NEW PRODUCT DEVELOPMENT BY DFMA AND RAPID PROTOTYPING

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ABSTRACT

In any manufacturing process, design is the first step where most of the important decisions are made which affects the final cost of the product. In this paper the researchers have used Design for manufacturing and assembly (DFMA) to re-design a fluid flow control valve and optimized its design to ensure the reduced number of parts, safety, reliability, time to market and customer satisfaction. In this research work the main emphasis was given to the design stage of a product development to obtain an optimum design solution for an existing product, DFMA concepts were used to produce alternative design ideas and the rapid prototyping process was used to develop a prototype for testing and validation of these alternative designs. Optimum design, low cost and good quality with quick delivery was the outcome of this research work.

Keywords: new product development, design for manufacturing and assembly, rapid prototyping, flow control valve.

INTRODUCTION

The basis of production begins with a need of product, which is identified by customer and market demands. The end product goes through two major processes from the concept generation to the finished part. These processes are the design process and the manufacturing process. These two functions are very important areas in any production and, therefore, the interrelationship between them always is of principal importance to any product designer. By DFMA concepts, design effectiveness is improved and integration is facilitated when:

- Fewer active parts are utilized through standardization, simplification and group technology retrieval of information related to existing or preferred products and processes.
- Manufacturability is enhanced through incorporation of DFM practices.
- Design alternatives are evaluated and design tools are used to develop a mature and producible design before release for manufacture.
- Product and process design includes a structure to balance product quality with design effort and product robustness.

Prototyping plays a most important role in obtaining a high quality product in any design practice and also allows for the quick creation and assessment of a product concept [1]. The prototype part is then tested under a certain range of setting that approximate the performance specifications. Information obtained from testing, after evaluation to account for possible variability in the tests, is ultimately used to manipulate any geometrical information about the part so that development decisions may be made with high confidence and at reduced risk.

Cleber Willian Gomes [2] explained Rapid prototyping is another tool that added to CAD/CAM/CAE facilitates new product development in automotive industries, household appliances, electronics, war equipment and medical equipment. YAN Yongnian, L.I. Shengjie *et al*., [3] studied Rapid Prototyping and Manufacturing Technology with various principles, techniques, Applications, and Development Trends. Selvaraj *et al*. [4] introduced an approach to design for manufacturing and assembly based on reduction of product development time and cost. Martin O'Driscoll [5] have discussed the use of DFM practices in the industries and explained the step by step approach to implement DFM in a manufacturing environment.

Design for manufacturing

Since the improvement of CAD/CAM technologies, the term DFM has been drawing more interest. Even though design takes into account of the manufacturing process, often DFM practices are not followed. In common, the interaction between design and production functions has been very less. In a non-CIM environment, this interaction is not so significant. In fact, poor interaction gives both the design and production departments some flexibility, and to some extent, independence in achieving their nominal objectives. Recently, CAD/CAM has forced a change in this approach because improvements in the product can be cost effective only through design over an extended time period. One might expect that in a CAD/CAM environment the design need not be perfect from a manufacturing point of view, because computers can accommodate last minute changes without difficulty. But, the converse is actually true. Designers must now give closer attention to their ideas and drawings from the manufacturability point of view. They are expected to design what the available tools and personnel are capable of producing. Designs, therefore, are customized according to the production and assembly facilities in which the products will be manufactured. The enormous power of CAD/CAM workstations assist in doing this by providing designers with detailed information on the capabilities of existing manufacturing resources [6]. Therefore term DFM emphasizes design production interface more significantly in a CAD/CAM environment than in a non-CIM environment.

The concepts behind DFM are not new as such; however its recent fame in the industry has propelled its implementation further toward the use of multifaceted software packages and modern techniques. DFM simply reinforces the need, within the functional necessities of the product, that designers must consider the manufacturability of their design. Boothroyd and Dewherst [7] advised designers to apply DFM concepts. DFM integrates product design, process planning, and production with the objectives of:

- Identifying product concept that is inherently easy to manufacture.
- Focusing on component design for ease of manufacture.
- Integrating product design with process design to attain optimum results.

The term DFM includes both production and assembly of components. In plants where assembly is the main activity and there are many such facilities. DFM mostly makes considerations well beyond the ease with which components will fit to also involve assembling processes and other downstream functions. With CIM, designers are expected to have significant knowledge of manufacturing processes and of the service department's requirements. Effective interactions among marketing, manufacturing, and service personnel are important as well. The designers must be proficient in cost estimation of raw materials and their characteristics as well as the processes by which parts are shaped, machined, and assembled. Only then can designers standardize the parts across the models and products, to reduce tooling and other fixed costs to get optimum design. Designers follow several rules to accomplish DFM. The rules depend on the type of production process. DFM rules vary widely among the process groups.

