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A TEMPLATE FUNCTIONAL-GAGE DESIGN USING PARAMETER-FILE TABLE IN AUTODESK INVENTOR

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Abstract

A systematic approach using Autodesk Inventor to design the functional gages of Geometric Dimensioning & Tolerancing (GD&T) is presented. The gages can be used to check straightness, angularity, perpendicularity, parallelism, and position tolerances of a part when geometric tolerances are specified with Maximum Material Condition (MMC). Four steps are proposed to accomplish the task: (1) creation of two-dimensional (2-D) initial template files, (2) generation of hierarchical folders for the template files, (3) creation a 3-D gage model from a specific template file, and (4) dimensioning and generation of the gage drawing. Results show that, by following this approach, students can effectively generate correct engineering drawings for functional gages.

1. Introduction of GD&T and Functional Gages

In the engineering drawing design, GD&T is a means of specifying engineering design and drawing requirements with respect to actual "function" and "relationship" of part features. If the technique of GD&T is properly applied, it will ensure the most economical and effective production of these features, and also provides a uniform integration and interpretation of design, production, and inspection for a part[1,2,3]. In the United States, the governing rules of using GD&T are based on ANSI 14.5M – 1994[4]," Dimensioning and Tolerancing".

Functional gages are used to check the geometric tolerances of a part when its geometric tolerances are specified with MMC. Using functional gages to check geometric tolerances has the following advantages[1,5]:

1. Minimizes time and resources involved to verify parts.
2. Represents functional interface of the concerned features.
3. Recognizes the subtle composite effects of size, orientation, and position as a "go" and "no go" result.
4. Provides a "hard" tool, which can be utilized by anyone with reasonable technical skill; does not require a highly skilled inspector.
5. Provides alternative methods for verification other than surface plate, open set-up, coordinate measuring, etc.
6. Will never accept a "bad" part.

Some disadvantages of a functional gage include[1]:

1. Could reject borderline good parts.
2. Must be reworked if the part is revised.
3. Raises the cost for building, storage, and maintenance.
4. Does not quantify results.

When considering the manufacturing cost of the gages, it will be more economical to use them when parts are manufactured in large-volume production. Functional gages can be applied to those geometric tolerances with an MMC modifier. Geometric tolerances with such characteristics include: (1) Straightness of center axis, (2) Angularity, (3) Perpendicularity, (4) Parallelism, and (5) Position tolerances.

2. Brief technical information for functional gages

When the topic of functional gages is included in the Engineering Drawing Design classes, the following information is recommended to teach students: (1) GD&T symbols and characteristics, (2) Material Conditions, and (3) Virtual Condition.

2.1 GD&T Symbols and Characteristics

As shown in the first column of Table 1, there are five types of geometric characteristics in the GD&T[1]: (1) Form tolerance, (2) Orientation tolerance, (3) Profile Tolerance, (4) Runout tolerance, and (5) Location tolerance. Form tolerances include Flatness, Straightness, Circularity, and Cylindricity; Profile tolerances include Profile of a Line and Profile of a surface; Orientation tolerances include Perpendicularity, Angularity, and Parallelism; Runout tolerances include Circular Runout and Total Runout; Location tolerances include Position, Concentricity, and Symmetry.

The third column of the table shows the symbols of geometric tolerances, and the fourth column of the table provides the characteristics of each geometric tolerance with datum. For example, each individual feature (one of the Form tolerances) is compared to a perfect geometric counterpart of itself. Therefore, no datum should be related to such a tolerance. For related features (Orientation and Location tolerances), each tolerance is related to a datum or datums. It's interesting to notice that the Profile Tolerances, based on their characteristics, can be either individual or related features.

