if the z component of the line direction vector is zero, the constructed line will be a 2D line. Otherwise, the constructed line will be a 3D line. The user can either accept the default name or type a new name for the constructed line.

7.5.2 Constructing Circle/Arc

To construct a circle or an arc, select menu **/Curve/Construct Curve/ Construct Circle** to bring up the *Construct Circle(Arc)* dialog box as shown in Figure 7.23. On the upper portion of the dialog box is the “*Construction Selection*” box for specifying whether a circle or an arc is to be constructed. When constructing a circle, the user only needs to type the circle center and the circle radius, the “*Arc Angles*” box will be

dimmed. When constructing an arc, the “Arc Angles” box will be enabled so that the user can specify the start and span angle for the arc. The start angle is a CCW angle starting from the x-axis direction of the world coordinate system. The span angle is also a CCW angle between 0 to 2π . If the angles are in degree, the “Degree” box should be checked. The constructed circle or arc is always parallel to the xy-plane of the world coordinate system. The user can either accept the default name or type a new name for the constructed circle or arc.

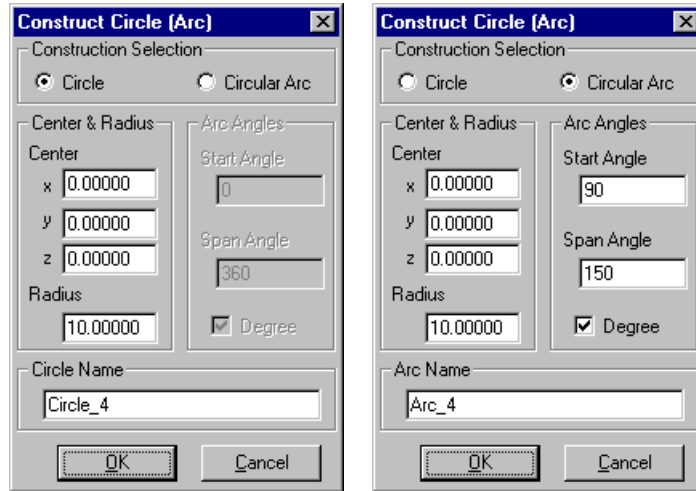


Figure 7.23 The *Construct Circle(Arc)* Dialog Box

7.6 Projecting 3D Curves to Working Plane

To perform 2D bestfit analysis, it is necessary to convert 3D curves to 2D curves. 3D lines, 3D NURBS curves and 3D spline curves can be converted into 2D curves by projecting them to a working plane. To project 3D curves to a working plane, select menu **/Curve/Project To Working Plane** to invoke the *Project Curve To Working Plane* dialog box as shown in Figure 7.24.

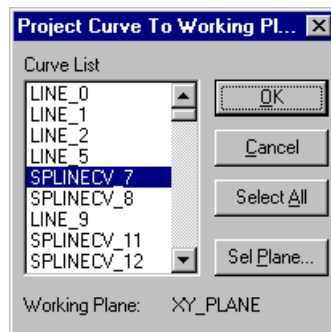


Figure 7.24 The *Project Curve To Working Plane* Dialog Box

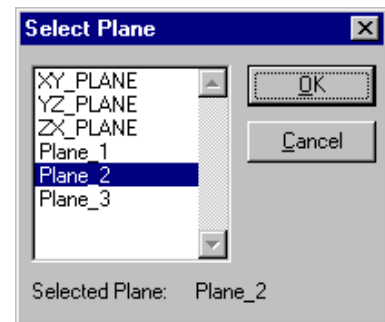


Figure 7.25 The *Select Plane* Dialog Box

When this dialog box pops up, all the 3D curves will be listed in the point cloud list and the XY_PLANE of the world coordinate system will be listed as the default projection plane. The user can click the **[Sel Plane]** button to bring up the *Select Plane* dialog box, as shown in Figure 7.25, to select a working different plane. After

selecting the working plane, the name of the selected working plane will be displayed at the bottom of the *Project Curve To Working Plane* dialog box. Once the working plane is selected, the user can select one or more 3D curves to project them to the selected working plane. Clicking the **[OK]** button will execute the projection and convert the selected 3D curves to 2D curves. If the **[Cancel]** button is clicked, the operation will be aborted.

7.7 Form Tolerance Support for Curves

IQ-FormFit supports form tolerances for 2D curves, and provides the interface for the user to specify the upper and lower limits of the form tolerance for each 2D curve. User interfaces for supporting form tolerance for 2D curves include setting form tolerance, editing form tolerance and showing/hiding form tolerance zone. The setting form tolerance function can be used to assign form tolerance to multiple 2D curves at a time while the editing form tolerance function is designed to modify the form tolerance of individual 2D curves one curve at a time. The user can use the show/hide form tolerance zone function to graphically display the form tolerance zone on the screen for 2D curves.

7.7.1 Setting Form Tolerance for Curves

To set form tolerance for 2D curves, select menu **/Curve/Set Form Tolerance** to bring up the *Set Curve Form Tolerance* dialog box as shown in Figure 7.26. When the dialog box pops up, it will only show 2D curves in the curve list. Any 3D curve will not be included in the curve list on the dialog box. The user can select 2D curves from the 2D curve list and specify the upper and lower limits of form tolerance zone as well as the show/hide flag for the form tolerance zone. When the show/hide flag is show, the tolerance zone for each curve will be displayed in dot-dashed line with the same color of the 2D curves. When the **[Set]** button is clicked, the specified form tolerance will be assigned to the selected 2D curves. The user can continue to set form tolerance for other 2D curves until the form tolerance information is set for all 2D curves.

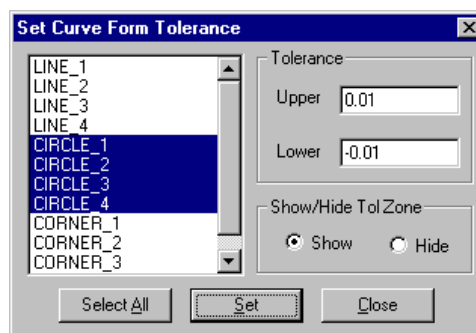
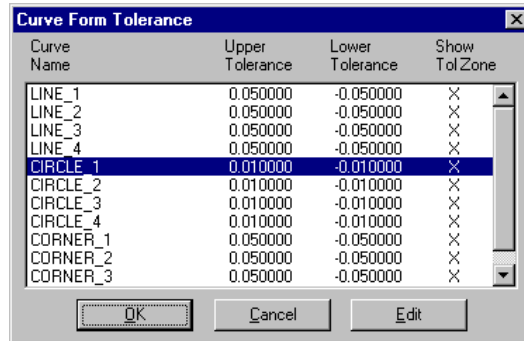
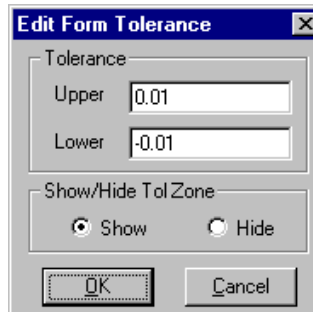


Figure 7.26 The *Set Curve Form Tolerance* Dialog Box

7.7.2 Editing Form Tolerance for Curves

To edit the form tolerance zone of a 2D curve, select menu **/Curve/Edit Form Tolerance** to bring up the *Curve Form Tolerance* dialog box as shown in Figure 7.27. This dialog box lists all 2D curves and displays the upper and lower limits of form tolerance as well as the display status of form tolerance zone for each 2D

curve. When the user selects a 2D curve from the 2D curve list and clicks the **[Edit]** button, the *Edit Form Tolerance* dialog box as shown in Figure 7.28 will pop up. Using this second dialog box, the user can change the form tolerance and the show/hide flag of form tolerance zone for the selected 2D curve. When the show/hide flag is show, the tolerance zone will be displayed in dot-dashed line with the same color of the 2D curve. The user can continue to edit the form tolerance information for other 2D curves until the form tolerance information is correct for all 2D curves.

Figure 7.27 The *Curve Form Tolerance* Dialog BoxFigure 7.28 The *Edit Form Tolerance* Dialog Box

7.7.3 Showing/Hiding Tolerance Zone for Curves

As explained in section 7.7.2, the user can change the show/hide flag for the form tolerance zone of each individual 2D curve using the editing curve form tolerance interface. IQ-FormFit also supports a new set of commands to toggle the show/hide flag of curve form tolerance zone for all the 2D curves. Menu selections for this set of commands are summarized as follows:

- Showing Form Tolerance Zone for All 2D Curves
 - ⇒ Menu access: **/Curve/"Show/Hide Tol Zone"/Show All**
 - ⇒ Function: Show tolerance zone for all 2D curve
- Hiding Form Tolerance Zone for All 2D Curves
 - ⇒ Menu access: **/ Curve /"Show/Hide Tol Zone"/Hide All**
 - ⇒ Function: Hide tolerance zone for all 2D curve
- Showing Form Tolerance Zone for Active Curve Only
 - ⇒ Menu access: **/ Curve /"Show/Hide Tol Zone"/Show Active Only**
 - ⇒ Function: Show tolerance zone for the active curve only

7.8 Position Tolerance Support for Circles

IQ-FormFit supports the evaluation of true position for circles. To facilitate the evaluation of true position of circles, position tolerances must be assigned to the circles.

7.8.1 Setting Position Tolerance for Circles

To set position tolerance for circles, select menu **/Curve/Set Circle Pos Tol** to bring up the *Set Circle Position Tolerance* dialog box as shown in Figure 7.29. When the dialog box pops up, it will only show circles in the list box. The user can select the circles from the list box and specify the position tolerance value in the “Tolerance” box. When the **[Set]** button is clicked, the specified position tolerance will be assigned to the selected circles. The user can continue to set position tolerance for other circles until the position tolerance is set for all circles.

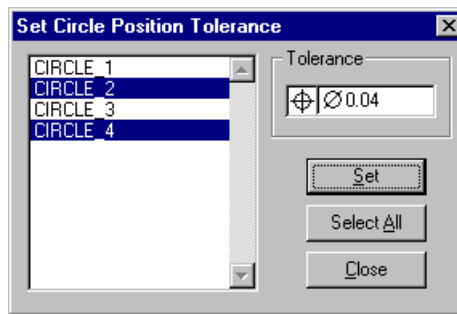


Figure 7.29 The *Set Curve Form Tolerance* Dialog Box

7.8.2 Editing Position Tolerance for Circles

To edit position tolerance of a circle, select menu **/Curve/Edit Circle Pos Tol** to bring up the *Circle Position Tolerance* dialog box as shown in Figure 7.30. This dialog box lists all circles and displays the position tolerance of each circle. When the user selects a circle from the circle list and clicks the **[Edit]** button, the *Edit Circle Pos Tol* dialog box as shown in Figure 7.31 will pop up to let the user change the position tolerance value for the selected circle. The user can continue to edit position tolerance for other circles until the position tolerance value is correct for all circles.

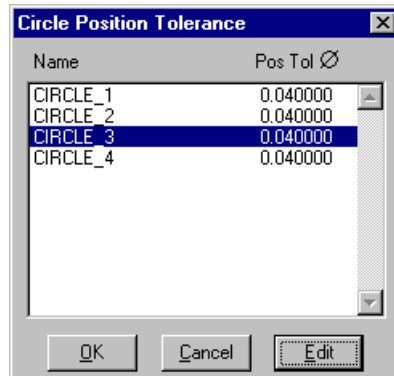


Figure 7.30 The *Circle Position Tolerance* Dialog Box

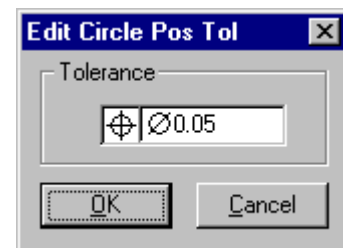


Figure 7.31 The *Edit Circle Pos Tol* Dialog Box

7.9 Testing Curve Normal

See section 7.2
on definition of
2D curve

In IQ-FormFit, the normal direction of a 2D curve is defined as a unit vector perpendicular to the 2D curve at the specified point on the 2D curve and pointing away from the material side of the 2D curve. For example, the normal direction of an inner circle (a hole) is the direction pointing to the inside of the circle, and the normal direction of an outer circle (a pin) is the direction pointing to the outside of the circle.

The normal direction of a 2D curve is used to decide the material side of the curve when computing deviation from a measurement point to the 2D curve. Therefore, normal direction of 2D curves should be set correctly according to material side of the part model. However, when a CAD model is imported from an IGES file, the normal direction of each curve is not specified. It is user's responsibility to test the normal direction of each curve and set it correctly before performing bestfit analysis. IQ-FormFit provides a set of tools for the user to check and correct normal direction for 2D curves.

7.9.1 Show All Curve Normal

In order for the user to check the normal direction of a 2D curve, the curve normal must be graphically displayed in some way. IQ-FormFit displays several normal vectors along a curve to show the current normal direction of a 2D curve. If the user select the menu **/Curve/Show All Curve Normal**, normal direction for all 2D curves will be displayed on the screen so the user can easily check if the normal direction of a 2D curve matches the material side of the CAD model.

When the **/Curve/Show All Curve Normal** menu is selected, the menu will be marked with a check mark. Select this menu a second time will turn off the display of the normal vectors for all 2D curves.

It is important to point out that IQ-FormFit does not allow 3D curves to be used in 2D analysis and normal vectors of 3D curves will not be displayed. In other word, any curve whose normal is not displayed when the show all curve normal command is in effect is a 3D curve.

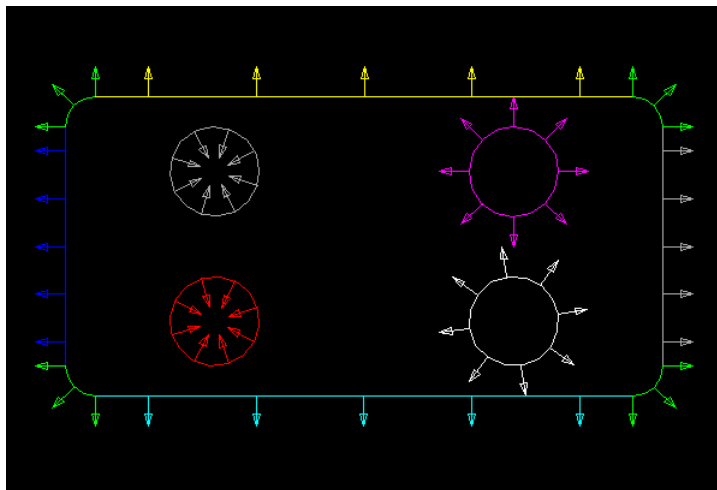


Figure 7.32 Show All Curve Normal

7.9.2 Test Curve Normal

See section 7.2
on definition of
2D curve

The **/Curve/Test Curve Normal** menu is for testing and setting 2D curve normal direction. When this menu is selected, normal vectors for all 2D curves will be displayed on the screen. This command also sets the mouse operation mode to TEST CURVE NORMAL mode. In this operation mode, the mouse cursor changes to the hand shaped cursor. If the user finds that the normal direction of a curve does not match the material side of the curve, for example the two circles on the right of Figure 7.32, the user can use the mouse to pick the curve and correct the normal direction of that curve. When a curve is picked, the *Test Curve* dialog box as shown in Figure 7.33 will pop up. The *Test Curve* dialog box will display the name of the picked curve and the picked curve will be displayed in highlight yellow color on the screen. If the mouse hits more than one curves, the **[Prev]** and/or the **[Next]** button on the *Test Curve* dialog box will be enabled to let the user to select the curve of interest. As the user scrolls through the curves hit by the mouse, the curve whose name is displayed on the *Test Curve* dialog box will be displayed in highlight yellow color on the screen. To correct the normal direction of the curve, simply click the **[Flip]** button to flip the normal direction of the picked curve.

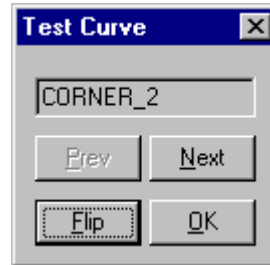


Figure 7.33 The *Test Curve* Dialog Box

The user can continue to pick curves whose normal directions do not match their material sides until all curve normal directions are correctly set. The user can hit the **<ESC>** key to end the testing curve normal operation. This will clear all the curve normal vectors displayed on the screen and restore the mouse cursor.

7.9.3 Auto Normal Testing

If a 2D CAD model is completely closed, i.e. no open loops or no gaps between connecting curves, IQ-FormFit can intelligently detect the material sides of 2D curves and set normal directions for the 2D curves accordingly. To let IQ-FormFit automatically determine the normal directions for all 2D curves, select menu **/Curve/Auto Normal Testing**.

In order to perform the automatically normal testing operation, a reference plane is needed. Therefore, the user will be asked to select a working coordinate system whose xy-plane will be used as the reference plane for automatic curve normal testing. Figure 7.34 shows the *Select Working Coordinate System* dialog box. The user can select the world coordinate system, the entity coordinate system of a 2D curve or the entity coordinate system of a plane as the working coordinate system for this operation. Once the working coordinate system is selected, the program will perform the necessary calculations to determine the curve material sides and set the curve normal directions. When this process is finished, the program will automatically enter the test curve normal operation as described in section 7.9.2.

Normal vectors will be displayed for all curves and the user can pick any 2D curves to overwrite the result from the auto normal testing operation. Hit the <ESC> key will end the test curve normal operation.

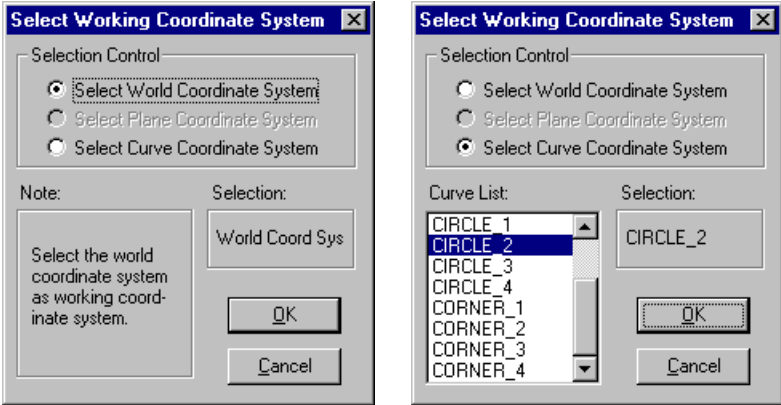


Figure 7.34 The Select Working Coordinate System Dialog Box

Chapter 8 Operations for Surfaces

8.1 Introduction

Common operations for surfaces are discussed in chapter 4. The most frequently used common operations for surfaces include selecting/picking active surface, transforming active surface, local standard view of the active surface, setting surface display properties, editing surface properties, and deleting surfaces. In this chapter, operations specific to surfaces will be discussed. These operations include displaying surface shading, fitting standard surfaces from point clouds, constructing surfaces, form tolerance support for surfaces, and testing surface normal direction.

8.2 Fitting Surfaces from Point Clouds

In metrology, it is often necessary to evaluate position/orientation, size and form errors of standard 3D surfaces from measurement data. To meet these needs, IQ-FormFit provides a full set of evaluation functions for fitting standard 3D surfaces from point clouds. By using this set of functions, the user can calculate the position/orientation, size and form errors of these standard 3D surface features. This set of functions include fitting plane, sphere, cylinder and cone.

