AC 2010-430: EVALUATION OF REDESIGNED PARTS CONSIDERING ANALYSIS, PRODUCTION AND DISTRIBUTION FACTORS

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Evaluation of Redesigned Parts Considering Analysis, Production and Distribution Factors

Abstract

Whenever a new or improved design is proposed, it is important to consider more than just the technical aspects of the new design (e.g., safety, deformation, strength, weight). It is essential to take into account several additional factors in the total production cycle of the new or improved product. Ideally, every factor in the life cycle of the product should be taken into account. As part of a Capstone Design Project, and with the goal of illustrating complete engineering design processes where factors besides the technical ones need to be taken into account, industry-sponsored projects are undertaken by teams of students. The project presented here deals with an automotive subassembly that needed to be redesigned and evaluated. The system is a power slider assembly which is installed in the rear of current-model trucks and powers the rear window. The current design is bulky, expensive, and takes too much time to install. The objective of the project was to introduce a new design for the power slider which would be more efficient in terms of operation, assembly process and delivery cost. A CAD model was created for the proposed design including new design features. Free body diagrams representing forces and couples acting on the system were evaluated using Finite Element Analysis (FEA.) Based upon FEA results, the design will sustain a maximum stress of 33.9 MPa concentrated at the lower segment of a new snap feature, thus yielding an acceptable safety factor. Failure Mode and Effect Analysis (FMEA) showed potential failures and their possible causes. The proposed design was prototyped and cycle tested to recommended standards, which provided evidence that the proposed design was ready for production. Benchmarking costs of the proposed design versus the current design was done. Significant benefits were found when stress analysis factors were taken into account alongside with manufacturing, production and distribution factors, thus illustrating the importance of a complete evaluation matrix. This project presented an excellent opportunity for the team of students to be exposed and actively participate in a real-life engineering design environment. The sponsoring industry is a tier I supplier to the automotive industry who provided very strong support towards the success of this senior design project. The feedback received from students was that they had learned a great deal and the experience was very rewarding.

Introduction

The engineering design process has different meanings to different people, which sometimes makes it difficult to have adequate design projects for Senior Design capstone activities. But when a project has the potential to involve more than the standard technical activities that engineering students usually understand as being what "design" is all about, the project lends itself to be a great opportunity to illustrate the actual meaning of the complete engineering design process.

At Western Michigan University (WMU) there is the requirement that all CEAS's undergraduate graduating students must complete a Senior Design Project in a two-semester sequence. Projects are presented by faculty members in the College, and students indicate their preferences. Subsequently, teams are formed, with the number of students in each team being decided by the technical advisor(s), the course coordinator, and any sponsor(s) in function of the expectations for the project. Most of the teams have three students, and students' preferences have shifted in the past years from having more interest on internal projects (i.e., no industry involvement) to having projects where an industry sponsor is involved. Among the many benefits and responsibilities that industry sponsored projects provide, one specific benefit is the opportunity to emphasize to the students that engineering design is more than just doing the calculations that were typically done in the classroom.

Faculty members need to search and request projects from their network of industry practitioners. That was the case for this project, a member of an Industry Advisory Board for the Department agreed to sponsor a project that will encompass a concept-to-testing endeavor, a great opportunity to expose students to a more complete engineering design process.

Objective

Current power slider assembly consists of three major components: a) mounting bracket housing, b) drum with the cable, and c) electric motor. This assembly is mounted on rear of current model trucks. Its function is to open and close the rear window. The current power slider has many design flaws, which should be corrected to make the design more efficient. The automotive supplier is looking for a new design that primarily would fix the majority of the design flaws. Initial designs that were proposed by the supplier were rejected by their client due to lack of analysis and testing. The objective of this project was to prove that a new proposed design is feasible and an effective alternative to the existing power slider assembly.

A secondary objective, more in the pedagogical side, was to expose the students to the practical aspects of an engineering design process. So, it was agreed by the sponsor and the faculty that a standard design process flowchart would be followed, deciding as well to hold weekly meetings of the entire team (i.e., students, sponsor and faculty) to monitor progress. The weekly meetings actually became tutorial sessions where industry and faculty provided important information to the students about topics that they were not familiar with (e.g., FMEA, testing standards and protocols.)

