ENVIRONMENTAL CONSCIOUS PRODUCT DESIGN USING CAD AND CAE

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Abstract— Environmental consciousness has been regarded as an important concept for survival in the contemporary scenario. Modern design engineers are in need of approaches for creating environmentally friendly products. In this context, this project reports a case study carried out in an Indian rotary switches manufacturing organisation. The existing components of rotary switch have been modelled using Computer Aided Design (CAD). Then the sustainability analysis has been carried out for determining the environmental impact. This is followed by the optimisation of the components using Computer Aided Engineering (CAE). The environmental impact has been measured in terms of carbon footprint, energy consumption and air/water impacts. It has been found that the optimised components possess minimal environmental impact. The sustainability improvement before and after the implementation of the proposed approach has been computed.

Keywords — CAD; CAE; Environmental Conscious Product; Product design and manufacture; Design for Environment.

I. INTRODUCTION

Contemporary manufacturing organizations recognize environmental consciousness as an important concept for surviving in the competitive world. They have been forced to adopt practices that are designed in a manner to keep the environment safety and minimize energy utilization. Sustainable organization also reduces production costs and prevents environmental problems for maintaining the Green and Clean atmosphere. Green system integrates product and process design issues with manufacturing planning and control problems in such a manner to identify, quantify, assess, and manage the flow of environmental waste with the goal of reducing environmental impact. Also, such system tries to maximize resource efficiency for production of sustained components. Environmental consciousness is a critical intersection between the following factors likes manufacturing and product design practices and environmental issues and concerns. The practical aspects of environmental conscious design involves minimal material usage, improved material choices, design for ease of disassembly, product reuse, minimal energy consumption, manufacture without producing hazardous waste and usage of clean technologies. In this context, this project reports a case study of ensuring environmental conscious design of components of a rotary switch manufactured by an Indian organization using Computer Aided Design (CAD) and Computer Aided Engineering (CAE). Though there are many eco-design studies reported, there has been no research reported from the perspective of integration of CAD and CAE for improving the sustainability of products. This formed the research objective of this project. This case study begins with CAD modeling of existing components followed by environmental consciousness analysis to determine environmental impact in terms of carbon footprint, energy consumption etc.. Then the components have been optimized using CAE. Then the environmental impact has been measured. The sustainability improvement before and after the implementation of the proposed approach has been computed The results of the case study indicated that the integration of CAD and CAE could lead to the development of environmental conscious product.

II. LITERATURE REVIEW

Gungor and Gupta (1996) have presented Environmentally Conscious Manufacturing and Product Recovery (ECMPRO). ECMPRO involves integrating environmental thinking into new product development including design, material selection, manufacturing processes and delivery of the product to the consumers, plus the end-of-life management of the product after its useful life. Bras (1997) has presented various issues and options of incorporating environmental issues in product design and realization. The author has presented a brief overview and classification of a number of approaches for reducing the environmental impact as well as their organizational impact. Madu *et al.* (2002) have presented a hierarchical framework for environmentally conscious design. The framework integrates both product designers and stakeholders to evaluate not only the product features but also its environmental burden. They have used the analytic hierarchy process (AHP) to develop priority indices for customer requirements to highlight key features that must be present in the product. Maxwel and Vorst (2003) have developed the concept of sustainable products as well as services evolving as a key element of Cleaner Production. The method proposed by them provides a framework for implementing sustainable product and/or service development (SPSD) throughout the entire lifecycle of a product and/or service. It can be used to identify, assess and implement the options for optimum sustainability in the design and development of a

