Manufacturability of Parts with 3D-Annotated Model Generated by 3D-CAD

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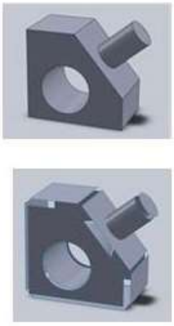
Abstract

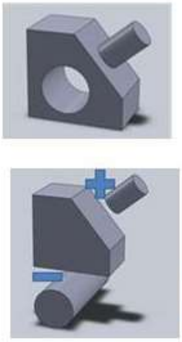
Design for manufacturing (DFM) is the application software of examining mechanical parts designs from the viewpoint of manufacturing techniques and measuring technology. DFM deals with a wide range of operations including machining, moulding, assembly, testing, parts supply, and the preparation of documented work instructions. In DFM, manufacturing know-how and knowledge are described as rules, and the portions that are difficult to manufacture or that tend to have defects are extracted from the shapes of products defined by three-dimensional computer-aided design (3D-CAD). The outline of this paper is as follows. First, we discuss the features defined by 3D-CAD and the 3D annotated models that define product characteristics as datum, dimensions, and tolerances. Next, we show the relationships between shapes defined by 3D-CAD and DFM rules concerning machining, sheet-metal processing, injection moulding, and press moulding. Then, we explain how to evaluate manufacturing processes and assembly processes utilizing CAD data. In addition, methods of verifying the settings of measurement coordinate systems and measurement probes on the basis of 3D annotated models are described. Finally, we present examples of the manufacturability of mechanical parts with the 3D-annotated models generated by 3D-CAD, also describe the relationship between the 3D annotated models defined in the mechanical design phase and the actual manufacturing techniques and measuring technology.

Keywords: *3D-CAD, Manufacturing, 3D annotated model.*

1. Introduction

Half a century has passed since the computer-aided design (CAD) project "Sketchpad" was reported. [1] Since then, the shape representation techniques called boundary representation (B-reps) and constructive solid geometry (CSG) have been proposed by BUILD and TIPS-1, respectively. [2] [3] Figures 1 and 2 show solids represented by B-reps and CSG, respectively, which are used as the basis of current solid-modelling techniques. In CAD for solid modelling [hereafter, three-dimensional (3D) CAD], shapes are defined using a feature-based modelling technique as shown in Figure 3. Computer-aided manufacturing (CAM) started with the development of the programming language Automatically Programmed Tool (APT) and is now practically applied to machining that requires the control of five axes of a machining center. Computer-aided engineering (CAE) started with research on the finite element method (FEM) and is now used as a general term to describe analysis and engineering simulations. The formulae for curves and surfaces have shifted from those for Coons, Bezier, and Gregory surfaces, and non-uniform rational B-Spline (NURBS) is the mathematical model currently used to represent curves and surfaces in many CAD systems. After the introduction of 3D measurement coordinate systems, computer-aided testing (CAT) was developed. The development of design for manufacturing (DFM) started on the basis of such technologies. The contents of DFM and its application to engineering education are reviewed in this paper.





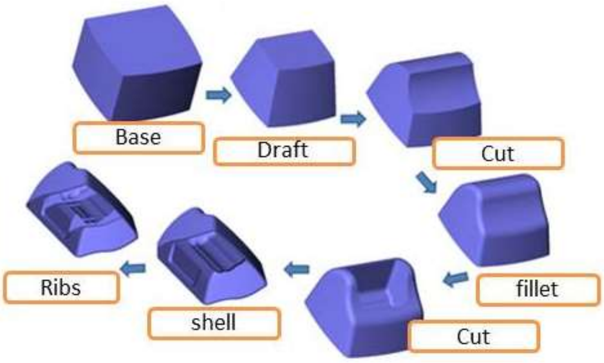
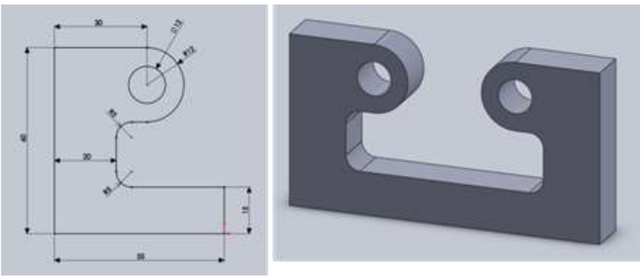


Figure 1. B-reps. Figure 2. CSG. Figure 3. Feature-based modelling.

