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COMPONENTS OPTIMISATION FOR FDM TECHNOLOGY (REQUIREMENTS AND OPTIONS)

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Abstract: This article presents the requirements for the redesign of spare parts made with additive manufacturing and the possibilities of their simplification. Through a few examples, it examines in detail the steps taken to meet the requirements and the utilisation of the potential possibilities in 3D printing.

Keywords: *FDM printing, machine element reconstruction*

1. INTRODUCTION

Nowadays, the widely available additive manufacturing technologies have opened new perspectives on the solution of replacing defective parts. Just as we have new options for recreating a 3D model of a defective component, their production can be much faster and easier.

The first step is the reconstruction of the given component, which has been one of the most basic engineering tasks. The essence of this creative activity is to determine the original geometry of a physical object, but in most cases worn (scraped, broken, damaged) part. An important step of the process is to create the technical drawing of the selected part with the size, tolerance and raw material information required for remanufacturing, if the production documentation is not available.

With modern additive manufacturing technologies, the projection representation step can be omitted from the reconstruction process. But even in the case of implementation with 3D printing, for example, the optimal geometry that can be created by the given technology and the maximum strength achievable must be strived for.

2. NECESSITY OF THE RECONSTRUCTION

The reconstruction of parts may be necessary in several cases. Such reasons may include the following (Dömötör, 2023).

- No spare parts and product support.
- Want to reduce downtime due to the long procurement time of the defective part (Sarka & Almási, 2024).
- Need for economical repair in the case of too expensive factory parts.

In each of the cases listed, it is essential to determine a geometry with precision that takes into account the aspects of mounting and operation (Szente & Bihari, 2011).

3. The task of reconstruction

Knowledge of the original geometry and the determination of the expected stress state due to normal operation, occasional overload or environmental effects are essential during the design, modification and if necessary, optimisation supported by FEM simulation of the CAD model of the spare part to be manufactured. Depending on the degree of damage, geometry can be determined with traditional measuring devices, with 3D coordinate measuring machines, with contact-based or contactless optical surface digitising devices. Another alternative solution may be the use of digital 2D imaging tools (Dömötör, 2023) (Sarka & Tóbis, 2017).

The geometry created using a 2D profile or generated by 3D scanning may require more post-processing. Some of these are simply to fix scanning errors. However, this article examines what further redesign geometry requires and enables due to the basic properties of the additive technology used for production. It is important to emphasize that both the repair and revision of the 3D model, as well as its real redesign, require comprehensive construction knowledge and design experience.

4. Redesign

So, once we have the original part geometry, we have the opportunity to develop it before production. Either by carrying out tests with the help of FEM or just examining the expected loads or the failure that has occurred further-more the space available for the component in the product, we can strengthen the cross-sections that are critical to the breakdown – mostly by adding material (Dömötör, 2023). In some cases, efficiency improvements or new functionality may even be developed.

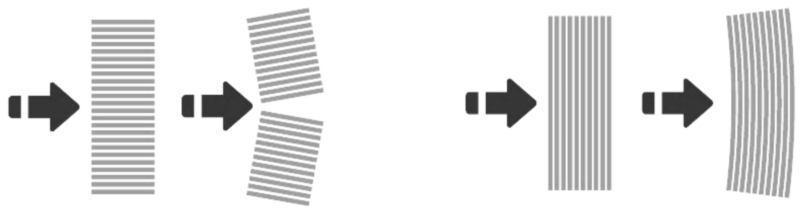
4.1. Requirements

During the redesign, as a result of the change in the material and the forming process, the first approximation must focus on the compliance with the requirements and boundary conditions arising from them.

Layer orientation

The research has shown that the direction of the structure of the parts, i.e. the plane along which the printing layers follow each other, has a relevant effect on the mechanical properties of the finished product (Kónya & Ficzere, 2023).

It is easy to see that in a technology where the unwanted separation of layers is a real problem, the loading directions resulting in their mechanical separation should be avoided. In the case of a product made up of layers, care must be taken to ensure that, for example, bending can be formed perpendicular to the layers.



a) b)

Figure 1. *The effect of the bending force in the direction of layers (a) and perpendicular to layers (b) on the printed specimen*
https://formero.com.au/blog/how-part-orientation-affects-a-3d-print/

Thread orientation and fill

In the same way, the thread orientation and the density of internal fill are parameters that we must choose consciously. For example, according to the results of a series of measurements carried out at the Department of Materials Technology of GAMF, a 45° fibre orientation resulted in test specimens with higher percussion-bending strength, higher tensile strength and higher elongation at rupture in all measured cases (Ádám & Polgár, 2019).

