Ergonomic lightweight design for workers in automotive production

Raphael Geiger, Steve Rommel
Fraunhofer Institute for Manufacturing Engineering and Automation, IPA
Additive Manufacturing Technology offers a unique design flexibility due to its layer based construction approach. This provides a new potential for lightweight construction. Bionic lightweight structures, integrated functionality and topology optimized structures are now possible to be manufactured. The process also offers the possibility for producing personalized products, individually fitted to human physiology.

Ergonomic workplace design can benefit from this technology, through individualized lightweight design, like handling tools for example. Baraldi and Kaminski\(^1\) could show benefits to the worker and the company, resulting in ergonomic workstations in the assembly line. The company benefits by improved productivity, product quality and workers’ quality of live. The workers don’t overstress their body and do better work with higher motivation and less sickness.

Finally the design and production process of an ergonomic lightweight stool for an assembly line is shown. Using topology optimization, a material combination of carbonfiber-reinforced (CFRP) tubes and additive manufactured polyamide parts an individual advice with over 50% weight reduction compared to the previous solution could be achieved.

1. **Additive Manufacturing**

Additive Manufacturing (AM) is a growing manufacturing technology with some advantages over conventional technologies. The expectation is that AM will be established in an industrial scale in the next 3-5 years for a variety of applications. Besides economic advantages for these applications additive manufacturing has also some limiting factors momentarily that need to be improved in the near future to broaden the range for application. These limits are at the moment surface quality, limited size of economic products, limited number of available materials, partially defined quality standards and the output volume per hour. Additive manufactured products have to be able to withstand the use-environment when compared to conventionally manufactured products. This does not mean that its shape, mechanical characteristics, chemical resistance and other material characteristics have to be exactly the same.\(^2\) Therefore the idea of combining additive manufacturing with other technologies to create hybrid products was born. This way the best of theses “worlds” will be utilized to achieve an outstanding result. Some of the first applications have been in the field of ergonomics to support the work force at repetitive processes.

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1 Baraldi, E.C., Kaminski P.C.
2 Rommel, S., Bauernhansl, T.
1.1 Process and Materials

The basic working principle of the additive manufacturing is to produce parts directly from digital data of the 3D-model without using tooling or other aids. Due to this setup it is no longer needed to follow the strict existing design guidelines known from other technologies i.e. injection molding like constant wall thicknesses, no undercuts and no small free formed holes inside. New design advantages like integrated functionality, combined functions to a lower number of parts in the product are possible as well as to mimic biological model structures inside the parts to meet loads and stresses or design the parts more aesthetic.

This is possible due to the fact that the data is separated into layers via the used software, then translated into G-Code for the manufacturing equipment in order to reproduce each of these layers in real material one after another. The part literally grows.

The range of technologies within additive manufacturing varies from binder jetting so extrusion to melting of powder. This range is also present in the materials used. There are the main groups of metal, plastics, and ceramics. The broadest range in material variety is currently offered by the plastics group. Materials come in the form of powder, liquid and hard wire (filament) as well as with properties from hard to soft.

1.2 Potentials ergonomic lightweight design

Due to the nature of the manufacturing technology and the processes within additive manufacturing offers a big potential to improve ergonomics by not only fitting products to the individual using them but also by applying new design possibilities and light-weight optimization in internal structures as well as the combination with semi-products used in the assembled product. Internal structures can be setup in a way to optimize the mass to weight to structural strength ration by applying the right amount of material and structure to the area where needed. These areas can be predicted, even though more advances in simulation software is needed for better prediction, by using simulation software and experiments in combination with real life testing.

2 Ergonomics in production processes

Ergonomics etymological origin is from the Greek words “ergon” – work, and “nomos” – natural law. It divides in cognitive ergonomics, organizational ergonomics and physical ergonomics. This work focusses on physical ergonomics.
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Ergonomics in production processes is a topic in a human working environment. Its aim is better working conditions and to increase productivity and quality. Due to the worker, a lot of different parameters matter, to increase the quality of ergonomics. The load-carrying capacity of a worker, for example, is individual depending to the workers’ sex, age or handicap.

In production processes each workstation needs to be adjusted to the people working there and the specific workload. The more specific the work is, the higher the ergonomic requirements of the workstation. In areas with a high physical workload, such as assembly lines or the building sector, machines like cranes and other tools assist the workers, to relieve their job.

2.1 Individualized ergonomics with additive manufacturing

Individualized ergonomics can offer better working conditions. In consumer products individualized products have a quicker dissemination. The added value through customization offers attractive financial reasons for the company. Individualized consumer products are shoes, cars, foods like cereals and a lot of others.

The same value can be used for individualized ergonomics, fitted to a particular workspace or worker. Additive manufacturing offers a technology, that doesn’t matter about complex structures and the quantity of mass production. It is economical to produce from lot size 1. With scanned body parts of a worker, for example, ergonomic products like tools can perfectly adjusted and produced through additive manufacturing. For wearable tools, the weight of the tool always matters for ergonomic aspects. By using lightweight structures, topology optimized design or lightweight materials those tools can be individual designed lightweight. These aspects predestine additive manufacturing technologies for individual ergonomics.