2. 3D annotated model

When discussing DFM, we first consider whether the CAD data clearly define product characteristics. There are various techniques for modelling a solid in 3D-CAD. For example, when modelling the symmetric shape shown in Fig. 4, one can model half of the shape and make a mirror copy. However, manufacturing departments cannot undertake machining or testing even when receiving such CAD data because only the shape of the solid is shown and no information is provided about the origin or reference axes. Conventionally, product characteristics have been defined using the function of constructing two-dimensional (2D) drawings from CAD models built into 3D-CAD systems. As a result, two types of design information, namely, 2D drawings containing product characteristics and CAD data defining shapes, have been provided by design departments to manufacturing and testing departments. The procedures for changing or modifying a design have been complicated by the presence of these two types of design information.

A means of incorporating product characteristics in CAD data was first proposed in 2000. When ASME Y 14.41 and ISO 16792 were established, 3D annotated models in which product characteristics are added to CAD data, as shown in Figure 5 and 6, were realized. The Japan Automobile Manufacturers Association and Japan Electronics and Information Technology Industries Association have proposed techniques to incorporate product and manufacturing information in 3D annotated models, respectively. The development of viewers for CAD models containing product characteristics using web browsers has enabled machinery operators and production engineers to easily review CAD data. As a result, manufacturing departments are now able to give feedback to design departments during the design phase of products. Figure 7 shows an example of such a viewer. [4]- [9]



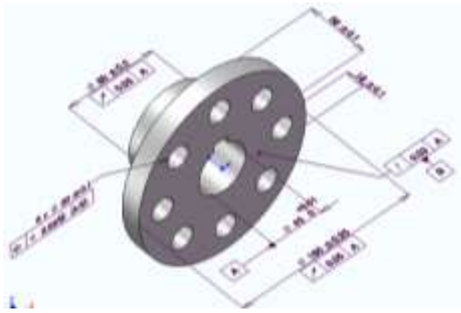


Figure 4. Modelling by mirror copy. Figure 5. Sample of 3D annotated model.

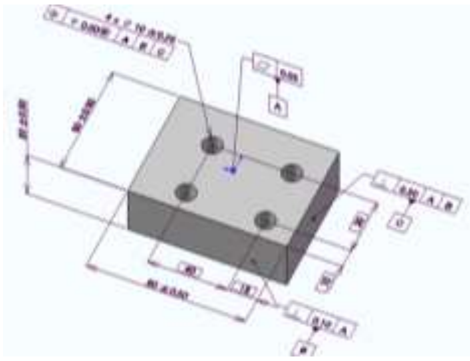


Figure 6. Sample of 3D annotated model.

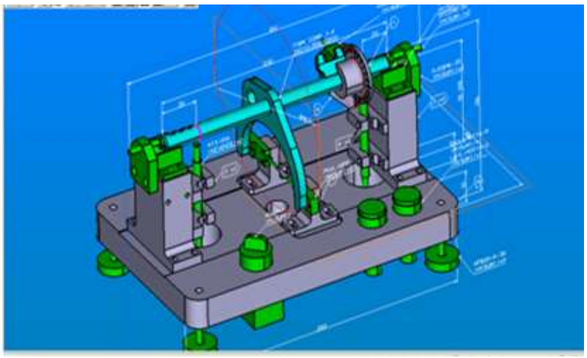
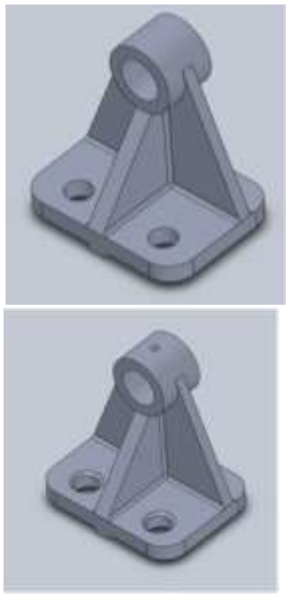


Figure 7. Sample of viewer.