Some typical guidelines to implement DFM to component design are [8]:

- Minimize part variations.
- Attempt multi-functionality of parts
- Design for ease of fabrication.
- Design with as few parts as possible.
- Design parts for multiple uses.

G. Boothroyd and P. Radovanovic [9] estimated the cost of machined components with the implementation of DFMA techniques during the conceptual design stage. Rong-Kwei Li and Cheng-Long Hwang [10] proposed a framework for automatic DFA evaluation procedure. Geoffrey Boothroyd [11] described various case studies with implementation of DFMA methodology and its application in early stage of product design. S. Dowlatshahi [12] has made proposal for an integrated, self-contained manufacture and assembly facility for pipe valves using DFM/DFA environment. Olivier Kerbrat [13] suggested a new DFM system which provides quantitative information during the product design stage and the advantages of using additive manufacturing process.

RAPID PROTOTYPING

The design analysis process provides enough data on the various design alternatives. The subsequent examination of the collected data is used to determine the degree of match between the actual design and the initial design goals and specifications. This is one part of the evaluation process. Every member of the engineering team performs an examination of the data and then recommends suitable changes in the design. The iterative nature of the design process makes it difficult to separate engineering design activities in the analysis and evaluation functions. The main factor of the computer based design software [14] is that it will analyze and evaluate design quality. The traditional way of performing the computer-based method at the evaluation stage is prototyping. Rapid prototyping, a technique used to build a part of a new design quickly, is a reliable tool in the evaluation process. These systems electronically divide a 3D CAD model of a part design into thin horizontal layers and then transform the design, layer by layer, into a physical model of the real part. RP systems are driven by very accurate microcomputer systems. Starting with a 3D CAD solid model part file, the CAD software converts the geometrical features into a file format compatible with the rapid prototype system [15]. A Fused deposition modelling (FDM) system, which is one the commonly practiced RP methods [16], uses an STL file format [17]. The prototype is an original model of the design built to evaluate operational features, before initiation of full production [18].

The tools used for standard prototyping are conventional production machines. Frequently, prototype parts are machined from nonferrous metal or plastic; however, with use of more complex plastic injected moulded parts in products, the prototype process becomes more difficult. Machining complex shapes of injection moulded parts is difficult, expensive, and time consuming. While prototyping a design is still a critical evaluation process, the requirement to cut lead-time to market requires faster prototyping techniques. Several other techniques called RP are used to reduce time required to develop prototype parts [19].

NEW PRODUCT DEVELOPMENT

In this research as the part of alternative product development process, techniques such as DFMA and Rapid prototyping has been used to produce optimum design solution which has low cost and good quality with required functionality. Figure-1 shows Generic Product Development Cycle and Figure-2 shows New Product Development Cycle in which DFMA and RP technique is used.

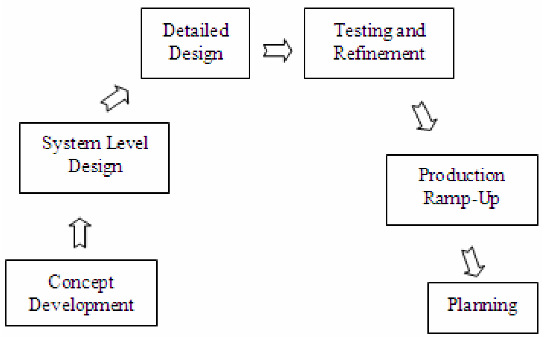

Figure-1. Traditional product development cycle.

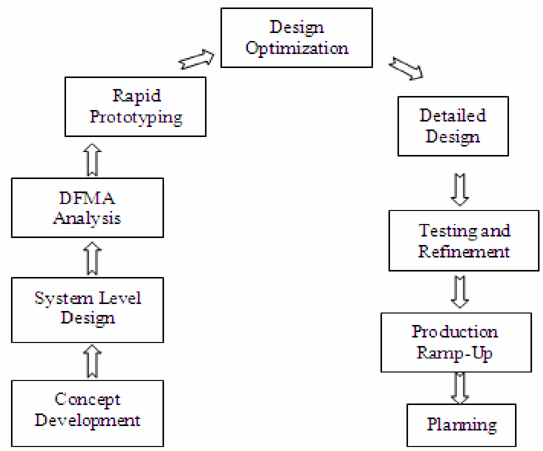

Figure-2. DFMA product development cycle.

