2006-1888: A DESIGN-FOR-MANUFACTURABILITY WORKBOOK

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A Design for Manufacturability Workbook

Abstract

As in other subjects, students can develop Design for Manufacturability (DFM) skills by solving problems in the classroom. A number of texts provide graphical examples of poor DFM with improved versions, but there are few exercises available for students to solve. With support from the Society of Manufacturing Engineers, a workbook of open-ended DFM problems is being prepared. These exercises and experience with their initial use in the classroom are discussed.

Introduction

The Society of Manufacturing Engineers has designated "product/process design" as a competency gap that should be corrected in manufacturing education. Design for manufacturability (DFM), assembly (DFA), and related topics, collectively referred to as "DFX" skills, are central to this gap. DFX texts and reference books are available[1-6], often containing design guidelines and a number of instructive before-and-after DFX examples, but few of them offer unsolved problems for students to work through on their own. Instructors occasionally bring hardware into the classroom to demonstrate DFX principles, and this can be very effective. However, it is time consuming, especially if the instructor wants students to work through problems on their own, and it can be less effective in large classes. There are not many other educational tools available for teaching DFX. Graphical exercises may provide an additional and useful tool for classroom use. They can be tailored to illustrate specific groups of design principles, and are easily administered in the classroom. A set of unsolved graphical DFX problems is being prepared at Arizona State University Polytechnic, with support from the Society of Manufacturing Engineers' Education Foundation. These exercises and experience from their initial classroom use are described here.

The DFX Exercises

Various lists of DFX principles are available. These range from the general ('reduce the number of parts'), to specific guidelines for a given manufacturing process ('optimum wall thickness for a structural foam molding is 6 mm'). These lists will vary from text to text, but core DFM principles are well represented in most of them. Guidelines occasionally conflict, for example when redundancy is advised to improve reliability, at the expense of manufacturability[5]. These contradictions are understandable in context, and can be resolved with good judgment. Guidelines are also categorized by objective: design for manufacturability, design for assembly, design for safety, design for ergonomics, etc. A complete listing cannot be given here, but Bralla[4] and Boothroyd[3] provide good coverage of key principles. The workbook exercises are intended to cover a large number of DFM and DFA principles, although issues with serviceability and other DFX topics may occasionally surface. Each exercise in the workbook is intended to present several different design shortcomings at once, for educational efficiency and to provide opportunity to work through overlapping or conflicting design issues.

General DFM Guidelines (Adapted from a more detailed list in Ref. 4)

- Simplify the design.
- Design to minimize labor cost.
- Avoid generalized statements on drawings.
- Dimension from surfaces, not from points in space.
- Dimension from a limited number of datum surfaces.
- Minimize part weight, but without compromising function.
- Design for general purpose tooling.
- Avoid sharp corners, in most cases.
- Minimize the need to reposition a part during manufacturing.
- Avoid stepped parting lines for molded, cast, and powder metal parts.
- Maintain uniform wall thickness for cast and molded parts.
- Space holes appropriately to avoid tooling weaknesses.

The exercises begin with exploded views of four different electrical plugs (Fig. 1). Each plug is currently on the market, and each is intended to meet the same functional objectives. These plugs consist of anywhere from 11 to 21 parts. Students are invited to explain why some designs require fewer parts than others, and the following perspectives for inquiry are suggested.

"Consider these questions as you evaluate the designs:

- How did the creative use of material properties and manufacturing techniques allow reduction in part count?
- In the simpler designs, were the functions of two or more parts combined into one part?
- Did simplifications impact function? Ergonomics? Reliability?
- Did reduction of part count result in simpler or more complicated individual parts?
- Did assembly operations become simpler or more complex?
- Is there a way to further simplify the better designs?
- Note that all four assemblies have essentially the same prongs, wire clamps and wire clamp screws, totaling 9 parts. Is there a way to reduce the number of parts required for this?"

