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MASS OPTIMIZATION USING GENERATIVE DESIGN FOR REAR ACCESSORY ASSEMBLY IN A TWO-WHEELER

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Abstract**—** Two wheelers play a major role in transportation in South Asian countries like India. Complexity reduction and weight optimization help the designers and manufacturers achieve the functionalities of an assembly at a lower cost. Generative design followed by additive manufacturing provides a greater opportunity for such an advantageous task. This research article is mainly focussed on the complexity reduction of the rear accessory assembly using generative design followed by additive manufacturing. Better strength, lighter weight, reduced complexity and attractive aesthetic finish are primary focuses of our research. This reduces the time for assembly in a production line in an automobile industry. Generative design helps in optimizing the design by making it simple, aesthetic and functional with same material and structural properties. This research article is also focussed on mass reduction when generative design is used to design an assembly instead of a conventional CAD design.

Index Terms**—** Two-wheeler assembly, rear accessory assembly, generative design, additive manufacturing, reducing complexity, mass optimization, better aesthetics.

1. INTRODUCTION

The field of design and development in engineering is expanding every day and promises to be more efficient in both technological and economic aspects compared to the conventional design methods present during earlier times [1,2]. The conventional design and manufacturing methods involved the manual physical indenture of 2D sketches and model [1,2]. The need for more aesthetic and optimized product design lead to the rise of modern design and manufacture techniques including CAD modelling, topology optimization, etc., [1-3].

A. TOPOLOGY OPTIMIZATION

The emergence of technologies like topology optimization improved the design field and enabled the designers to improvise and optimize their designs. Topology optimization is an advanced structural design method to design products meeting the required load conditions [1-3]. There are several topology optimization methods including the density-based method, the evolutionary structural optimization (ESO), the level set method (LSM), etc... [1,2]. In density method, a continuous optimization problem is developed from a 0-1 discrete optimization problem in order to relax the binary design form [1-3]. LSM adopts high-dimensional level set functions to describe structural boundary [1-3]. Topology optimization followed by additive manufacturing is one of the feasible methods to achieve rapid optimization of the design [1,2]. In topology optimization for additive manufacturing, the integration of material, structure, process and performance is important to pursue high-performance, multi-functional and lightweight production [1].

Topologically optimized structures are generally characterized with complex geometric configuration and therefore it is difficult to manufacture these innovate structures via conventional processes [1-5]. Additional treatments are often necessary to improve manufacturability which hardly realizes the full potential of topology optimization [1-4]. Although these technologies prove to be effective in design, there were some drawbacks in the early stages like some of the results of certain designs obtained from topology optimization were impractical to manufacture using conventional manufacturing methods [1,2]. Those impractical design results were made possible to manufacture using additive manufacturing like 3D printing, rapid prototyping, etc., [1,2]. The numerical schemes of topology optimization followed by additive manufacturing needs more contents to be developed for its optimized performance [1-5]. The field of design and manufacturing became even more effective after the development of generative design and other similar technologies [1-7].

B. DEVELOPMENT OF CLOUD BASED CAD

Today's design arena is supported by CAD software that allow designers to design according to their needs [8]. CAD is a key factor in product life cycle management since 1960s [8-10]. CAD modelling allows innovative and exploratory design options for the designers to get more than one design for their desired product [8,9]. These technologies offered more features for the designers to design and optimize the product for efficient performance [8,9]. The combination of scientific, industrial and social activities on a controlled hierarchy is the concept of mechanical design [8,9]. Cloud based CAD ensures convenient, on-demand network access to a shared pool of configurable computing resources [8,9]. This allows the designers to design a product realization model and share the resources and knowledge and manufacture with reduced cost through social networking and negotiation platforms between service providers and consumers [8-10]. Cloud based design and manufacturing is a networking model which combines cloud source design and manufacturing [8,9].