Types	Characteristic	Symbols	Feature with Datum
Form	Flatness		Individual
	Straightness	—	
	Circularity	○	
	Cylindricity		
Profile	Profile of a Line		Individual or Related
	Profile of a Surface		
Orientation	Perpendicularity	⊥	Related
	Angularity	∠	
	Parallelism	∥	
Runout	Circular Runout		
	Total Runout		
Location	Position	⊕	
	Concentricity	◎	
	Symmetry	=	

Table 1. GD&T types, characteristics, symbols, and feature with datum.

2.2. Material Conditions Associated with GD&T

In addition to the information in Table 1, there are thee material conditions associated with geometric tolerances: (1) Maximum Material Condition (MMC), (2) Regardless of Feature Size (RFS), and (3) Least Material Condition (LMC). Among these three conditions, MMC is the most commonly seen in the design drawings. To indicate that a geometric tolerance is specified with MMC, a symbol μ is added to either a geometric tolerance or a datum. For internal parts (such as holes or grooves, etc.), MMC is at its minimum size. For external parts (such as pins or studs, etc.), MMC is at its maximum size. When a geometric tolerance is specified with MMC, the part may have extra geometric tolerance when its feature of size is closer to LMC[1,5]. Unlike Maximum Material Condition, Regardless of Feature Size (RFS) provides no additional geometric tolerance regardless the variation of its feature of size. Least Material Condition is totally opposite of Maximum Material Condition and is rarely seen in most engineering applications.

2.3. Virtual Condition (VC)

Virtual Condition is a boundary generated by the following two collectively effects: (1) size feature's MMC or LMC and (2) geometric tolerance for that material condition[1,2]. In this paper, as MMC is the most commonly seen in engineering design drawings, Virtual Condition with LMC is ignored. Virtual Conditions for external and internal features are determined by using the following two equations[1]:

$$VC_{external} = MMC + Geometric\ Tolerance \qquad (1)$$

$$VC_{internal} = MMC - \text{Geometric Tolerance} \qquad\qquad (2)$$

The feature dimension (holes or pins) of a functional gage is set to be equal to its VC from a part drawing.

3. Functional-Gage Design Using Autoesk Inventor

When teaching Geometric Dimensioning and Tolerancing at the Department of Engineering Technology at Old Dominion University, students usually have two main problems to generate correct functional-gage drawings:

(1) Compute Virtual Conditions for functional gages.
(2) Indicate critical dimensions in gage-design drawings.

In Problem (1), students are usually confused with MMC for external and internal parts, as described in Section 2.2. As a result, the correct VC cannot be obtained from Equations (1) and (2). In Problem (2), students need to identify critical and non-critical dimensions when generating gage drawings. Critical dimensions, which need to be accurately made, include basic dimensions[1,4,5] (the boxed dimensions in the part drawings) and VCs. The other dimensions, such as height and thickness of the gage, are classified as non-critical dimensions. In the dimensioning of gage drawing, critical and non-critical dimensions are shown in four and two decimal places respectively. A systematic approach using Autodesk Inventor[6] is applied to solve these problems. The procedures are listed as following:

(1) Start with an example of a part drawing.
(2) Create a 2-D template file to start each design.
(3) Design a naming scheme so that students can easily locate the template file for a specific gage design.
(4) Generate a 3-D model using the extrusion command in the Autodesk.
(5) Create the design drawing.