3. Machined parts and DFM

Many industrial products have a similar shape. Previously obtained experience and manufacturing skills are useful in such cases. Humans can compare multiple shapes and easily distinguish between similar and different features, which is, however, difficult for 3D-CAD systems. Figure 8 shows the differences between two CAD data sets recognized on the basis of their features and parameters. Extracting and comparing the features of a shape enable the automatic recognition of changes in a design, contributing to DFM. Also, the shape of a material before machining or a cast material can be obtained if the shape data are simplified by removing features such as holes and fillets. A simple example of this is shown in Figure 9.

CAM is essential for three-axis and five-axis machining using machining centers. In CAM, operators specify the areas of curved surfaces and holes to be machined and calculate the cutter location (CL) data while considering the order and methods of machining. Attempts have been made to automatically optimize the machining process by focusing on the features of a shape. [10] The CAM of a die plate with many holes to be filled with predetermined pins, such as that shown in Figure 10, can be automated by color-coding the attributes of holes. However, the shapes defined by CAD models are not always so simple. To cope with this, a feature-based CAM system has been developed to automate the machining process and generate tool paths by extracting machining features such as holes and slots from CAD models (see Figure 11) and pre-setting the machining conditions for each feature. Studies have also been carried out to develop systems in which a built-in calculation module automatically analyses the specified shape model and outputs the optimum machining process. [11] [12]



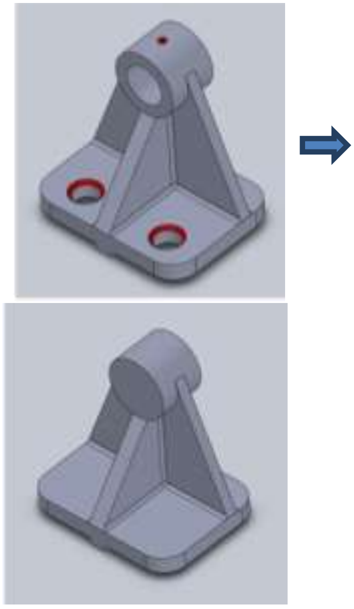


Figure 8. Differences between two models.

Figure 9. Simplify of shape.

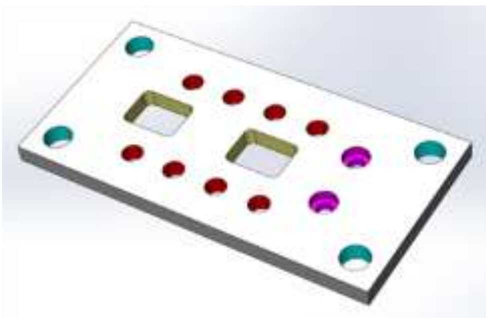


Figure 10. Sample of die plate.

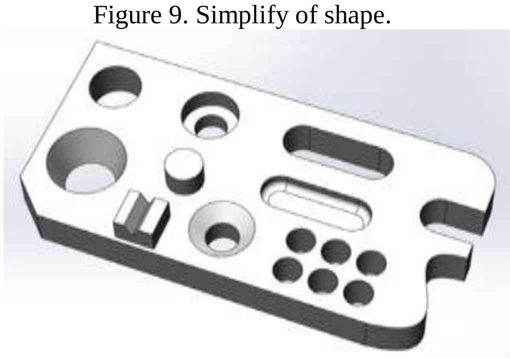


Figure 11. Features for CAM.

If the features of a shape to be machined are extracted, the likelihood of defects and problems arising in relation to the features during mass production can be examined on the basis of rules defined in DFM. Figure 12 shows examples of drilling. Figure 13 shows examples of lathe machining. Sheet-metal parts are manufactured by bending a developed shape. Sheet-metal parts have holes. Figure 14 shows the DFM rules for punching holes. The tools required for bending metal sheets, as shown in Figure 14, should also be examined in DFM.