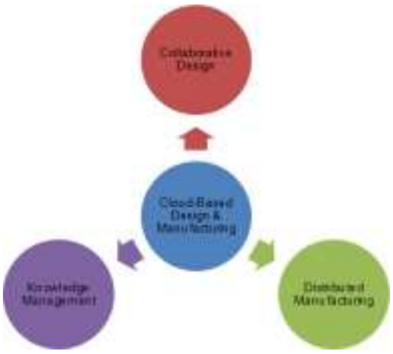

Fig.1. Research opportunities related to CBDM [4]

C. ARTIFICIAL INTELLIGENCE IN CAD MODELLING

Traditional CAD tools doesn't contain feasible conditions to design and analyse a product quickly and optimize the design [12]. Machine learning techniques like artificial neural networks in analysis of CAD model dataset helps the designer to predict the design output and minimise the errors during the design process [12]. Artificial intelligence enables the designer to optimize the design to its maximum efficiency by performing a greater number of iterations and thereby improving its performance characteristics [12,13]. Compared to normal data, the augmented data containing the details of previous designs gives more accuracy by major decrease in errors and in feed forward neural networks [12,13]. This feature allows the designer to work freely and also enables the designer to explore more practically possible design options and achieve greater possibilities of CAD modelling with high accuracy [12].

2. GENERATIVE DESIGN

Manufacturing industry is growing from time to time and the introduction of newer design and manufacturing methods have made the designers and manufacturers optimize the products for their highest performance [14-16]. Artificial intelligence based generative design is making a major change in design and manufacturing [14]. The idea of giving load and constraints for a setup and generating the design according to those conditions is actually the generative design technology [14]. This involves the designers setting up the loads and constraints, specifying the manufacturing method and generating the design with the required material conditions and properties [14,15]. Generative design is implemented parametrically through creating algorithms [14-18]. This technology is more effective as it allows the designer to vary the inputs and constraints parametrically and assess the output design's performance [14]. Artificial intelligence plays a major role in the development of generative design that allows designers to design according to the needs [14-18].

It is artificial intelligence that provides a design when the designer enters basic forms and variables together [14]. Generative design provides the designers faster and optimized results compared to other advanced design processes [16-19]. In generative design, first the designer sets up the conceptual design, then, the conceptual design is converted into basic designs and the designer selects the appropriate design from the provided basic designs [17]. The artificial intelligence then comes up with appropriate material and manufacturing method for the optimized product to be manufactured [17-21].

The designer then confirms the design, material and the manufacturing process and then artificial intelligence performs the successive iterations to give out the optimized product [17-19]. A major difference between topology optimization and generative design is that the latter uses algorithms based on the framework to redefine the area and the material remaining after the optimization calculation for remaining tasks [18].

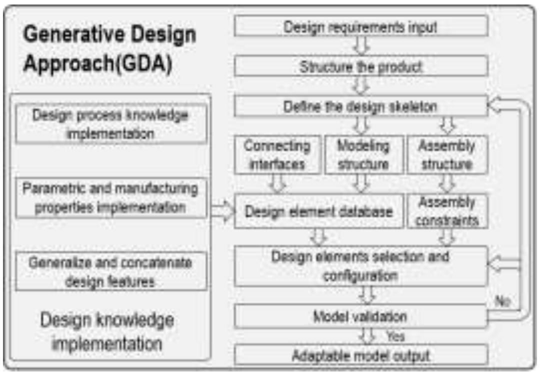

Fig. 2. Framework of GDA [19]

Generative design using Autodesk's Fusion 360 produces lighter and stronger product after performing the required number of iterations taking into account of all the loads and constraints set up by the designer [14-21]. Generative design also helps the designers to design various assemblies, reducing their complexity and improving their functional facilities and optimizing the design to its fullest [14-21].

At the design level, usually, large assemblies are difficult to visualise, as part selection for editing and information extracting requires a lot of navigation tools manipulations [14-22]. For achieving optimized assemblies, where the appearance, structure, architecture of the design is to be maintained, optimization techniques are applied, to minimize the weight, maximize the strength, minimize the overall cost of the particular subassembly, etc., [20-26]. In generative design, the preserve geometry should keep the interfaces with the machine and with the active parts [14-22]. The next step involved in generative design is defining the objectives and manufacturing conditions for the new design [14-22]. The refinement of the mesh affects the topology and coarse mesh is less time consuming, but produces coarse surface finishes while smooth mesh is more time consuming, but produces a smooth surface and better optimized results [14-22]. Parallel computing using cloud-based CAD technologies plays a major role in generative design of assemblies [14-22].