product and/or service. Kaebernick *et al.* (2003) have presented the integration of environmental requirements into every single stage of product development from the very beginning, leading to a new paradigm for sustainable manufacturing. The authors have developed some of the tools for individual stages in the product development process. These tools form part of an overall concept for sustainable product development. Masui *et al.* (2003) have presented a methodology called Quality Function Deployment of Environment (QFDE) for environmentally conscious design in the early stage of product development. The proposed methodology by the authors incorporates the environmental aspects into QFD to handle both traditional and environmental quality requirements. Bevilacqua *et al.* (2007) have presented a methodology for integrating Design for Environment and LCA techniques both into new product development and into the process of redesigning a set of existing products. The proposed methodology benefits the use of data both during new product development and when modifying old products, with the aim of continuously reducing the overall environmental impact of products during their life cycle. Bovea and Wang (2007) have presented a novel redesign approach that allows integrating environmental requirements into product development, taking into account cost and customer preferences. The proposed methodology allows the identification of environmental improvement options and the study of the effect that the incorporation of these options has over other traditional product requirements. Ijomah *et al.* (2007) have presented a process of bringing used products to a 'like-new' functional state with warranty to match is being regarded as a vital strategy in waste management and environmentally conscious management. They presented an outline of the elements of the remanufacturing concept to improve the robustness of design-for-remanufacturing (DFRem). Rusinko (2007) has presented an exploratory study of the relationship between specific environmentally sustainable manufacturing practices and competitive outcomes in a US based commercial carpet industry. It has been observed that, the need to focus on environmentally sustainable practices and outcomes in other under-researched manufacturing and service industries. Gehin *et al.* (2008) have presented a strategy called End of Life (EoL) to assess product EoL process, which would be profitable for an enterprise given the business model in place. design aids which permits designers to compare their products to ''Remanufacturable Product Profiles''.

III.RESEARCH METHODOLOGY

The methodology followed during this research is shown in Figure 1.

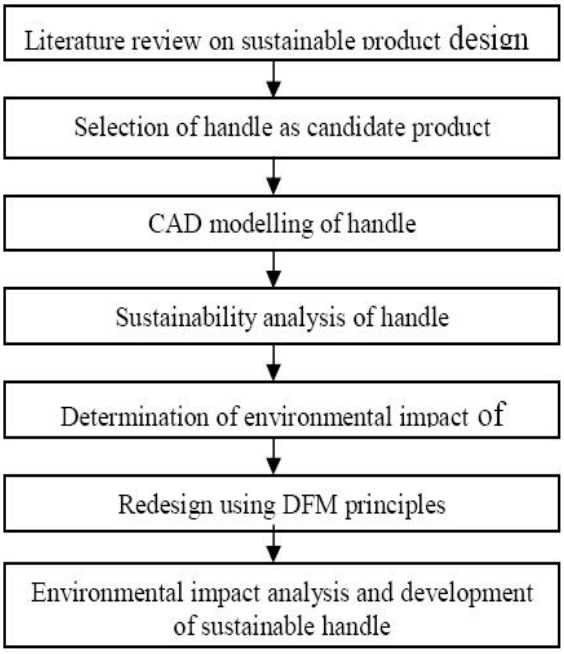

Figure 1. Research Methodology

As shown, the study begins with the literature review on sustainable product design. The research gap has been indentified and the candidate organization has been selected. Then the candidate product has been identified. Then the CAD modelling of handle has been performed. This is followed by the conduct of sustainability analysis of handle. The environmental impact of handle has been assessed. Then the handle design has been redesigned using DFM principles and the environmental impact is again measured. The inferences are derived from the conduct of the case study.

IV. CASE STUDY

This section presents the details about the case company, product, CAD modelling, sustainability analysis and redesign aspects using DFM.

4.1 About case company

The case study has been carried out in an Indian modular switches manufacturing organization (hereafter referred to as ABC). ABC manufactures relays, starters and modular switches. The case organisation has implemented ISO 14001 Environmental Management System. The authors have been collaboratively pursuing research projects in the field of sustainable manufacturing. There existed a need for the case organisation to utilise technologies for ensuring sustainability.

4.2 CAD Modeling

After collecting the two dimensional drawing of the handle from ABC, the CAD model of the existing handle has been created using Pro/Engineer software package. Such developed existing handle model is shown in Figure 2.

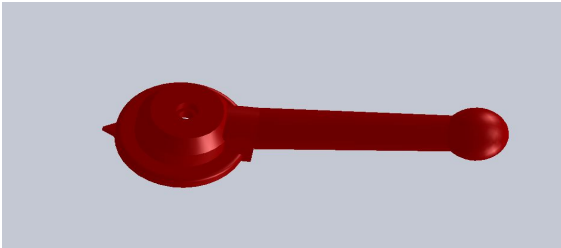

Figure 2. Screen depicting the existing handle design

4.3 Sustainability analysis

The sustainability analysis has been carried out using Sustainability module of SolidWorks software package. The material has been specified as Nylon. The volume, surface area and weight are computed. The manufacturing process has been specified as CNC machining. Figure 3 shows the results of sustainability analysis. Four important environmental parameters considered in this study are carbon footprint, air acidification, total energy consumed and water eutrophication.