CONCEPT DEVELOPMENT

In this research a component considered for analysis was ball operated flow control valve which was generally used in hydraulic systems. To get the optimum design with less number of component parts, three concepts of ball valve design was developed. First concept was developed in which the entry of ball is from the centre while assembling and then only other components of the ball valve are assembled. In second concept, entry of ball was from one side of the ball valve i.e. either from left or right side and in third concept, entry of ball is from the top and then all other component parts were assembled.

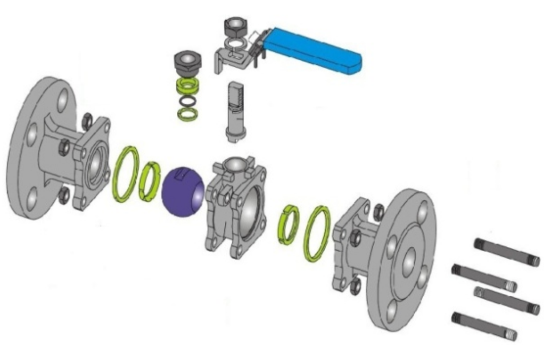

Figure-3. Existing flow control valve centre entry design with 18 components.

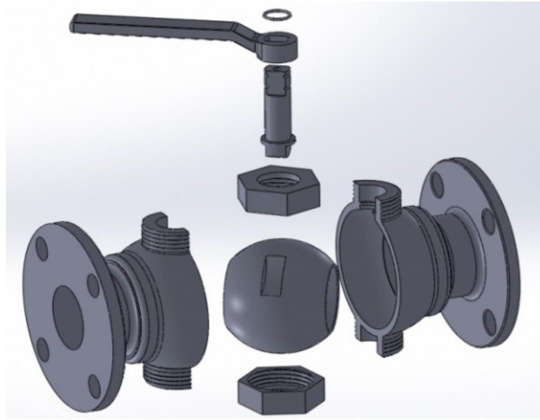

Figure-4. DFMA of flow control valve centre entry design with 8 components.

Figure-5. Existing flow control valve side entry design with 18 components.

Figure-6. DFMA of flow control valve side entry design with 7 components.

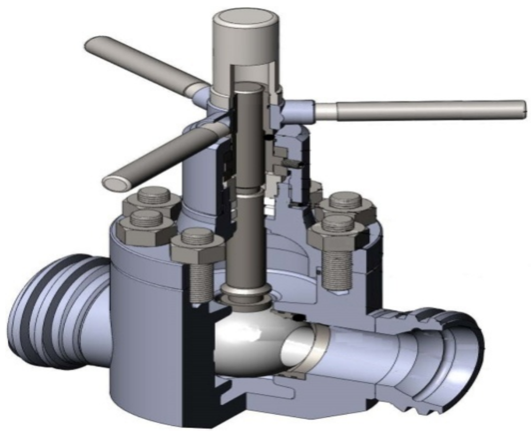

Figure-7. Existing flow control valve top entry design with 23 components.

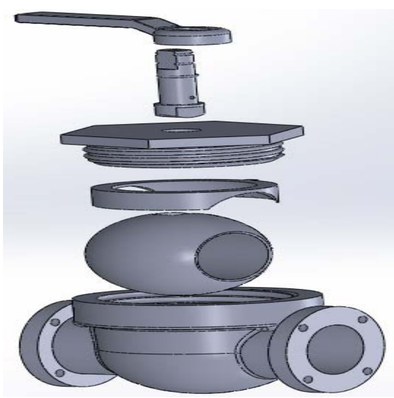

Figure-8. DFMA of flow control valve top entry design with 6 components.

CONCEPT SELECTION

Out of the three concept, one concept was selected which is having less number of components parts. So that the final product which is having less cost as well as less time required to manufacture it. In this case, top entry ball valve design was optimum as it has only 6 component parts as shown in Figure-8.

DESIGN EVALUATION AND OPTIMIZATION

Three Designs are optimized with the implementation of the design for manufacturing and assembly concepts which was invented by Boothroyd and Dewherst. DFMA concepts which are followed in this research are stated as follows:

- Reduce number of parts.
- Eliminate redundant adjustment.
- Test the need of each part.
- Eliminate mechanical fastener.
- Multifunctional part design.
- Self aligning.
- Reduce cost.
- Reduce assembly time.
- Assemble in single linear motion.

