Geometric Redundancy in CAD Instructions

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Abstract

Commonly methods of mechanical assembling involve geometric redundancy. It can be confusing to students especially those in mechanical engineering technology. Methods to avoid redundancy is proposed.

Keywords

CAD, geometric redundancy, manufacturing datum, tool design

Introduction

Students in mechanical engineering technology are taught to use CAD. In creating an assembly from parts, relations are applied for interconnections. Very often, the interconnection relations are such that a same degree of freedom of a part is restricted redundantly by two or more assembly relations. The concepts behind these CAD constructions are in direct conflict with the concepts taught in manufacturing courses such as in tool design.

The short paper addresses this geometric redundancy in CAD and proposes improvement in teaching.

Geometric Redundancy in CAD Constructions

Two examples in the below will illustrate geometric redundancy. They were randomly taken. One was from a CAD textbook[1], an academic source; the other was from a CAD tutorial[2], an industry source.

In the first example shown in Figure 1 in the below, a bearing is assembled to a base. The CAD assembly method presented in the reference uses two relations: a "Mate" relation and an "Axial Align" relation. The Mate relation has the bottom of the bearing in full contact with the top of the base, which restricts three degrees of freedom of the bearing: the position along the vertical axis and the orientations about the two horizontal axes. The Axial Align relation aligns the axis of the bearing with the axis of the base hole, which restricts four degrees of freedom of the bearing: the positions along the two horizontal axes and the orientations about these axes. Here, the orientations of the bearing about the two horizontal axes are controlled by both the contact of part faces and by the alignment of the axes and one of the them is called redundant. When the center axis is perfectly perpendicular to the face as in the case of the CAD model, the redundancy does not cause conflict and the assembling is successful. When the center axis has an allowable perpendicularity error to the face as in manufacturing, the redundancy would cause conflict. It should be important to address to students the vital difference between CAD and manufacturing.
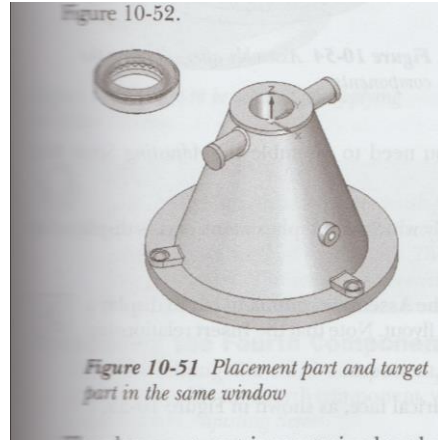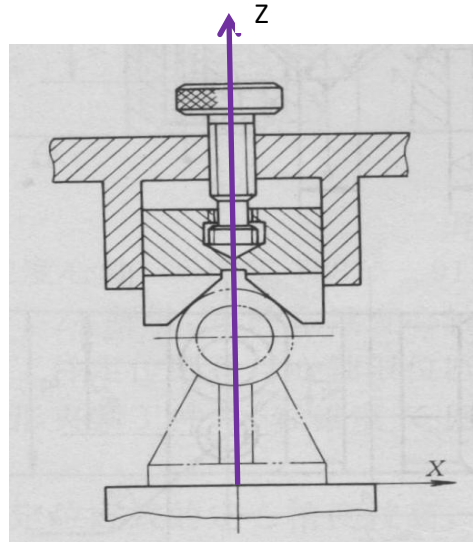
Figure 1

In the second example in Figure 2 below, a rod with end plates is assembled to a base that has a concave surface to match the rod. The CAD assembly method presented in the reference uses three relations: an "Axial Align" of the rod cylinder with the base concave surface, a "Mate" of an end plate with the end of the base, and a "Planar Align" to make a side of an end plate parallel to the top of the base. Similar to the previous example, the Axial Align relation aligns the axis of the rod with the longitudinal of the base thus setting the orientations of the rod about the vertical axis and about the lateral horizontal axis. The Mate relation restricts the same two orientations of the rod. The Planar Align also restricts the orientation about the lateral horizontal axis. So the orientation of the rod about the lateral horizontal axis is controlled by three relations: the axial alignment, the end contact, and the parallelism of the side of the end. Each of three accommodates the other two only if the end is perfectly perpendicular to the long axis and the side is perfectly parallel to the long axis. If the assembly method is taught, it should only be taught in course exclusively for CAD.