8.2.1 Fitting Plane from Point Cloud

To fit a plane from a point cloud, select menu **/Surface/Fit From Pnt Cloud/Fit Plane** to bring up the *Fit Plane* dialog box as shown in Figure 8.1. The dialog box lists all visible point clouds including both 2D and 3D point clouds in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a plane from the selected point cloud. When the *Fit Plane* dialog box pops up, the default selection is the active point cloud.

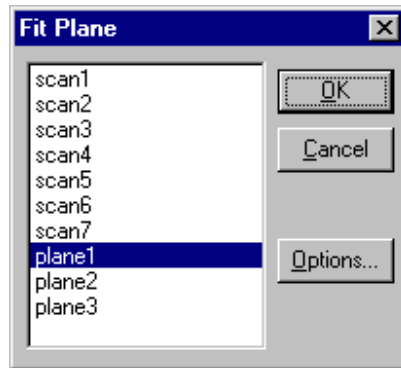


Figure 8.1 The *Fit Plane* Dialog Box

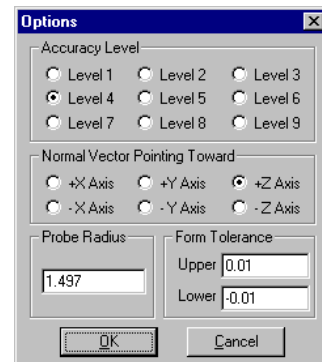


Figure 8.2 The *Options* Dialog Box

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can change the fitting options by clicking the **[Options]** button on the *Fit Plane* dialog box to bring up the *Options* dialog box as shown in Figure 8.2. From the *Options* dialog box, the user can set the desired accuracy level, select normal direction of the plane, specify probe radius for probe compensation, and input form tolerance values for the fitted plane and the generated deviation cloud.

The normal vector of a plane is defined as the unit vector perpendicular to the plane and pointing away from the material side of the plane (Figure 8.3). The program uses this information to decide the material side of the plane and the direction for probe radius compensation. The user should set the normal vector direction option according to the normal vector direction of the plane with respect to the world coordinate system. (Note: this is different from the case of fitting 2D line where the option for line normal direction is with respect to the local coordinate system of the 2D point cloud.)

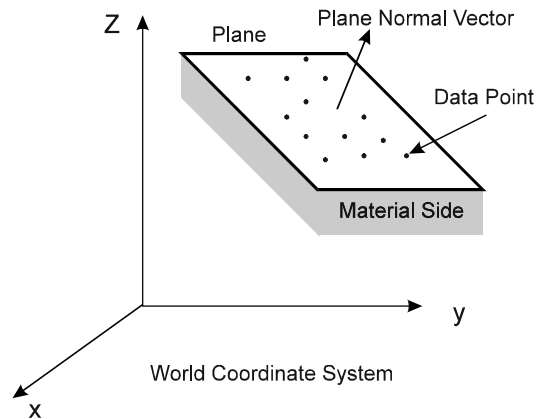


Figure 8.3 Plane Normal Direction

The probe radius is used for probe compensation. When the *Options* dialog box pops up, the probe radius associated with the selected point cloud will be displayed in the “*Probe Radius*” box. The user can type a different value in the “*Probe Radius*” box for probe radius compensation. However the probe radius value associated with the selected point cloud will not be updated.

The user can specify the form tolerance zone for the plane to be fitted from the point cloud. This form tolerance zone will be passed to the fitted plane and the generated deviation cloud. After selecting all the options, the user should click the **[OK]** button on the *Options* dialog box to return to the *Fit Plane* dialog box.

The operation of fitting a plane from a point cloud will generate a plane that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted plane. Figure 8.4 is the *Plane Fitting Results* dialog box that displays the plane parameters as well as deviation and form error information. The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

In IQ-FormFit, a plane is defined as the xy-plane of the plane local coordinate system (Figure 8.5). The orientation matrix in the “*Plane Parameters*” box represents the orientation of the plane local coordinate system relative to the world coordinate system. Since the plane normal vector is always parallel to the z axis of the plane local coordinate system, the third column of the orientation matrix is the plane normal direction vector. The position vector in the “*Plane Parameters*” box is the origin of the plane’s local coordinate system. The fitted plane always has a rectangular shape, and the origin of the local coordinate system is set to the center of the fitted plane. Other information displayed in the *Plane Fitting Results* dialog box is self explanatory. The user can switch the current view to the local standard view of the fitted plane to view the fitted plane and the generated deviation cloud graphically.

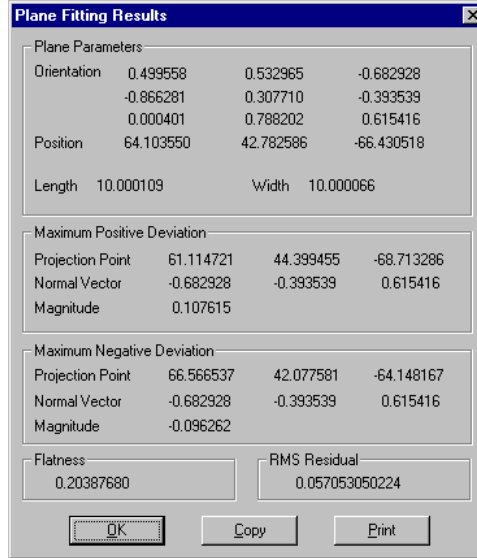


Figure 8.4 The Plane Fitting Results Dialog Box

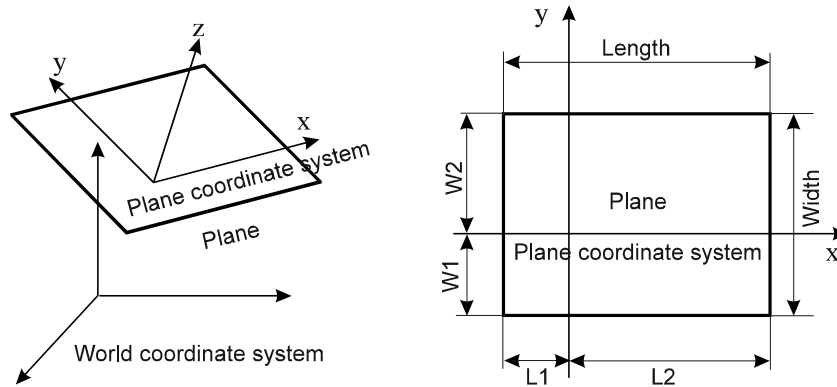


Figure 8.5 Plane and Plane Coordinate System

8.2.2 Fitting Sphere from Point Cloud

To fit a sphere from a point cloud, select menu **/Surface/Fit From Pnt Cloud/ Fit Sphere** to bring up the *Fit Sphere* dialog box as shown in Figure 8.6. The dialog box lists all visible point clouds including both 2D and 3D point clouds in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a sphere from the selected point cloud.

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can change the fitting options by clicking the **[Options]** button on the *Fit Sphere* dialog box to bring up the *Options* dialog box as shown in Figure 8.7. From the *Options* dialog box, the user can set the desired accuracy level, select normal direction of the sphere, specify probe radius for probe compensation, and input form tolerance values for the fitted sphere and the generated deviation cloud. The normal vector of a sphere is “Outward” when the sphere is part of a ball and “Inward” when the sphere is part of a cavity.

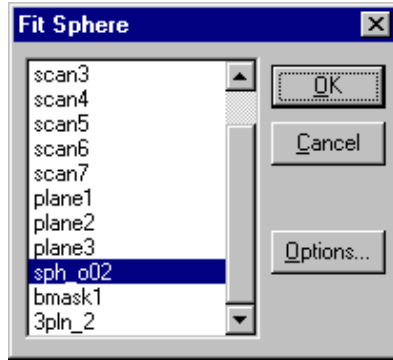


Figure 8.6 The *Fit Sphere* Dialog Box

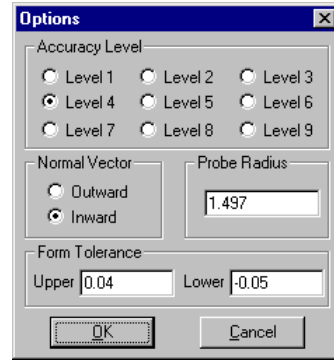


Figure 8.7 The *Options* Dialog Box

The operation of fitting a sphere from a point cloud will generate a sphere that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted sphere. Figure 8.8 is the *Sphere Fitting Results* dialog box that displays the sphere parameters as well as deviation and form error information. In the “*Sphere Parameters*” box, the orientation matrix of the fitted sphere is an identity matrix and the position vector is the center of the fitted sphere, as illustrated in Figure 8.9. Other information displayed in the *Sphere Fitting Results* dialog box is self-explanatory. The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

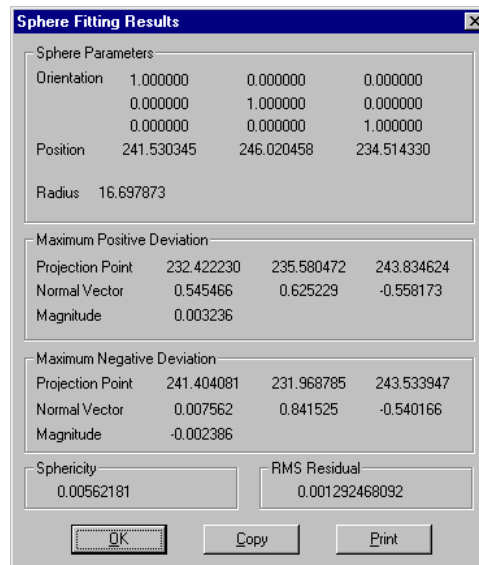


Figure 8.8 The *Sphere Fitting Results* Dialog Box

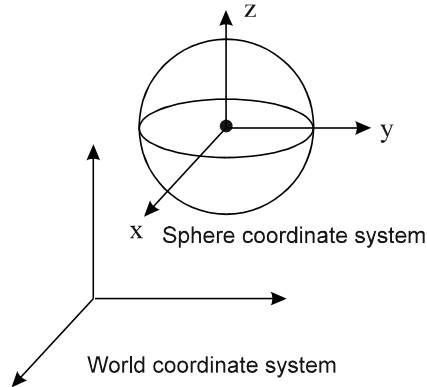
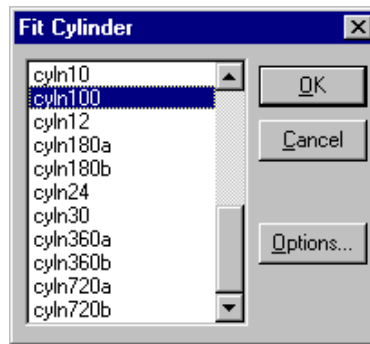


Figure 8.9 Sphere and Sphere Coordinate System

8.2.3 Fitting Cylinder from Point Cloud

To fit a cylinder from a point cloud, select menu **/Surface/Fit From Pnt Cloud/ Fit Cylinder** to bring up the *Fit Cylinder* dialog box as shown in Figure 8.10. The dialog box lists all visible point clouds including both 2D and 3D point clouds in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a cylinder from the selected point cloud.

Figure 8.10 The *Fit Cylinder* Dialog Box

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can change the fitting options by clicking the **[Options]** button on the *Fit Cylinder* dialog box to bring up the *Options* dialog box as shown in Figure 8.7. From the *Options* dialog box, the user can set the desired accuracy level, select normal direction of the cylinder, specify probe radius for probe compensation, and input form tolerance values for the fitted cylinder and the generated deviation cloud. The normal vector of a cylinder is “Outward” when the cylinder is part of a pin and “Inward” when the cylinder is part of a hole.

The operation of fitting a cylinder from a point cloud will generate a cylinder that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted cylinder. Figure 8.11 is the *Cylinder Fitting Results* dialog box that displays the cylinder parameters as well as deviation and form error information.

The orientation matrix in “*Cylinder Parameters*” box gives the orientation of the local coordinate system of the fitted cylinder. Since the z-axis of the cylinder coordinate system is the cylinder axis (Figure 8.12), the third column of the orientation matrix is the direction of the cylinder axis. The position vector in the “*Cylinder Parameters*” box is the center of the cylinder’s bottom face. Other information displayed in the

Cylinder Fitting Results dialog box is self explanatory. The user can click the **[OK]** button to close the dialog box or click the **[Copy]** button to copy the fitting results to the clipboard.

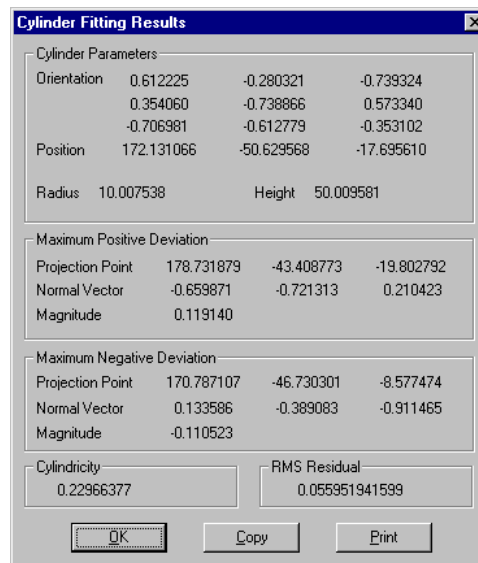


Figure 8.11 The *Cylinder Fitting Results* Dialog Box

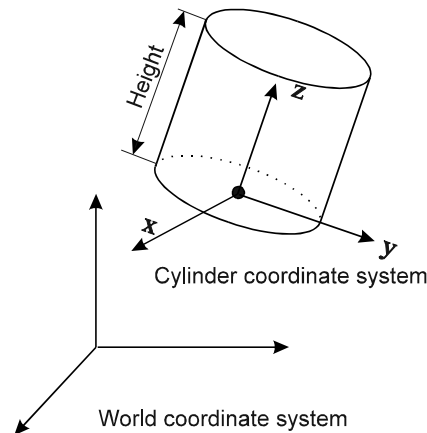


Figure 8.12 Cylinder and Cylinder Coordinate System

8.2.4 Fitting Cone from Point Cloud

To fit a cone from a point cloud, select menu **/Surface/Fit From Pnt Cloud/Fit Cone** to bring up the *Fit Cone* dialog box as shown in Figure 8.13. The dialog box lists all visible point clouds including both 2D and 3D point clouds in the point cloud list. The user can select a point cloud from the point cloud list and then click the **[OK]** button to fit a cone from the selected point cloud.

See section 7.3.1 for discussion on accuracy level selection for feature calculation

The user can change the fitting options by clicking the **[Options]** button on the *Fit Cone* dialog box to bring up the *Options* dialog box as shown in Figure 8.7. From the *Options* dialog box, the user can set the desired accuracy level, select normal direction of the cone, specify probe radius for probe compensation, and input form tolerance values for the fitted cone and the generated deviation cloud. The normal

vector of a cone is “Outward” when the cone is part of a pin and “Inward” when the cone is part of a hole.

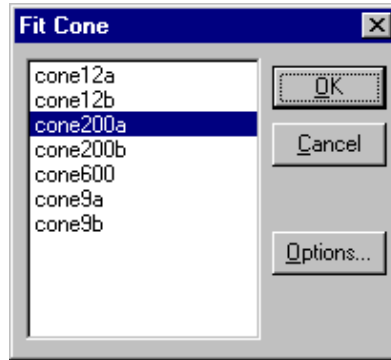


Figure 8.13 The *Fit Cone* Dialog Box

The operation of fitting a cone from a point cloud will create a cone that bestfits the point cloud and a deviation cloud that contains the deviation vectors from each point to the fitted cone. Figure 8.14 is the *Cone Fitting Results* dialog box that displays the cone parameters as well as deviation and form error information. The orientation matrix in the “*Cone Parameters*” box gives the orientation of the local coordinate system of the fitted cone. Since the z-axis of the cone coordinate system is the cone axis (Figure 8.15), the third column of the orientation matrix is the direction of the cone axis. The position vector in the “*Cone Parameters*” box is the center of the cone’s bottom face. Other cone parameters are illustrated in Figure 8.15. The user can click the [OK] button to close the dialog box or click the [Copy] button to copy the fitting results to the clipboard.

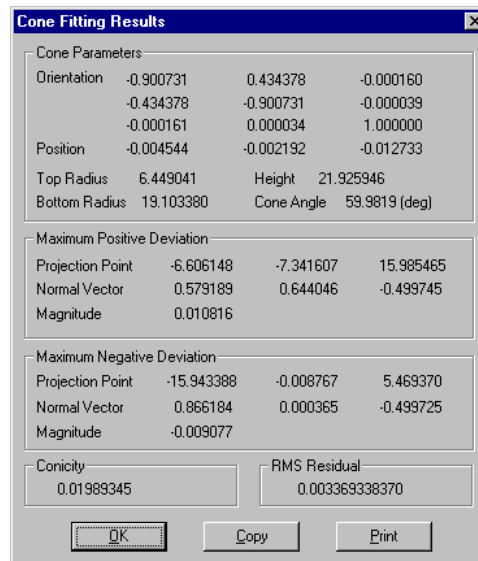


Figure 8.14 The *Cone Fitting Results* Dialog Box

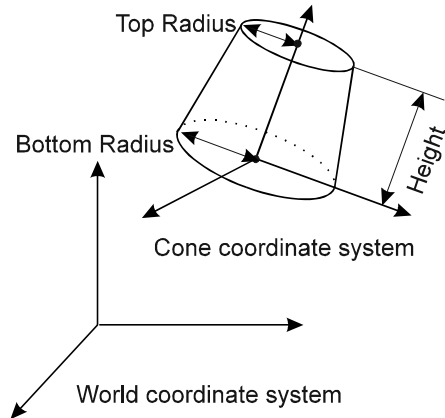
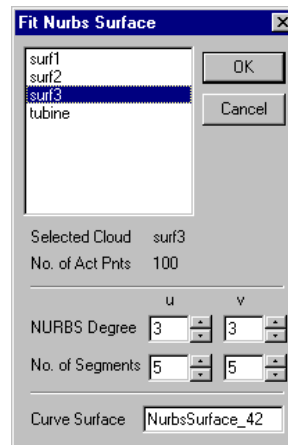


Figure 8.15 Cone and Cone Coordinate System

8.2.5 Fitting NURBS Surface from Point Cloud

To fit a NURBS surface from a point cloud, select menu **/Surface/Fit From Pnt Cloud/Fit Nurbs Surface** to bring up the *Fit Nurbs Surface* dialog box as shown in Figure 8.16. The dialog box lists all visible point clouds including both 2D and 3D point clouds in the point cloud list. When a point cloud is selected from the point cloud list, the name and the number of points of the selected point cloud will be displayed under the list box. The options for fitting a nurbs surface including the degree and number of segments in u and v parameter directions. The combination of these parameters determines the complexity of the surface. When the **[OK]** button is clicked, a nurbs surface will be fitted from the selected point cloud and displayed in the graphics window. The fitted nurbs surface can be exported to an IGES file as discussed in section 3.2.6.

Figure 8.16 The *Fit Nurbs Surface* Dialog Box

8.3 Constructing Surfaces

IQ-FormFit provides a set of user interfaces for the construction of standard surfaces. By using these surface construction functions, the user can create a simple 3D CAD model inside IQ-FormFit.

8.3.1 Constructing Plane

In order to perform certain operations such as projecting point clouds to working plane, the user often needs to construct the desired working plane. To construct a plane, select menu **/Surface/Construct Surface/Construct Plane** to bring up the *Construct Plane* dialog box as shown in Figure 8.17.

