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Concept Development for CAD Model Adaptation to a Change from Injection Molding to Additive Manufacturing

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Abstract. The continuous spread of additive manufacturing also raises the question of what procedure to recommend when changing the manufacturing method of already constructed parts from injection molding to additive manufacturing. To answer this question, the differences between the two manufacturing processes and the respective end products are first presented. Based on this presentation, a concept for the adaptation of the CAD models affected by the changeover is developed. The goal is a procedural change that is as complication-free as possible. At the end, the finished concept will be reviewed in terms of its utility and its applicability to a specific example. In addition, a boundary between the CAD model adaptation and a new design of the components is drawn in the sense of a stress-related design.

Keywords. Additive Manufacturing, Injection Molding, Computer Aided Design

Introduction

Additive manufacturing processes – also known as 3D printing – are enjoying increasingly popularity during the last few years. Due to the versatile new possibilities in part design and the ever-improving technical properties of additively manufactured components, a strong increase in the market volume of additive manufacturing processes has been recorded, especially in the last ten years [1]. One reason for the rising demand for additive-manufactured components are the falling unit costs [2][3].

It can be observed that additive manufacturing processes are no longer used only for the production of design patterns and prototypes, but increasingly also for functional components and end products [4]. In this area, they are developing into a serious alternative to conventional methods such as injection molding [5].

In case of a change from injection molding to additive manufacturing, the question arises as to whether and which changes to the CAD models of the affected plastic components must be made in order to ensure manufacturability in the new process without a necessary redesign [6]. In particular, this process should be stable and robust to be implemented with any CAD data from various sources in the data exchange service center www.OpenDESC.com [7].

To answer this question, a concept is necessary [8] which describes necessary adjustments and also specifies a procedural method to facilitate the decision making [9].

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1. Background

In recent decades, numerous additive manufacturing processes have been developed that differ greatly both in the process and in their end products. Accordingly, not all of these methods are suitable as an alternative to injection molding.

A comparison of the different processes showed that the end products of two processes are comparable in their technical properties to injection molded parts: Selective laser sintering (SLS) and HP Multi Jet Fusion (MJF). These processes are so-called powder bed processes in which the material is provided in powdered form and individual powder particles are purposefully fused together by the action of temperature [10]. In powder bed processes, the component geometry is introduced into existing powder layers, with the complete construction platform being coated with powder. Because of its suitability as a replacement process for injection molding, the whole developed concept is limited to only these two processes.

In order to demonstrate the differences between additive manufacturing processes and injection molding, it is necessary to document and compare the process-related restrictions. These are subdivided into general aspects to be considered in both procedures and respective process-specific aspects:

- General aspects: component size, component distortion, surface quality and voids as well as sink marks.
- Aspects of injection molding: demolding, mold filling and gate positioning.
- Aspects of additive manufacturing: component alignment and powder removal.

In addition, the material properties of the processed plastics are compared with each other. This comparison is divided into topics such as mechanical properties, temperature properties, resistance to media attack, optical properties and other characteristics. The resulting differences between the processes and the manufactured components form the basis for the choice of materials as well as the model adaptation proposals in the developed concept.

2. Our Concept

The concept for CAD model adaptation in context of a change from injection molding to additive manufacturing consists of a catalog of the typical design elements of plastic components. For each design element it is described which limits exist in an additive manufacturing, what needs are to be considered separately and which adaptations have to be made for an additive manufacturing.

The conceptual approach can be divided into five steps and is shown in Figure 1.

Figure 1. Conceptual approach.

In the first step, a suitable substitute material for the additive manufacturing of the component is selected. This is done in compliance with the material properties described above. Afterwards, the CAD model of the component is analyzed and a list of the present design elements cataloged in the concept is created.

Besides, the component alignment in the additive manufacturing machine is determined based on the procedural constraints described above.

In the next step, all captured design elements are looked up in the concept catalog and the necessary adjustments are recorded in an adjustment plan. Afterwards, the CAD model adaptation is carried out according to the previously created adaptation plan. Finally, after the successful model adjustments, the component's suitability for additive manufacturing is validated.