Surface roughness

Surface anisotropy is also a characteristic of products created by additive processes. This means that the surface roughness is direction-dependent, which must be taken into account when choosing the direction of stratification in the case of parts that are in contact with each other, but even more so in the case of parts that operate with relative displacement to each other (Ficzere, 2024).

Selection of materials

The choice of raw material for FDM printing is also a decisive factor if the goal is to make a product with a relatively long lifespan. The most commonly used raw materials are ABS, ASA and PLA (Marada & Bihari, 2022) and their additive versions. Of these, PLA, known for its easy (lower temperature) printability, is perhaps the most popular. Of course, accordingly, its heat tolerance is also lower than usual, limited to a maximum of 60 °C. This must be kept in mind when printing finished products that may be exposed to higher temperatures at their installation site or during operation, which can be triggered by strong sunshine in everyday conditions. CPLA (crystalline PLA), a material designed for products with higher heat requirements, can be a solution. The heat resistance of the printed parts from CPLA is up to 80 °C.

If you expect more stress, TPLA (tough PLA) with increased mechanical performance is a good choice. The name TPLA refers to talc-doped PLA, where talc is a natural mineral that helps PLA form a harder material. Thus, while maintaining easy printability, we can obtain increased impact resistance, but only with the lower heat resistance characteristic of PLA.

Component-specific development

In addition to the general principles, specific components must also be examined in a targeted manner, e.g. Is it necessary / Is it possible / Is it justified:

- … to increase the wall thickness?
- … to replace the certain load-bearing parts? (e.g.: with a metal shaft)
- … to create holes suitable for accommodating stiffening inserts within the load-bearing parts?
- … to design additional connecting elements that improve rigidity between the functional parts?
- ... to minimize the support created during printing by designing supports that remain in its place?

4.2. Options

In addition to the boundary conditions arising from the material and technology, further redesign of the models of printable products is also possible, but these can no longer be formulated as a requirement, but rather as an opportunity.

Simplification

The original manufacturing technology of the defective part to be replaced may result in features that can be left or simplified in the case of the new technology. All this can only be done if these parts do not carry a function of use and do not participate in load bearing. For example, the omission of conicity and lateral bevelling, which is necessary in the manufacture of injection-moulded plastic parts to facilitate the opening of the tools and the ejection of the finished product but becomes unjustified in the case of products created with an additive process.

Custom manufacturing and manual assembly

Also, due to the change in the original forming and assembly processes, we have the opportunity to merge parts that have been dismantled due to automatic assembly, or to omit or simplify the forming elements that help mechanical gripping and automatic orientation.

New features

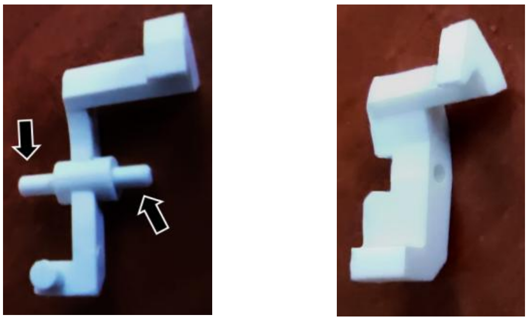
New technology and material not only play a role in reducing the production time or cost of spare parts but can also create opportunities for new functions. For example, you can take advantage of the directional behaviour of additive manufacturing products against loads.

5. Illustrative examples

It is worth examining the application of the principles discussed in the previous paragraphs through some illustrative examples. In each case, the presented parts were made to replace a damaged original product, and thus their reproduction was a real reconstruction design task.

5.1. Switch Lever

Figure 2 shows a component with a small footprint, which is the switch arm of a mechanical time-controlled switch. In the case of this element, the original geometry has undergone several necessary modifications, which are always justified by the chosen technology.



a) *b)*

Figure 2. *(a) Original and (b) redesigned switch arm*

In order to best withstand the bending stress, the broken small cross-section arm has been given maximum thickness taking into account the available space, installation position and the range of motion of the component. Another change is that the rotation shaft ends of the original injection moulded part made of the same material, marked with arrows in Figure 2.a, have been replaced by a hole of the same diameter, into which a steel shaft can later be inserted. This increases the life expectancy of the machine element (Figure 3).

In the case of a spare part produced in this way, it is evident, but it is important to emphasize that it is advisable to print in a horizontal state, taking into account the expected loads.