This section is followed by a series of drawings of poorly designed assemblies – a flashlight, a corkscrew, etc – typically shown both assembled and exploded. DFX errors in these drawings are diverse, and to serve novices, they are sometimes egregious as well. A single drawing may contain over a dozen DFX weaknesses. Finally, drawings of individual parts are provided, each with a number of manufacturability weaknesses. The parts are sometimes taken from the previous assembly drawings to help establish context. After introducing basic DFX principles, an instructor can guide students through some of these examples, and then present them with problems to solve on their own.

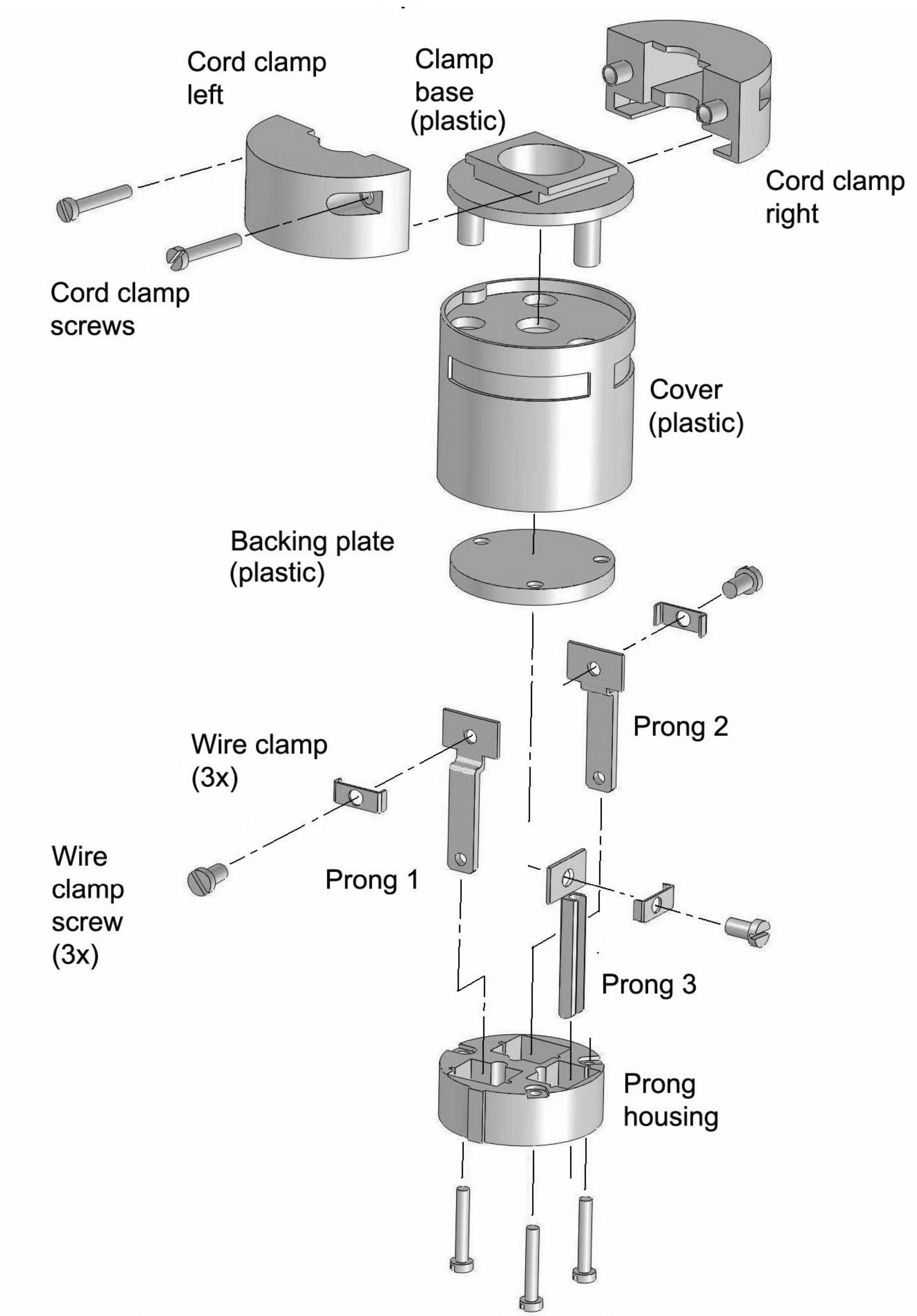

Figure 1. An electrical plug, to be compared with other designs for number of parts and other manufacturability issues.