3. Use Case

In order to describe the conceptual procedure more detailed, it is exemplified by an Application to an injection molded part.

For this purpose, an injection molded V-belt pulley made of PA 12, which resembles a representation in source [11], is optimized for a change to additive manufacturing.

The pulley is divided into two halves for the purpose of a complication-free demolding, wherein both halves are identical, so that they can be manufactured with the same injection mold. The joining of the two halves is done by four snap hook connections. Figure 2 shows the V-belt pulley in mounted condition.

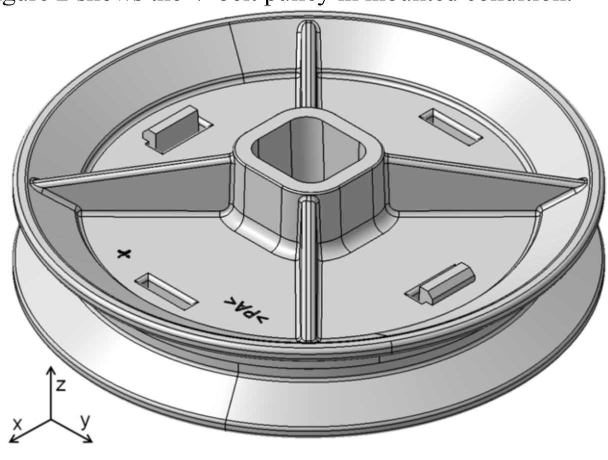

Figure 2. CAD: Isometric view of the assembled V-belt pulley (based on [11]).

The machine in which the V-belt pulley is installed is no longer produced. However, the manufacturer guarantees the purchasers of the machine spare parts availability for a certain period of time. The associated injection mold requires a general overhaul due to wear, before further components can be manufactured. Due to the low quantity required, the manufacturer decides to change the manufacturing process of the V-belt pulley from injection molding to additive manufacturing for financial reasons. It shall be manufactured in the SLS process on an EOS FORMIGA P110.

Step 1: material selection

The material used in the injection molding of the component is the PA 12 VESTAMID® L1670 nc (nf) from Evonik Industries AG. As replacement material, the

PA 12 PA 2200 Performance 1.0 from EOS GmbH is selected. Table 1 shows the mechanical properties of the two materials with the respective deviation of the AM material from the injection molding material.

Table 1. Property comparison between injection molding and AM material (taken from [12]).

Material property	VESTAMID® L1670 nc (nf)	PA 2200 Performance 1.0	Deviation
Density [g/cm³]	1,01	0,93	-7,92 %
Elasticity modulus [MPa]	1400	1700	+21,43 %
Tenacity [MPa]	46	50	+8,7 %
Breaking elongation [%]	> 50	20 (XY-plane)	-60 %

The mechanical properties of the AM material have only slight deviations of less than ten percent in density and tensile strength. The elasticity modulus is about 21 percent higher than that of the injection molding material, which is also acceptable. However, the elongation at break, in particular along the Z-axis of the AM material, is significantly lower, which must be taken into account in the later model adaptation.

Step 2: model analysis

The CAD model of the V-belt pulley contains the following design elements:

- Wall thickness
- Corners and edges
- Draft angles
- Gaps
- Geometric stiffeners
- Integrated part markings
- Snap connections
- Static assembly

For these design elements, in the following section, individual model change recommendations in form of an adaptation plan are defined.

Due to the circular geometry, the V-belt pulley should be aligned with the flat side along the XY plane of the additive manufacturing machine (see alignment in Figure 2) [13].

Step 3: Adaptation plan

Wall thickness:

The wall thickness of the two halves of the V-belt pulley is almost constant 4 mm, which can be seen in the sectional view of one half shown in Figure 3. This value is above the minimum wall thickness described in the catalog [14].

A generation of cavities with support structure is theoretically possible with this wall thickness. However, the component strength should be verified with Finite Element Analysis (FEA), since the V-belt pulley transmits a torque and must withstand the resulting stress [14]. In addition, powder removal from the elongated, narrow cavities is problematic. This model is also a static assembly, which means, that the two assembled halves can be seen as one product, because they have no degrees of freedom to each other. Static assemblies can be unified [15]. Under certain circumstances, the wall thickness of the combined component can be reduced. However, this should also be validated using FEA.