3.1 An example used in this approach

Figure 1 shows an industrial drawing when a position tolerance using MMC modifier is applied to control the location of eight $\phi 0.200$ holes. The position tolerance is based on a primary datum A. Two boxed dimensions in this drawing represent Basic dimensions, which are theoretically exact locations of a feature. They are the basis from which the permissible variations are specified in the geometric tolerances. Because the position tolerance is applied with the size of $\phi 0.200$, the position tolerance for the holes must be within $\phi 0.003$ when the size of a hole is at its MMC (ϕ 0.198). The position tolerance can be increased to $\phi 0.007$ when the size of a hole is at its LMC ($\phi 2.002$).
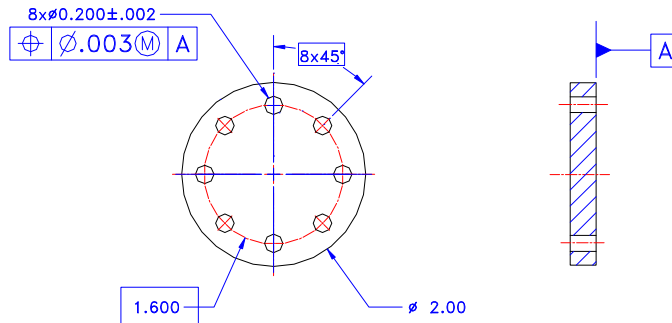
Figure 1. A Position Tolerance specified with Maximum Material Condition.
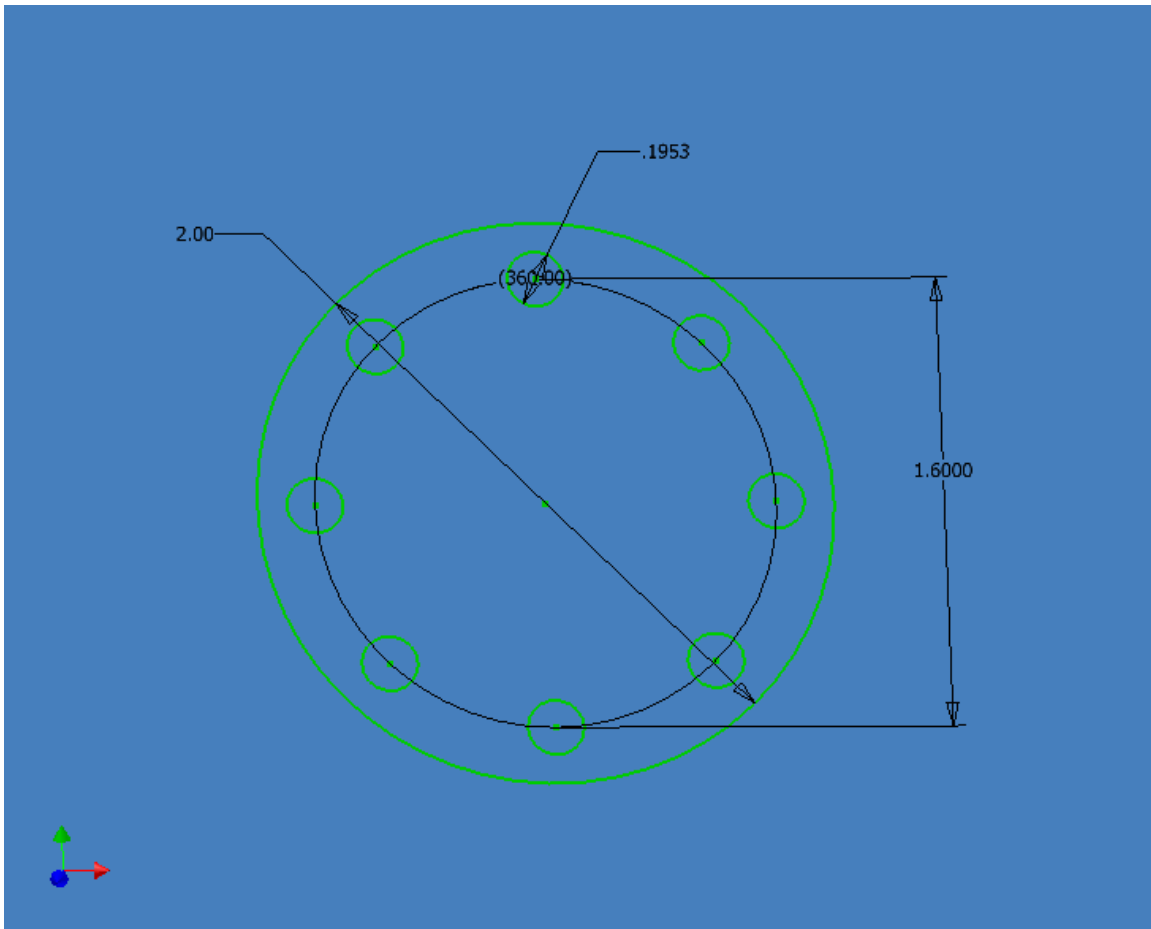
3.2 A 2-D Template File for Each Design