2.2 Ergonomics of line assembly

Baraldi, E.C. and Kaminski, P.C compared two different production lines with one product. They could show benefits to the worker and the company, resulting on ergonomic workstations in the assembly line. The company benefits by improved productivity, product quality and workers’ quality of live. The workers don’t overstress their body do better work through higher motivation and less sickness.

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3, 4 Baraldi, E.C., Kaminski P.C.
4 Frieling, E., Buch, M., Wieselhuber, J
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The workload in the assembly line is triggered by a recurring stress, by the clock cycle. A sequence of working steps leads to the final product. In automotive production, the first working steps, like sheet-metal working and the painting line are almost fully automated and robotic handled. In the following work steps, the final assembly of the interior for example, more and more workers get involved.

Figure 1: Overhead working inside car

Figure 2: Lifting of working tools

Figure 1 shows a mechanic, using a stool and a handheld unit, working in the car in an overhead position. The tools create a more ergonomic working space, but it can still be improved. The lighter the handheld unit, the less force effects the workers muscles and backbone.

Figure 2 shows the next working step. The worker takes the stool, going to the next car, to assemble the interior roof parts. At this working step weight matters again.

Figure 3: Assembly line, cyclic work load

Especially the cyclic workload of an automotive line assembly with high clock speed needs lightweight, personalized working tools. (figure 3 assembly line)

3 Ergonomic lightweight design

Looking on the previous requirements of an automotive assembly line, ergonomic design for handhold devices leads also to ergonomic benefit through weight reduction. The following steps show the detailed development progress of ergonomic lightweight design.
The use of different techniques, like topology optimization, simulation and multi material design, leads to an ergonomic lightweight solution. The development target is a height-adjustable ergonomic stool for the use in a shift work environment. It needs to be stable, suitable to the workers in the team, lighter and tougher than the former one. It will be produced in small batch series, with competitive production costs.

3.1 Topology optimization

Topology is the mathematical study of shapes and topological spaces. Optimization, in this context means an iterative, numerical process to generate optimized shapes and structures. It is possible to optimize the structure especially for lightweight construction by generating just the required material.

The process starts by defining a design space, according to the size of the prospective part, figure 1. The force applies from topside through the central tube and distributes over the five star tubes. The software is optimizing the material inside the defined design space, regarding boundary conditions like maximum loads, for example, figure 2. Due to that fact, topology optimization should start in the very early phase of the design process.6

Figure 4: Topological design space of a starbase

Figure 5: Result topology optimization

6 Harzheim, L.
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Figure 4 and 5 showing a stools five-star base. In this example the material connects the central tube with the five outer tubes. The shape is optimized to save material and reduce weight.

The generated structure gives an idea about the ideal distribution of Material. With additive manufacturing this design is directly printable in 3D shape. The design of the prototype is a revised model of this structure, with a finer surface and design, figure 6.

![Revised 3D Model star-base, based on topologic optimized structure.](image)

3.2 FEM Analytics

The Design Model is evaluated with FEM analytics. To simulate with realistic values, the different materials and the bonding are built up in the virtual design space (figure 7). The force effect is simulated perpendicular. The force used for simulation results of a male person while dropping at the stool.

Figure 8 shows the stress-strain behavior of the star-base. The figure shows an exaggerated deformation, for better visualization. The highly stressed part is in the radius, connecting the central tube with the outer tubes.
The top part, enclosing the central tube does not take any load at all. This causes on the defined design space from the topology optimization. The FEM analyses more redundant material, which can be saved. The optimized shape with a lower shaft is used in the final stool design (figure 10 material mix).

### 3.3 Hybrid lightweight construction

The final stool combines optimized additive manufactured parts with the carbon fibre reinforced (CFRP) tubes⁷, rubberknobs and the seat pad. The structural components glued together.

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⁷ Henning F., Moeller E.
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The material combination (figure 9a, 9b) of stiff CFRP tubes with selective-lasersintering polyamide parts leads to a robust product. The rubberknobs and the seat offer a comfortable damping behavior, while seating and reduce stress peaks of the complete stool.

3.4 Ergonomic lightweight stool

The final stool design offers an ergonomic lightweight construction for the workers at the assembly line. It can be adapted to the specific needs of the workplace, such as the body size and shape of the team members or the texture of the ground.

![Ergonomic lightweight stool](image)

Figure 10: Final design ergonomic lightweight stool

It is introduced in the production line.

4 Conclusion

The ergonomic lightweight stool could reduce the weight to the compared previous model by more than 50% and is introduced in the production line.

Ergonomically improved workplaces reduce production errors and thus contribute to a better quality product, reduced reject rates and a more profitable production. Improved working conditions, considering the background of demographic change, become even more important in the future.

Additive manufacturing processes allow individualization in the field of workplace ergonomics. Specially adapted workplaces for individuals or groups are easy to realize. By manufacturing without mold production costs for individual solutions and small series are low.
Bibliography


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