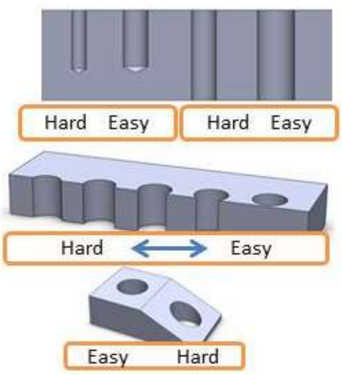


Figure 12.Drilling

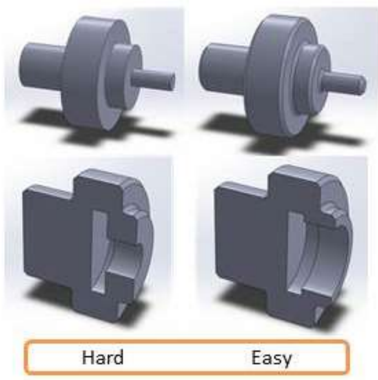


Figure 13.Lathe machining

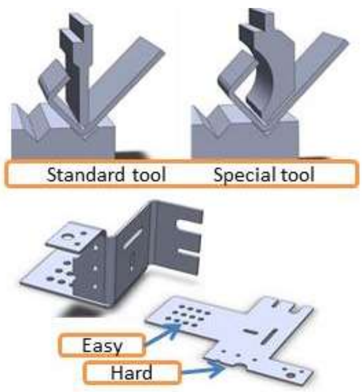
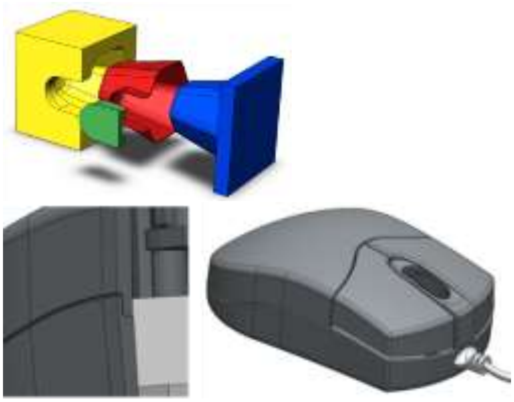


Figure 14.Punching holes and tools

4. Molded products and DFM

Moulding starts with determining the portion of a product shape to be undercut and examining the suitability of the definition of draft angles. Methods for automating such processes have already been proposed. [13] Current 3D-CAD systems have the function of examining draft angles or extracting undercuts as shown in Figure 15. Because the quality of moulded products is affected by the fluidity of the resin injected into a cavity, a mould flow analysis is carried out during the design phase of plastic parts to examine the fluidity shown in Figure 16. The rules for this examination are established in DFM. When multiple plastic parts are assembled, the fitting of joint surfaces is defined as shown in Figure 17. The fitting can be examined by calculating the gap between surfaces in 3D-CAD assembly.



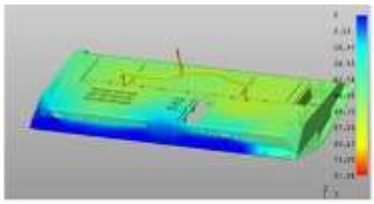
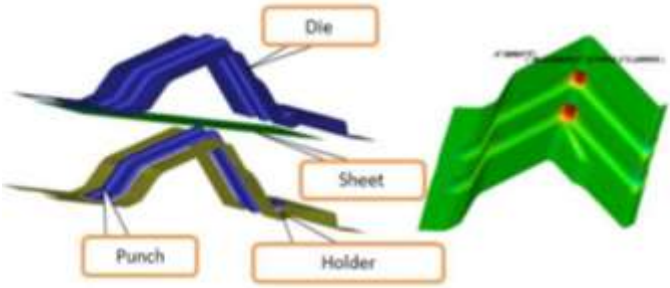


Figure 15. Mould. Figure 16 .Mould flow. Figure 17. Fitting of plastic parts.

In press moulding, cracks may develop in sheet materials because they undergo plastic deformation. The spring-back becomes large when the tension stress of the material is high. Therefore, the suitability of press moulding should be examined by performing a forming simulation. Figure 18 shows an example of a forming simulation. DFM for press forming strongly depends on the experience and know-how of mould manufacturers. In particular, press forming using a progressive die, as shown in Figure 19, depends on the skills of die manufacturers and in-house machinery departments.