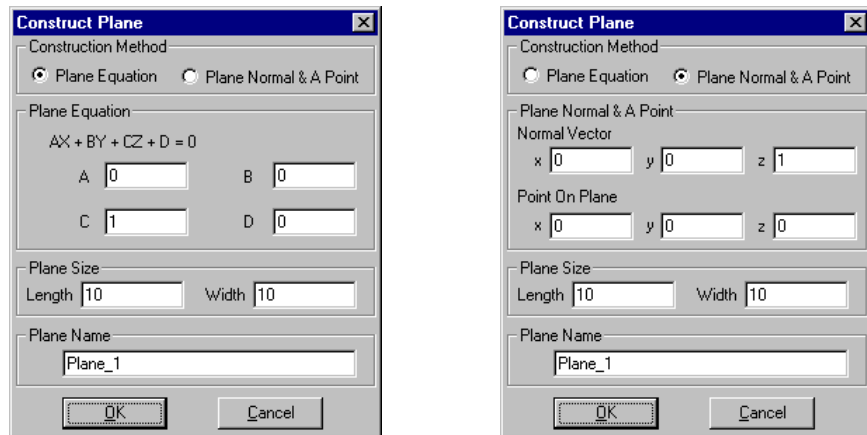


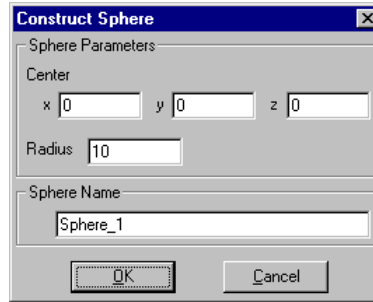
Figure 8.17 The *Construct Plane* Dialog Box

On the upper portion of the *Construct Plane* dialog box is the construction method option box. Two construction methods are supported. The user can use either the plane equation or the plane normal vector plus a point on the plane to construct a plane. The middle portion of the dialog box will change according to the selected plane construction method. When using plane equation to construct a plane, the user needs to type the four coefficients of the plane equation in the respective boxes. If using the normal vector plus a point, the user needs to type the three components of the normal vector and the three coordinates of the point. The length and width parameters are used to specify the size of the plane.

The origin of a constructed plane is set to one corner of the plane and the constructed plane is always in the first quadrant of the xy-plane of its local coordinate system (i.e. in Figure 8.5, $L1 = W1 = 0$, $L2 = \text{Length}$, $W2 = \text{Width}$).

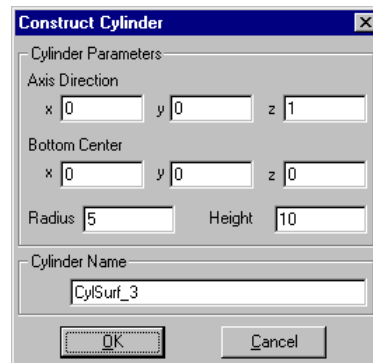
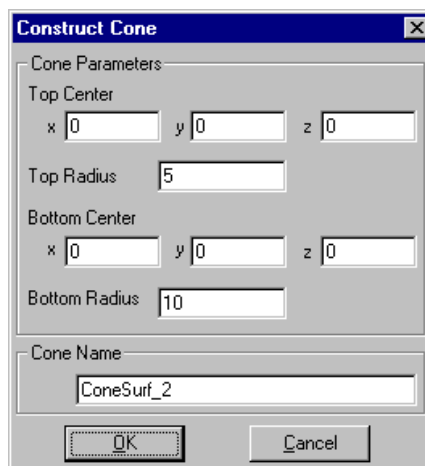
8.3.2 Constructing Sphere

To construct a sphere, select menu **/Surface/Construct Surface/Construct Sphere** to bring up the *Construct Sphere* dialog box as shown in Figure 8.18. Using this dialog box, the user can specify the center and the radius of the sphere to be constructed. The local coordinate system of the constructed sphere is always parallel to the world coordinate system. The user can accept the default name or type a new name for the sphere.

Figure 8.18 The *Construct Sphere* Dialog Box

8.3.3 Constructing Cylinder

To construct a cylinder, select menu **/Surface/Construct Surface/Construct Cylinder** to bring up the *Construct Cylinder* dialog box as shown in Figure 8.19. Using this dialog box, the user can specify the cylinder axis direction, the center of the cylinder's bottom face, the radius and the height of the cylinder to be constructed. The user can accept the default name or type a new name for the cylinder.

Figure 8.19 The *Construct Cylinder* Dialog BoxFigure 8.20 The *Construct Cone* Dialog Box

8.3.4 Constructing Cone

To construct a cone, select menu **/Surface/Construct Surface/ Construct Cone** to bring up the *Construct Cone* dialog box as shown in Figure 8.20. Using this dialog box, the user can specify the center and radius of the cone's top face and the center and radius of the cone's bottom face. The user can accept the default name or type a new name for the cone.

8.4 Repair Surface Trim Boundary

Each surface imported from an IGES file carries two sets of boundary curves. One set of the boundary curves is the wire frame boundary which represent the wire frame of the surface. The other set of boundary curves is called the trim boundary that are used to trim the surface when the surface is displayed in TRIM mode or in shading. These two sets of boundary curves should match in space because they represent the same boundary of a surface. However, some CAD systems only export one set of the boundary curves while in other cases the two sets of boundary curves do not match each other in space. Figure 8.21(a) shows an example where the shading and the wire frame of the same surface do not match in space. This is because the trim boundary of the surface is incorrectly exported from the original CAD system. In this case, IQ-FormFit can repair the trim boundary of the surface by re-creating the trim boundary from the wire frame boundary.

See section 8.6.1
on displaying
surface shading

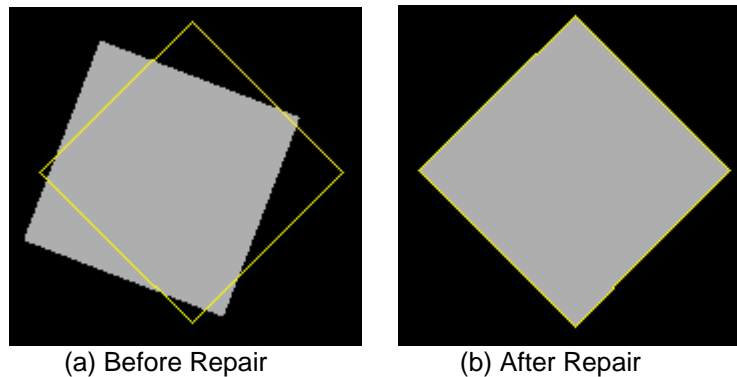


Figure 8.21 Repair Surface Trim Boundary

To repair the trim boundary of a surface, select menu **/Surface/Repair Trim Boundary** to bring up the *Repair Surface Trimming Boundary* dialog box as shown in Figure 8.22.

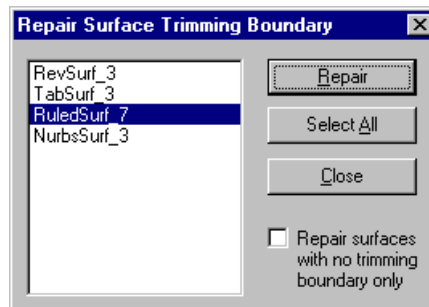


Figure 8.22 The *Repair Surface Trim Boundary* Dialog Box

If the “Repair surfaces with no trimming boundary only” box is checked, the dialog box will only list those surfaces that do not have a trim boundary. Otherwise, all surfaces will be listed in the surface list. The user can select the surface whose trim boundary curves need to be repaired or re-generated from its wire frame boundary. When the **[Repair]** button is clicked, the program will re-create the trim boundary for the selected surface and re-display the surface with the newly generated trim boundary. Figure 8.21 (b) shows the surface after its trim boundary is repaired. It can be seen that the boundary of the shading of the surface matches the wire frame boundary of the surface.

8.5 Form Tolerance Support for Surfaces

IQ-FormFit supports form tolerances for surfaces and provides user interfaces for the user to assign and modify form tolerance for surfaces. User interfaces for supporting form tolerance for surfaces include setting form tolerance and editing form tolerance. The setting form tolerance function can be used to assign form tolerance to multiple surfaces at a time while the editing form tolerance function is designed to change the form tolerance of individual surfaces one surface at a time.

8.5.1 Setting Form Tolerance for Surfaces

To set form tolerance for surfaces, select menu **/Surface/Set Form Tolerance** to bring up the *Set Surface Form Tolerance* dialog box as shown in Figure 8.23. The user can select surfaces from the surface list and specify the upper and lower limits of form tolerance zone. When the **[Set]** button is clicked, the specified form tolerance will be assigned to the selected surfaces. The user can continue to set form tolerance for other surfaces until the form tolerance information is set for all surfaces. The “Show/Hide Tol Zone” box on the dialog box is grayed out because the display of surface form tolerance zone is not currently supported.

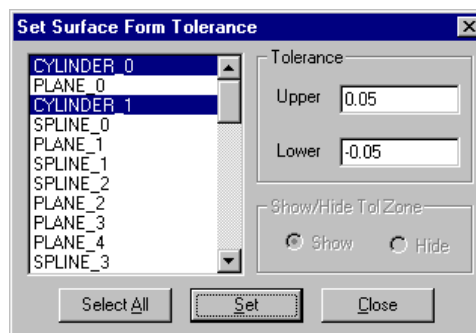


Figure 8.23 The *Set Curve Form Tolerance* Dialog Box

8.5.2 Editing Form Tolerance for Surfaces

To edit form tolerance for a surface, select menu **/Surface/Edit Form Tolerance** to bring up the *Surface Form Tolerance* dialog box as shown in Figure 8.24. This dialog box lists all surfaces and displays the upper and lower limits of form tolerance of each surface. Since the display of surface form tolerance zone is not supported, the “Show Tol Zone” column is grayed out. When the user select a surface from the surface list and clicks the **[Edit]** button, the *Edit Form Tolerance* dialog box as

shown in Figure 8.25 will pop up to let the user change the form tolerance for the selected surface. Again, the “Show/Hide Tol Zone” box on the *Edit Form Tolerance* dialog box is grayed out. The user can continue to edit form tolerance information for other surfaces until the form tolerance information is correct for all the surfaces.

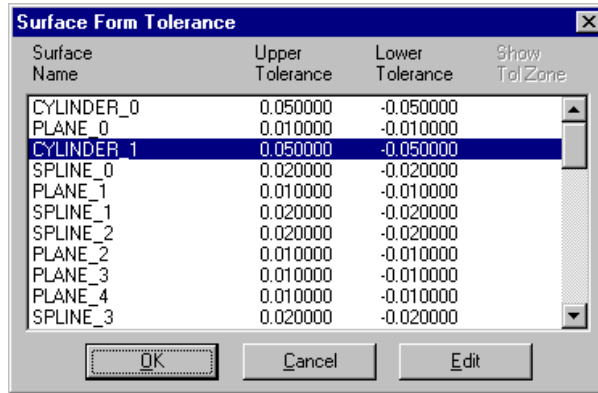


Figure 8.24 The *Surface Form Tolerance* Dialog Box

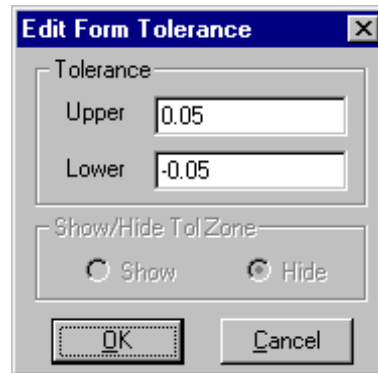


Figure 8.25 The *Edit Form Tolerance* Dialog Box


8.6 Testing Surface Normal

In IQ-FormFit, the normal direction of any surface is defined as a unit vector perpendicular to the surface at the specified point on the surface and pointing away from the material side of the surface. For example, the normal direction of an inner cylinder (a hole) is the direction pointing to the inside of the cylinder, and the normal direction of an outer cylinder (a pin) is the direction pointing to the outside of the cylinder.

In the process of calculating normal deviations from measurement points to nominal surface model, the normal direction of a surface affects the sign of each calculated geometric deviation vector. Therefore, the normal direction of each surface must be set correctly according to the material side of the surface. However, when a CAD model is imported from an IGES file, the normal direction of each surface is not specified. It is user's responsibility to test the normal direction of each surface and set it correctly before performing bestfit analysis. IQ-FormFit provides a set of tools for the user to check and correct surface normal direction.

8.6.1 Displaying Surface Shading

In chapter 4, we discussed various display options of surface class. One of the important display options of a surface is its display. The display mode of a surface controls the appearance of a surface on the screen. Each individual surface can be displayed in WIRE mode, MESH mode or TRIM mode. In WIRE mode, the surface boundary curves are displayed. In MESH mode, a mesh is displayed to represent the surface without trimming boundaries. In TRIM mode, the surface mesh that is trimmed by its boundary curves is displayed to represent the surface. The display mode parameter can be controlled for each individual surface.

It is well known that a surface can also be displayed in shaded graphics that gives a more realistic solid feeling about the object. IQ-FormFit supports the display of surface shading through a globally controlled switch. To display surfaces in shading, select menu **/Surface/Display Surface Shading** or simply click the **[Display Surface Shading]** button  on the tool bar as shown in Figure 2.2. When this menu is selected, the menu item will be marked with a check mark and the **[Display Surface Shading]** button will remain recessed until the display surface shading status is cancelled. To cancel the display surface shading status, select the **/Surface/Display Surface Shading** menu again or click the **[Display Surface Shading]** button a second time.

When the display surface shading switch is on, shading will be displayed for all surfaces regardless of their visible status flag. This is for the purpose of showing the complete CAD model and giving the user a better solid feeling about the object.

When surface shading is displayed, individual surfaces will not be displayed except for the current active surface. This is for the purpose of preventing the graphical display becoming over crowded.

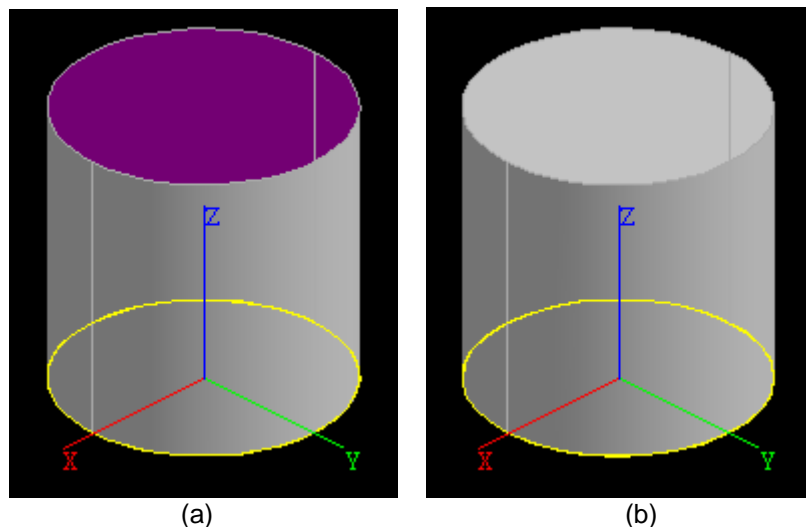


Figure 8.26 Surface Shading with Different Normal Direction

When the shading of a surface is displayed, the two sides of the surface will be displayed in different colors. The outer side of the surface is displayed in gray color and the inner side of the surface is displayed in magenta color. Therefore, we can easily identify those surfaces whose normal directions do not match their material sides. For example, Figure 8.26(a) shows a CAD model where the normal direction of the top surface is incorrect while Figure 8.26(b) shows the same CAD model with the correct surface normal.

8.6.2 Test Surface Normal

The **/Surface/Test Surface Normal** menu is for testing and setting surface normal direction. When this menu is selected, the mouse will be set to the TEST SURFACE NORMAL operation mode. In this operation mode, the mouse cursor changes to the hand shaped cursor. If the user finds that the normal direction of a surface does not match the material side of the surface, for example the top surface in Figure 8.26(a), the user can use the mouse to pick the surface and correct the normal direction of that surface. When a surface is picked, the surface will be displayed in yellow highlight color and normal vectors will be drawn over the picked surface to show its normal direction. At the same time, the *Test Surface* dialog box as shown in Figure 8.27 will pop up. The *Test Surface* dialog box will display the name of the picked surface. If the mouse hits more than one surfaces, the **[Prev]** and/or the **[Next]** button on the *Test Surface* dialog box will be enabled to let the user to select the surface of interest. As the user scrolls through the surfaces hit by the mouse, the surface whose name is displayed on the *Test Surface* dialog box will be displayed in highlight yellow color on the screen with normal vectors also being displayed. To correct the normal direction of the surface, simply click the **[Flip]** button to flip the normal direction of the picked surface.



Figure 8.27 The *Test Surface* Dialog Box

The user can continue to pick surfaces whose normal directions do not match their material side until all surface normal directions are correctly set. The user can hit the **<ESC>** key to end the testing surface normal operation.

8.6.3 Auto Normal Testing

If a 3D CAD model is completely closed, i.e. no open surfaces or no gaps between adjacent surfaces, IQ-FormFit can intelligently detect the material sides of surfaces and set normal directions for the surfaces accordingly. To let IQ-FormFit automatically determine the normal directions for all surface, select menu **/Surface/Auto Normal Testing**. A message box will be displayed to remind the user that this auto normal testing feature is most useful when it is used to test surface normal directions for a complete 3D CAD model. If the CAD model is not a complete 3D volume, then the testing result might not be correct. If the user confirms the operation, the program will perform the necessary calculations to determine the surface material sides and set the surface normal directions. When this process is finished, surface shading will be automatically displayed so that the user can visually verify the result. If the normal direction of any surface is incorrect, the user should use the test surface normal operation discussed in the previous section to manually correct the normal directions for those surfaces.

Chapter 9 Operations for Deviation Clouds

9.1 Introduction

Common operations for deviation clouds are discussed in chapter 4. The most frequently used common operations for deviation clouds include selecting/picking active deviation cloud, transforming active deviation cloud, local standard view of the active deviation cloud, setting deviation cloud display properties, editing deviation cloud properties, and deleting deviation clouds. In this chapter, operations that are specific to deviation clouds will be discussed. These operations include changing display mode of deviation clouds, magnifying/demagnifying deviation vectors, obtaining statistics information for selected deviation clouds, obtaining statistics information for circle-selected deviations, viewing deviation information, and exporting deviation clouds to a file.

9.2 Deviation Display Mode

As discussed in section 4.5.4, each deviation of a deviation cloud can be displayed in one of the four display modes: POINT, SPIKE, CONNECT, SPK&CONN. In POINT mode, only the end point of each deviation vector is displayed. In SPIKE mode, spikes(whiskers) are drawn for each deviation vector. In CONNECT mode, the end points of deviation vectors are connected with line segments to illustrate profile. In SPK&CONN mode, both the spikes and the connecting line segments are displayed.

As explained in sections 4.9.4 and 4.10.4, the display mode of each individual deviation cloud can be changed by using the setting deviation cloud display properties function or the editing deviation cloud properties function. Here, we introduce a more convenient way to change the display modes for all the deviation clouds in a database.

To change the display modes of all deviation clouds in a database, simply select the desired display mode from the options of menu **/Deviation/Display Mode** or simply select from the "Dev Display Mode" button on the tool bar, as shown in Figure 9.1.