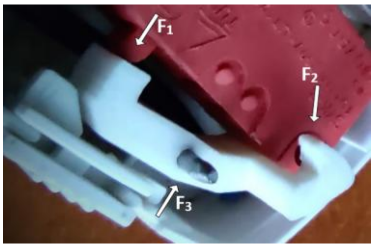


Figure 3. *Printed arm with metal shaft*

Of course, because of the creeping of plastics it must be considered a kind of loss of function that the 3D printed spare part cannot be operated reliably and with a long service life in an environment hotter than ~40-50 °C due to the lower temperature resistance characteristic of TPLA, which is the raw material. During its operation, it is subjected to continuous bending stress due to the spring force (F1) of the electrical switch controlled by it, which can also be seen on the left side of Figure 3, due to the switching force (F2) transmitted at the glide head on the other side of the component and the support force (F3) at the axle running through the middle. As an experience, it can be said that the workpiece manufactured this way did not fail within 4 years from the date of installation and continuously works properly.

5.2. Model car part

A great example of the creation of new functions is the part shown in Figure 4, which is a closed, flanged sleeve at one end that serves to clamp the front swingarm axle of a radio remote-controlled model car. Due to the variability of the chassis geometry, its design is not rotationally symmetrical, but slightly flattened, and the circular cross-section cavity formed in it is not located in the middle (Figure 4.a).

a) b) c)

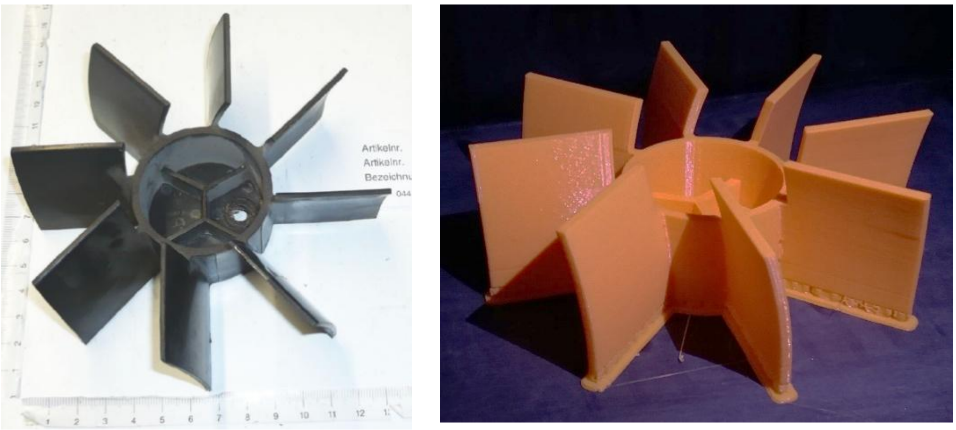
Figure 4. *a) CAD model of axis positioning sleeve*
b) Multiple printed spare parts c) Built-in condition in the model car

User experience shows when it manufactured with a layer perpendicular to the axis of the hole, this simple part can also get a new function. In normal operation, it has a long service life similar to the original part, but in the event of a collision, it acts as a breaking element, as it can prevent deformation or breakage of other expensive parts (e.g. the rotating shaft or the swing arm) by snapping more easily along the layers.

5.3. Cooling fan

The next machine element examined is a cooling fan of a compressor, which is also exposed to more intense heat load during operation. However, in the case of this component, you do not have to count with static forces, but with low-frequency vibrations. At the same time, due to the high speed, a centrifugal force occurs, which is considered to be a fictitious force of inertia directed radially outwards. In the case of poorly chosen stratification, this centrifugal force, together with the vibration, can cause the fan blades to break off and ruin the bearings of the shaft. However, as shown in Figure 5.b, if the part is built from planes perpendicular to its axis, these effects no longer cause problems.

To achieve a long service life of the component, it is worth increasing the wall thickness in several places. Thus, the CAD model, designed as a starting point following the original geometry, underwent several modifications, three of them are shown in Figure 6.



a) *b)*

Figure 5. *a) Original Einhell spare part*
b) Finished part in the printing workspace
https://www.einhell-service.com/en_DE/402050502044.html

a) *b)* *c)*

Figure 6. *Reinforced parts of the fan a) Fan base plane reinforcement*
b) Widened stiffening ribs c) Thickened blades

The base plane perpendicular to the axis of rotation (Figure 6.a) is the most important connecting surface of the part, because it lies on the eccentric shaft end of the motor, which is the part of the 3D exploded view shown in Figure 7 marked with number 48.