Figure 2

The figure[3] below shows an example of what students are taught in manufacturing courses such as in a course of tool design.

	Linear			Angular		
	X	Y	Z	X	Y	Z
The base			√	√	√	
The long V	√		movable	movable		√

Figure 3

In the figure above, the workpiece shown in the non-solid fantom font is located by the bottom base plate and the movable V block from above, which also functions as a clamp. The table below the sketch is an analysis of work degrees of freedom controlled by the two locators. A concept taught to the students here is each degree of freedom, shown as one column in the table, can only be controlled by one locator such that each column of the table may only have one check mark.

The V-block has been so designed that it is free to swivel forward and backward about the X-axis. The rotation about X-axis degree of freedom of the V block must be taken away otherwise it would lower the locating quality of the base plate because real workpieces do not have perfect parallelism of the cylindrical surface with respect to the bottom surface.

Using the concept of avoiding locating redundancy in manufacturing design is often a challenge to students. As the author has experienced in his classes, typically only 60% to 70% of the class was able to handle it very well.

Comparing Examples 1 and 2 with Example 3, we can see that typical examples and exercises in CAD assembling instructions can easily put wrong concepts into students' mind.

Proposed Improvement Method 1

Two methods are suggested for teaching mechanical assembling on CAD without overly involving redundancy.

The first suggestion is instructors could develop new assembling steps than what is being commonly given in literature. CAD has many commands for assembling and the common assembling methods involving redundancy are only options, which are probably more straightforward but have less educational benefits.

Here is an example. The course lab that converts the CAD model of a toggle clamp in Figure 4 that has rigid connections for all the links to a model whose arms can be opened or closed as shown in Figure 5 requires link-to-link assembling. As a specific example we will show how
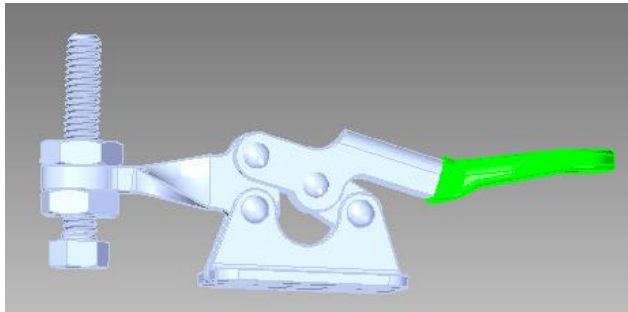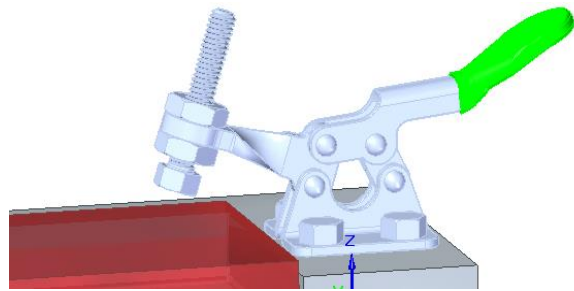