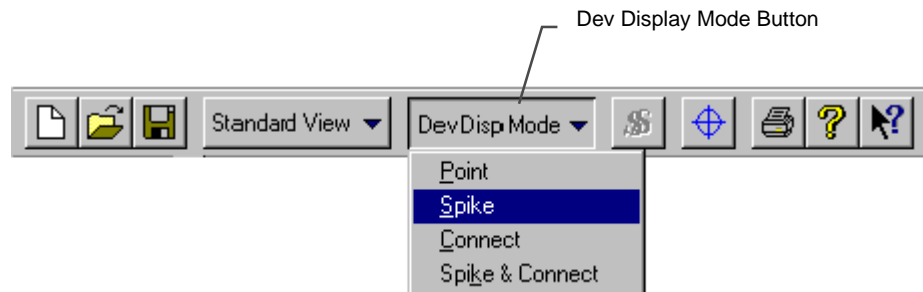




Figure 9.1 Deviation Display Mode Button

9.3 Deviation Magnification

Usually, the magnitudes of the deviation vectors are quite small compared to the dimension of the nominal model of a part. In order to make the deviation vectors graphically visible, the deviation vectors must be magnified. The following three functions are supported for the magnification of the deviation vectors.

- Magnification
 - ⇒ Menu access: **/Deviation/Magnification/Magnify**
 - ⇒ Button access: **[Magnify Deviation]** button 
 - ⇒ Function: Magnifying magnitude of all deviation vectors by 2

- Demagnification
 - ⇒ Menu access: **/Deviation/Magnification/Demagnify**
 - ⇒ Button access: **[Demagnify Deviation]** button 
 - ⇒ Function: Demagnifying magnitude of all deviation vectors by 2

- Magnification Factor
 - ⇒ Menu access: **/Deviation/Magnification/Magnification Factor**
 - ⇒ Button access: No button access
 - ⇒ Function: Bringing up the *Set Magnification Factor* dialog box for the user to type a desired magnification factor.

When the *Set Magnification Factor* dialog box pops up, the current magnification factor is displayed in the "New Factor" box. To change the magnification factor, type a new value in the "New Factor" box and click the **[OK]** button. If the **[Cancel]** button is clicked, the operation will be aborted.

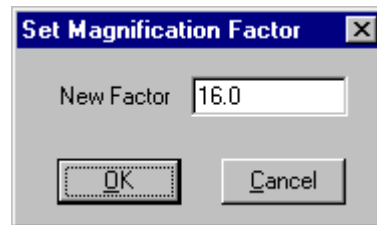


Figure 9.2 The *Set Magnification Factor* Dialog Box

9.4 Modifying Deviation Clouds

For reporting purpose, it is sometimes necessary to modify the deviation clouds. This section will introduce the tools provided for the user to modify the deviation clouds. These tools include circle-selecting deviation clouds, sorting deviation clouds and merging deviation clouds.

9.4.1 Circle-Select Deviation Clouds

The circle-select deviation clouds function is design for the user to delete some deviation points from a deviation cloud or combine deviation points from different deviation clouds to create a new deviation cloud.

To carry out the operation of circle-selecting deviation points, first select menu **/Deviation/Circle-Select Dev Points** to set the mouse operation mode to DRAW POLYGON mode. In this mode, the cursor will change to the pencil-shaped cursor, and the user can use the mouse to draw a circling polygon on the screen, as shown in Figure 9.3. The circling polygon is drawn through a sequence of click-release of the left mouse button. A final double click of the left mouse button will close the circling polygon and end the drawing.

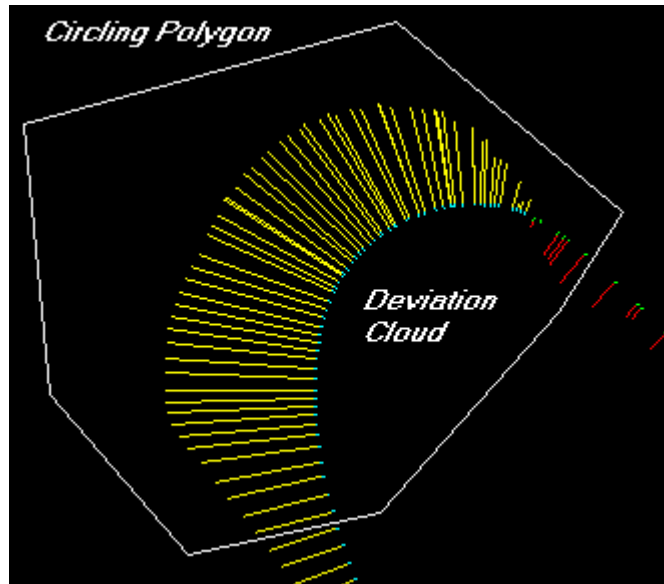


Figure 9.3 Circle-Selecting Deviation Points

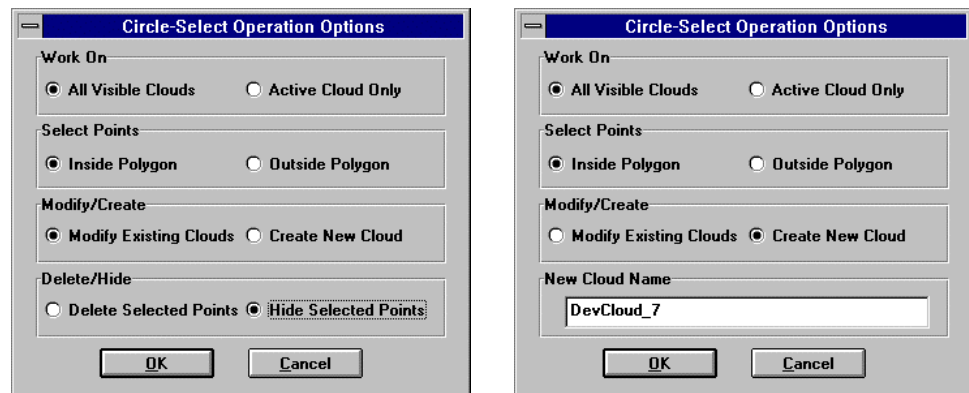


Figure 9.4 The *Circle-Select Operation Options* Dialog Box

After finishing drawing the circling polygon, the *Circle-Select Operation Options* dialog box, as shown in Figure 9.4, will pop up. The four pairs of radio buttons are used to specify what to do in the operation. The first pair of radio buttons specify if you want the operation only applies to the active deviation cloud or all visible deviation clouds. The second pair of radio buttons specify if you want to select the deviation points inside the circling polygon or the deviation points outside the circling polygon. The third pair of radio buttons specify if you want to use the selected deviation points to create a new deviation clouds or modify the existing deviation clouds. When the “*Modifying Existing Clouds*” radio button is selected, you can choose either to hide the selected deviation points in the existing deviation clouds or

delete the selected deviation points from the existing deviation clouds. When the “*Create New Cloud*” radio button is selected, the “*New Cloud Name*” box will be enabled. The user can accept the default cloud name or type a new name for the new deviation cloud to be created. After checking the appropriate radio buttons, click the [OK] button to complete the operation. The contents of the existing deviation clouds will not be altered if the “*Create New Cloud*” option is selected.

9.4.2 Sorting Deviation Clouds

In IQ-FormFit, deviation clouds are either generated from the operation of calculating a curve or a surface from a point cloud or generated from bestfit analysis which includes calculating normal deviation from point clouds to nominal model and bestfitting point clouds to nominal model. For deviation clouds that are generated from bestfit analysis, the deviation clouds keep the parametric value of each deviation point. For example, when the normal deviation from a point to its corresponding curve is calculated, the parameter value (i.e. the u parameter value) of the normal projection point on the curve is associated with the calculated normal deviation. Similarly, when the normal deviation from a point to its corresponding surface is calculated, the parameter values (i.e. both the u parameter value and the v parameter value) of the normal projection point on the surface is associated with the calculated normal deviation. Using the u parameter value and/or the v parameter value, the user can sort the order of the deviation points in a deviation cloud. This is useful in processing deviation clouds that are of 2D nature, e.g. deviation clouds generated from 2D bestfit analysis or deviation clouds that are generated from 3D cross section scan data.

To sort deviation clouds, select menu **/Deviation/Sort Dev Cloud** to bring up the *Sort Deviation Clouds* dialog box as shown in Figure 9.5. The user can selected the deviation clouds to be sorted from the deviation cloud list and specify options for sorting direction and sorting order. Clicking the [Sort] button will carry out the sorting operation. If the deviation clouds are displayed in “CONNECT” mode or “SPK&CONN” mode, the user will notice the order change after the sorting operation.

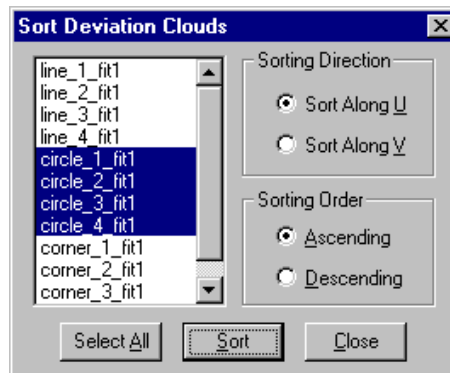


Figure 9.5 The *Merge Pnt Clouds to Create New Cloud* Dialog Box

9.4.3 Merging Deviation Clouds to Create New Deviation Cloud

To merge existing deviation clouds together to create a new deviation cloud, the user should select menu **/Deviation/Merge Dev Clouds** to bring up the *Merge Deviation Clouds* dialog box, as shown in Figure 9.6. Select the deviation clouds to

be added together from the deviation cloud list and click the **[Merge]** button, the selected deviation clouds will be merged and a new deviation cloud will be created. If the “*Keep Old Clouds*” box is checked, the operation will not delete the selected existing deviation clouds. The user can accept the default new cloud name or type a different name for the new deviation cloud to be created.

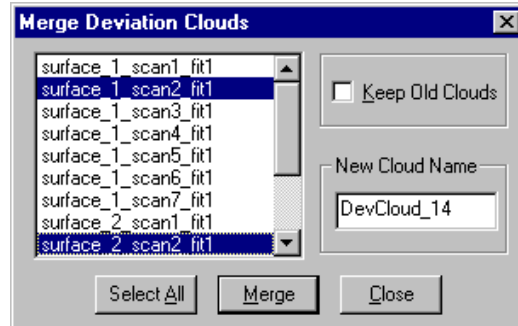


Figure 9.6 The *Merge Deviation Clouds* Dialog Box

9.5 Form Tolerance Support for Deviation Clouds

IQ-FormFit allows the user to associate a form tolerance with each deviation cloud. The form tolerance associated with a deviation cloud serves as tolerance limits and enables IQ-FormFit to display out-of-tolerance and in-tolerance deviation vector in different colors. Tolerance information associated with a deviation cloud also allows IQ-FormFit to provide the user with statistical information for reporting purposes.

IQ-FormFit provides the interface for the user to specify the upper and lower limits of the tolerance zone for each deviation cloud. User interfaces for supporting tolerance limits for deviation cloud include setting form tolerance and editing form tolerance. The setting form tolerance function can be used to assign form tolerance to multiple deviation clouds at a time while the editing form tolerance function is designed to change the form tolerance of an individual deviation cloud one by one.

9.5.1 Setting Form Tolerance for Deviation Clouds

To set form tolerance for deviation clouds, select menu **/Deviation/Set Form Tolerance** to bring up the *Set DevCloud Form Tolerance* dialog box as shown in Figure 9.7. The user can select deviation clouds from the deviation cloud list and specify the upper and lower limits of form tolerance zone. When the **[Set]** button is clicked, the specified form tolerance will be assigned to the selected deviation clouds. The user can continue to set form tolerance for other deviation clouds until the form tolerance information is set for all deviation clouds. The “*Show/Hide Tol Zone*” box on the dialog box is grayed out because the display of form tolerance zone for deviation cloud is not supported. However, once the form tolerance is set for each deviation cloud, the deviation vectors will be displayed in different color for out-of-tolerance deviation and in-tolerance deviation when the deviation clouds are in “*SPIKE*” or “*SPK&CONN*” display mode.

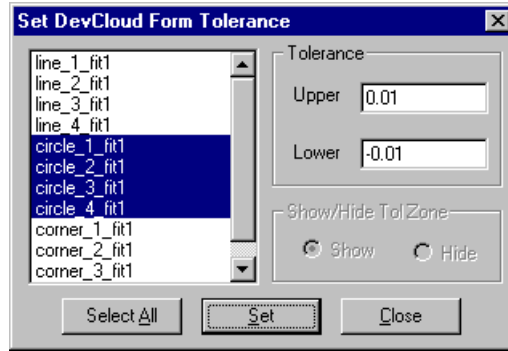


Figure 9.7 The *Set DevCloud Form Tolerance* Dialog Box

9.5.2 Editing Form Tolerance for Deviation Clouds

To edit the form tolerance of a deviation cloud, select menu **/Deviation/Edit Form Tolerance** to bring up the *DevCloud Form Tolerance* dialog box as shown in Figure 9.10. This dialog box lists all the deviation clouds and displays the upper and lower limits of form tolerance for each deviation cloud. Since the display of form tolerance zone for deviation cloud is not supported, the “*Show Tol Zone*” column is grayed out. When the user select a deviation cloud from the deviation cloud list and clicks the **[Edit]** button, the *Edit Form Tolerance* dialog box as shown in Figure 9.11 will pop up to let the user change the form tolerance for the selected deviation cloud. The user can continue to edit the form tolerance information for other deviation clouds until the form tolerance information is correct for all deviation clouds.

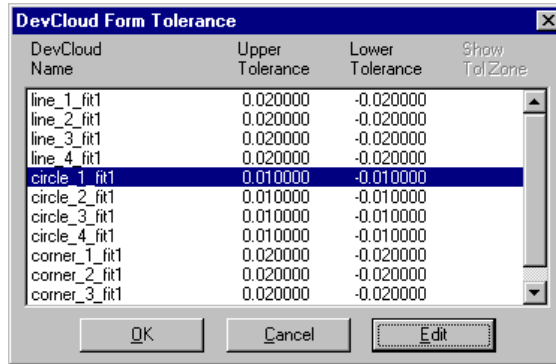


Figure 9.10 The *DevCloud Form Tolerance* Dialog Box

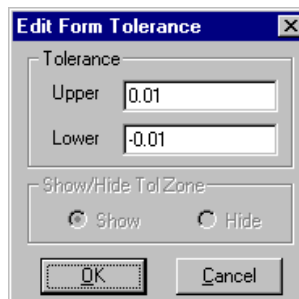



Figure 9.11 The *Edit Form Tolerance* Dialog Box

9.6 Analyzing Deviation Information

After obtaining the deviation clouds from the operation of fitting standard features from point clouds or bestfitting point clouds to nominal CAD model, the user often needs to analyze the deviation. Here we introduce a set of commands for the user to analyze and view the deviation information. This set of commands include marking worst deviation in each deviation cloud, obtaining statistics information for selected deviation clouds, obtaining statistics information by circle-selecting deviations, interrogating deviation and viewing deviation list of a deviation cloud.

9.6.1 Marking Max/Min Deviation Points

Sometimes, the user is more concerned about the worst deviation points resulted from a feature calculation or a bestfit operation. IQ-FormFit implements a switch for the user to mark or un-mark the maximum and minimum deviation points in each deviation cloud. This switch can be toggled by menu **/Deviation/Mark Max/Min**

Deviation or the **[Mark Max/Min Dev]** button  on the tool bar. When this switch is on, the maximum deviation point and the minimum deviation point will be marked by a target symbol on the screen so that the user can easily identify the worse deviations of the part being analyzed.

9.6.2 Obtaining Statistics Information for Deviation Clouds

To obtain the statistics information of deviation clouds, select menu **/Deviation/Stats for Dev Clouds** to bring up the *Statistics for Selected Dev Clouds* dialog box as shown in Figure 9.12. The user can select the deviation clouds of interest from the deviation cloud list. When the **[Statistics]** button is clicked, the *Statistics Information* dialog box as shown in Figure 9.13 will pop up to display the statistics information for the selected deviation clouds. The information displayed on the *Statistics Information* dialog box includes total number of points, number of points that are within tolerance, number of points that are out of tolerance, magnitudes of maximum deviation and magnitude of minimum deviation and their difference. The average deviation and the root mean square value of the selected deviation clouds are also displayed on the *Statistics Information* dialog box. The user can click the **[Copy]** button to copy the information to the clipboard and insert into a report.

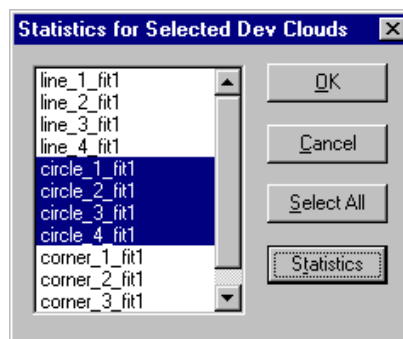
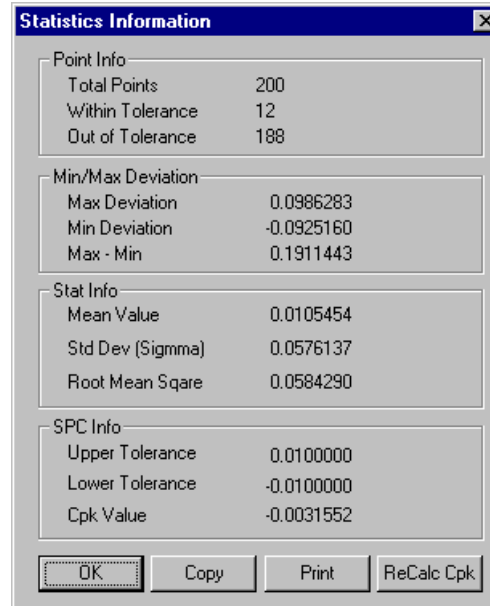


Figure 9.12 The *Statistics for Selected Dev Clouds* Dialog Box

Figure 9.13 The *Statistics Information* Dialog Box

9.6.3 Obtaining Statistics Information by Circle-Selecting Deviations

To obtain the statistics information for a group of circle-selected deviation points, the user needs to first select menu **/Deviation/Stats by Circle-Select** to set the mouse operation mode to DRAW POLYGON mode. In this mode, the cursor will change to the pencil-shaped cursor, and the user can use the mouse to draw a circling polygon on the screen, as shown in Figure 9.3. The circling polygon is drawn through a sequence of click-release of the left mouse button. A final double click of the left mouse button will close the circling polygon and end the drawing.

After finishing drawing the circling polygon, the *Statistics Information* dialog box, as shown in Figure 9.13, will pop up to display the statistics information for the circle-selected deviation points. The information displayed on the *Statistics Information* dialog box includes total number of circle-selected deviation points, number of points that are within tolerance, number of points that are out of tolerance, magnitudes of maximum deviation and magnitude of minimum deviation and their difference among the circle-selected deviation points. The average deviation and the root mean square value of the circle-selected deviation points are also displayed on the *Statistics Information* dialog box. The user can click the **[Copy]** button to copy the information to the clipboard and insert into a report.

9.6.4 Interrogate Deviation

This function is designed to help the user to easily inquire the information of individual deviation point in a deviation cloud on the screen with a mouse pick. To use this function, first select menu **/Deviation/Interrogate Point** to set the mouse operation mode to INTERROGATE DEVIATION mode. In this mode, the mouse cursor will change to the hand shaped cursor to prompt the user to pick a deviation vector on the screen. Once the deviation is picked, the picked deviation will be marked and a small yellow window, as shown in Figure 9.14, will popup to display

the information of the picked deviation. The top row displays the coordinates of the starting point of the deviation vector. The second row displays the direction IJK of the deviation vector. The last row displays the magnitude of the deviation vector. The user can continue to pick other deviation vectors to query their coordinates and magnitudes until the **<ESC>** key is hit to end this operation mode. The yellow window that displays the deviation information will automatically disappear when a time interval elapses or when the mouse cursor is moved.

