4) Design rules and guidelines for DFM

4.1. DFM RULES AND GUIDELINES

> "Designing a product to be produced in the most efficient manner possible (in terms of cost, resources, and time) taking into consideration how the product will be processed, utilizing the existing skill base (and avoiding the learning curve) to achieve the highest yields possible"
>
> Phil Zarrow

The goal of the Design of Manufacturing is to design a product that is easily and economically manufactured. In any Design for Manufacturing system the most important thing is a set of design principles or guidelines that are structured to help the designer reduce the cost and difficulty of manufacturing an item. Below is a listing of these guidelines.

1. **Reduce the total number of parts.** The reduction of the number of parts in a product is probably the best opportunity for reducing manufacturing costs. Less parts implies less purchases, inventory, handling, processing time, development time, equipment, engineering time, assembly difficulty, service inspection, testing, etc. In general, it reduces the level of intensity of all activities related to the product during its entire life. A part that does not need to have relative motion with respect to other parts, does not have to be made of a different material, or that would make the assembly or service of other parts extremely difficult or impossible, is an excellent target for elimination. Some approaches to part-count reduction are based on the use of one-piece structures and selection of manufacturing processes such as injection molding, extrusion, precision castings, and powder metallurgy, among others.

2. **Develop a modular design.** The use of modules in product design simplifies manufacturing activities such as inspection, testing, assembly, purchasing, redesign, maintenance, service, and so on. One reason is that modules add versatility to product update in the redesign process, help run tests before the final assembly is put together, and allow the use of standard components to minimize product variations. However, the connection can be a limiting factor when applying this rule.

3. **Use of standard components.** Standard components are less expensive than custom-made items. The high availability of these components reduces product lead

times. Also, their reliability factors are well ascertained. Furthermore, the use of standard components refers to the production pressure to the supplier, relieving in part the manufacture's concern of meeting production schedules.

4. **Design parts to be multi-functional.** Multi-functional parts reduce the total number of parts in a design, thus, obtaining the benefits given in rule 1. Some examples are a part to act as both an electric conductor and as a structural member, or as a heat dissipating element and as a structural member. Also, there can be elements that besides their principal function have guiding, aligning, or self-fixturing features to facilitate assembly, and/or reflective surfaces to facilitate inspection, etc.

5. **Design parts for multi-use.** In a manufacturing firm, different products can share parts that have been designed for multi-use. These parts can have the same or different functions when used in different products. In order to do this, it is necessary to identify the parts that are suitable for multi-use. For example, all the parts used in the firm (purchased or made) can be sorted into two groups: the first containing all the parts that are used commonly in all products. Then, part families are created by defining categories of similar parts in each group. The goal is to minimize the number of categories, the variations within the categories, and the number of design features within each variation. The result is a set of standard part families from which multi-use parts are created. After organizing all the parts into part families, the manufacturing processes are standardized for each part family. The production of a specific part belonging to a given part family would follow the manufacturing routing that has been setup for its family, skipping the operations that are not required for it. Furthermore, in design changes to existing products and especially in new product designs, the standard multi-use components should be used.

6. **Design for ease of fabrication.** Select the optimum combination between the material and fabrication process to minimize the overall manufacturing cost. In general, final operations such as painting, polishing, finish machining, etc. should be avoided. Excessive tolerance, surface-finish requirement, and so on are commonly found problems that result in higher than necessary production cost.

7. **Avoid separate fasteners.** The use of fasteners increases the cost of manufacturing a part due to the handling and feeding operations that have to be performed. Besides the high cost of the equipment required for them, these operations are not 100% successful, so they contribute to reducing the overall manufacturing efficiency.

In general, fasteners should be avoided and replaced, for example, by using tabs or snap fits. If fasteners have to be used, then some guides should be followed for selecting them. Minimize the number, size, and variation used; also, utilize standard components whenever possible. Avoid screws that are too long, or too short, separate washers, tapped holes, and round heads and flatheads (not good for vacuum pickup). Self-tapping and chamfered screws are preferred because they improve placement success. Screws with vertical side heads should be selected vacuum pickup.

8. **Minimize assembly directions.** All parts should be assembled from one direction. If possible, the best way to add parts is from above, in a vertical direction, parallel to the gravitational direction (downward). In this way, the effects of gravity help the assembly process, contrary to having to compensate for its effect when other directions are chosen.

9. **Maximize compliance.** Errors can occur during insertion operations due to variations in part dimensions or on the accuracy of the positioning device used. This faulty behavior can cause damage to the part and/or to the equipment. For this reason, it is necessary to include compliance in the part design and in the assembly process. Examples of part built-in compliance features include tapers or chamfers and moderate radius sizes to facilitate insertion, and nonfunctional external elements to help detect hidden features. For the assembly process, selection of a rigid-base part, tactile sensing capabilities, and vision systems are example of compliance. A simple solution is to use high-quality parts with designed-in-compliance, a rigid-base part, and selective compliance in the assembly tool.