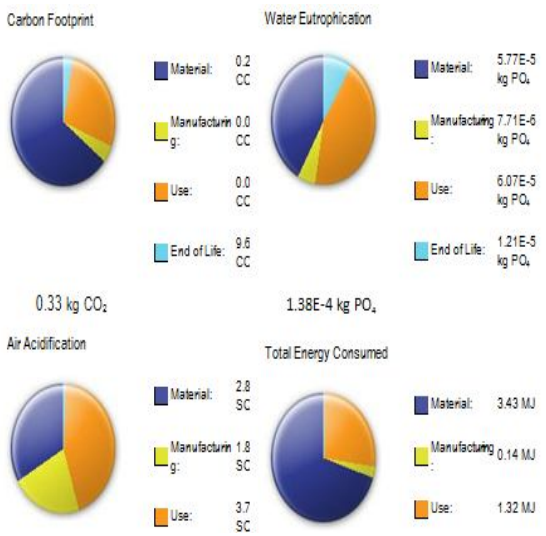

Figure 3. Results of sustainability analysis of existing handle

Air Acidification represents the sulphur dioxide, nitrous oxides other acidic emissions to air cause an increase in the acidity of rainwater, which in turn acidifies lakes and soil. This impact is typically measured in units of either kg sulphur dioxide equivalent (SO2e) or moles H*þ* equivalent. Carbon footprint represents Carbon-dioxide and other gases which result from the burning of fossil fuels accumulate in the atmosphere which in turn increases the earth's average temperature. Global warming is blamed for problems such as loss of glaciers, extinction of species and more extreme weather, among others. Total Energy Consumed is a measure of the non-renewable energy sources associated with the part's lifecycle in units of megajoules (MJ). Total energy consumed includes not only the electricity or fuels used during the product's life cycle, but also the upstream energy required to obtain and process these fuels, and the embodied energy of materials which would be released if burned. Water eutrophication represents over abundance of nutrients are added to a water ecosystem. This impact is typically measured in either kg phosphate equivalent (PO4e) or kg nitrogen (N) equivalent.

4.4 Redesign using DFM principles

DFM principles have been used to redesign the handle from the perspective of easy manufacturability. Since the part is to be manufactured using plastic injection moulding process, the design rules pertaining to injection moulding has been used. DFM principles incorporated in the design are the maintenance of uniform wall thickness to avoid internal stresses and warpage; in the places, where thickness variations are needed, generous fillets have been provided; sharp corners have been avoided by providing appropriate radii. Then the sustainability analysis has been carried out and the redesigned handle is found to possess minimal environmental impact.

V. RESULTS AND DISCUSSIONS

Sustainability analysis measures the environmental impact over the life cycle of handle in terms of carbon footprint, Air Acidification, Total Energy Consumed and water eutrophication. The selected four environmental parameters global warming, acidification, eutrophication and energy resources represent the impact categories (Pehnt 2006). These environmental impact parameters are comprehensive and widely used measures.

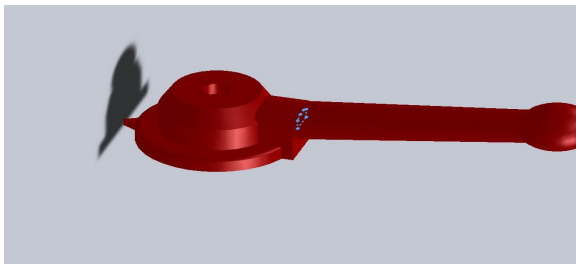

Figure 4. Screen depicting the redesigned handle

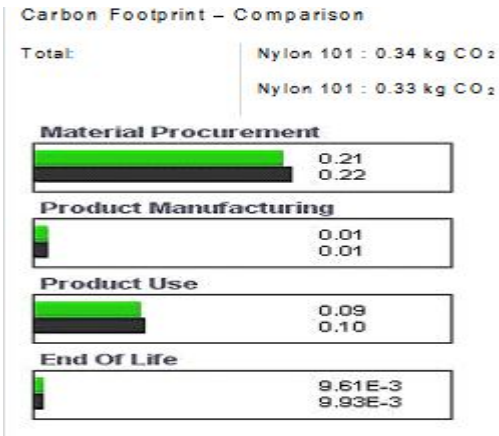

Figure 5. Comparison of Carbon Footprint among the baseline and new design across the life cycle