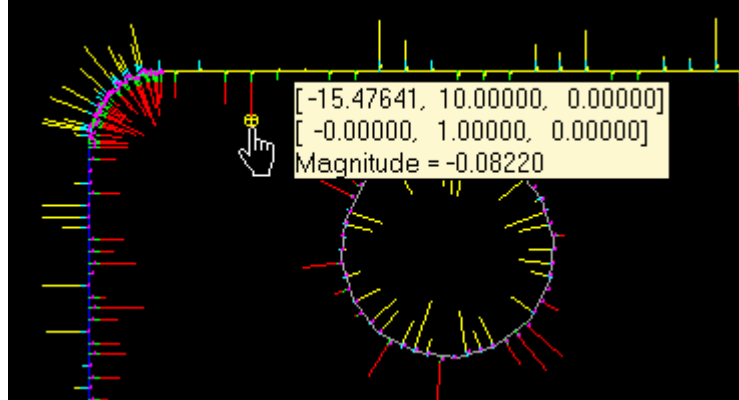


Figure 9.14 Interrogate Deviation

9.6.5 Viewing Deviation Information

The information of an individual deviation vector includes its starting point, normal vector, magnitude and end point. To check the information of each individual deviation inside a deviation cloud, select menu **/Deviation/View Dev Information**. A deviation information window will be created as shown in Figure 9.15.

The deviation information window is split into two parts, on the left is a list of the currently available deviation clouds, on the right is the detailed information of each individual deviation in the selected deviation cloud. When the user double clicks a deviation cloud in the deviation cloud list, the deviation information of the selected deviation cloud will be shown on the right of the screen.

The name of the selected deviation cloud, total number of deviations in the deviation cloud, and the locations of the maximum and the minimum deviation point will be shown on the caption of the right half of the window. The first column is the sequential number of each deviation. Columns 2-4 show the coordinates of the starting point of each deviation vector. The starting point of a deviation vector is also the normal projection point from a measured point to the nominal part model. Columns 5-7 display the direction of a deviation vector which is also the normal vector at the normal projection point on the nominal part model. The magnitude of each deviation is listed in column 8. The last three columns display the coordinates of the end point of each deviation vector. The maximum deviation vector is displayed in blue color and the minimum deviation vector is displayed in red color.

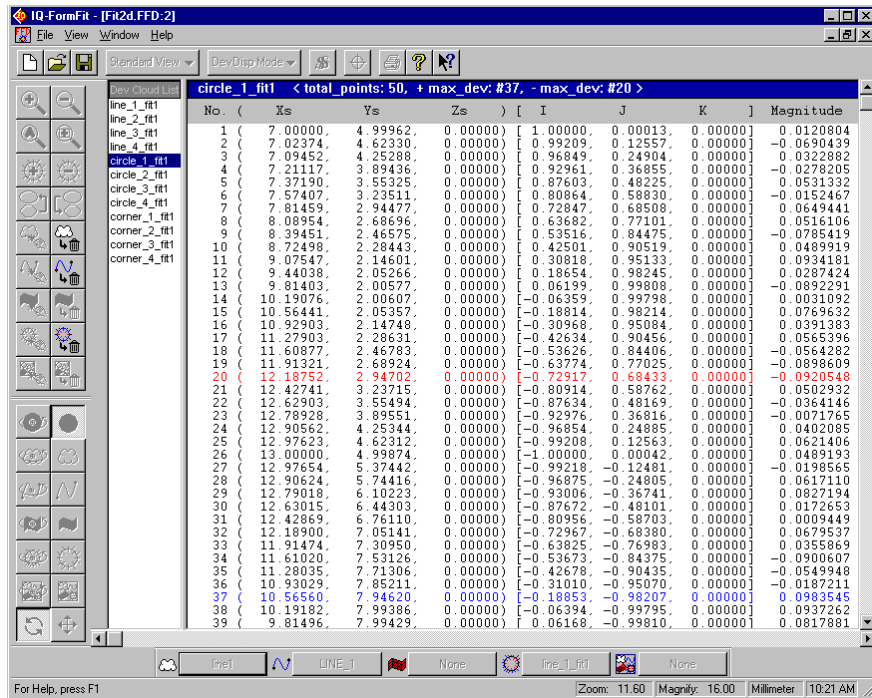


Figure 9.16 Viewing Deviation Information

The user can select what information to display in the deviation information window. The view options for deviation information window are under the **/View** menu which includes **/View/Point Number**, **/View/Start Point**, **/View/I-J-K**, **/View/Magnitude**, **/View/End Point**. The view options can also be changed by invoking the *Change View Options* dialog box through menu **/View/Options**.

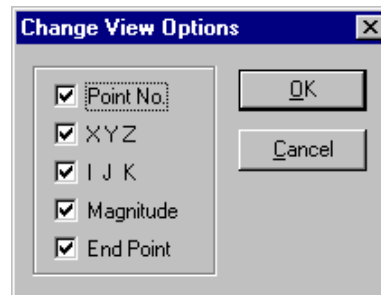


Figure 9.17 The *Change View Options* Dialog Box

To switch back to graphics window, the user can either select a window listed under the **/Windows** menu or select menu **/View/Graphics**. Closing the deviation information window will also switch back to the graphics window.

Chapter 10 Bestfit Analysis

10.1 Introduction

This chapter introduces the procedures related to the calculation of normal deviations from measurement data to a nominal part model and the bestfit of measurement data to a nominal part model. Calculating normal deviations from measurement data to a nominal part model directly compares the data points with the part model and gives the normal deviations from each data point to the part model. However, if there is misalignment between the measurement data and the nominal part model, these normal deviations do not reflect the real surface errors. In order to evaluate the deviation errors of a part surface accurately, bestfit operation must be performed to eliminate the misalignment so that the geometric deviations can be obtained with the highest possible accuracy.

10.2 2D Bestfit Analysis

2D bestfit analysis includes the calculation of normal deviations from 2D point clouds to 2D curves and the bestfit of 2D point clouds to 2D curves. The operation of calculating normal deviations from 2D point clouds to 2D curves calculates the shortest normal distance from each data point to the 2D curves. The operation of bestfitting 2D point clouds to 2D curves computes a transformation matrix which transforms the 2D point clouds to optimally match the 2D curves in the least squares sense.

IQ-FormFit uses the normal vectors of 2D curves to distinguish the material side of each curve for probe compensation and to determine the sign of the deviation from a data point to a curve. The normal vectors of the participating 2D curves must be tested and set correctly using the testing curve normal function described in section 7.9.

10.2.1 Working Plane and Conditions for 2D Bestfit Analysis

See section 6.3 for definition of 2D point cloud

See section 7.2 for definition of 2D curve

See later discussion on selection of working coordinate system

Working plane is discussed in section 6.3 and section 7.2 for dealing with 2D point clouds and 2D curves. Working plane is represented by the xy-plane of the working coordinate system. In IQ-FormFit, working plane and working coordinate system are used interchangeably. Working plane and working coordinate system play an important role in 2D bestfit analysis as we will see in the following discussion.

To perform 2D bestfit analysis, all data points and all curves must be on a common plane which is the working plane. To guarantee this basic condition, the following requirements for curves and point clouds that will be used in 2D bestfit analysis operations must be observed.

- Conditions for curves in 2D bestfit analysis
 1. All participating curves must be 2D curves;
 2. All participating curves must be co-planar to each other;
 3. All participating curves must be parallel to the working plane;

The first condition requires that all participating curves must be 2D curves. 3D curves can be converted to 2D curves using the curve modification method described in section 7.6. The second and the third condition require that each 2D curve must lie on the working plane or at least parallel to the working plane.

- Conditions for point clouds in 2D bestfit analysis

1. All participating point clouds must be 2D point clouds;
2. All participating point clouds must be co-planar to each other;
3. All participating point clouds must be parallel to the working plane;

The first condition requires that all point clouds must be 2D point clouds. 3D point clouds can be converted to 2D point clouds by projecting to a working plane as described in section 6.3. The second and the third condition require that each 2D point cloud must lie on the working plane or at least parallel to the working plane.

The above conditions for curves and point clouds guarantee that all data points and curves will be on the working plane or at least parallel to the working plane. In practice, the point clouds and the curves are usually on the xy-plane of the world coordinate system (Figure 10.1). However, this condition is not a requirement for performing 2D bestfit analysis operations. IQ-FormFit can perform 2D bestfit analysis for point clouds and curves lying on an inclined plane of a part as long as the point clouds and the curves are on the same plane (Figure 10.2).

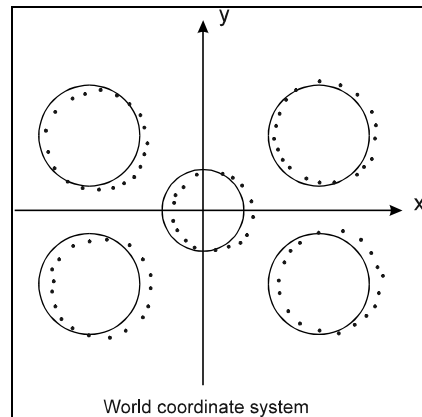


Figure 10.1 Point Clouds & Curves on xy-plane of World Coordinate System

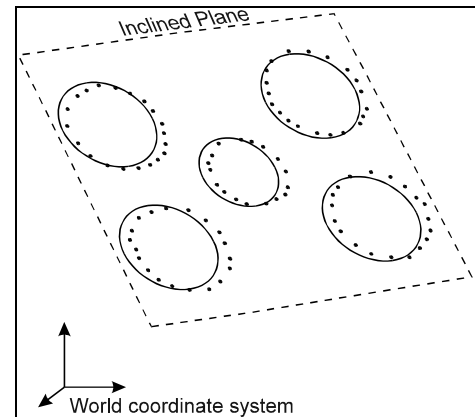


Figure 10.2 Point Clouds & Curves on an Inclined Plane

During the operation of 2D bestfit analysis, the program will automatically filter out 3D curves and will only allow the user to select 2D curve for 2D bestfit analysis. Therefore the first condition for participating curves is enforced by the program without user intervention.

The program will check if all the selected 2D curves are co-planar to each other. If the program detects that the selected 2D curves are not co-planar to each other, i.e. they do not lie on a common plane or at least parallel to a common plane, the program will give a fatal warning message as shown in Figure 10.3. In this case, the operation can not be continued. For 2D bestfit analysis, the user must only select those 2D curves that are on the same plane or at least parallel to a common plane.

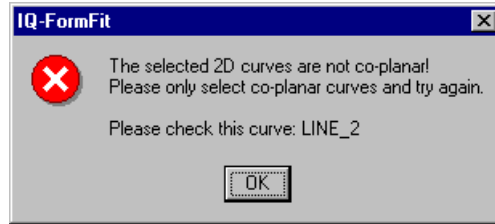


Figure 10.3 Warning Message 2D Curves Not Co-Planar

See later discussion on selection of working coordinate system

The program will also check if the common plane of the selected 2D curves is parallel to the xy-plane of selected working coordinate system. This is to ensure that the selected 2D curves are parallel to the selected working plane. If the common plane of the selected 2D curves is not parallel to the selected working plane, a fatal warning message as shown in Figure 10.4 will be displayed. In this case, the operation can not be continued. The user must select the correct working coordinate system in order to proceed.

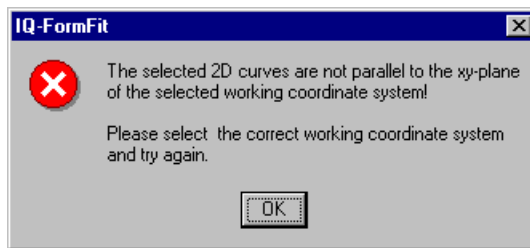


Figure 10.4 Warning Message for 2D Curves Not Parallel to Working Plane

IQ-FormFit will allow the user to select 3D point clouds for 2D bestfit analysis. However, once the program detects that a 3D point cloud is selected for 2D bestfit analysis, a warning message as shown in Figure 10.5 will be displayed. In this case, the user has the option to continue the operation or abort the operation. If the **[No]** button is clicked, the operation will be aborted. However, if the user chooses to continue the operation by clicking the **[Yes]** button, the program will automatically modifying all the selected point clouds by projecting them to the xy-plane of the selected working coordinate system. After such modification, the modified point clouds will be on the same plane, which is the xy-plane of the working coordinate system.

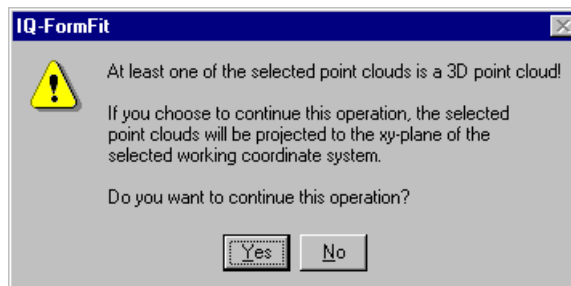


Figure 10.5 Warning Message 3D Point Clouds

If the selected point clouds are all 2D point clouds, the program will then check if the selected 2D point clouds are co-planar to each other. If the selected 2D point clouds do not lie on or parallel to a common plane, the program will give a prompt message

as shown in Figure 10.6. In this case, the user has the option to continue the operation or abort the operation. If the **[No]** button is clicked, the operation will be aborted. However, if the user chooses to continue the operation by clicking the **[Yes]** button, the program will automatically modifying all the selected point clouds by projecting them to the xy-plane of the selected working coordinate system. After such modification, the modified point clouds will be on the same plane, which is the xy-plane of the working coordinate system.

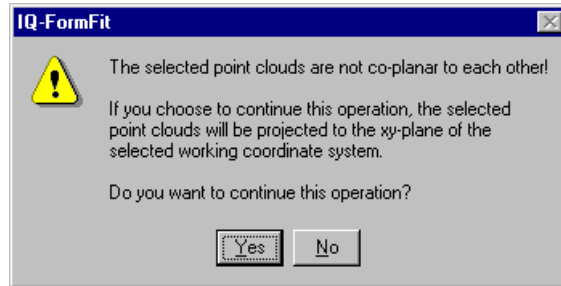


Figure 10.6 Prompt Message for 2D Point Clouds Not Co-Planar

If the selected 2D point clouds are already co-planar to each other, then the program will check if the common plane of the selected 2D point clouds is parallel to the xy-plane of the selected working coordinate system. This is to ensure that the selected 2D point clouds are parallel to selected working plane.

For the operation of calculating normal deviation from 2D point clouds to 2D curves, a warning message as shown in Figure 10.7 will be given when the common plane of the 2D point clouds is not parallel to the selected working plane. In this case, the user can choose to continue the operation or abort the operation. If the user select to continue the operation, the program will automatically modifying all the selected point clouds by projecting them to the xy-plane of the selected working coordinate system before calculating normal deviations. After such modification, the modified point clouds will be on the xy-plane of the working coordinate system.

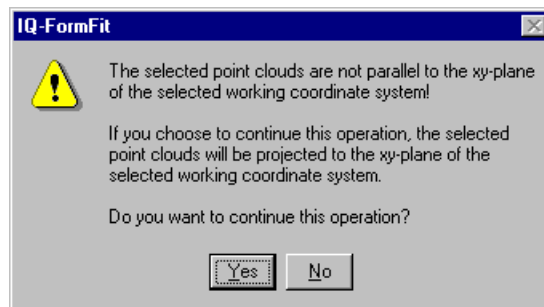


Figure 10.7 Warning Message for 2D Point Clouds Not Parallel to Working Plane

For the operation of bestfitting 2D point clouds to 2D curves, a warning message as shown in Figure 10.8 will be given if the common plane of the 2D point cloud is not parallel to the selected working plane. In this case, the user can choose to continue the operation or abort the operation. If the user select to continue the operation, the program will automatically level off the selected point clouds to the xy-plane of the selected working coordinate system before performing 2D bestfit calculations.

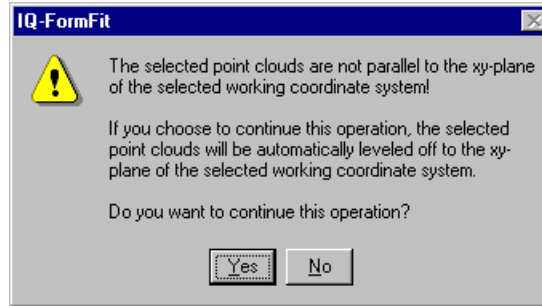
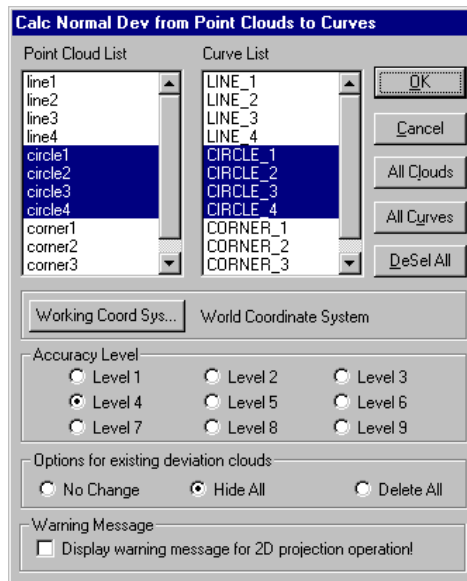


Figure 10.8 Warning Message for 2D Point Clouds Not Parallel to Working Plane

10.2.2 Calculating Normal Deviations from Point Clouds to 2D Curves

To calculate normal deviations from 2D point clouds to 2D curves, select menu **/Bestfit/2D Calc Dev** to bring up the *Calc Normal Dev From Point Clouds to Curves* dialog box as shown in Figure 10.9. The dialog box has two list boxes. All visible point clouds and point cloud groups are listed in the point cloud list box. All visible 2D curves and 2D curve groups are listed in the curve list box. The user can select point clouds from the point cloud list and 2D curves from the curve list. Clicking the **[All Clouds]** button will select all point clouds in the point cloud list box, and clicking the **[All Curves]** button will select all curves in the curve list box.

Figure 10.9 The *Calc Normal Dev from Point Clouds to Curves* Dialog Box

A working coordinate is needed for this operation. The default selection for the working coordinate system is the “World Coordinate System”, which means the program will use the world coordinate system as the working coordinate system for the operation. To select a different working coordinate system, the user can click the **[Working Coord Sys]** button to bring up the *Select Working Coordinate System* dialog box as shown in Figure 10.10.