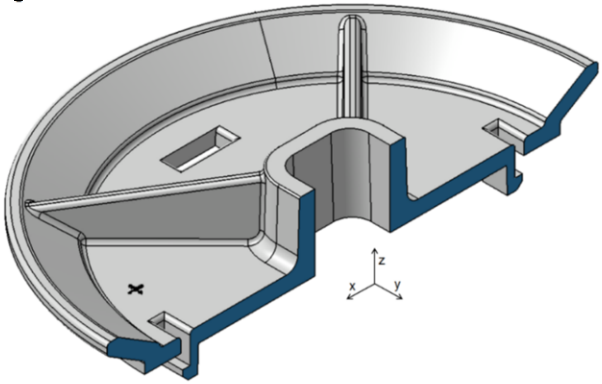

Figure 3. CAD: Section view of one V-belt pulley half.

<u>Corners and edges:</u>
The component has no tapered edges. Accordingly, the minimum wall thickness is not undershot. The angle of the bevel on the belt guide is about 32 ° (see Figure 4), which is above the minimum angle value described in the concept [14]. Therefore, no visible step effect is caused here.

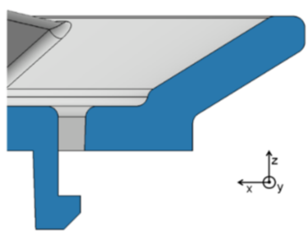

Figure 4. CAD: Section view of snap hook and belt guide.

<u>Draft angles:</u>
There are several draft angles on the component, which are colored light blue in Figure 5. All draft angles can be removed. It should be noted that the shaft mount is bevelled on two opposite sides for better demolding. Therefore, only two sides of the shaft mount contact with the shaft (see Figure 5). Since the two halves of the V-belt pulley are joined orthogonally offset, all four sides of the shaft mount contact with the shaft, whereby it is centered. When removing the draft angles in the shaft mount, it is beneficial to adjust the dimension of the affected sides, so that they also contact the shaft.

<u>Gaps:</u>
Due to the two snap hooks per pulley half, there are four gaps on each half:

- Two gaps for the tool breakthroughs on the snap hook, each with 2.5 mm gap width.
- Two gaps for the tool breakthroughs on the snap hook receptacles, each 4.5 mm gap width.

A comparison with the minimum dimensions for gaps given in the concept shows that the production of these gaps with a wall thickness of 4 mm is possible [13].

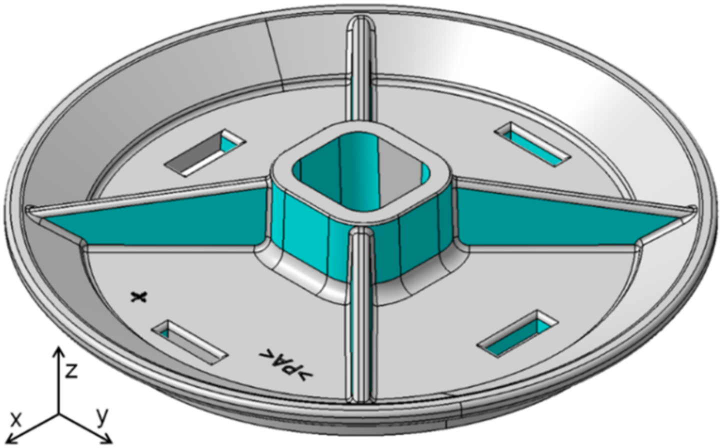

Figure 5. CAD: V-belt pulley with highlighted draft angles.

<u>Geometric stiffeners:</u>
The component has a total of four stiffening ribs between shaft mount and V-belt guide. Since the elasticity modulus of the replacement material is higher than that of the original material, no additional stiffening measures are needed [16]. In addition, with the help of FEA, a stress-related optimization of the component can be carried out, thus the component mass can be reduced.