The template file to start the design for a functional gage is made by using the Model Parameters under the top menu tools in the Autodesk Inventor. Figure 2 gives an example of the template file, which is used to design the functional gage for the part shown in Figure 1. For this simple example, there are only four parameters in the 2-D drawing:

d0: Outer diameter of the gage.
d1: Number of pins for this gage. In this case, there are eight pins.
d5: Pin size of the gage.
d6: Location of the Pin.

An equation is used to calculate the pin size d5 by using the information provided in the Comment column. A graphical representation for this template file is shown in Figure 3. If those parameters are indicated as critical dimensions, a higher precision dimensioning will be specified when generating the gage drawing.

Figure 2. Model Parameters for the Functional Gage of Figure 3.

Figure 3. A 2-D drawing based on the template file.

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3.3 Naming Scheme for Template Files

As there are many different functional gages for different geometric tolerances, a good naming scheme certainly helps students locate the specific template file for each design. Figure 4 proposes a hierarchical search for a template file in Position Tolerance. Students can first click the main folder of GD&T FunctionalGages and then choose Position Tolerance. Based on the part drawing, they can choose internal parts for holes and then select Polar Coordinate.
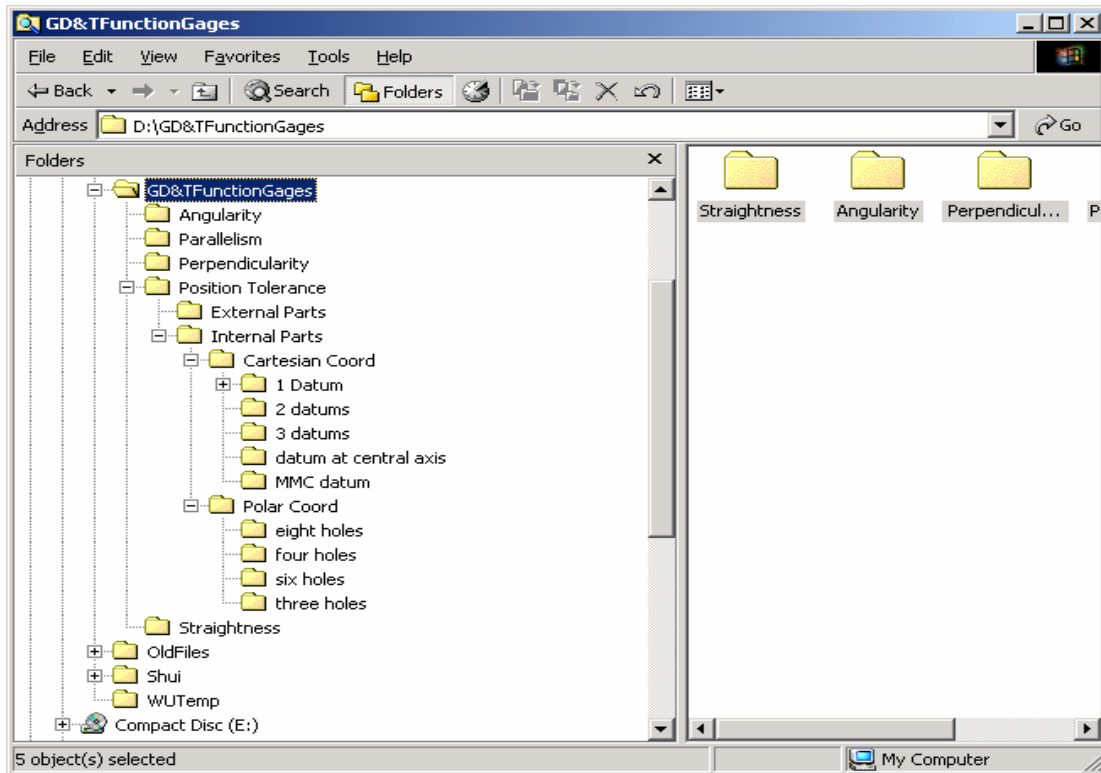

Figure 4. A hierarchical search of a template file located in the position tolerance.