3. GENERATIVE DESIGN – OPTIMIZATION APPROACH

A. MATERIALS FOR AUTOMOBILE APPLICATIONS

Material selection in the automobile industry is a skilful balance between cost and recyclability [23]. Lightweight materials play a major role in the automotive industry [23]. Lightweight, and great design flexibility, compared with metals, plastic parts can save about 20–30% of weight under the same strength of them [23]. Optimization of the plastic materials and the subsequent design changes improve the performance characteristics of an automobile greatly, and also ensures reduced cost, improved aesthetics, etc., [23].

Material	Tensile strength (MPa)	Density (g/cm^3)	Recyclability
ABS plastic	29.6	1.040	Type 7
CFRP	577	1.430	Not classified
PVC	11	1.3	Type 3
Polystyrene	44.800	1.021	Type 6

Table.1. Material properties

B. ADDITIVE MANUFACTURING AND 3D PRINTING

Additive manufacturing technologies enables optimized production of moderate to large quantities of products along with the option of individual customisation [23]. Additive manufacturing is the solution to the problems faced using traditional manufacturing processes, which enables the flexible production of customized products without significant impact on costs and lead time and fabricating complex lightweight structures which at the same time possess good rigidity [23,24]. Additive manufacturing is generally the process of depositing successive thin layers of material upon each other, producing a final three-dimensional product and the thickness of each layer varies from 0.002 to 0.1 inches (Wohler's' Associates Inc., 2013) [23,24]. 3D printers have been optimised and printing capabilities have been improved at a comparatively lower cost than that of the earlier 3D printers [23,24]. Additive manufacturing process includes CAD modelling, STL conversion and file manipulation, printing, removal of prints and post-processing the manufactured product [23,24].

In the automobile industry, additive manufacturing allows the designers and manufacturers to design and manufacture light-weight optimized components with better functional characteristics [23]. In the global automobile market, additive manufacturing turns out to be the product innovation and supply chain transformation driver, improving the automobile industry performance worldwide [23-26]. Additive manufacturing can be futuristically applied to manufacture interior and seating, wheels and suspension, framework and doors, some of the engine components and some exterior parts [23-26]. Automotive additive manufacturing is mostly carried out using polymers, resins and even some metals [23]. It provides the manufacturers with various advantages like quicker production, cost effectiveness, increased data security, efficient product testing, etc., [23-26]. Though it offers more advantages, the growing technology also possesses some drawbacks like the production velocity, tedious distinctive material production at the same time, etc., [23-26].

4. GENERATIVE DESIGN APPROACH AND ITERATIONS

In this research paper, an experiment has been performed applying the generative design technique on the rear accessory assembly of a two-wheeler. First, reverse engineering technique was used to design the rear accessory assembly. The rear accessory assembly was designed by incorporating the image of a two-wheeler model into Autodesk Fusion 360.

The main objective of this research paper is to use generative design to reduce the complexity of an assembly without compromising its functional requirements. The research paper is also aimed at reducing the mass of an assembly while maintaining its strength and other properties. During this generative design of rear accessory assembly, the aesthetic aspect of the assembly was also taken into account.

Fig.3. Rear accessory assembly of a two-wheeler modelled in Fusion 360

Dimensions of the rear accessory assembly: 220 × 152.6 × 325.96 mm
Mass of the assembly: 550 g
Material used: Acrylonitrile butadiene styrene (ABS plastic)

The pre-steps that were considered during the design of the assembly are the seat mounting (rear), side reflector mounting (rear), rear indicator light mountings and number plate mounting (as per government standards). ABS plastic was selected as the material for designing the rear accessory assembly due to its tensile strength, recyclability, density, etc., as discussed earlier in Table – 1. This was the first phase of research experiment.

The second phase of the experiment was applying the generative design technique to the designed rear accessory assembly.

Since there are no appropriate forces acting on the rear accessory assembly other than its self-weight in its static condition, it is safe to take into account of some reasonable amount of load alone during setting up the constraints in the generative design experiment.

The constraints were setup in the generative design workspace and ABS plastic was selected to be the material to design the assembly, the manufacturing method was set to additive manufacturing. Additive manufacturing was selected due to its various advantages as discussed above.

5. RESULTS AND DISCUSSION

Fig.3. represents the iteration results of nearly 48 iterations performed during the generative design of the rear accessory assembly

Fig.4. Iteration results during generative design

From the results obtained above, it is clearly evident as the number of iterations increases, the amount of material required by the assembly to withstand the specified load under the specified constraints decreases and the same material properties are retained as that of the original design.