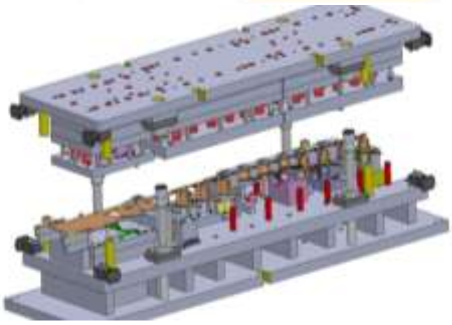


Figure 18.Forming simulation. Figure 19.Progressive die.

5. Assembly work, flow of parts, and DFM

The ease of assembly and maintenance should be considered in the design of products. Production engineering departments prepare a Gantt chart such as that shown in Figure 20 on the basis of the estimated numbers of man-hours required to assemble the products and the number of personnel and hours required to efficiently carry out the work. DFM can be applied to the preparation of Gantt charts. When the assembly structure in 3D-CAD data is rearranged in the order of work processes, as shown in Figure 21, the assembly work and the order of work processes correspond to the engineering bill of materials (E-BOM) and the manufacturing bill of materials (M-BOM), respectively. A Gantt chart such as that shown in Fig. 22 can be created by exporting the list of work processes in comma-separated value (CSV) format and opening the file in a spreadsheet application to carry out a calculation.

Figure 20.Gantt chart.

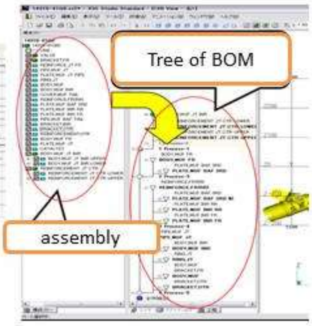


Figure 21.Assembly to tree of BOM.

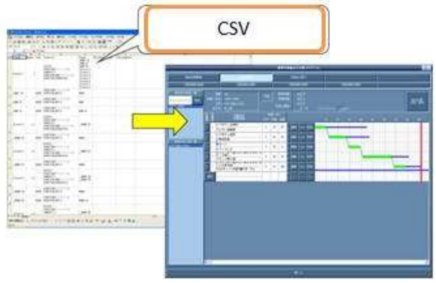


Figure 22.CSV to Gantt chart.

Once the assembly work process is determined, it is next necessary to prepare work instructions. Work instructions have already been documented on the basis of assembly animations and 3D-CAD data as shown in Figure 23. The detection of problems such as a tool that cannot be inserted into an intended location, as shown in Figure 24, is another aspect of DFM in assembly work. In addition, the movements of workers and the work space can be checked on a computer, as shown in Figure 25 and 26, which has enabled production engineering departments to suggest to the design departments a suitable layout of the workbenches and the jigs and holders used for assembly work during the design phase of products. Moreover, the locations at which parts tend to accumulate can be determined in the assembly work by observing animations of the parts supply. [14]

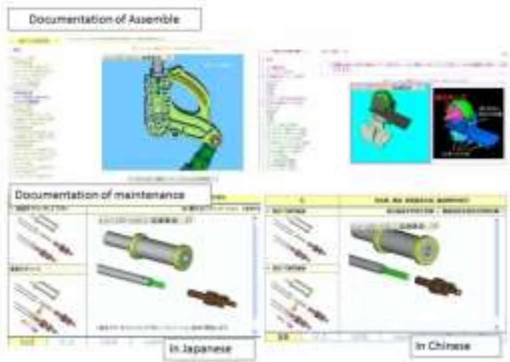


Figure 23.Documentation using web3D.

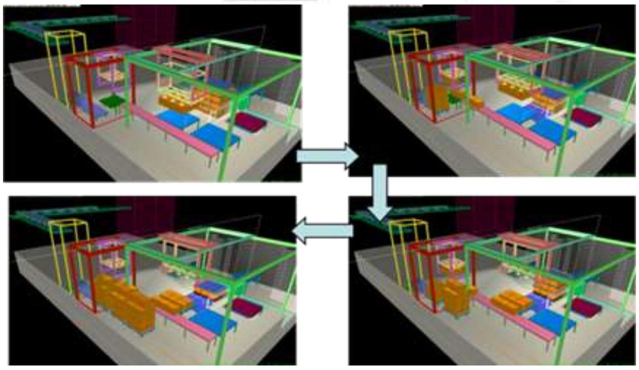


Figure 26.Animation of parts supply.

