New to Power Equipment Design Approaches with Additive Manufacturing prospects

O V Belova and M D Vulf

Bauman Moscow State Technical University (National Research University)
Russia, 105005 Moscow, 2nd Baumanskaya, 5

Abstract. Direct three-dimensional printing is a new manufacturing method that can improve the efficiency of the energy equipment. Additive manufacturing allow reduce the weight of products, to increase the toughness, to improve the shape of parts, reduce the number of components, etc. An example of a new approach to the design is the improvement of heat exchanges for which it is possible to use new materials, increase in the area of heat transfer, make turbulators create items, create heat exchanger as a single part, etc. The actual problem is the improvement of pipeline systems through the reduction of local hydraulic resistance. Additive manufacturing are used for the development of new turbomachinery with complex cooling channels. Moreover, the advantage of additive manufacturing is full integration in PLM digital interface. However, the revolutionary new Design for Additive Manufacturing (DFAM) approach must be developed.

1. Introduction

Nowadays the Additive manufacturing (AM), or 3D-printing has the very different areas of application: medicine, dentistry, jewellery, aerospace and automotive industries, entertainment and cartoons, house building and so on.

These new technologies called revolutionary and locomotive of the new era of industry.

The main advantages of AM are:
- any complex "bionic" shape are;
- "complexity for free" conception is fool applicable;
- joining several materials with a gradual change in properties;
- joining several parts in one;
- the digital Product Lifecycle Management (PLM) approaches is fully incorporated
- CAD-model transferred directly to the 3D-printer with unmanned matter.

Additive Manufacturing changes the approach to the entire Product Life Cycle, creating new opportunities and new challenges for marketers, technologists, materials and supply chain managers.

In [1] the new virtual design-to-product transformation process of the six phases of AM is discussed (Figure 1).

AM are significantly different from the traditional manufacturing. The first reason is the variance in processes and raw materials, and the second is that the composition of the materials and the CAD geometry are being created simultaneously. That is why because in subtractive manufacturing we know the final material properties of a metal billet before milling, and in AM the resultant material properties are not completely known until the part has been formed.
Figure 1. End-to-end digital spectrum in AM [1].

These differences change the entire design-to-product process. It is through this view that we can replace physical implementations of activities with highly accurate digital replicates enables us to develop a virtual design-to-product transformation process. This process has several potential benefits in terms of both utility and quality.

In terms of quality, the inter-disciplinary replicates or simulations allow us to test and optimize all aspects of the build and post process domains significantly improving the quality of the part. This, in turn, will increase utility by reducing production costs, including those associated with finishing and failed builds.

2. "Design For Additive Manufacturing" Conception

The designers face the challenge of developing a new design methodology, since AM allows the use of the concept of “Free Form Complexity”, i.e. the Design Methodology for Additive Manufacturing. The development of such design methods for Additive Manufacturing (Design for Additive Manufacturing - DFAM) is carried out by many researchers [2-7].

Existing DFAM methods for functional improvement are divided into two groups and reviewed respectively [8]. For the first group of design methods which primarily focus on the improvement of parts’ functional performance, topology optimization plays the most important role on all design aspects. For the second general DFAM methods, most low-level research only focuses on part-level design. Only a few successfully design cases are illustrates the advantages of part consolidation and other product-level general design and takes design-for-assembly consideration.

Thus, a general design method for additive manufacturing which can consider both assembly and functionality of designed products is required. These method can provide a broad view to consider both functional performance and other product life-cycle objectives in a systematic framework on both part and product level.
In [9] a global design methodology for any additive manufacturing method, including specific function optimizations, for a mechanical system is proposed and the calculation of the functional improvement rate expound. The methodology can be applied to design a part or a system and consists of 3 stages with 11 steps (Figure 2). Another topological designing method for conceptual structural design, pushing the limit of product performance based on computer simulation and optimization technologies is considered in [10].

Topological optimization is achieved by [11]
- designing geometry,
- minimizing unneeded geometry
- maximizing the load carrying capacity of the part.

The main rule is to add material only where it is needed for a part to perform its function. AM removes all constraints of subtractive manufacturing and can realize complex geometries to fulfill the load carrying requirements of a part.

The proposed in [9] solution is based on an integrated CAD and Computer Aided Engineering (CAE) workflow enabled by Dassault Systemes. As shown in the flow chart in Figure 3, a geometric model is initially prepared in a CAD software (CATIA), and then a finite element model is created and a simulation based topological design process is executed using SIMULIA-Tosca. Further shape optimization can be performed by the optimized smoothed design.

Thus, in [12], a topological optimization of the blade design was carried out using the example of a typical uncooled turbine blade of a low-pressure turbine of a gas turbine engine in order to detach from the resonance frequencies of oscillations and obtain a minimum mass. As a result of optimization, the blade design was obtained with a mass of 30% less than the prototype weight while maintaining the blade profile.

In addition, this technique allows improve the design of the part for traditional manufacturing techniques.

3. Additive Manufacturing for improving the energy equipment efficiency

Heat-power equipment is traditionally referred to as heat exchangers, pumps, compressors, gas storage equipment, ventilation and air conditioning equipment, pipelines and fittings, as well as electrical equipment and electrical grids. Power equipment is used to convert certain types of energy into other types. Consequently, the efficiency increasing power equipment means increasing the efficiency of the energy conversion process. According to Russian Federal State Statistics Service the increasing electricity consumption and other industry energy sources in Russia reflects the low efficiency of resources use and renovation of production process. AM revolutionary technologies make it possible to bring the efficiency of equipment to a new level.