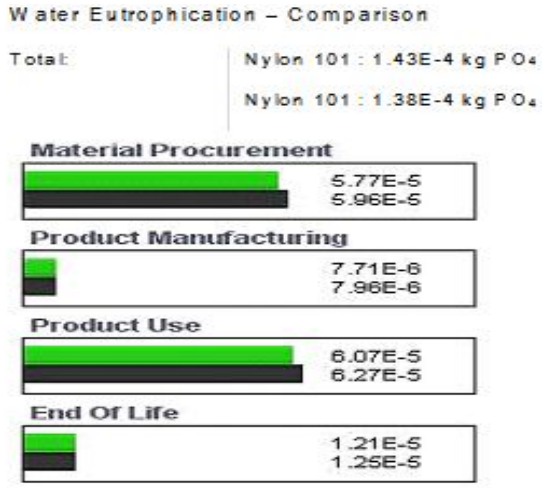

Figure 6. Comparison of Water Eutrophication among the baseline and new design across the life cycle

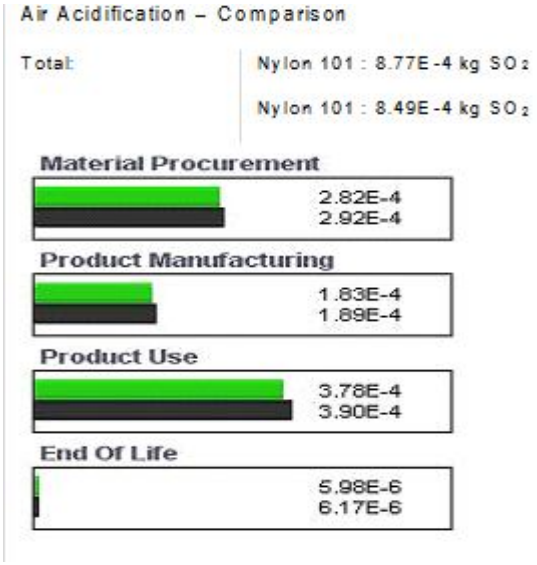

Figure 7. Comparison of Air Acidification among the baseline and new design across the life cycle

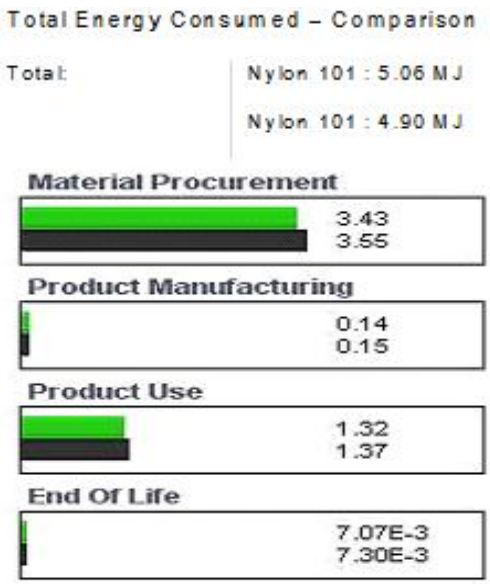

Figure 8. Comparison of Total Energy Consumed among the baseline and new design across the life cycle

CONCLUSIONS

The manufacturing organizations have been witnessing a paradigm shift on designing services from manufacturing to sustainability. The contemporary manufacturing organisations are focussing on ensuring clean and green atmosphere by means of reduction of production cost and prevention of environmental problems (Sadiq and Khan, 2006). Environmental issues have become an imperative apprehension for most companies in relation to modern product development. The need for developing special methods during product development so as to ensure green initiatives is the vital focus of today's industries. Sustainable system focuses on maximization of resources efficiency for the production of sustained products (Bovea and Wang, 2007). Based on the literature review, the integration of CAD and DFM for enabling sustainable product design has been selected as the research problem. The handle has been modelled using CAD and sustainability analysis has been performed. Sustainability analysis measures the environmental impact over the life cycle of handle in terms of carbon footprint, air acidification, total energy consumed and water eutrophication. This is followed by the redesign of handle using DFM principles. After redesigning, the environmental impact on handle design has been reduced which lead to the inference that CAD and DFM would act as enablers of sustainable product design.