Methodology

The design process has many variations but, in general, it can be seen as a tool that helps engineers achieve efficient design and produce a quality product. The design process consists a sequence of steps, which are: identify the need, define the problem, research related topics, apply constraints and criteria, brainstorm solutions, analyze solution(s), select the best solution, document the solution, communicate the solution, do further research, build the prototype, perform tests, and finally verify and evaluate that proposed solution.

A project plan was set up along with a fixed timeline (Gantt chart) which guided us to achieve our goal. In order to complete this endeavor, background research on different aspects of the overall project needed to be carried out. Different alternatives were brainstormed in order to achieve accuracy. Detailed analysis on the proposed design was performed which included free body diagrams, finite element analysis (FEA), generation of prototype parts followed by design validation cycle tests. Results obtained from the test were compared with the computer aided engineering analysis to validate and verify the accuracy of the tests. Results showed the robustness of design in terms of manufacturing assembly, cycles time, maintenance cost, improved process of conveyance, and reduction of shipping cost. Final results were used make further recommendations to the industry sponsor.

A final proposed design that is considered a solution to the current problems was selected after the initial steps of the engineering design process. This new design splits the original plastic mounting bracket into two parts, thus allowing the assembly to be shipped separated, and three snap features were added to assemble the two parts. The drum and the electric motor stayed the same in the new design. Figure 1a and 1b shows the existing and the proposed bracket design, respectively.

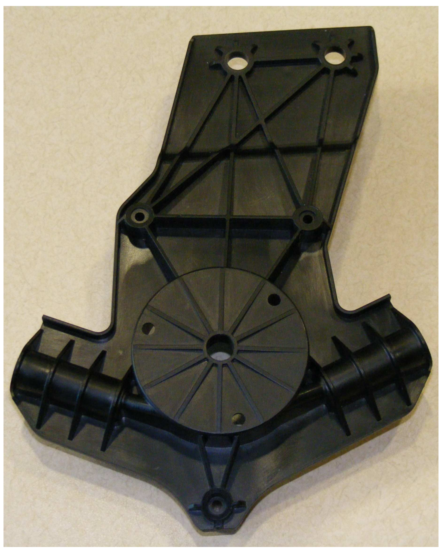

Figure 1a. Current Design

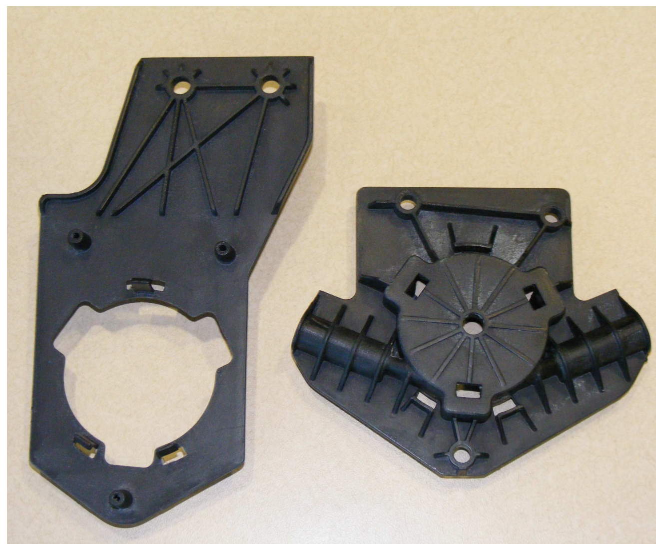

Figure 1b. Proposed Design

The next tasks were directed towards proving that the proposed design is feasible and validate its robustness. The major steps carried out were as follows:

1. CAD modeling and Finite Element Analysis (FEA). The initial step is CAD solid modeling and, before FEA can begin, some FBD (free body diagrams – Figure 2) had to be generated and evaluated in order to have proper forces specified in the FEA. The FEA was used to simulate real life operating conditions on the component[5]. Through this process, the forces calculated in the FBDs, with the corresponding boundary conditions, were applied.
2. Failure Mode and Effect Analysis (FMEA). FMEA is a process that is used to analyze all the different types of failure that could occur to the product[1,6]. FMEA improves the product functionality, reduces manufacturing and assembly problems and industrial process problems. This procedure will lead to savings of time and money in the production of the component. Knowing all these problems will also reduce warranty costs in the future. This is typically an ongoing analysis that is applied throughout the design and production process.
3. Physical prototyping. When all the initial design and analyses were completed the prototyping process started[2,4]. There were two alternatives dealing with the prototype. One

option was the rapid prototyping process (SLA) to create the components. This is a quick process that can have a prototype ready in about a day. A negative aspect of this option is that it is not acceptable for most testing because it is not a functional prototype. The second option was rapid tooling. This process uses a plastic composite to make a production die. Rapid tooling produces actual parts, ideal for testing and verification of the design. It will also serve as a production die until metal tooling can be completed. It was critical that all design and analysis processes had been carefully applied by this stage. To go back to the design phase at this stage would have been detrimental to successfully completing the project. This was the most expensive phase of the project, costing several thousand dollars.

4. Design validation testing. The finished prototype was then subjected to design validation testing. In this procedure the prototype was subjected to life cycle testing. We tested according to auto industry specifications (i.e., Chrysler). A standard cycle uses 2 movements, open and close. Three samples are required for testing. Each sample must go through 21,900 cycles at ambient temperature. The data collected provided us with knowledge about the safety and durability of the product. The data also served as evidence to authenticate the design.
5. Benchmarking. This is a process that was ongoing throughout the entire project. During this phase we compared our proposed design to the existing design. This analysis included assembly time, number of parts, maintenance, and ease of assembly. The process also identifies the areas of cost such as labor, parts, and even shipping. Finalizing benchmarking and reporting results and recommendations marked the end of the project.

Results

In order to prove the robustness of the proposed design the design team worked through the established methodology. The results along with analysis and interpretation of the FEA, FMEA, rapid prototyping, design validation, and benchmarking are included in this section.

<u>Modeling and Analysis</u>. CAD modeling and finite element analysis were the first steps. FEA becomes a trial-and-error approach in order to get valid results[3]. For both, modeling and analysis, CATIA software was used. For FEA, the maximum force was calculated to be 200 lb (889.6 N) acting through the cables. This was calculated using a GM specification of 70 lb (311.36 N) stall force along with 30 lb (133.44 N) of friction in the system; this was multiplied by a safety factor of 2. The maximum stress in the system is located towards the bottom of the motor mount on the inside of the snap. The magnitude of that stress is 33.9 MPa (Figure 2). This part is made out of Polyamide 66. This material has a tensile stress at fracture of 210 MPa. These FEA results show that this system is operating with a static safety factor of approximately 6. All materials specified are able to withstand that level of stress. The proposed design showed no signs of failing throughout the FEA phase.

Once the analysis was completed the two parts were dimensioned using GD&T. The pins and pin holes were a focus point during this process. It is important that the pins and their holes line up during assembly. If they do not, the part will not fit together. A tolerance stack up was done on these two components to make sure they were dimensioned correctly. Close attention was also paid to the snap features, they must engage every time in order for the assembly to function properly.