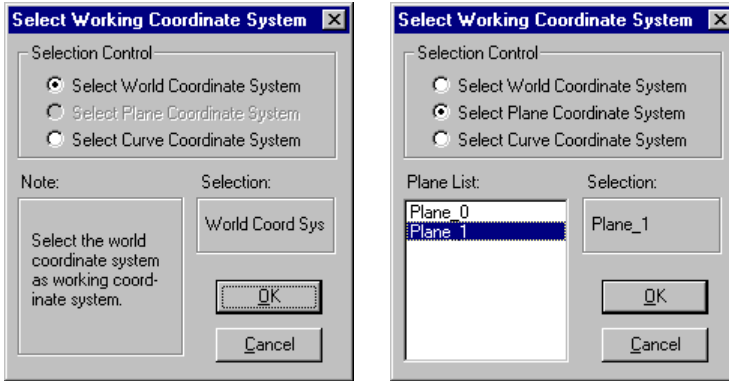


Figure 10.10 The *Select Working Coordinate System* Dialog Box

If the selected 2D curves are on the xy-plane of the world coordinate system, the user may select the world coordinate database as the working coordinate system. If any plane is available in the system, the user may select a plane as the working plane provided that the selected curves are on the plane or parallel to the plane. The user can also select the local coordinate system of any 2D curve as the working coordinate system. After the selection of working coordinate system, the user should click the **[OK]** button to return to the *Calc Normal Dev From Clouds to Curves* dialog box, and the working coordinate system on the dialog box will be updated.

From the *Calc Normal Dev From Point Clouds to Curves* dialog box, the user can select the desired accuracy level for the operation of calculating normal deviation from 2D point clouds to 2D curves. There are nine selectable accuracy levels. The relationship between the accuracy levels and the accuracy of the calculated deviations can be approximately considered as follows: “for the n -th accuracy level, the calculated normal deviations will be approximately accurate to the n -th digit after the decimal point”. The default accuracy level is “Level 4”. If the working unit is *mm*, the accuracy of the calculated deviations will be sub-micron under this accuracy level. The user can select a higher accuracy level depending on accuracy requirement from the actual application.

Selection of accuracy level for calculating normal deviations

If there are deviation clouds generated from previous operations existing in the database, the user can choose to keep them, hide them or delete them. By hiding or deleting the existing deviation clouds, you can have a better view of the deviations that will be generated from this operation.

The program will automatically carry out probe compensation for any point cloud that has a non-zero probe radius associated with it. The probe radius value for each point cloud can be changed using the commands discussed in section 6.4.

After selecting the point clouds and the curves, setting the working coordinate system and choosing the accuracy level, the user should click the **[OK]** button on the *Calc Normal Dev From Point Clouds to Curves* dialog box to carry out the operation of calculating normal deviations from the selected point clouds to selected 2D curves.

The program will first examine the conditions for the selected point clouds and curves as discussed in section 10.2.1. If the *“Display warning message for 2D projection operation”* box is checked, the program will display warning messages based on the various different situations discussed in section 10.2.1. If the check

box is not checked, no warning messages will be displayed and the program will proceed without asking for user confirmation.

The program will calculate the shortest normal deviations from each selected point cloud to the selected 2D curves. When the calculation is finished, deviations will be generated for every data point. The generated deviations are collected into deviation clouds according to the curves they are associated with. The default name for each deviation cloud will be the name of its corresponding curve plus “_cnd” which stands for “calculating normal deviations”. Also, a sequence number will be attached to the end of the deviation cloud names to indicate from which operation the deviation clouds are generated.

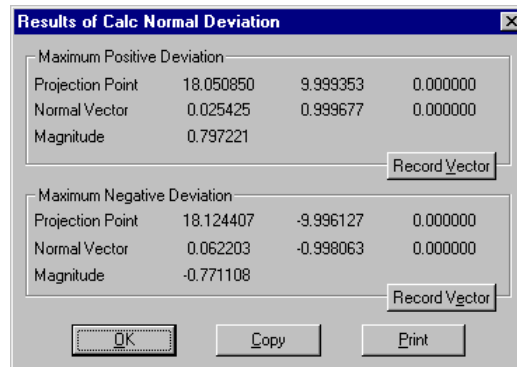


Figure 10.11 The *Results of Calc Normal Deviation* Dialog Box

Among all the calculated deviations obtained from this operation, the maximum positive deviation and the maximum negative deviation will be displayed on the *Results of Calc Normal Deviation* dialog box as shown in Figure 10.11. The user can click the **[Copy]** button on this dialog box to copy the results to the clipboard. Once the results are copied to the clipboard, the user can paste them to a text editor or a word processor for further editing or insert the results into a report. Clicking the **[Print]** button will print the result to a printer.

The user can also click the **[Record Vector]** buttons to keep a record of the maximum positive deviation vector and the maximum negative deviation vector. These recorded vectors can be used to translate a point cloud or a point cloud group by the amount of the maximum positive vector or the maximum negative vector. When the **[Record Vector]** button is clicked, another dialog box will pop-up to let the user type the name of the vector to be recorded. The user can accept the default vector name or type a new name in the “Name” box. Figure 10.12 shows the dialog box for recording the maximum positive deviation vector.

See section 4.4.2 on how to translate point cloud

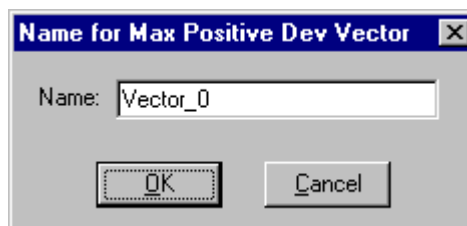


Figure 10.12 The *Name for Max Positive Dev Vector* Dialog Box

10.2.3 Bestfitting Point Clouds to 2D Curves

See section 4.4 for details on how to transform point cloud using scroll bars

In bestfitting 2D point clouds to 2D curves, if the point clouds and the curves are totally mis-aligned, the obtained transformation matrix might not be correct. To ensure that the bestfit process gives the correct answer, the user should use the tools provided by IQ-FormFit to roughly align the point clouds with the curves before carrying out the bestfit operation. Roughly aligning point clouds with curves before doing bestfit can also reduce the computational time needed for bestfit calculation.

Once the point clouds are roughly aligned with the 2D curves, the user can select menu **/Bestfit /2D Bestfit** to bring up the *Bestfit Point Clouds to Curves* dialog box as shown in Figure 10.13. The dialog box has two list boxes. All visible point clouds and point cloud groups are listed in the point cloud list box. All visible 2D curves and 2D curve groups are listed in the curve list box.

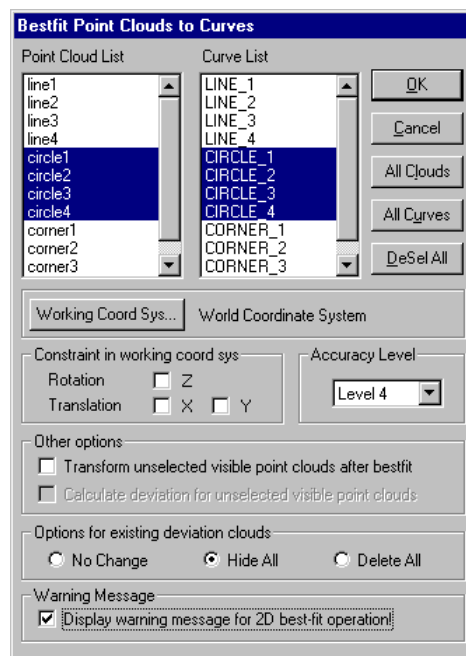


Figure 10.13 The *Bestfit 2D Clouds to 2D Curves* Dialog Box

The user can select point clouds from the point cloud list and 2D curves from the curve list. Clicking the **[All Clouds]** button will select all point clouds in the point cloud list box, and clicking the **[All Curves]** button will select all curves in the curve list box. When selecting 2D curves for the 2D bestfit operation, the user must keep in mind that the selected 2D curves must be co-planar to each other.

For 2D bestfit operation, the user has the control of three different types of options, i.e. bestfit constraints, working coordinate system and bestfit accuracy level.

In 2D bestfit operation, the participating 2D point clouds and the 2D curves are confined to the working plane represented by the xy-plane of the working coordinate system. The data points can only be rotated around the normal vector of the working plane or translated within the working plane. In other words, the possible transformations for the data points are the rotation around the z-axis of the working coordinate system, and the translations along the x-axis and the y-axis of the working coordinate system. Accordingly, we can apply a constraint to any of the

three transformations. To disallow the rotation around the z-axis of the working coordinate system, the user should check the “Z” check box for the rotation constraint. Similarly, to disallow the translation along the x-axis and/or y-axis of the working coordinate system, the respective check boxes should be checked.

We should emphasize that the constraints for 2D bestfit operation are applied with respect to the selected working coordinate system. By selecting different working coordinate system, the user can restrict the translation along any desired direction within in the plane where the curves lie on.

Since the constraints for 2D bestfit operation are applied with respect to the selected working coordinate system, selecting different working coordinate system will give different results for constrained 2D bestfit. The selection of working coordinate system for 2D bestfit operation is similar to the selection of working coordinate system for the operation of calculating normal deviation from 2D point clouds to 2D curves which is discussed in section 10.2.2.

The bestfit process is an optimization process. The bestfit operation tries to calculate a transformation matrix that can be applied to the participating point clouds to optimally match them to the participating curves in the sense that the RMS residual is minimized. The computation of bestfit is carried out in an iterative fashion. IQ-FormFit lets the user select the accuracy level to control the termination condition for the optimization process. There are nine selectable accuracy levels. The relationship between each accuracy level and the accuracy of the bestfit results can be approximately described as “for accuracy level n , the final RMS residual will be accurate to the n -th digit after the decimal point”. The default accuracy level is “Level 4” which means the RMS residual will be accurate to the fourth digit after the decimal point.

Selection of
accuracy
level for bestfit

IQ-FormFit will automatically transform the selected point clouds using the transformation matrix obtained from the bestfit calculation. After transforming the selected point clouds, IQ-FormFit will also calculate normal deviations from the selected point clouds to the nominal model. The user can choose to transform the unselected point clouds using the same transformation matrix so that the unselected point clouds can float along with the selected point clouds together. The user also has the option to calculate normal deviations from the transformed unselected point clouds to the nominal model.

If there are deviation clouds generated from previous operations existing in the database, the user can choose to keep them, hide them or delete them. By hiding or deleting the existing deviation clouds, you can have a better view of the deviations that will be created from this operation.

The “*Display warning message for 2D bestfit operation*” check box controls whether the warning messages related to the conditions of 2D bestfit will be displayed. If this option is checked, the program will display warning messages based on the situation as discussed in section 10.2.1. If the option is not checked, no warning messages will be displayed and the program will proceed without asking for user confirmation.

When the **[OK]** button on the *Bestfit Point Clouds to Curves* dialog box is clicked, the 2D bestfit process will start. While the bestfit computation is in progress, the *Bestfit Progress* dialog box as shown in Figure 10.14 will be displayed to show the progress of bestfit computation. The iteration number and the RMS residual are displayed in the “*Iteration Information*” box on the *Bestfit Progress* dialog box. In the

“Convergence Ratio Per Iteration” box, the convergence ratio is displayed in percentage. The convergence ratio is the deduction of RMS residual in the i -th iteration over the RMS residual of the $(i-1)$ -th iteration, i.e. $((RMS)_{i-1} - (RMS)_i) / (RMS)_{i-1}$. It can be used as an indicator for convergence speed.

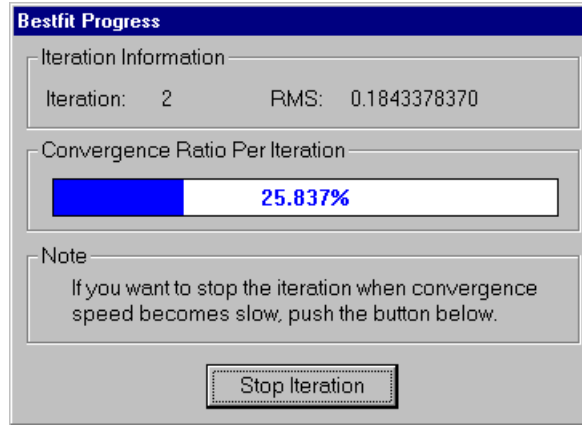


Figure 10.14 The *Bestfit Progress* Dialog Box

When the bestfit calculation converges to the selected accuracy level, the iteration process will terminate and the *Bestfit Progress* dialog box will disappear. If a very high accuracy level is selected, the bestfit calculation might be prolonged. In this case, the user can terminate the iteration process by clicking the **[Stop Iteration]** button when the convergence ratio becomes very small.

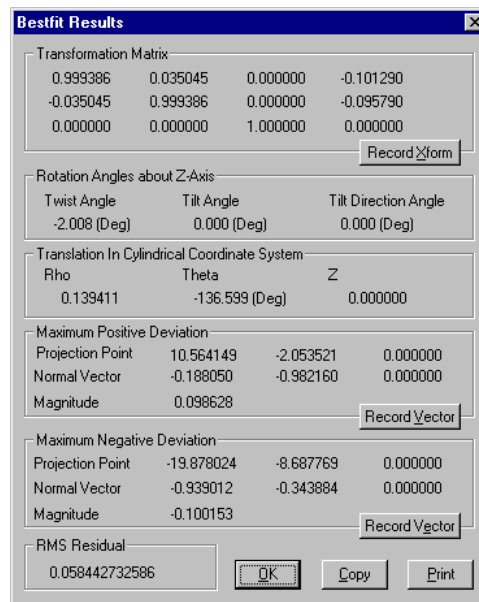


Figure 10.15 The *Bestfit Results* Dialog Box(for 2D bestfit)

After the bestfit computation is finished or terminated by the user, the optimal transformation is obtained. The obtained transformation is always converted to be with respect to the world coordinate system. The obtained transformation will be displayed on the *Bestfit Results* dialog box as shown in Figure 10.15. From the

obtained transformation matrix, a set of rotation angles about the z-axis of the world coordinate system is also calculated and displayed on the *Bestfit Results* dialog box. This set of angles includes twist around the z-axis, tilt from the z-axis and the tilt direction angle, and they are illustrated in Figure 10.16. For the convenience of users who use cylindrical coordinate system, the translation part of the transformation matrix are also converted to cylindrical coordinate system and displayed on the *Bestfit Results* dialog box. The translation parameters in cylindrical coordinate system are illustrated in Figure 10.17.

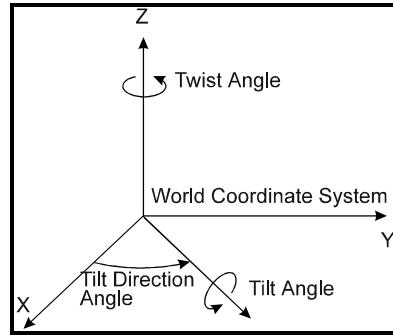


Figure 10.16 The Rotation Angles

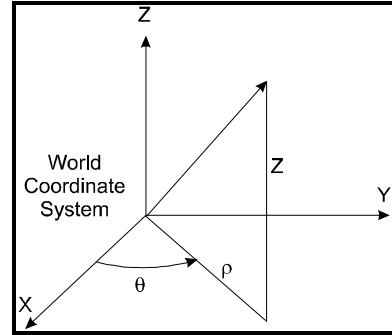


Figure 10.17 Translation Parameters

The program will calculate normal deviations from the transformed 2D point clouds to the selected 2D curves. The normal deviations are collected into deviation clouds according to the curves they are associated with. The default name for each deviation cloud will be the name of its corresponding curve plus “_fit” which indicates that the deviation cloud is generated from a bestfit operation. Also, a sequence number will be attached to the end of the deviation cloud names to indicating from which operation the deviation clouds are generated.

Among all the generated deviations, the maximum positive deviation and the maximum negative deviation will also be displayed on the *Bestfit Results* dialog box. The final RMS residual value is displayed in the “*RMS Residual*” box. The user can click the **[Copy]** button on the *Bestfit Results* dialog box to copy the results to the clipboard or the **[Print]** button to print the results to a printer.

See section 4.4.4 on how to transform a point cloud using a transformation

The user can click the **[Record Xform]** buttons to keep a record of the obtained transformation for later use in transforming a point cloud or a point cloud group. When the **[Record Xform]** button is clicked, the *Name for Transformation* dialog box as shown in Figure 10.18 will pop up to let the user type the name for the transformation to be recorded. The user can accept the default transformation name or type a new name in the “*Name*” box.

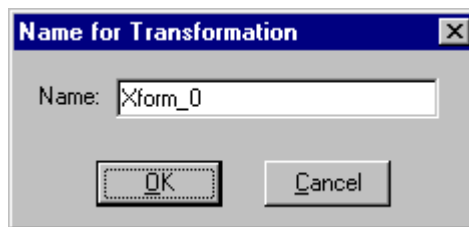


Figure 10.18 The *Name for Transformation* Dialog Box

See section 4.4.2 on how to translate a point cloud by a vector

The user can also click the **[Record Vector]** buttons to keep a record of the maximum positive deviation vector and the maximum negative deviation vector. These recorded vectors can be used to translate a point cloud or a point cloud group by the amount of the maximum positive vector or the maximum negative vector.

10.2.4 Calculate True Position for Circles

Figure 10.19 shows an example of a hole pattern which has five circles. After data points are measured from each circle, a 2D best-fit operation can be performed to align the measurement data with the nominal model. For assembly purpose, it is often necessary to find out the position error of each circle. The position error of a circle is the deviation from the center of the actual circle to the center of the nominal circle.

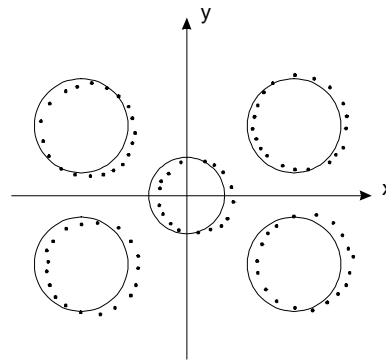


Figure 10.19 Hole Pattern and Position Error

After a 2D bestfit operation, each measurement point will be correctly associated with its nominal circle. Based on this association, IQ-FormFit can easily calculate the position error for each individual circle. To display position errors for circular features, select menu **/Bestfit/Circle True Pos** to bring up the *Circle True Position* dialog box as shown in Figure 10.20. Among the results displayed on this dialog box, “dx” and “dy” are the deviation from the center of the actual circle to the normal circle along the x and y axis respectively. “PosError” is the true position error. “Out-of-tol” column shows how much the true position error is out of tolerance. If the true position is within tolerance, no data will be display in this column. If the “Show PosError and Out-of-tol in RADIUS” box is checked, these two qualities will be displayed in terms of radius. Otherwise, they will be displayed in terms of diameter.

See section 7.8 on how to assign position tolerance to circles

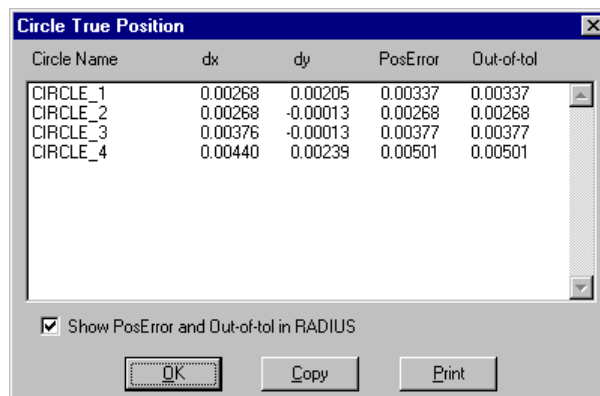


Figure 10.20 The *Circle True Position* Dialog Box

10.3 3D Bestfit Analysis

3D bestfit analysis includes the calculation of normal deviations from point clouds to surfaces and the bestfit of point clouds to surfaces. The operation of calculating normal deviations from point clouds to surfaces calculates the shortest normal distance from each data point to the surfaces. The operation of bestfitting point clouds to surfaces computes a transformation matrix that transforms the point clouds to optimally match the surfaces in the least squares sense.