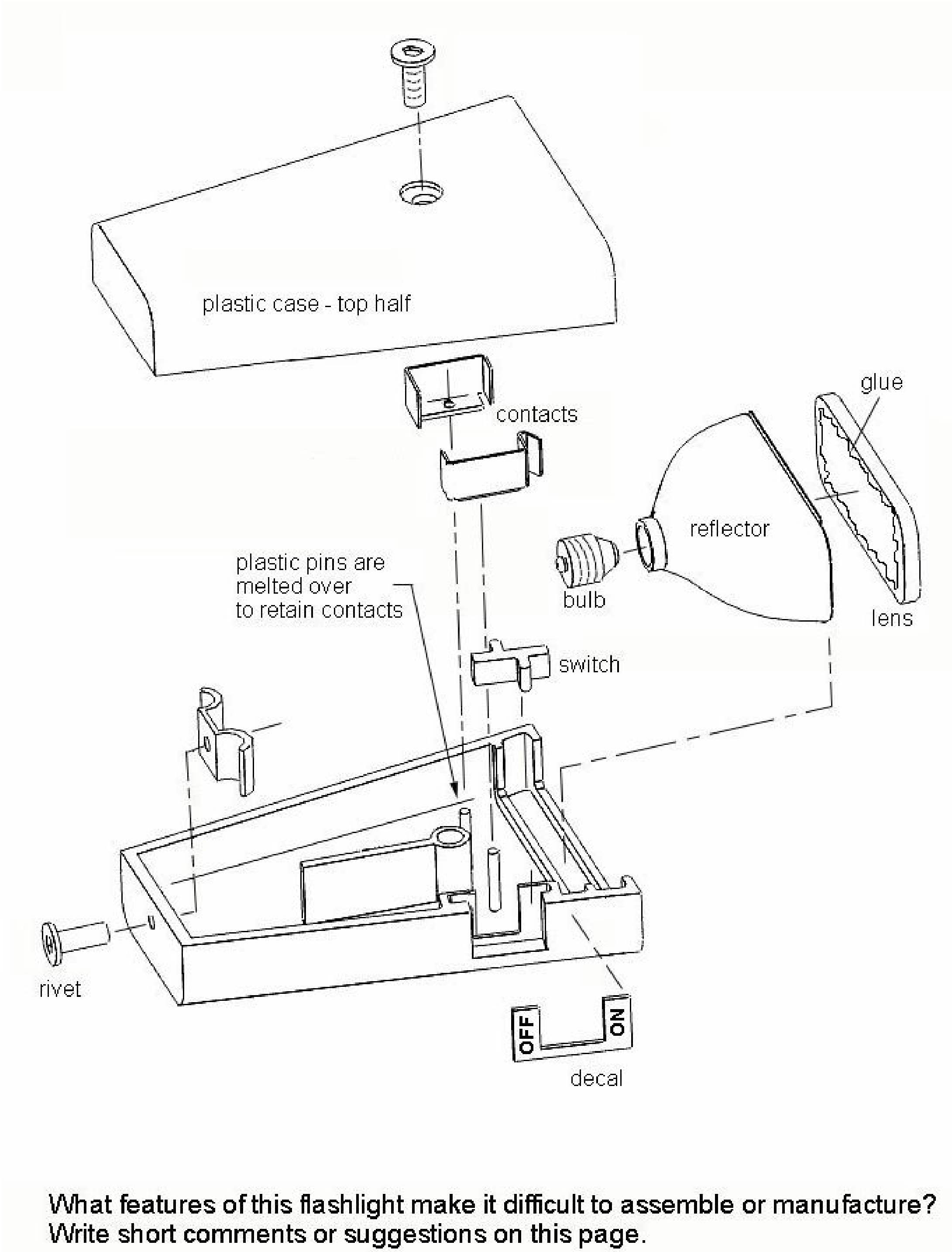

Figure 2. A poorly designed pocket flashlight.