For power machine building AM are interesting because here the objects are subjected to high mechanical and thermal forces. These equipment demands special requirements on the products nature and here all advantages of AM can be applied.

The one of the main advantages of AM for the power engineering industry is the any specific geometry for example for intersection channels.

So, well-known the global engineering company with Additive Manufacturing competences Renishaw plc, UK, is helping to Land Rover BAR America’s Cup project team’s Technical Innovation Group to improve the hydraulic system of catamaran’s boat [13]. Land Rover BAR’s Chief Technology Officer, Andy Cloughton said: “The potential of Additive Manufacturing in terms of saving weight and improving efficiency is tremendous… with Additive Manufacturing you can build it with smooth rounded corners that significantly improves efficiency in the fluid transfers involved” [14]. Renishaw has manufactured several parts for the hydraulic system, resulting in a weight reduction in the new manifold design of 60%, with an increase in performance efficiency of over 20%.

The design team at Land Rover BAR recognized the potential of AM to allow weight savings and improve efficiency on the R1 boat. The aim of Renishaw’s new design was the hydraulics system (Figure 4). For example, hydraulic manifold is used to take fluid from one part of the boat and deliver
Figure 2. Flowchart of the coupled optimization procedure Product lifecycle on design and manufacturing steps [9].

Figure 3. Workflow of topological designing using Dassault Systemes software solutions [10].

it to another part of the boat and it is very important that the component is efficient in delivering the fluid into the correct place. Manifold have multiple fluid passageways, because using AM it can construct these in a way which is most efficient for the function of the component and can give the flow path a nice conformal sweeping bend, increasing its flow efficiency. Thus the manifold components were manufactured using metal AM technology (Figure 5).

4. Additive Manufacturing for heat exchangers design

Topology optimization is a mathematical technique that aims to find an optimum material distribution in a design domain, given a set of constraints and boundary conditions [15]. To formally define a topology optimization problem, the following mathematical entities majority of internal coolant ducts is characterized by internal channels optimized for pressure losses with the presence of turbulators, such as ribs and pin fins, increasing the heat exchange. The shape and the position of these features is
subject of multi-disciplinary optimization studies aiming to increase the heat transfer, minimize the thermal gradients and reduce the stagnation pressure losses.

The higher degree of freedom given by AM allows the production of a new generation of complex and efficient geometries, with an expected strong impact in the coolant system. The natural next question is how to find new suitable geometries, according to all the constraints discussed. The volume-based cost calculation of a part, as opposed to a complexity-based one, motivates designers and engineers to actively and economically explore more complex shapes, working towards an optimal functional design.

Aluminium flow cooler [13] with complex internal channels (Figure 6) effectively demonstrates the unique design capabilities of the AM process. Heat exchangers are designed to dissipate heat, for example the heat generated by electronic and mechanical devices. The surface area highly influences the performance of the heat sink, but typically the available space is rather limited. That means maximizing the surface area within the dimensional boundaries is the key challenge. A metal AM heat sink manufactured in aluminium for an industrial application is shown on Figure 7 [13].

The AM allows make a heat-exchangers ducts with any form and shape, so the designer’s challenge are to create and draw the most effective 3d-model. A few examples are shown on Figure 8.

The next examples of topological optimization of different channels are shown in the Figure 9-14.

For the standard U-bend (Figure 9) a horizontal section is made on the return channel at 3/4 of its height. The positive vertical velocity is present on the left of the section, showing the presence of a recirculation region (Figure 10), whereas for the optimized geometry (Figure 11), the velocity profile is closer to the analytical solution of the flow in a pipe. By comparing the pressure losses gain vs the baseline U-Bend configuration the new geometry shows a 60% improvement.
The multi-objective optimization is performed on another test with thermal exchange between fluid and solidified region. The channel is heated from the outside and no thermal sources are present across the domain. The wall temperature is then kept constant and the colder flow is injected normally at the inlet. The domain used to perform the simulation is a straight duct with back facing step, shown in Figure 12.

The serpentine configuration presents an increased contact surface between fluid and solid region that allows a more efficient heat exchange (Figure 13). A straight duct is also optimized to increase the heat transfer and to minimize the pressure losses (Figure 14).

Figure 8. Conceptual Heat exchangers for AM: a - double-helical coil; b - Helical coil; c - with different channel profiles in one item

Figure 9. Computational domains of the U-bend

Figure 10. Construction of flow benders for different inflow velocities. On the left 6 m/s, on the right 10 m/s

Figure 11. Optimised shape for the U-bend channel for different inflow velocities. On the left 6 m/s, on the right 10 m/s

Figure 12. Schematic of the test cases

Figure 13. Construction of serpentine duct for pressure drop and heat transfer optimization

Figure 14. Optimised shape of the straight duct for pressure drop and heat transfer optimisation
The two last examples are shown the fundamentally new opportunities that are opened in connection with the advent of additive manufacturing technologies, the possibility of free-form design and the application of topological optimization.

5. Summary

Thus, the power engineering industry receives a new impetus, since AM allow the creation of products with increased energy efficiency due to:

- improving fuel efficiency;
- creating new functionality to improve efficiency;
- weight reduction;
- improvement of heat transfer;
- increase of reliability due to reduction of all-in-one and detachable connections;
- increasing the heat resistance of materials;
- using of new materials, for example, ceramics instead of metals or pure copper instead of alloys.

The development of new efficient energy equipment requires the development of new approaches to Design for Additive Manufacturing and new PLM approaches.

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