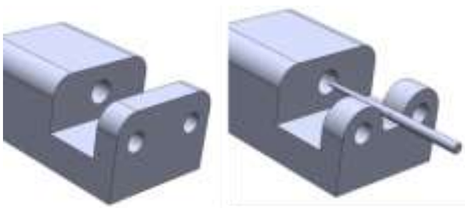


Figure 24.Check of tool and jig.

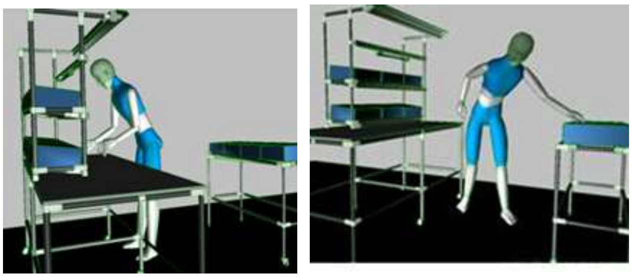


Figure 25.Check of work space.

6. Testing and DFM

DFM-based consideration, such as how to hold and measure the designed products, is required in testing, similarly to in machining. On the basis of the understanding of product characteristics defined in the design phase, a coordinate system is first set with the base on a datum and then the dimensions and geometric tolerances of the products are measured. When the measurement requires multiple probes, as in the case shown in Figure 27, the probe paths should be determined so as not to interfere with the product to be measured. It is also necessary to change the probes to more suitable ones when there are small-diameter or deep holes. Because 3D-coordinate-measuring machine application software has the function of matching CAD data to measured data, there have been attempts to utilize Web-3D and spreadsheet applications to prepare testing reports, as shown in Figure 28. Upon receiving such feedback, design departments can validate the suitability of machining methods and the dimensional and geometric tolerances.

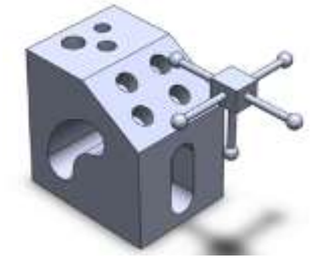


Figure 27. Probes for measurement.

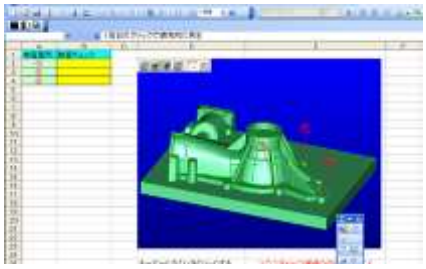


Figure 28. Report using web3D.

7. Examples of manufacturability of parts

Professional education on cutting theory, plastic theory, metal materials, and injection molding is provided in the field of mechanical engineering. When DFM is considered in the series of phases from design to analysis, manufacturing, and testing, manufacturing know-how and machining rules can be dealt with in education on design and drawing (see Figure 29). For example, Figure 30 shows a part to be machined and Figure 31 shows a possible machining method. Then, a functional gauge used for testing the part shown in Figure 32 is selected. Because the maximum material condition is specified for this part, the functional gauge shown in Figure 32 is used. Figure 33 shows a possible measuring process. On the basis of the understanding of manufacturing information and the consideration of DFM, the feedback from manufacturing and testing operations is given to design departments.

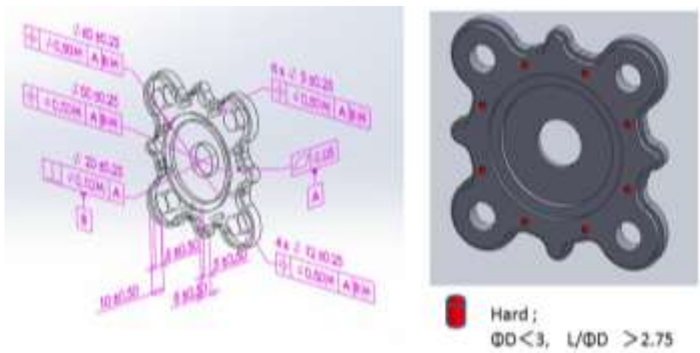


Figure 29. 3D-CAD and DFM.