There are at least a dozen flaws in the flashlight in Figure 2, such as superfluous parts, parts that can be assembled incorrectly, inefficient and inconsistent fastening methods, lack of “top-down” assembly, quality control risks, and inefficient use of the design options available when stamping and molding processes are used. Students are asked to make brief annotations on the drawings pointing out weaknesses or suggesting improvements; for example, a student might write "Mold on/off into the case" next to the decal, or perhaps "this is unnecessary".

In "Capstone" projects, some instructors may notice that students show a preference for machined parts in their designs. This may result from the ready availability of educational machine shops and familiarity with those manufacturing processes. Machined parts are often relatively expensive in production and geometrically simple. In addition to their value in DFX education, problems like these may help students develop visualization skill with complex 3-D parts and assemblies, or lead them to consider using additive manufacturing processes more often in design.

Grading

Good conceptual design practice calls for the generation of many alternative ideas, and some authors believe criticism can discourage this activity. Certainly, students may be reluctant to make suggestions or take a risky, creative approach if they believe an error could cost them points. It seems counter-productive to subtract points for inappropriate responses in these exercises. Instead, correct responses alone can be acknowledged with a point or check mark. If a significant error must be addressed, a simple written comment will do, but generally students will recognize the absence of a check mark as the sign of an inappropriate or ineffective suggestion.

Because the maximum possible score on open-ended design problems like these is indeterminate, the highest score in a class can be taken as the basis for 100%. This approach to grading is simple, and has worked well in practice. It is remarkably quick and easy to grade problems such as the one in Fig. 2 this way, and one author has graded over 120 of these at once without undue strain. Grades from these problems may be useful as one quantitative measure of effectiveness in design education.

Observations from Initial Classroom Use

The authors have used examples from the workbook to teach brief DFX sections in several design project classes at two different institutions, with similar experiences. DFX principles were introduced first, illustrated with some solved textbook examples. The instructor then led students through unsolved examples in class, basing the discussion on the students' suggestions and observations. Different problems were later assigned as homework or quizzes. Occasionally, a problem has been assigned individually, and then again as a group exercise for three students, to reinforce appreciation for collaborative work. The group solution usually wins the higher score.

These exercises seem to be viewed as puzzles rather than problems, and students seem to enjoy the activity. Students may find the graphical format and the emphasis on visual thinking a refreshing change from the written format they usually use in school. The lack of a grade penalty for poor responses may also give students a modest sense of creative freedom, and response to the problems has been very positive.

Scores tend to be uniformly distributed over a fairly wide range. Some students with low scores may not have studied, but others in this category made surprisingly few annotations on the drawings despite apparent knowledge of DFX basics. These students may be unfamiliar with this problem style. It is advisable to explicitly encourage students to make as many annotations on the drawings as they can, and to remind them that only the correct responses will be scored and there is no penalty for an error.

The exercises occasionally expose some unexpected educational weaknesses. In one drawing, a wire shown screwed to the top of an assembly is labeled as a "ground wire". At both widely dissimilar trial institutions, a fairly consistent 10-15% of mechanical students suggested moving the wire to "the bottom", because it was labeled as a "ground wire". While some mechanical students are known to have weak electrical skills, few might suspect a problem at this level. Student annotations also give the instructor the opportunity to recognize and correct misunderstandings about process capabilities, material properties, or other issues troubling specific students.

Conclusion

A workbook of open-ended, design-oriented exercises will soon be available as a tool to support DFX education, thanks to the support of the SME Education Foundation. It will provide graphic examples of poor designs at both the assembly and part level, with an emphasis on manufacturability and assembly. Selected examples have been used in the classroom, and were well received by students. It is expected that the workbook will be available through the SME sometime in the near future. Over time, it may be possible to establish a growing and freely available collection of workable DFX exercises through the contribution of thoughtful problems from skilled design practitioners. No formal repository or mechanism is yet in place to do so, but the authors will investigate the possibility of making this workbook 'expandable'.

References

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