3.4 Extrusion of the 2-D drawing to a 3-D Model

Based on length or depth from the part drawing, the 2-D model (Figure 3) generated from the template file can be extruded to a 3-D model. Figure 5 shows the 3-D image of the functional gage for the part shown in Figure 1. The 3-D model provides the information to generate its design drawing. Two additional 3-D functional gages for Cartesian-Coordinate systems are given in Figures 6 and 7. They are used to inspect the position tolerance for four holes, based on a single primary datum and three datums respectively.
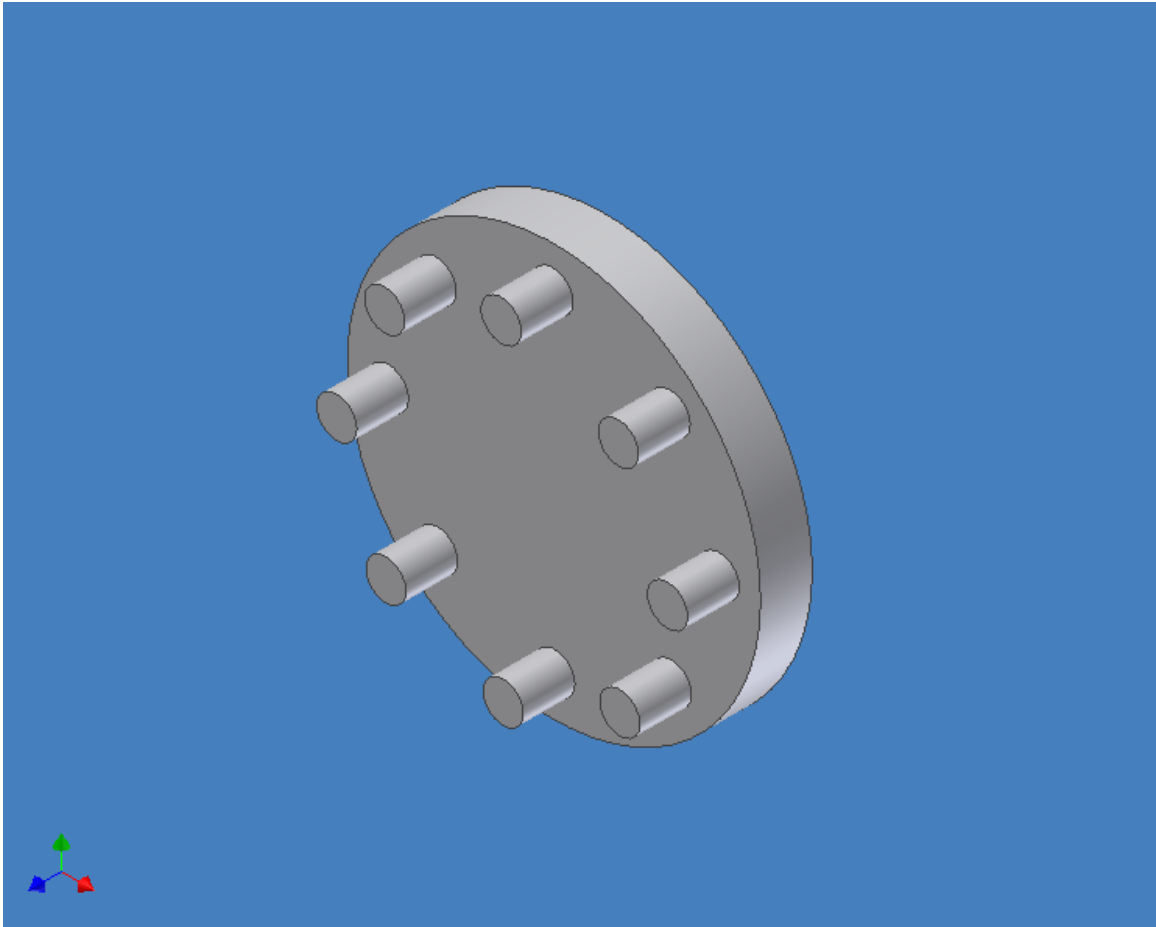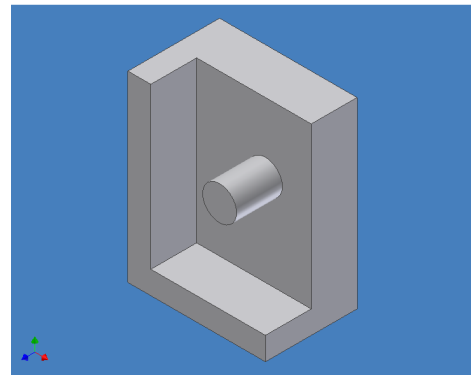
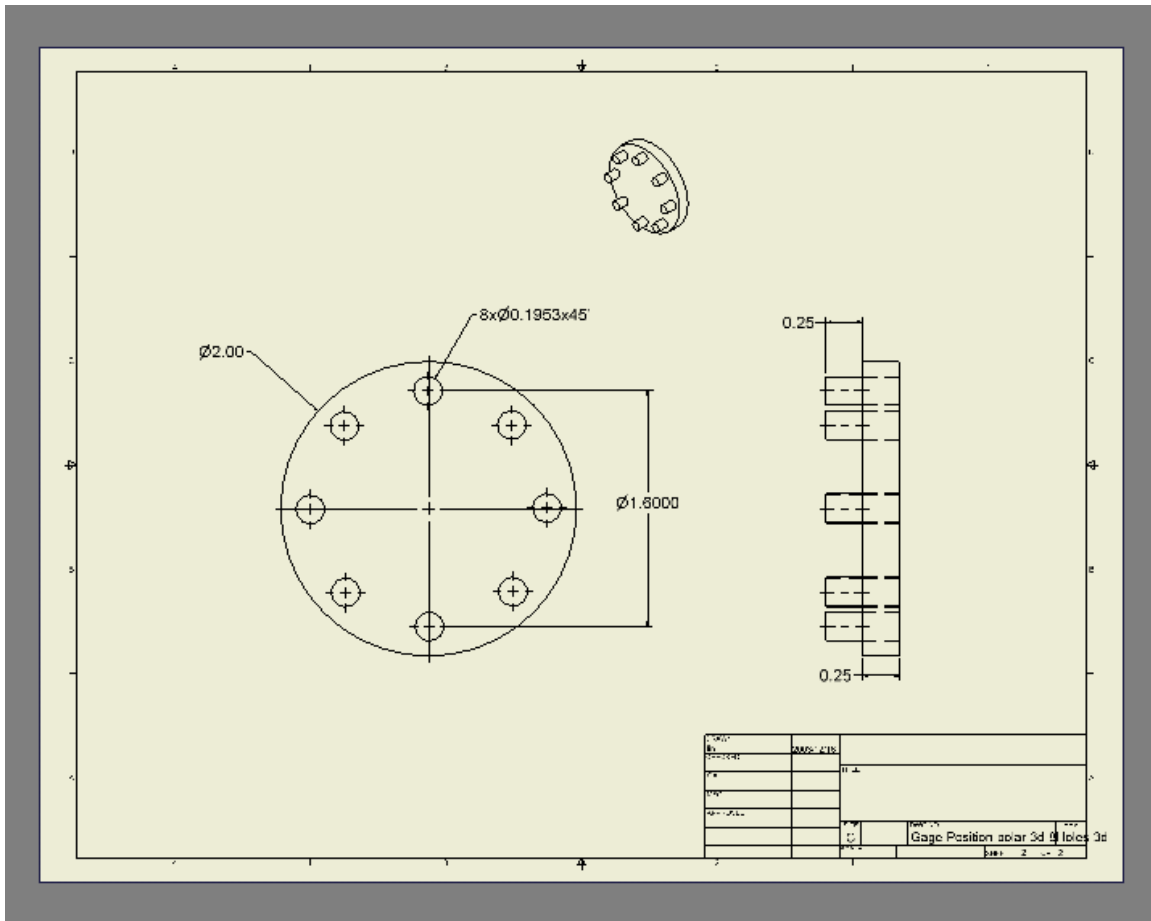**Figure 5.** A 3-D Model Functional Gage.
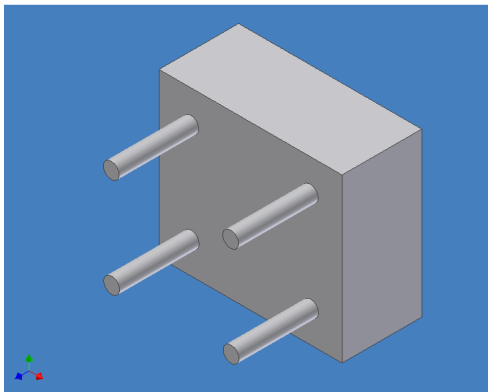
Figure 6. A functional gage for Cartesian coordinate system.