DFA Index or assembly efficiency is given by the ratio of theoretical minimum assembly time to the actual assembly time.

$$\text{DFA Index } (E_{ma}) = N_{min}.t_a / t_{ma} \quad (1)$$

Where,
N_{min} = Theoretical minimum number of parts.
t_a = The basic or average assembly time for one part equal to 3 sec.
t_{ma} = Estimated time to complete the assembly of the actual product.

By taking into consideration the above method, the number of parts have been reduced which are included in results Table and DFA index was calculated using Equation (1) for the existing design and optimum design. Assembly time, part count is shown in Table-1.

Table-1. Details of parts and Assembly time for existing design.

Item	Number	Theoretical part count	Assembly time in, s
Ball	1	1	3
Body	1	1	9
Bonnet	1	1	8
Stem	1	1	5
Bracket	1	0	4
Core handle	1	0	6
Gland	1	0	5
Seat	2	0	6
Weco 602	2	0	8
Valve cover	1	0	3
Stem nut	1	0	5
Key	1	0	3
Handle	3	1	9
Bearing	2	0	9
Filler	2	0	6
O-ring	4	0	8
Hex socket flat	1	0	4
Socket flat	1	0	4
Stud	8	0	16
Heavy hex nut	8	0	24
Total	43	5	145

DFA index = 5 x 3 / 145 = 10.34%

Table-2. Details of parts and Assembly time for modified design.

Item	Number	Theoretical Part count	Assembly time in, s
Casing	1	1	5
Ball	1	1	3
Sleeve	1	1	3
Cover	1	1	9
Stem	1	1	5
Handle	1	1	4
Total	6	6	29

DFA index = 6 x 3/29 = 62.06 %

DESIGN VALIDATION

To validate the design in this research rapid prototyping technique has been used. In which optimum design having less number of components was manufactured by Rapid Prototyping technique. There are various methods in rapid prototyping technique but in this research fused deposition modeling (FDM), which is additive type of manufacturing process was used with material ABS (Acrylonitrile Butadiene Styrene) to manufacture the product.

Machine used for manufacturing Product was uPrint® SE and uPrint® SE Plus. Figures 9 and 10 shows product assembly and its parts.

Figure-9. DFMA of the flow control valve top entry design manufactured by rapid prototyping.

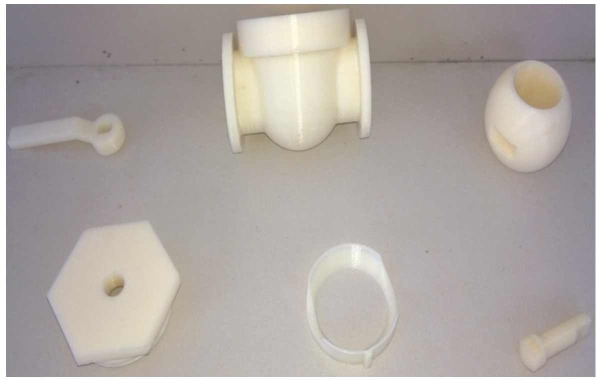

Figure-10. Individual components of the top entry flow control valve manufactured by rapid prototyping.

RESULTS

By using DFMA techniques and Theoretical Part Count Efficiency method the number of parts have been reduced. For central entry design number of parts was reduced to 8 while for side entry design it reduced up to 7. Top entry design was selected as optimum design because the number of parts was reduced to 6 and DFA index was 51.72 % higher for the modified design which is shown in Table-3.

Table-3. Details of existing and modified design components.

Type of design	No. of components	
	Existing design	Modified design
Centre Entry Design	18	8
Side Entry Design	18	7
Top Entry Design	23	6

CONCLUSION

Product was re-designed by DFMA technique and prototype product was developed by Rapid Prototyping machine. The ball valve flow control valve is taken as a case study to design, optimize and validate the product by DFMA and RP technique. Combination of the above technique has proven itself to be a worthwhile investment with significant observations of ensuring optimal quality, reduced number of parts, reliability, time-to-market, lifecycle, safety and customer satisfaction. Early consideration of manufacturing issues also shortens product development time, minimizes cost, and ensures a smooth transition into production for quick time to market. Also by implementing these concepts in product development good designs can be produced.

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