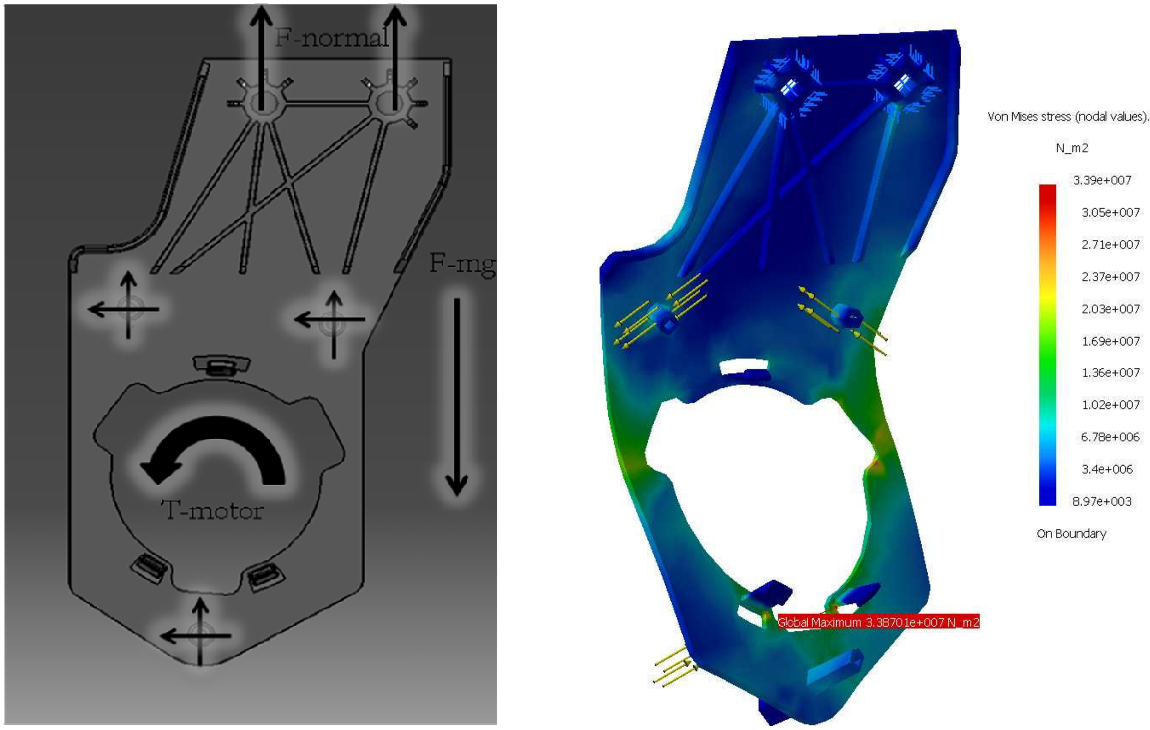

Figure 2. Free Body Diagram and FEA Results

Failure Mode and Effect Analysis. For FMEA, design and process FMEA documents (DFMEA and PFMEA) were generated. Results in the FMEA document are measured in terms of a RPN number. RPN numbers of FMEA documents for the proposed design were between 30 and 40. Industry standards indicate that RPN numbers less than 100 are well within the range of safety standards. The highest RPN number in this project was 54, and that was located in our PFMEA. That case corresponds to having a snap break when the motor bracket and drum housing are assembled. If one snap breaks the assembly is no longer a proper one. If the operator uses the pins as guides for assembly the snaps will be lined up correctly, and should not break[7]. Even though the problem is severe, it has a low occurrence rate and is easily detectable. That is why the RPN number is below 100, and no further action is necessary. Finite element analysis and failure mode and effect analysis showed that no changes were needed for the proposed design.

Physical Prototyping. Production of any new design will require hundreds of thousands of dollars invested in tooling and equipment. The product must survive durability tests for its intended use, long before tooling can be considered. To achieve this, a combination of stereolithography and rapid prototype casting was selected to produce actual parts for real testing under auto industry standard conditions. The total discounted cost of this process was close to $3K, which is still a small fraction of the actual cost of fabricating production tooling (~$250K). It included an SLA model of each part, two silicon molds, and ten urethane castings of each part.

Testing. The testing phase will further verify the results of analysis. This portion will now validate the reliability and durability of the product. This should provide the data needed to offer the product solution to major corporations for production. This testing was performed to Chrysler specifications. This phase consisted of 3 samples that were tested at ambient temperature. The samples had to survive three bogeys for the part to pass. Each bogey consisted of 7,300 cycles, which is considered one operation lifetime. Each sample will run through 21,900 cycles. Any failures to complete this process are documented for further studies.

The first two parts passed the test, the third part only survived one operation lifetime, failing at the snap during the second set. Based on this information, an FEA sensitivity study was ran to see how the thickness of the snaps affects the stress at the snaps. These analyses showed that, if the snap thickness was increased by 1mm, the stress in the snap would be reduced by 32% to 23.2 MPa, and that the critical point would move to the side of the part where the smallest cross section is located. This change was included in the final design. But no resources were available to perform another set of tests.