Figure 30. 3D-annotated model and check of DFM.

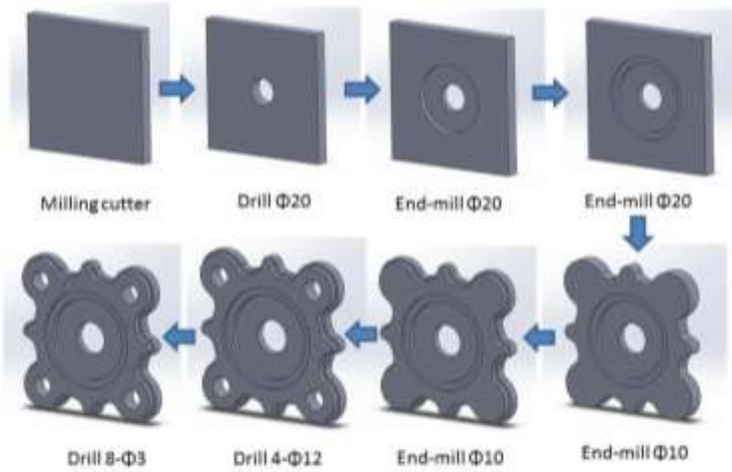


Figure 31. Sequence of machining.

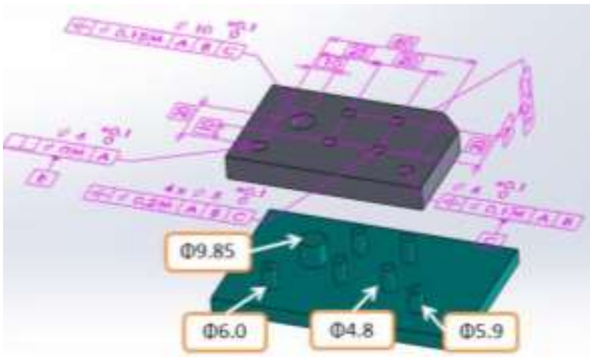


Figure 32. 3D-annotated model and functional gauge.

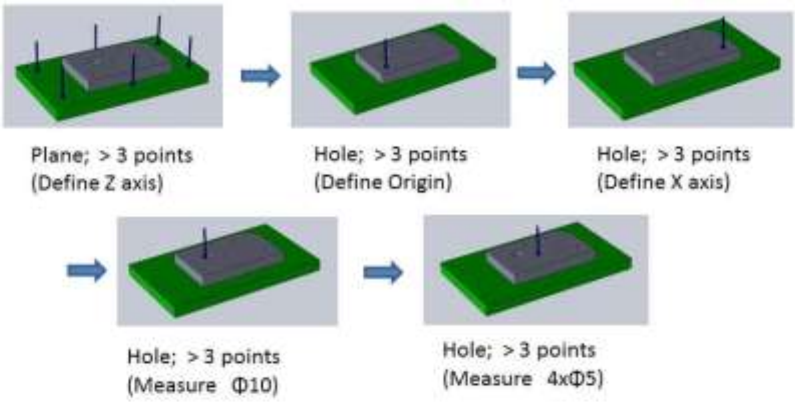


Figure 33. Measuring process using 3D coordinate system

6. Conclusion

Starting from the modeling of 3D shapes, 3D-CAD systems currently provide engineers with various functions that are required for mechanical design. One of these functions is DFM, which deals with a broad range of manufacturing operations. In this paper, we have discussed DFM in association with machining, sheet-metal processing, molding, press forming, assembly work, and 3D measurement. It is difficult to describe or formulate manufacturing know-how and rules. Most of the research and development on DFM therefore focuses on the utilization of shapes defined by 3D-CAD data. Methods of manufacturing and quality control are as important as creative design in engineering education.

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