10. **Minimize handling**. Handling consists of positioning, orienting, and fixing a part or component. To facilitate orientation, symmetrical parts should be used when ever possible. If it is not possible, then the asymmetry must be exaggerated to avoid failures. Use external guiding features to help the orientation of a part. The subsequent operations should be designed so that the orientation of the part is maintained. Also, magazines, tube feeders, part strips, and so on, should be used to keep this orientation between operations. Avoid using flexible parts - use slave circuit boards instead. If cables have to be used, then include a dummy connector to plug the cable (robotic assembly) so that it can be located easily. When designing the product, try to minimize the flow of material waste, parts, and so on, in the manufacturing operation; also, take packaging into account, select appropriate and safe packaging for the product.

4.2. DFM EXAMPLES FROM INDUSTRY

MILLING MACHINE PART

Poor Design Drawing

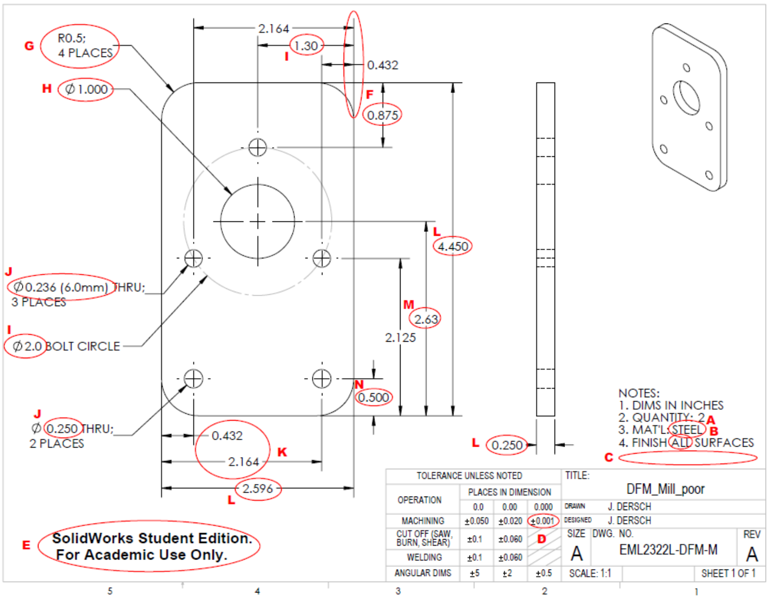

Fig. 4.1 Poor design drawing

Improved Design Drawing

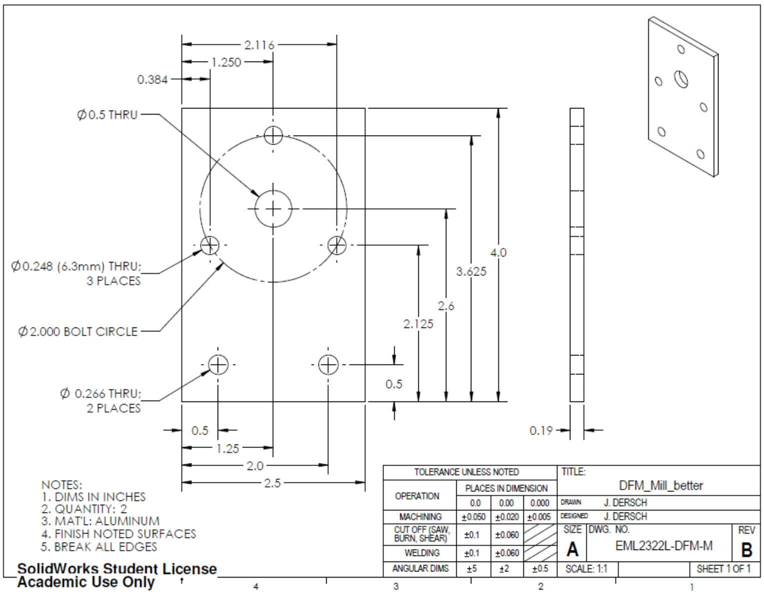

Fig. 4.2 Improved design drawing

Explanation of DFM Changes

- Steel is more difficult to machine than aluminum. Whenever possible, use the weakest material that satisfies the strength requirement (or other material constraints) which in this case, is aluminum.
- Finishing surfaces takes time. Unless a finished surface is required for function or appearance, clearly indicate no surface finish is required.
- For safety during assembly and part handling, always require that sharp edges are broken (removed).
- A tolerance of ±0.001” is difficult to achieve and increases manufacturing time. Always design parts with the loosest tolerances that allow the part (and future assemblies) to function correctly. Consider ±0.005” to be the tightest reasonable tolerance for lab parts (with the exception of reamer applications).
- Each dimension datum requires an additional “zeroing” and thus increases manufacturing time and locational error. Generally, only use one datum per axis unless an overriding reason exists.
- Fillets increase manufacturing time and are generally unneeded, so remove unless necessary for part function.
- Tight tolerances and larger hole sizes increase manufacturing time. Always design parts with the loosest tolerances that allow the part (and future assemblies) to function correctly. In this case, a clearance hole is needed through which the motor shaft can pass.
- When matching a hole pattern on another part, tight tolerances are required to ensure proper fitment between parts. Ensure the largest tolerances (i.e. “worst-case dimensions”) of both parts will still allow part function and assembly. In this case, a tolerance of ±0.005” is appropriate.
- Non-nominal dimensions make reading a drawing more difficult which may result in manufacturing mistakes and/or increased manufacturing time. Design with nominal dimensions when possible. Always design with the loosest tolerances that allow the part (and future assemblies) to function correctly.
- Use nominal stock sizes and loose (greater than ±0.010) tolerances when possible. Rev. A requires a 3" x 4.5" x 0.25^{+}" piece of material to manufacture while Rev. B only requires a 2.5" x 4.0" x 3/16" piece of material. Note that, due to the tight tolerances on the thickness of the part, only stock material with a thickness greater than 0.250" may be used. In lab, stock material is usually within ±0.010” of the nominal size. Additionally, Rev. B reduces part cost by eliminating excess material above the top hole. Finally, always leave at least 1 diameter of material between the edge of a hole and the edge of the part.
- Loosening this tolerance will result in a part that is easier to manufacture.
- Tight tolerances increase manufacturing time. Always design parts with the loosest tolerances that allow the part (and future assemblies) to function correctly. Since this motor mount bracket attaches to a mobile platform which will operate on a floor that is far from flat, ±0.020” is an appropriate tolerance.