Benchmarking. The final step was to compare our proposed design to the design currently being used. Factors like time for assembly, number of parts, maintenance, ease of assembly, and in particular cost were considered. This step demonstrates the importance of the project and if any improvements are being made this the proposed design.

The proposed design consists of one more part than the current design. This extra part comes for the fact that the motor bracket is split into two separate parts, becoming the drum housing and the motor bracket. Snaps were added to easily assemble the two parts. In this case, the benefits justify the addition of one part. When assembling the proposed design one more step is added, the drum housing and motor bracket are snapped to each other. The proposed design is just as easily assembled as the current design. Snapping the two parts together is a simple task, and is made even easier by the inclusion of three pins. The pins guide the two parts together. The proposed design does not hinder maintenance.

Real time saving will come when components are shipped. In the current design, the assembly must be placed into a box, the box has to be folded and put into place by an operator. It also takes up more space in the shipping container. In the proposed design, the window is shipped with the motor bracket screwed into the motor and separate from the drum and drum housing snapped together. These two separate components can be taped onto the glass without being placed into a large box to secure them. The proposed design will allow for a significant cost savings for packaging and shipping. There are also further savings when labor costs are taken into account. There will be reduction in the amount of floor space usage. The focus of this project included shipping costs and packaging savings. A cost matrix was developed to calculate the cost savings. A box is used to pack assembly of current power slider. The cost of the box is 39 cents each. Total cost savings due to elimination of box will be $156,000 for 400,000 parts per year. And it is an environmentally friendly solution as well. Other savings for shipping cost will come from increased rack density. Currently there are 20 parts stacked in each rack which are shipped in a semi trailer which carries 32 of those racks. A total of 640 units are shipped in one semi trailer, 624 semi trailers are required to ship 400,000 units. The proposed design increases the rack density from 20 to 36 parts in each rack. This will increase the total number of assemblies in each semi trailer from 640 to 1152. To ship 400,000 units, 348 semi trailers will be required. There will be 44% reduction in shipping cost which will be direct cost savings, and a benefit for the environment. Total savings of more than $600,000 will be realized by implementation the new design (Figure 3). This figure does not included possible savings from reduction in labor. On the other hand, it will cost approximately $200,000 for the new tooling. This cost can be recouped within the first several months of implementing the proposed design, giving a healthy ROI of 4 months.

Total cost savings

Boxes per year	400,000
Piece cost of packaging box	$ 0.39
Yearly savings for packaging	$ 156,000.00
Yearly shipment savings	$ 445,280.00
Yearly project savings	$ 601,280.00
Retooling cost	$ 200,000.00

Figure 3. Total Cost Savings.

Conclusions and Recommendations

This project required the effective application of all stages in the design process. This industry-sponsored project was an ideal endeavor for a Capstone Senior Design Project. Students were exposed to real-life engineering environment, learned about methodologies not covered in the classroom, and had to follow a strict project management plan with time and budget constraints. On the technical side, problems with the current power slider design were addressed and a complete solution was given with the proposed design. The proposed design had to be validated and it had to be shown that it was an improvement over the existing design. FEA was used for the analysis of the proposed design, and FMEA was used to examine its functionality. In order to run real-life tests, prototypes were created and design validation testing was completed on those prototype. Finally, benchmarking of existing versus proposed design was done, with the proposed design passing all the validation tests, with an added benefit of at least $400K savings a year and a of being a green product.

The value of this project as a collaboration university-industry is that it presented the opportunity to directly affect a part that most likely will make it to market. Based on feedback from the students and the sponsor, it can be said that it was an excellent experience for everyone involved.

Since the results of analyses and testing show that the proposed design is a major improvement over the current design, the recommendation is that the proposed design should be implemented as soon as possible. Further research and testing should be done to see if this design can be applied to any other window assembly, resulting in even greater benefits. The client for the power slider is interested in the new design and it might be used on their new models.

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