REFERENCES

[1] Anderson K, Eide M H ,Lundqvist U, Mattsson B. The feasibility of including sustainability in LCA for product development Journal of Cleaner Production 1998; 6:289–298.

[2] AzzoneG,Noci G. Measuring the environmental performance of new products: an integrated approach. International Journal on Production Research 1996; 34(11):3055-3078.

[3] Benedetto L D, Klemes J. The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process. Journal of Cleaner Production 2009; 17:900–906.

[4] Bevilacqua M, Ciarapica FE, Giacchetta G. Development of a sustainable product lifecycle in manufacturing firms: a case study. Int. J. of Prod. Res. 2007; 45(18–19): 4073–4098.

[5] BrentAC,Labuschagne C. Sustainable Life Cycle Management: Indicators to assess the sustainability of engineering projects and technologies.International Engineering Management Conference 2004.

[6] Bovea MD, Wang B.Redesign methodology for developing environmentally conscious products. International Journal on Production Research 2007; 45(18-19):4057-4072.

[7] Chen K, Wang J. The data mining technology based on CIMS and its application on automotive remanufacturing. Workshop on Knowledge Discovery and Data Mining 2008.

[8] Daniel C R, Hesamedin O A G. Comparing LCA results out of competing products: developing reference ranges from a product family approach. Journal of Cleaner Production 2009; 1–10.

[9] Gungor A, Gupta SM. Issues in environmentally conscious manufacturing and product recovery: a survey. Computers and Industrial Engineering 1999; 36:811-853.

[10] Hanssen O J. Sustainable product systems—experiences based on case projects in sustainable product development. Journal of Cleaner Production 1999; 7(1): 27-41.

[11] Hugo A N, Pistikopoulos E N. Environmentally conscious long-range planning and design of supply chain networks. Journal of Cleaner Production 2005; 13(15);Pages 1471-1489.

[12] Ijomah W L. Development of robust design-for-remanufacturing guidelines to further the aims of sustainable development.Int. J. of Prod. Res. 2007;45(18-19): 4513-4536.

[13] Kaebernick H, Kara S, Sun M. Sustainable product development and manufacturing by considering environmental requirements. Robotics and Computer Integrated Manufacturing 2003;19:461-468.

[14] Krozer J, Vis J C. How to get LCA in the right direction?'Journal of Cleaner Production 6 1998; 53- 61.

[15] Kumazawa T, Kobayashi H. Feasibility study on sustainable manufacturing system. Proceedings of Ecodesign 2003: Third International Symposium on Environmentally Conscious Design and Inverse Manufacturing Tokyo, Japan 2003.

[16] Lisa M, Ellram W T, Craig R C. Applying 3DCE to environmentally responsible manufacturing practices. Journal of Cleaner Production 2008; 16(15):1620-1631.

[17] Nagel M H, Tomiyama T. Intelligent Sustainable Manufacturing Systems, Management of the Linkage between Sustainability and Intelligence, an Overview.IEEEInternational Conference on Systems, Man and Cybernetics 2004;4183-4188

[18] Nes N V, Cramer J. Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. Journal of Cleaner Production 2006; 14(15-16):1307-1318.

[19] Michelini R C, Razzoli R P. Product-service eco-design: Knowledge-based infrastructures. Journal of Cleaner Production 2004; 12(4): 415-428.

[20] Robèrt K H, Schmidt-Bleek J, Larderel A, Basile G, Jansen J L., Kuehr R, Thomas P, Suzuki M, Hawken P, Wackernagel M. Strategic sustainable development — selection, design and synergies of applied tools. Journal of Cleaner Production 2002; 10(3): 197-214.

[21] Rusinko C A. Green Manufacturing: An Evaluation of Environmentally Sustainable Manufacturing Practices and Their Impact on Competitive Outcomes. IEEE Transactions on Engineering Management 2007; 54(3): 445-454.

[22] Sadiq R, Khan F I. An integrated approach for risk-based life cycle assessment and multi-criteria decision-making Selection, design and evaluation of cleaner and greener processes. Business Process Management Journal 2006;12(6):770-792.

[23] Senthilkumaran D, Ong S K, Tan B H,Nee AYC. Environmental life cycle cost analysis of products. Environmental Management and Health 2001; 12(3):260-276.

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