Lathe part

Poor Design Drawing

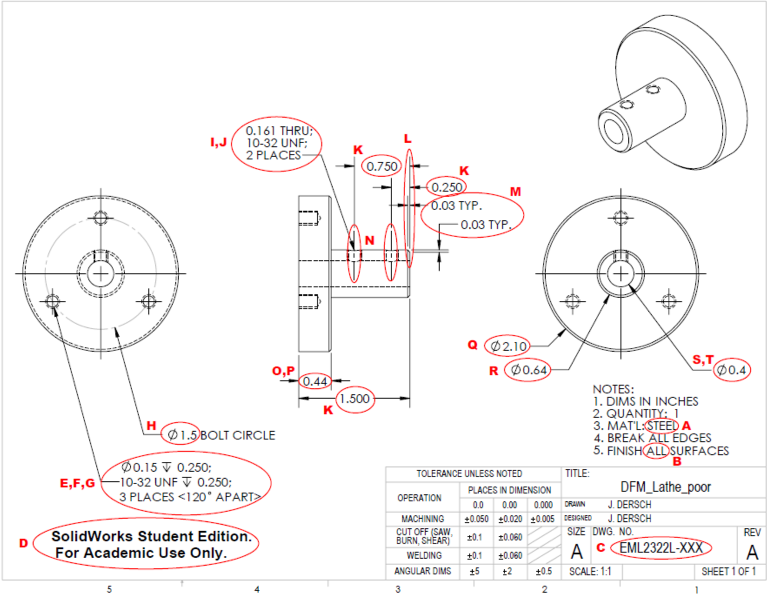

Fig. 4.3 Poor design drawing

Improved Design Drawing

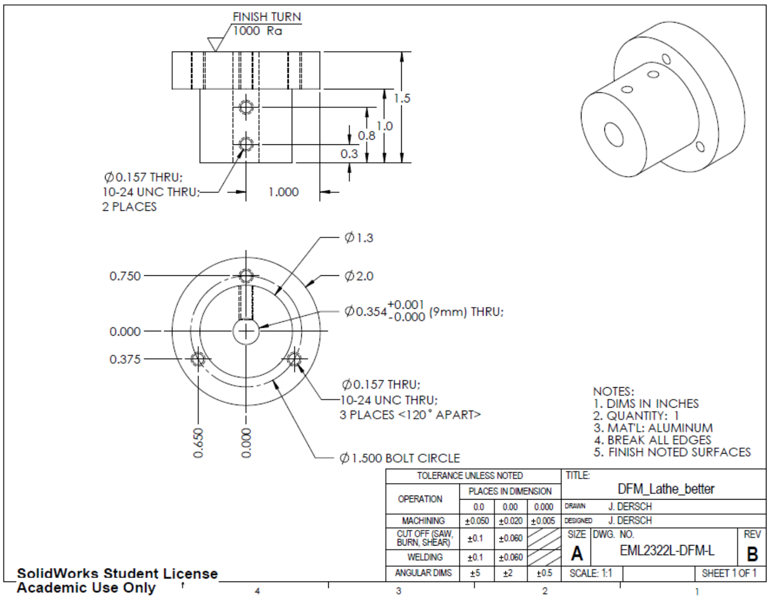

Fig. 4.4 Improved design drawing

Explanation of DFM Improvements

- Steel is more difficult to machine than aluminum. Whenever possible, use the weakest material that satisfies the strength requirement (or other material constraints) which in this case, is aluminum.
- Finishing surfaces takes time. Unless a finished surface is required for function or appearance, clearly indicate no surface finish is required.

- Provide a unique drawing name and number for organizational purposes.
- Blind holes often increase manufacturing time. Design with thru holes when possible.
- Specifying tolerances that are too loose can result in broken taps or weak threads. Specify tap drill sizes to ±0.005” (or tighter) tolerances.
- When the material is changed from steel to aluminum, a coarse thread becomes the correct choice, since it will be stronger in this weaker material; therefore, specify a 10-24 UNC instead of 10-32 UNF.
- When matching a hole pattern on another part, tight tolerances are required to ensure proper fitment between parts. Ensure the largest tolerances (i.e. “worst-case dimensions”) of both features will still allow part function and assembly. In this case, a tolerance of ±0.005” is appropriate.
- When the material is changed from steel to aluminum, a coarse thread becomes the correct choice, since it will be stronger in this weaker material; therefore, specify a 10-24 UNC instead of 10-32 UNF.
- Tighter tolerances increase manufacturing time, so always design parts with the loosest tolerances that allow the part (and future assemblies) to function correctly. The separation distance between the setscrews is not important for part function, so increase the allowable tolerance range.
- Each dimension datum requires an additional “zeroing” and thus increases manufacturing time and locational error. Generally, only use one datum per axis unless an overriding reason exists.
- Chamfers increase manufacturing time and are generally unneeded, so remove unless necessary for part function.
- Poor drawing format is unprofessional, increases the likelihood of manufacturing errors, and increases the cost of outsourced parts. Only dimension holes (size and location) in a view in which they are circular.