Figure 7. A functional gage based on three datums in a Cartesian coordinate system.

3.5 Design drawing for the functional gage

After a 3-D model has been created, students can generate their design drawing by using the drawing function available at Autodesk Inventor. Students can choose different number of orthographic-projection views and dimensioning on chosen views by click **Get Model Annotations -> Get Model Dimensions**[7]. They can also adjust the text size and set up the precision for critical dimensions specified in the Model Parameters. Figure 8 shows the final design drawing for the part shown in Figure 1.

Figure 8. A Design Drawing Generated from the 3-D Modeling in Figure 11.

4. Summary

A systematic approach to design a functional gage of a part specified in the GD&T is proposed. Through a hierarchical naming system, students can effectively locate a template file to set up all the critical dimensions identified in the "Comment" column of the Model Parameters. Equations to compute the virtual condition of the gage are also listed in the model parameters available at Autodesk Inventor. Information for the equations can be obtained by reading the size and geometric tolerances from the part

drawings. By using this design approach, students can also expedite and save their design for future application in the industry.

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Biography

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Cheng Y Lin is an Associate Professor of Engineering Technology at Old Dominion University. Dr. Lin is a registered Professional Engineer of Virginia. He teaches Machine Design, CAD, CNC, and Robotics and is active in local industrial research and consultation. He earned his B.S. and M.S. degrees of Mechanical Engineering from National Cheng-Kung University in 1975 and 1977 and a Ph.D. of Mechanical Engineering from Texas A&M University in 1989.

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Professor Moustafa received his BS in Mechanical Engineering from the Higher Institute of Technology in Egypt in 1964. He received a Masters of Engineering degree in Machine Design from the University of Illinois, 1976 and another Masters of Engineering in Structures and Stress Analysis from the University of Illinois in 1979. He completed the Ph.D. course requirements in Structural Analysis in Civil Engineering at Old Dominion University. Professor Moustafa's interest is in the area of Mechanical Systems design such as computer-aided design, computer graphics, 3-D modeling, stress analysis and design for safety. Professor Moustafa is a certified manufacturing engineer and is active in professional societies such as SME, ASME, ASEE and has served in many executive capacities and presented a number of papers in scientific conferences. He also participated in a number of projects with the Technology Application Center at Old Dominion University. Professor Moustafa has served as an independent expert witness in court cases involving safety issues.