Since IQ-FormFit uses the normal vectors of the surfaces to distinguish the material side for probe compensation and to determine the sign of the deviation from a data point to a surface, the normal vectors of the participating surfaces must be tested and set correctly using the method described in section 8.6.

10.3.1 Calculating Normal Deviations from Point Clouds to Surfaces

To calculate normal deviations from point clouds to surfaces, select menu **/Bestfit/3D Calc Dev** to bring up the *Calc Normal Dev From Point Clouds to Surfaces* dialog box as shown in Figure 10.21. The dialog box has two list boxes. All visible point clouds(including 2D point clouds and 3D point clouds) and point cloud groups are listed in the point cloud list box. All visible surfaces and surface groups are listed in the surface list box. The user can select point clouds from the point cloud list and surfaces from the surface list. Clicking the **[All Clouds]** button will select all point clouds in the point cloud list box, and clicking the **[All Surfaces]** button will select all surfaces in the surface list box. The user can also select the desired accuracy level for the operation of calculating normal deviations from point clouds to surfaces. Please refer to section 10.2.2 for discussion about selection of accuracy level for calculating normal deviations.

See section 10.2.2 for discussion on accuracy selection for operation of calculating normal deviations

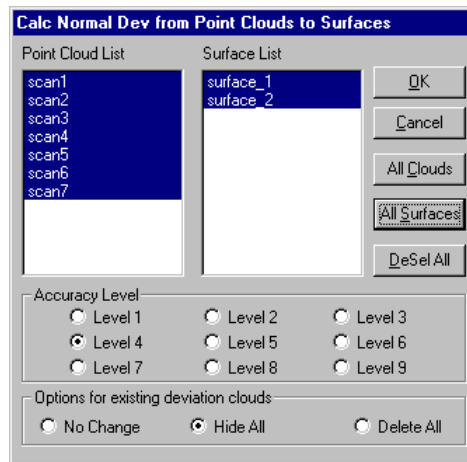


Figure 10.21 The *Calc Normal Dev from Clouds to Surfaces* Dialog Box

If there are deviation clouds generated from previous operations existing in the database, the user can choose to keep them, hide them or delete them. By hiding or deleting the existing deviation clouds, you can have a better view of the deviations that will be created from this operation.

This operation will calculate the shortest normal deviation from each selected data point to the selected surfaces. The calculated deviations will be collected into

different deviation clouds based on the surfaces that the deviations are associated with and the point clouds that the data points, from which the deviations are generated, belong to. For example, if we have a data point in point cloud named "scan1" and the shortest normal deviation from this data point is the normal projection to a surface named "surface1", then the program will put the deviation generated from the projection of this data point in "scan1" to surface "surface1" in a deviation cloud named "surface1_scan1_cnd", where "cnd" stands for "calculating normal deviations". Also, a sequence number will be attached to the end of the deviation cloud names to indicating from which operation the deviation clouds are generated.

Among all the calculated deviations, the maximum positive deviation and the maximum negative deviation will be displayed on the *Results of Calc Normal Deviation* dialog box as shown in Figure 10.22.

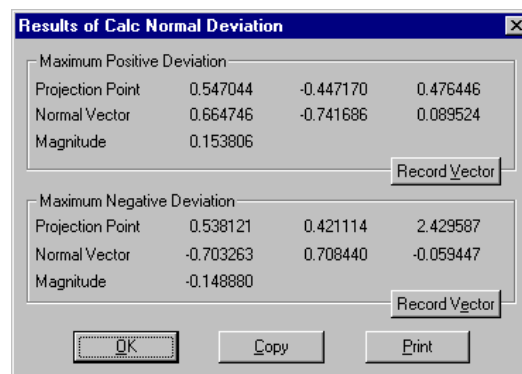


Figure 10.22 The *Results of Calc Normal Deviation* Dialog Box

The user can click the **[Copy]** button on this dialog box to copy the results to the clipboard. The user can also click the **[Record Vector]** buttons to keep a record of the maximum positive deviation vector and the maximum negative deviation vector. These recorded vectors can be used to translate a point cloud or a point cloud group by the amount of the maximum positive vector or the maximum negative vector.

See section 4.4.2 on how to translate point cloud

10.3.2 Bestfitting Point Clouds to Surfaces

In bestfitting point clouds to surfaces, if the point clouds and the surfaces are totally mis-aligned, the obtained transformation matrix might not be correct. To ensure that the bestfit process gives the correct answer, the user should use the tools provided by IQ-FormFit to roughly align the point clouds with the surfaces before carrying out the bestfit operation. Roughly aligning point clouds with surfaces before doing bestfit can also reduce the computational time needed for bestfit calculation.

See section 4.4.1 for details on how to transform point cloud using scroll bars

Once the point clouds are roughly aligned with the surfaces, the user can select menu **/Bestfit/3D Bestfit** to bring up the *Bestfit Point Clouds to Surfaces* dialog box as shown in Figure 10.23. The dialog box has two list boxes. All visible point clouds and point cloud groups are listed in the point cloud list box. All visible surfaces and surface groups are listed in the surface list box.

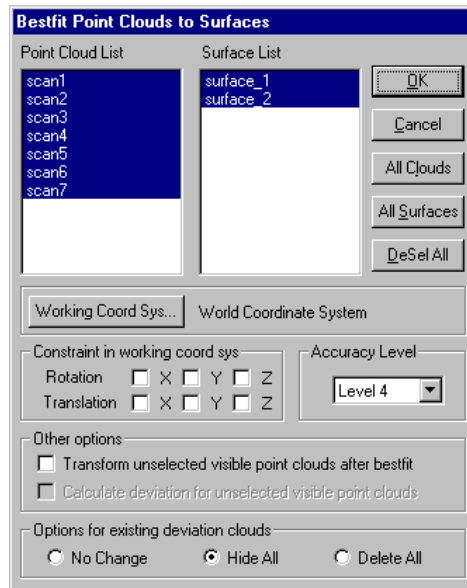


Figure 10.23 The *Bestfit Point Clouds to Surfaces* Dialog Box

The user can select point clouds from the point cloud list and surfaces from the surface list. Clicking the **[All Clouds]** button will select all the point clouds in the point cloud list box, and clicking the **[All Surfaces]** button will select all the surfaces in the surface list box.

See section 10.2.3 for discussion on selection of accuracy level for bestfit operation

For 3D bestfit operation, the user has the control of three different types of options, i.e. bestfit constraints, working coordinate system and bestfit accuracy level. The selection of bestfit accuracy level for bestfit operation is discussed in section 10.2.3.

For 3D bestfit operation, there are six degrees of freedom: three rotations and three translations. Any of the six degrees of freedom can be constrained by checking the respective check box. If all six degrees of freedom are disabled, the resulting deviations from this operation will be the same as those obtained from the operation of calculating normal deviations from point clouds to surfaces.

It is important to point out that the constraints for 3D bestfit operation are applied with respect to the working coordinate system. For example, the constraint for the translation in x direction disallow the translation along the x-axis of the working coordinate system, and the constraint for the rotation around z-axis disallow the rotation around the z-axis of the working coordinate system. By selecting different working coordinate system, the user can restrict the translation along any desired direction and the rotation around any desired vector. Since different working coordinate system will give different bestfit results for constrained 3D bestfit operation, it is important to select the right working coordinate system for constrained 3D bestfit operation. For non-constrained 3D bestfit operation, the selection of working coordinate system will not affect the bestfit results.

The default working coordinate system for 3D bestfit operation is the world coordinate system. To select a different working coordinate system for 3D bestfit operation, the user can click the **[Working Coord Sys]** button to bring up the *Select Working Coordinate System* dialog box as shown in Figure 10.24. The user can select the world coordinate system as the working coordinate system. If any plane is available in the database, the user may select the coordinate system of a plane as

the working plane. If any non-plane surface is available in the system, the user can also select the local coordinate system of a surface as the working coordinate system. After selecting the working coordinate system, the user should click the **[OK]** button to return to the *Bestfit Point Clouds to Surfaces* dialog box, and the working coordinate system on the dialog box will be updated.

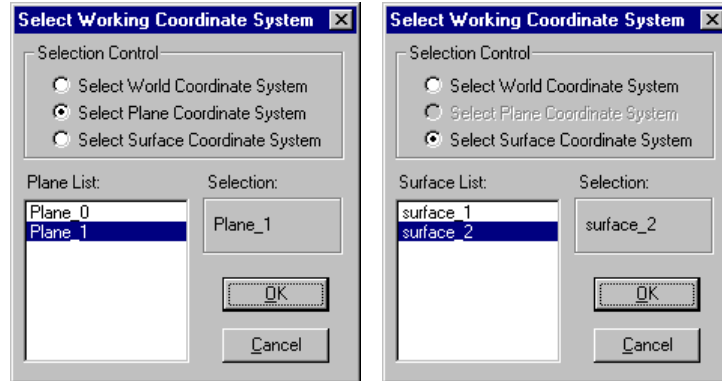


Figure 10.24 The *Select Working Coordinate System* Dialog Box

IQ-FormFit will automatically transform the selected point clouds using the transformation matrix obtained from the bestfit calculation. After transforming the selected point clouds, IQ-FormFit will also calculate normal deviations from the selected point clouds to the nominal model. The user can choose to transform the unselected point clouds using the same transformation matrix so that the unselected point clouds can float along with the selected point clouds together. The user also has the option to calculate normal deviations from the transformed unselected point clouds to the nominal model.

If there are deviation clouds generated from previous operations existing in the database, the user can choose to keep them, hide them or delete them. By hiding or deleting the existing deviation clouds, you can have a better view of the deviations that will be created from this operation.

See section 10.2.3 for detailed discussion about the Bestfit Progress dialog box

When the **[OK]** button on the *Bestfit Point Clouds to Surfaces* dialog box is clicked, the 3D bestfit process will start. While the bestfit computation is in progress, the *Bestfit Progress* dialog box as shown in Figure 10.13 will be displayed to show the progress of bestfit computation. When the bestfit calculation converges to the selected accuracy level, the iteration process will terminate and the *Bestfit Progress* dialog box will disappear. If a very high accuracy level is selected, the bestfit calculation might be prolonged. In this case, the user can terminate the iteration process by clicking the **[Stop Iteration]** button when the convergence ratio becomes very small.

After the bestfit computation is finished or terminated by the user, the optimal transformation is obtained. The obtained transformation is always converted to be with respect to the world coordinate system. The obtained transformation will be displayed on the *Bestfit Results* dialog box as shown in Figure 10.25. From the obtained transformation matrix, a set of rotation angles about the z-axis of the world coordinate system is also calculated and displayed on the *Bestfit Results* dialog box. This set of angles includes twist around the z-axis, tilt from the z-axis and the tilt direction angle, and they are illustrated in Figure 10.16. For the convenience of users who use cylindrical coordinate system, the translation part of the

transformation matrix are also converted to cylindrical coordinate system and displayed on the *Bestfit Results* dialog box. The translation parameters in cylindrical coordinate system are illustrated in Figure 10.17.

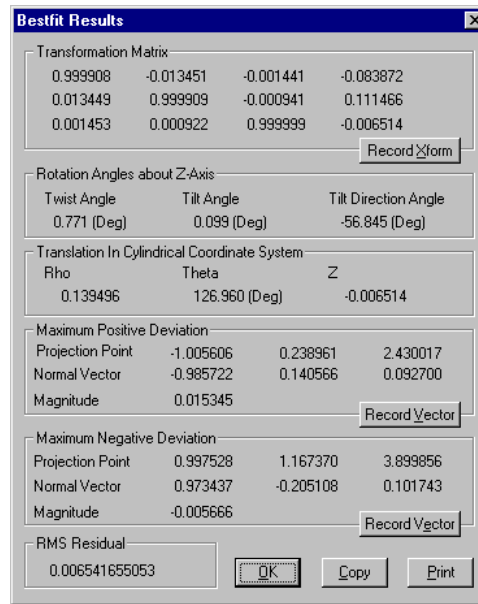


Figure 10.25 The *Bestfit Results* Dialog Box(for 3D bestfit)

The program will calculate normal deviations from the transformed point clouds selected for the bestfit operation to the selected surfaces. The calculated deviations will be collected into different deviation clouds based on the surfaces that the deviations are associated with and the point clouds that the data points, from which the deviations are generated, belong to. For example, if we have a data point in a point cloud named “scan1” and the deviation generated from this data point is associated to a surface named “surface1”, then the program will put the deviation generated from this data point in “scan1” to surface “surface1” in a deviation cloud named “surface1_scan1_fit”, where “_fit” indicates that the deviation cloud is created from a bestfit operation. Also, a sequence number will be attached to the end of the deviation cloud names to indicating from which operation the deviation clouds are generated.

Among all the generated deviations, the maximum positive deviation and the maximum negative deviation will also be displayed on the *Bestfit Results* dialog box. The final RMS residual value is displayed in the “*RMS Residual*” box. The user can click the **[Copy]** button on the *Bestfit Results* dialog box to copy the results to the clipboard or the **[Print]** button to print the results to a printer.

The user can click the **[Record Xform]** buttons to keep a record of the obtained transformation for later use in transforming a point cloud or a point cloud group.

The user can also click the **[Record Vector]** buttons to keep a record of the maximum positive deviation vector and the maximum negative deviation vector. These recorded vectors can be used to translate a point cloud or a point cloud group by the amount of the maximum positive vector or the maximum negative vector.

See section 4.4.4 on how to transform a point cloud using a transformation

See section 4.4.2 on how to translate a point cloud by a vector

Appendix A ASCII Data File Format

```

////////////////////////////////////
// Revision History:
// + 04-07-98 ZCY +-----
// |               | [1] Modified to add unit & probe radius support
// + 10-16-96 ZCY +-----
// |               | [1] Modified for User's Guide and added example data file
// + 03-26-96 ZCY +-----
// |               | [1] Created this document
////////////////////////////////////

```

General Rules

1. Each line must be less than 1024 bytes including CR and LF

2. Data Line
 - ==> Data line should not have line number or sequential number
 - ==> Each data line must have at least
 - 2 columns of data for 2D data point
 - 3 columns of data for 3D data point
 - ==> Each column of data is separated by either "white space", "tab",
 ",", or ";" (these four characters are called delimiting characters)
 - ==> The coordinates of a data point can be surrounded by a pair of
 square brackets "[]" or a pair of parentheses "()"
 - ==> Anything after the third column is discarded

3. Comment Lines:
 - ==> Comment lines start with non-numeric characters. This means any line starts
 with a non-numeric character will be skipped.
 - ==> Recommend starting characters for comment lines: !@#\$\$%*/
 - ==> Blank lines will be skipped, but not treated as comment lines.

4. The user can specify measurement data unit in one of the comment lines. Data unit must be
 preceded with one of the following specifiers:

Measruement Unit	or	Measruement Unit:
Measurement_Unit		Measurement_Unit:
Data Unit		Data Unit:
Data_Unit		Data_Unit:
Unit		Unit:

The following units names are supported:

Inch	or	IN
Millimeter		MM
Foot		FT
Mile		MI
Meter		M
Kilometer		KM
Mil		MIL
Micron		UM
Centimeter		CM
Microinch		UIN
Yard		YD

 - ==> unit specifiers and unit names are case insensitive
 - ==> unit must be specified at the beginning of the file before any data lines
 - ==> one data file can only have one unit

```
==> Example:
    % data_unit: inch
    2.3, 4.5, 8.6
    1.7, 3.6, 5.4
    2.2, 4.3, 8.7
```

5. Different point clouds can be in the same file but must be separated by comment lines

```
==> Example:
    // data_unit: MM
    % this is the first point cloud
    2.3, 4.5, 8.6
    1.7, 3.6, 5.4
    2.2, 4.3, 8.7

    # the second point cloud starts from here
    2.4, -2.4, -1.2
    -7.8, -0.3, 9.5
    2.2, -7.5, 3.4
```

6. The user can specify a point cloud name for each point cloud in one of its comment lines, but point cloud name must be preceded with one of the following specifiers:

```
cloud name    or    cloud name:
cloud_name    cloud_name:
name          name:
```

```
==> point cloud name specifiers are case insensitive
==> Default name for the first point cloud in a file will be the data file name.
==> Default name for point clouds after the first point cloud will be data file name
    plus the sequence number of the point cloud in the data file.
```

```
==> Example:
    // data_unit: MM
    % this is the first point cloud
    % cloud name pntcloud#1
    2.3, 4.5, 8.6
    1.7, 3.6, 5.4
    2.2, 4.3, 8.7

    # the second point cloud starts from here
    # name: cloud_no2
    2.4, -2.4, -1.2
    -7.8, -0.3, 9.5
    2.2, -7.5, 3.4
```

7. The user can specify a probe radius for each point cloud name in one of its comment lines, but probe radius must be preceded with one of the following specifiers:

```
probe radius    or    probe radius:
probe_radius    probe_radius:
probe diameter  probe diameter:
probe_diameter  probe_diameter:
```

```
==> probe radius specifiers are case insensitive
==> probe radius must have the same unit as the data points
==> default probe radius for each point cloud is zero if not specified
```

```
==> Example:
    * data_unit: MM
    % this is the first point cloud
    % cloud name pntcloud#1
    # probe radius 0.5
    2.3, 4.5, 8.6
    1.7, 3.6, 5.4
    2.2, 4.3, 8.7
```



```
# the second point cloud starts from here
# name: cloud_no2
# probe_diameter: 1.0
2.4, -2.4, -1.2
-7.8, -0.3, 9.5
2.2, -7.5, 3.4
```

8. For scan data and grid data:
 ==> scan data: each scan line must be separated by a blank line
 ==> grid data: each grid line must be separated by a blank line

2D Data Format

A. Arbitrary data

```
==> comment: what ever comment
==> body   : x1, y1
            x2, y2
            .....
            xn, yn
```

B. Scan line data

```
==> comment: what ever comment
==> body   : x11, y11      <--- 1st point of 1st scan line
            x12, y12
            .....
            x11, y11
                                     <--- blank line
            x21, y21      <--- 1st point of 2nd scan line
            x22, y22
            .....
            x2m, y2m
                                     <--- blank line
            . . .
            . . .
                                     <--- blank line
            xn1, yn1      <--- 1st point of last scan line
            xn2, yn2
            .....
            xnk, ynk
```

C. Grid line data

```
==> comment: what ever comment
==> body   : x11, y11      <--- 1st point of 1st grid line
            x12, y12
            .....
            x1m, y1m
                                     <--- blank line
            x21, y21      <--- 1st point of 2nd grid line
            x22, y22
            .....
            x2m, y2m
                                     <--- blank line
            . . .
            . . .
                                     <--- blank line
            xn1, yn1      <--- 1st point of last grid line
            xn2, yn2
            .....
            xnm, ynm
```

3D Data Format

A. Arbitrary data

```
==> comment:  what ever comment
==> body   :  x1, y1, z1
              x2, y2, z2
              .....
              xn, yn, zn
```

B. Scan line data

```
==> comment:  what ever comment
==> body   :  x11, y11, z11      <--- 1st point of 1st scan line
              x12, y12, z12
              .....
              x11, y11, z11
              <--- blank line
              x21, y21, z21      <--- 1st point of 2nd scan line
              x22, y22, z22
              .....
              x2m, y2m, z2m
              <--- blank line
              . . .
              . . .
              . . .
              <--- blank line
              xn1, yn1, zn1      <--- 1st point of 1st scan line
              xn2, yn2, zn2
              .....
              xnk, ynk, znk
```