Figure 8.a clearly shows that the compressor fan is a part fitting to the end of the eccentric shaft of the crank mechanism. During the reconstruction measurements, it was essential to determine the most accurate hole position possible in order to ensure impact-free running. The eccentricity was 12.8 mm, which is the distance between the central axis of rotation and the axis of the hole on the part.

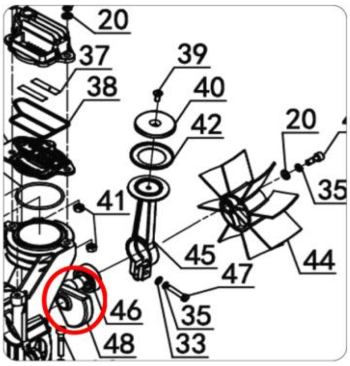
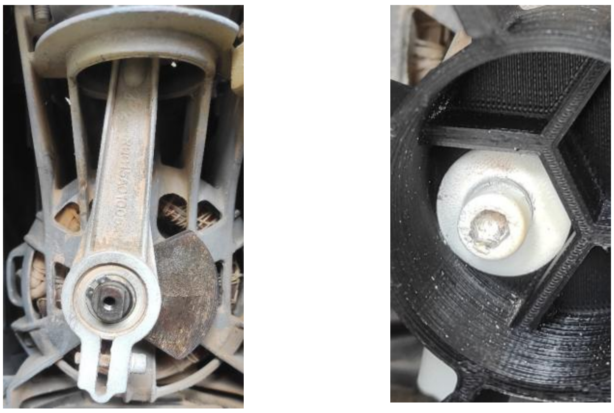


Figure 7. *Detail of the exploded figure*
https://www.isc-gmbh.info/nl_NL/4020516-th-ac-200-40-of.html



a) *b)*
Figure 8. *a) Crank mechanism with eccentric shaft end*
b) Metal washer supporting stable fastening

With greater stability and better thermal tolerance in mind, the flat surface has been increased from 1.2 mm to 1.7 mm. In addition, in order to reduce the surface pressure, a large metal washer was placed under the screw with an internal key opening that attaches to the shaft end (Figure 8.b).

In order to hold the impeller in place with a larger washer, the trail of the ribs used to strengthen the hub underwent a minor modification. While maintaining the 100% infill ratio, the wall thickness has also been increased in the case of the ribbed mesh on both sides of the face-up surface, which is illustrated by the parts highlighted in darker colour in Figure 6.b.

In addition to these obvious and necessary changes, another important modification was made to the component, which meant that the thickness of the blades was increased (Figure 6.c). With this change, a search for an optimum was already part of the process. Thicker blades not only have a beneficial effect on the impeller but also cause an increase in centripetal acceleration during operation due to the increase in mass from the built material further away from the axis of rotation. In addition, too thick blades would also be a disadvantage from a fluid dynamics point of view.

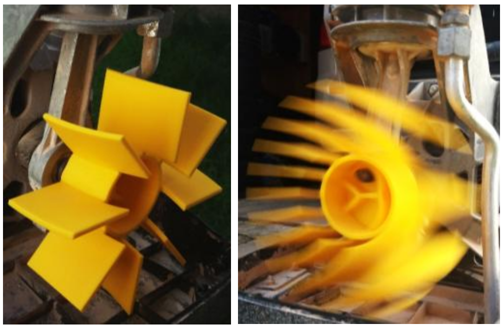


Figure 9. *Impeller in installed position*

During operation, the stiffening of the blades with a flange was also suggested as a further development proposal, which is illustrated in Figure 10. This is a circumferential flange that is suitable for increasing the service life due to its stiffening effect but does not block the path of air flowing out in the radial direction towards the cylinder compartment. The row of blades is connected only at one of the outer corners at the bottom of the printing, so that the basic requirement of the printing support is minimised. As a result of the changes made to the model, the product has been operating without problems for years with periodic use. (Figure 9)

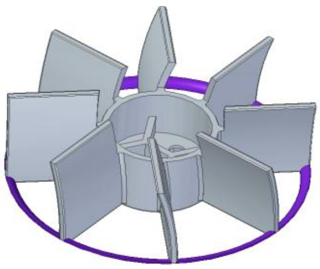


Figure 10. *Stiffening blades with flanges*

6. SUMMARY

Additive manufacturing technologies have opened new horizons in the field of spare parts production. However, original part geometries often require redesign. The reason for this is that both the material and the forming process change at the same time. Based on these, general principles can also be formulated. But in most cases, special changes are necessary and possible, considering the geometry, load condition, functions and operation of the individual part.

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