Figure 4

Figure 5

we assemble the nut in Figure 6. It will be a very simple but illustrative example. Instead of using the conventional redundant approach of having the face of the nut Mate to the arm surface and also the center axis of the nut Align with the center axis of the arm hole or the center axis of the spindle, we still have the face of the nut Mate with the arm but then have a point on the center
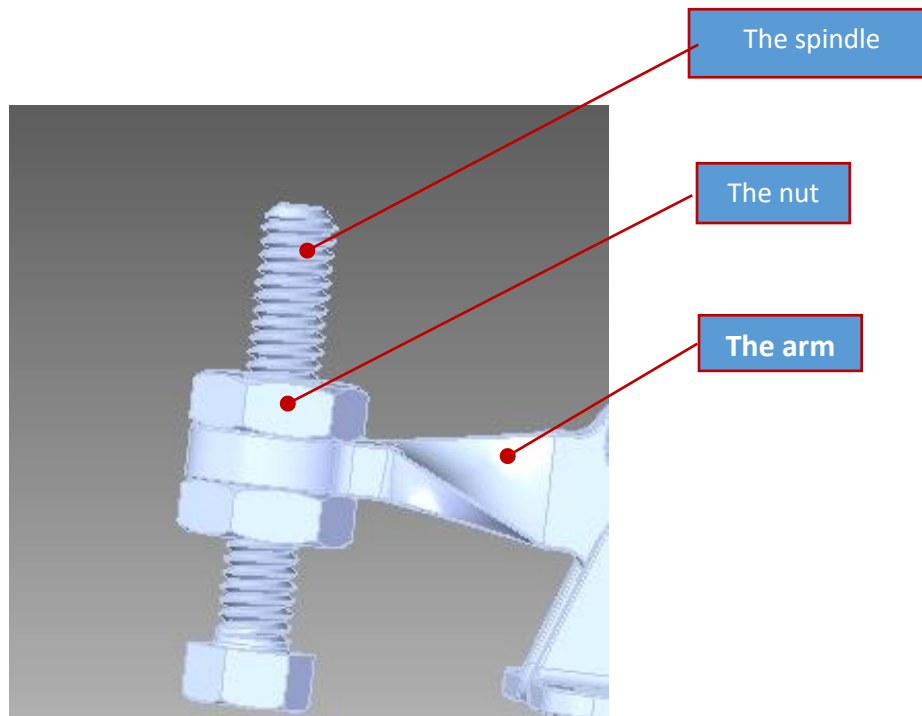
Figure 6

axis of the arm Connect to the arm hole axis or the spindle axis. Connecting a point to a line controls only two degrees of freedom: the positions of the point in the two directions perpendicular to the line. This instruction is also an excellent example to the students on how to count the number of degrees of freedom restricted.

Proposed Improvement Method 2

The fundamental reason why the assembling methods that work well in CAD do not work for manufacturing design and analysis is because CAD uses ideal parts of perfect geometry and manufacturing design considers non-ideal parts. To give students true concepts of real parts, CAD models can be purposely made imperfect.

For example, when the CAD model of the red-color rectangular work-piece in Figure 7 was created to be a rectangular prism in the past, its bottom, the right side, and the rear side could be Mated to the respective surfaces of the body. It was frustrating while students learned the 3-2-1 locating principle in the lecture they used Mate-Mate-Mate on the CAD during the lab and each Mate confined three degrees of freedom. This year we asked the students to modify the ideal-shape CAD model so that the side surfaces are not exactly perpendicular to one another. Such a work-piece can only located by the 3-2-1 principle.
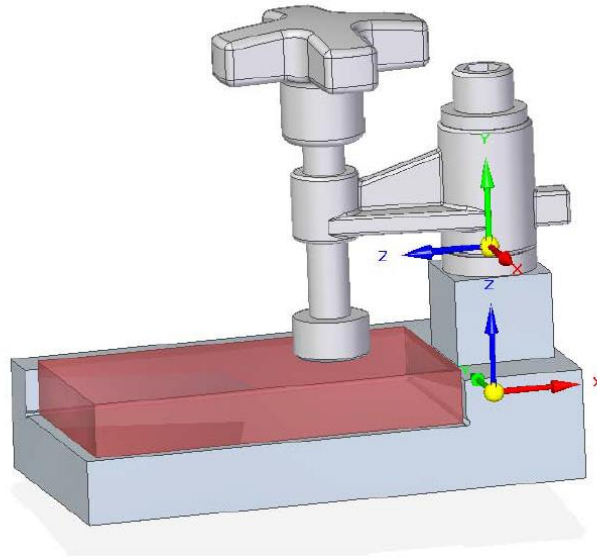
Figure 7

Conclusion

This paper presents an observation of the author that instruction materials of CAD systems, Pro-Engineer, AutoCAD, Solid Edge, or Solid Works etc, teach assembly methods that actually involve redundant geometric relations and are in conflict with basic concepts in manufacturing design. Suggestions were given to handle the situations.

References

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