- Non-nominal dimensions make reading a drawing more difficult which may result in manufacturing mistakes and/or increased manufacturing time. Design with nominal dimensions if possible. Always design parts with the loosest tolerances that allow the part (and future assemblies) to function correctly.
- Increasing this dimension reduces the amount of material that must be removed and thus decreases the manufacturing time.
- Use nominal stock sizes and looser (larger) tolerances when possible. Rev. A requires turning down a 2.5" diameter piece of material while Rev. B only requires a 2" piece of material. In lab, stock material is usually within ±0.010” of the nominal size. Finally, always leave at least 1 diameter of material between the edge of a hole and the edge of the part.
- Removing material increases manufacturing time, so remove the smallest amount of material possible for part function (unless weight is a functional goal that justifies the associated increase in part cost).
- Specifying tolerances that are too large can result in unintended consequences. In this case, the motor shaft on which this wheel is to be attached measures Ø 0.354" (9mm). Consequently, the loose tolerance

(±0.050”) could result in an interference fit between the hub and motor shaft, which would damage the precision motor shaft and gearing. Alternatively, the loose tolerance could result in a large (0.050") clearance fit between hub and motor shaft, causing unacceptable runout between the axis of rotation of the wheel hub and motor shaft.

- For properly function, the wheel hub should very precisely mate with the motor shaft to which it is attached so the two components rotate concentrically. If the motor shaft measures Ø 0.354" in diameter, the hole size through the center of the wheel hub should be between Ø 0.354" (a line fit) and Ø 0.355" (one thousandth o an inch larger), as denoted by the tight tolerances in Rev. B.

4.3. REFERENCES

[1] Computer-Aided Manufacturing, Second Edition, Tien-Chien chang, Richard A Wysk, and Hsu-Pin Wang. Pages 596 to 598. Prentice Hall 1998

[2] ”Design for Manufacturing – Guidelines”, Mechanical Engineering Design I Course, The University of New Mexico, Albuquerque, New Mexico

[3] ”Design for Manufacturability (DFM) Examples”, MAE Design and Manufacturing Laboratory, Department of Mechanical & Aerospace Engineering, Univeristy of Florida, Gainesville, Florida