C. Grid line data

```
==> comment:  what ever comment
==> body   :  x11, y11, z11      <--- 1st point of 1st grid line
              x12, y12, z12
              .....
              x1m, y1m, z1m
              <--- blank line
              x21, y21, z21      <--- 1st point of 2nd grid line
              x22, y22, z22
              .....
              x2m, y2m, z2m
              <--- blank line
              . . .
              . . .
              . . .
              <--- blank line
              xn1, yn1, zn1      <--- 1st point of last grid line
              xn2, yn2, zn2
              .....
              xnm, ynm, znm
```

Example Data File

```

@=====
$ Example 2D data point cloud
% cloud name: cloud_1
% MEASUREMENTS ARE IN MM
% PROBE DIAMETER
 3.985538
@=====
POINT LIST:
      x           y
 0.002717  -32.103327
 62.990634, -32.151729
-77.878918; -32.194409

$=====
$ Example 3D data point cloud
% cloud name: cloud_2
MEASUREMENTS ARE IN IN
PROBE DIAMETER
3.985538
$=====
[ 54.972503, -39.697226, 39.937004]
[  0.000518, -39.758385, 67.991793]
[  0.007152, -45.837381, 60.110731]
[ 48.825736, -46.176942, 35.480883]
[  0.000695, -46.173673, 60.357393]

% cloud name: cloud_3
( x, y, z ) ( i, j, k )
( 58.191211, -36.694350, 42.276617) ( 0.484322, -0.800997, 0.351903) <-- data line
(  0.001062, -36.737581, 71.956323) (-0.000045, -0.800986, 0.598683) <-- data line
( -0.000000, -39.710364, -67.957073) (-0.000020, -0.801001, -0.598663) <-- data line
( 54.972503, -39.697226, 39.937004) ( 0.484322, -0.800997, 0.351903) <-- data line
END OF DATA FILE
    
```


Appendix B ASCII Deviation File Format

```

////////////////////////////////////
// Revision History:
// + 01-05-97 ZCY +-----
// |           | [1] Create this document for User's Guide
// |           |
////////////////////////////////////

```

----- General Rules -----

1. Each line must be less than 1024 bytes including CR and LF
2. Data Line
 - ==> Data line should not have line number or sequential number
 - ==> Each data line must have seven data columns for the deviation starting point (x,y,z), the deviation direction vector (i,j,k) and the deviation magnitude mag
 - ==> Each column of data is separated by either "white space", "tab", ",", or ";" (these four characters are called delimiting characters)
 - ==> The coordinates of the deviation starting point(x,y,z) and the deviation direction vector (i,j,k) can be surrounded by a pair of square brackets "[]" or a pair of parentheses "()"
 - ==> Anything after the seventh column is discarded
3. Comment Lines:
 - ==> Comment lines start with non-numeric characters. This means any line starts with a non-numeric character will be skipped.
 - ==> Recommend starting characters for comment lines: !@#\$%*/
 - ==> Blank lines will be skipped, but not treated as comment lines.
4. User can specify deviation cloud name in one of the comment lines, but cloud name must be followed by specifier "name: ".
 - ==> Examples:


```

          % dev cloud name: dev_cloud_1
          # dev name: dev_x
          
```
 - ==> Default name for the first deviation cloud in a file will be the deviation file name.
 - ==> Default name for deviation clouds after the first deviation cloud will be deviation file name plus the sequence number of the deviation cloud in the deviation file.
5. Different deviation clouds can be in the same file but must be separated by comment lines

B-2 Appendix B ASCII Deviation File Format

Example Data file

```
-----  
//-----  
// name: line0_fit  
//-----  
// X Y Z I J K Magnitude  
//-----  
-17.63724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0500752  
-16.91723 10.00000 0.00000 0.00000 1.00000 0.00000 0.0187808  
-16.19724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0626633  
-15.47724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0835074  
-14.75724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0178514  
-14.03723 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0012955  
-13.31724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0680396  
-12.59724 10.00000 0.00000 0.00000 1.00000 0.00000 -0.0353836  
-11.87723 10.00000 0.00000 0.00000 1.00000 0.00000 0.0905723  
-11.15723 10.00000 0.00000 0.00000 1.00000 0.00000 0.0558282  
-----  
//-----  
// name: line1_fit  
//-----  
// X Y Z I J K Magnitude  
//-----  
(-20.00000, -7.83813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0534741  
(-20.00000, -7.51813, 0.00000)(-1.00000 -0.00000 0.00000) 0.0154063  
(-20.00000, -7.19813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0660133  
(-20.00000, -6.87814, 0.00000)(-1.00000 -0.00000 0.00000) -0.0868328  
(-20.00000, -6.55813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0211524  
(-20.00000, -6.23813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0045720  
(-20.00000, -5.91813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0712916  
(-20.00000, -5.59813, 0.00000)(-1.00000 -0.00000 0.00000) -0.0386112  
(-20.00000, -5.27813, 0.00000)(-1.00000 -0.00000 0.00000) 0.0873692  
(-20.00000, -4.95813, 0.00000)(-1.00000 -0.00000 0.00000) 0.0526496  
-----  
//-----  
// name: line2_fit  
//-----  
// X Y Z I J K Magnitude  
//-----  
( 17.64154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0513655  
( 16.92154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] 0.0174904  
( 16.20155 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0639536  
( 15.48155 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0847977  
( 14.76154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0191418  
( 14.04154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0025859  
( 13.32155 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0693299  
( 12.60154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] -0.0366740  
( 11.88154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] 0.0892819  
( 11.16154 -10.00000 0.00000) [0.00000, -1.00000, 0.00000] 0.0545379  
END OF DATA FILE  
-----  
//-----
```

Appendix C IQ Feature List File Format

```

////////////////////////////////////
// Revision History:
// + 01-05-97 ZCY +-----
// |                | [1] revised to include name, transformation and different
// |                | form for feature parameters
// + 10-16-96 ZCY +-----
// |                | [1] added feature list file examples
// + 03-08-96 ZCY +-----
// |                | [1] added format for plane, sphere, cylinder and cone
// + 03-04-96 ZCY +-----
// |                | [1] created this document
////////////////////////////////////

```

----- General Rules -----

1. Each line must be less than 1024 bytes including CR and LF
2. comment Lines:
 Comment lines start with non-numeric characters. This means any line starts with a non-numeric character will be skipped.

 ==> Recommend starting characters for comment lines: !@#\$\$%*/
3. Feature Parameter Line
 ==> Each feature must start with a new line with its feature type number as the first parameter;

 ==> Each feature parameter must be followed by a comma "," except the last parameter which must be followed by a semicolon ";"

 ==> Feature name field should not contain ",", ";" and white space in between;

 ==> Feature name field can be blank, but the delimiting character can not be omitted; Other parameter fields can not be blank.
 e.g. 110,,0.1,0.3,0.5; <--- name field is blank

 ==> Feature parameters can be put in multiple lines. But the delimiting character "," should not be the first character of the continuous parameter lines.
 e.g. 110,,0.1, <--- entity start line
 0.3, <--- continuous parameter line
 0.5; <--- continuous parameter line
4. Different features can be in the same file. The user is allowed to insert comment lines between features;
5. All angles must be in radian.

Format for vector & Xformation

1. Vector

~~~~~

110,name,x,y,z;

where

110 : type number for vector entity  
name : what ever name for the vector entity or blank field  
x, y, z : three components of the vector

2. Xformation

~~~~~

120,name,r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3;

where

120 : type number for transformation entity
name : what ever name or blank field
r11, r12, r13, p1 : 1st row of transformation matrix
r21, r22, r23, p2 : 2nd row of transformation matrix
r31, r32, r33, p3 : 3rd row of transformation matrix

Note: rotation matrix must be an orthonormal matrix with determinant of 1

Format for curve features

1. line

~~~~~

```
200,name,form,parameters[,xformation];
```

```
where
```

```
200      : feature type number for line
name     : what ever name or blank field
form     : form flag for line parameters, 0, 1 or 2
```

```
parameters : line parameters
```

```
form = 0 ==> parameters = alpha, ld, d1, d2
```

```
where
```

```
alpha  : angle between line direction and x-axis
ld     : normal distance from origin to line
d1, d2 : line boundary
```

```
form = 1 ==> parameters = x0, y0, x1, y1
```

```
where
```

```
x0, y0 : line starting point
x1, y1 : line ending point
```

```
form = 2 ==> parameters = x0, y0, z0, x1, y1, z1
```

```
where
```

```
x0, y0, z0 : line starting point
x1, y1, z1 : line ending point
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

**2. arc**

~~~~~

```
201,name,form,parameters[,xformation];
```

```
where
```

```
201      : feature type number for arc
name     : what ever name or blank field
form     : form flag for arc parameters, 0 or 1
```

```
parameters : arc parameters
```

```
form = 0 ==> parameters = xc,yc,r
```

```
where
```

```
xc,yc  : circle center
r      : circle radius
```

```
form = 1 ==> parameters = xc,yc,r,st_ang,sp_ang
```

```
where
```

```
xc, yc : arc center
r      : arc radius
st_ang : angle of starting point w.r.t x-axis (ccw)
sp_ang : span angle (ccw)
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

3. circle

~~~~~

```
202,name,form,parameters[,xformation];
```

where

```
202      : feature type number for circle
name     : what ever name or blank field
form     : form flag for circle parameters, must be 0
```

```
parameters : circle parameters
```

```
form = 0 ==> parameters = xc,yc,r
```

```
where
```

```
xc yc   : circle center
r       : circle radius
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

### 4. ellipse

~~~~~

```
203,name,form,parameters[,xformation];
```

where

```
203      : feature type number for ellipse
name     : what ever name or blank field
form     : form flag for ellipse parameters, 0 or 1
```

```
parameters : ellipse parameters
```

```
form = 0 ==> parameters = xc,yc,alpha,a,b
```

```
where
```

```
xc, yc  : center of ellipse
alpha   : angle between major axis and x-axis
a, b    : major and minor radii of ellipse
```

```
form = 1 ==> parameters = xc,yc,alpha,a,b,st_ang,sp_ang
```

```
where
```

```
xc, yc  : center of ellipse
alpha   : angle between major axis and x-axis
a, b    : major and minor radii of ellipse
st_ang  : angle of starting point w.r.t x-axis
Note: 1. here angle is not angle in space
~~~~~   of parameter t
2. st_ang is not w.r.t major axis of
         ellipse
```

```
sp_ang  : span angle of the elliptical arc (ccw)
Note: 1. here angle is not angle in space
~~~~~   of parameter t
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

5. parabola

~~~~~

```
204,name,form,parameters[,xformation];

where
  204      : feature type number for parabola
  name     : what ever name or blank field
  form     : form flag for parabola parameters, must be 0

parameters : parabola parameters
  form = 0 ==> parameters = xf,yf,alpha,f,st_ang,sp_ang
                    where
                      xf, yf : coordinates of focal point
                      alpha  : angle between parabola axis and x-axis
                      f      : focal length
                      st_ang : angle of starting point w.r.t x-axis
                             Note: 1. st_ang is not w.r.t the axis
                                   ~~~~ of parabola
 sp_ang : span angle of the parabolic arc(ccw)

xformation : xformation for the feature, can be omitted
 xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

6. nurbs curve

~~~~~

```
209,name,form,parameters[,xformation];

where
 209 : feature type number for nurbs curve
 name : what ever name or blank field
 form : form flag for nurbs curve parameters, must be 0

parameters : nurbs curve parameters
 form = 0 ==> parameters = curve_type,
 rational_flag,
 form_flag,
 degree,
 n,
 t0,
 ending_parameter
 knot[0],knot[1],...,knot[nk],
 x0,y0,z0,w0,
 x1,y1,z1,w1,

 xn,yn,zn,wn

 where
 curve_type : int, curve type
 0 ----- unspecified
 1 ----- line
 2 ----- circular arc
 3 ----- elliptical arc
 4 ----- parabolic arc
 5 ----- hyperbolic arc
 rational_flag : int, rational flag
 0 ----- non-rational
 1 ----- rational
 -1 ----- homo
 form_flag : int, form flag
 0 ----- open
 1 ----- closed
 2 ----- periodic
 degree : int, degree
 n : int, # of control points
```

```
t0 : double, starting parameter
t1 : double, ending parameter

knot[0], : \
knot[1], : | double, knot sequence
... , : | nk = n + degree + 1
knot[nk] : /

x[0],y[0],z[0],w[0], : \
x[1],y[1],z[1],w[1], : | double, control points
..... : | and weight
x[n],y[n],z[n],w[n] : /

xformation : xformation for the feature, can be omitted
 xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

---

 -----  
**Format for surface features**  
 -----
**1. plane**

~~~~~

```
300,name,form,parameters[,xformation];
```

```
where
```

```
300 : feature type number for plane
name : what ever name or blank field
form : form flag for plane parameters, 0 or 1
```

```
parameters : plane parameters
```

```
form = 0 ==> parameters = alpha,beta,gamma,ld,x1,y1,x2,y2
```

```
where
```

```
alpha : \
beta : | Euler angles for plane coordinate system
gamma : /
ld : normal distance from origin to plane
x1, y1 : starting corner in xy-plane of
 plane coord system
x2, y2 : ending corner in xy-plane of
 plane coord system
```

```
form = 1 ==> parameters = x1,y1,x2,y2
```

```
where
```

```
x1, y1 : starting corner in xy-plane of
 plane coord system
x2, y2 : ending corner in xy-plane of
 plane coord system
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

**2. sphere**

~~~~~

```
301,name,form,parameters[,xformation];
```

```
where
```

```
301 : feature type number for sphere
name : what ever name or blank field
form : form flag for sphere parameters, must be 0
```

```
parameters : sphere parameters
```

```
form = 0 ==> parameters = xc,yc,zc,r
```

```
where
```

```
xc,yc,zc : center of sphere
r : radius of sphere
```

```
xformation : xformation for the feature, can be omitted
```

```
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3
```

**3. cylinder**

~~~~~

```
302,name,form,parameters[,xformation];
```

```
where
```

```
302 : feature type number for cylinder
name : what ever name or blank field
form : form flag for cylinder parameters, 0 or 1
```

```

parameters : cylinder parameters
 form = 0 ==> parameters = alpha,beta,gamma,ld,r,d1,d2
 where
 alpha : \
 beta : | Euler angles for cylinder coordinate system
 gamma : /
 ld : normal distance from origin to cylinder axis
 r : cylinder radius
 d1 : distance from perpendicular point to
 cylinder's bottom face
 d2 : distance from perpendicular point to
 cylinder's top face

 form = 2 ==> parameters = r, h
 where
 r : cylinder radius
 h : cylinder height

xformation : xformation for the feature, can be omitted
 xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3

```

#### 4. cone

~~~~~

```

303,name,form,parameters[,xformation];

where
303 : feature type number for cone
name : what ever name or blank field
form : form flag for cone parameters, 0, 1, 2 or 3

parameters : cone parameters
 form = 0 ==> parameters = alpha,beta,gamma,ld,lambda,dv,d1,d2
 where
 alpha : \
 beta : | Euler angles for cone coordinate system
 gamma : /
 ld : normal distance from origin to cone axis
 lambda : half cone angle
 dv : distance from perpendicular point to
 cone vertex
 d1 : distance from perpendicular point to
 cone's bottom face
 d2 : distance from perpendicular point to
 cone's top face

 form = 1 ==> parameters = alpha,beta,gamma,ld,lambda,dv,r1,r2
 where
 alpha : \
 beta : | Euler angles for cone coordinate system
 gamma : /
 ld : normal distance from origin to cone axis
 lambda : half cone angle
 dv : distance from perpendicular point to
 cone vertex
 r1 : radius of cone's bottom face
 r2 : radius of cone's top face

 form = 2 ==> parameters = lambda,dv,d1,d2
 where
 lambda : half cone angle
 dv : distance from perpendicular point to
 cone vertex
 d1 : distance from perpendicular point to
 cone's bottom face
 d2 : distance from perpendicular point to

```

```

 cone's top face

form = 3 ==> parameters = lambda,dv,r1,r2
 where
 lambda : half cone angle
 dv : distance from perpendicular point to
 cone vertex
 r1 : radius of cone's bottom face
 r2 : radius of cone's top face

form = 4 ==> parameters = r1,r2,h
 where
 r1 : radius of cone's bottom face
 r2 : radius of cone's top face
 h : cone height

xformation : xformation for the feature, can be omitted
 xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3

```

**5. nurbs surface**

~~~~~

```

304,name,form,parameters[,xformation];

where
304 : feature type number for nurbs surface
name : what ever name or blank field
form : form flag for nurbs surface parameters, must be 0

parameters : nurbs surface parameters
form = 0 ==> parameters = surface_type,
 rational_flag,
 form_flag_u,
 degree_u,
 nu,
 u0,
 u1,
 form_flag_v,
 degree_v,
 nv,
 v0,
 v1,
 knotu[0],knotu[1],...,knotu[nku],
 knotv[0],knotv[1],...,knotv[nkv],
 x[0][0], y[0][0], z[0][0], w[0][0],
 x[1][0], y[1][0], z[1][0], w[1][0],

 x[nu][0],y[nu][0],z[nu][0],w[nu][0],

 x[0][1], y[0][1], z[0][1], w[0][1],
 x[1][1], y[1][1], z[1][1], w[1][1],

 x[nu][0],y[nu][0],z[nu][0],w[nu][1],

 x[0][nv], y[0][nv], z[0][nv], w[0][nv],
 x[1][nv], y[1][nv], z[1][nv], w[1][nv],

 x[nu][nv],y[nu][nv],z[nu][nv],w[nu][nv]

where
surface_type : int, surface type
 0 ----- unspecified
 1 ----- plane
 2 ----- right circular cylinder

```

```

3 ----- cone
4 ----- sphere
5 ----- torus
6 ----- surface of revolution
7 ----- tabulated cylinder
8 ----- ruled surface
9 ----- general quadric surface

rational_flag : int, rational flag
0 ----- non-rational
1 ----- rational
-1 ----- homo

form_flag_u : int, form flag for u direction
0 ----- open
1 ----- closed
2 ----- periodic

degree_u : int, degree in u
nu : int, # of control points in u
u0 : double, starting parameter in u
u1 : double, ending parameter in u

form_flag_v : int, form flag for v direction
0 ----- open
1 ----- closed
2 ----- periodic

degree_v : int, degree in v
nv : int, # of control points in v
v0 : double, starting parameter in v
v1 : double, ending parameter in v

knotu[0], : \
knotu[1], : | double, knot sequence in u,
... : | nku = nu + degree_u + 1
knotu[nku] : /

knotv[0], : \
knotv[1], : | double, knot sequence in v,
... : | nk v = nv + degree_v + 1
knotv[nkv] : /

x[0][0], y[0][0], z[0][0], w[0][0], : \
x[1][0], y[1][0], z[1][0], w[1][0], : |
..... : | double,
x[nu][0],y[nu][0],z[nu][0],w[nu][0], : | control
..... : | points
..... : | and
x[0][1], y[0][1], z[0][1], w[0][1], : | weight
x[1][1], y[1][1], z[1][1], w[1][1], : |
..... : |
..... : |
..... : |
..... : |
x[0][nv], y[0][nv], z[0][nv], w[0][nv], : |
x[1][nv], y[1][nv], z[1][nv], w[1][nv], : |
..... : |
x[nu][nv],y[nu][nv],z[nu][nv],w[nu][nv] : /

```

xformation : xformation for the feature, can be omitted  
xformation = r11,r12,r13,p1,r21,r22,r23,p2,r31,r32,r33,p3



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