After nearly 48 iterations, an optimized design of the assembly was obtained. After this convergence, the model was redesigned for rear indicators and rear reflectors in the Fusion 360 workspace as shown below in the figure 4. Hybrid designing is followed for adding rear handle and the light mounts to combine various features, thus reducing the component assembly process.

Fig. 5. Converged rear accessory assembly with rear handle, rear indicator and rear side reflector mounts

As mentioned above, the main objective of this research paper is to reduce the complexity of the assembly and mass while maintaining the functional properties and the aesthetic aspects of the assembly. With that being stated, the rear accessory assembly that included the rear handle, tail light mount, indicator mount and number plate mount was designed through generative design to yield as a single most component that combined those aforementioned sections. This may increase the complexity of the final design but when the manufacturing aspect was visualized in additive manufacturing concept, intricate designs are possible to manufacture. Fused Deposition Modelling (FDM) which is a viable method of additive manufacturing can be employed to manufacture the designed component.

Additionally, when viewed the final outcome in a broad aspect of product development, employing generative designs and additive manufacturing to design such component not only gains advantage in mass reduction and enhanced material usage but also aids in mass customization of components to a consequential extent. With customers preferring personalized design of any product to its standard market design, generative design lends hand in instituting customers to various explored designs. For instance, we have seen that the approach done by us had resulted in 48 iterations with each design varying in its own mass and aesthetic appearance. Customers can choose their desired design from the emerged results or they can collaborate with the designers to customize their products. Hybrid engineering can be employed for enhancing the design model with additional features.

`The graph shown below indicates the convergence of the design (stress and mass comparison) as the number of iterations increases.

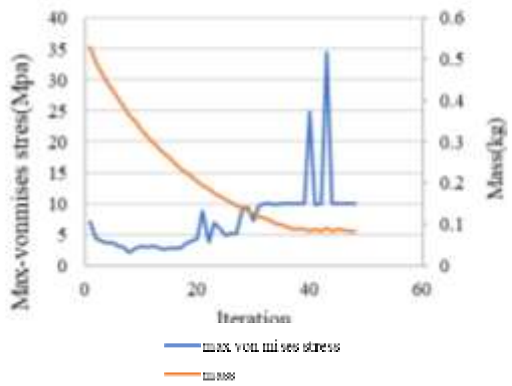

Fig.6. Stress and mass comparison of the iterations in generative design of rear accessory assembly

From the generative design convergence curve, the mass of the rear accessory assembly obtained in 48th iteration designed by generative design using ABS plastic is 0.076 kg.

$$\%\ \text{Mass reduction} = \left(\frac{0.550 - 0.076}{0.550}\right) \times 100 = 86.18\ \%$$

Nearly, 86 % of the mass of the rear accessory assembly has been reduced by generative design of the assembly using the same ABS plastic as the material. The mass of the assembly has been subsequently reduced while maintaining the same functional and structural properties as that of the original design.

From the 48 iterative designs obtained, the design with lower stress (higher strength) and lower mass can be chosen as the design to be manufactured with the required functional and structural parameters.

48th iteration result has been chosen to be the required design in this research paper as it possesses lower mass with a good strength (lower stress) and it meets the required functional and structural (aesthetic) characteristics.

The aesthetic aspect of the assembly has also been established using the generative design technique while reducing the mass and the cost of manufacturing.

6. CONCLUSION

In this research paper, the main aim of reducing the complexity of the assembly is achieved using generative design. The complexity is reduced and an aesthetic design is produced. The mass of the component is also greatly reduced by generative design using the same material ABS plastic. Additive manufacturing will also be helpful in manufacturing designs developed using generative design. Generative design is now playing an important part in the design and manufacturing industry. The optimized designs obtained from generative design is also functionally equivalent to the conventionally designed and manufactured products. The complexity of certain designs and assemblies can be eased and they can be manufactured with same functionality. The concept of mass reduction and aesthetics can also be achieved using generative design. Generative design followed by additive manufacturing is proving to be a promising technology in the design and manufacturing field and will be used for all the fields later on improving the technology to fulfil all the design needs in all fields.

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