<u>Integrated part markings:</u>
On the top of each pulley half – along the XY plane – there are two integrated part markings:

- A debossed marking of the material (see Figure 6, right). The font size is 3.5 mm and the inlet depth is 1 mm.
- An embossed marking of the production year including quarter (see Figure 6, left). The font size is 1 mm for the quarterly figures and 0.5 mm for the year. This marking is 0.2 mm raised.

Both the font dimensions and the depth of insertion of the material marking are above the minimum dimensions specified in the concept for integrated part markings [13]. Since the additively manufactured type of plastic is the same as the injection-molded one, the material marking can remain unchanged.

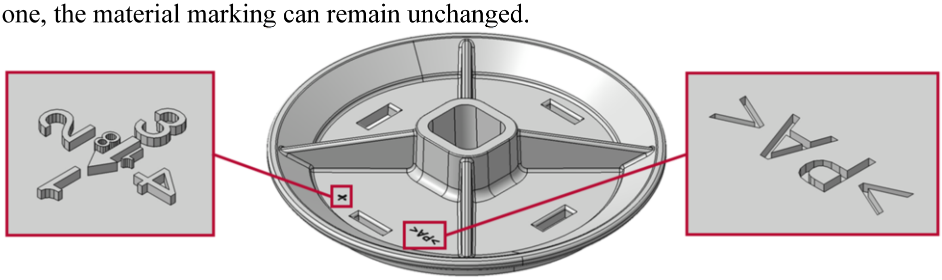

Figure 6. CAD: Integrated part markings on the V-belt pulley.

The font size of the date designation, however, falls below the minimum dimensions and, thus, must be changed. In this case, a general change of the label is recommended, since the current variant is optimized for injection molding. With additive manufacturing, the date can be easily changed in the CAD model, so that only the current annual and quarterly numbers must be engraved.

Snap connections:
The V-belt pulley is fitted with a total of four identical snap connections with the following dimensions (see Figure 4):

- 4 mm snap hook length
- 2 mm snap hook thickness
- 2 mm undercut

Due to the component orientation determined in step 2, the snap hooks are made along the Z axis. Since the AM material is a brittle plastic, the permissible snap hook elongation is assumed to be half the elongation at break in the Z-direction, which is 10 % (see Table 1). The permissible snap hook elongation is therefore 5 % [13].

The calculation of the permissible undercut of the snap hook with the formula given in the concept provides the result that it falls below the minimum intersection for additively manufactured snap hooks [17]. An adaptation of the length of the snap hook is not possible, since this is bound to the component wall thickness and also by adjusting the snap hook thickness the minimum undercut can not be achieved because the deviation is too large.

Therefore, it is necessary to joint the two V-belt pulley halves otherwise than with a snap connection. The approach is described below.

Static Assembly:
Since the V-belt pulley is a static assembly, the two halves can be unified, making the pulley one component [15]. As a result, the problem caused by the snap connection is avoided.

Step 4: Model adaption
The V-belt pulley CAD model has been changed according to the previously created adaptation plan. The following adjustments were made:

- Remove the draft angles and adjust the shaft mount
- Remove the gaps for the snap connections
- Change the marking of the production date
- Remove the snap hooks and the associated gaps
- Unifie the two halves of the V-belt pulley to form one component

The fully adapted CAD model is shown in the isometric view in Figure 7.

Step 5: Validation
After the conducted CAD model adaptations, the V-belt pulley is suitable for additive manufacturing. To fully exploit the benefits of additive manufacturing, stresses in the component should be simulated in a FEA. For example, the results of this simulation can be used to optimize the wall thickness or to create cavities with supporting

structures and to prove their strength in a design review. However, this also increases the time required for the model adaptation.

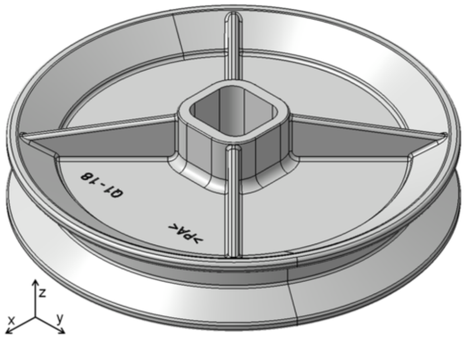

Figure 7. Isometric view of the adapted V-belt pulley.

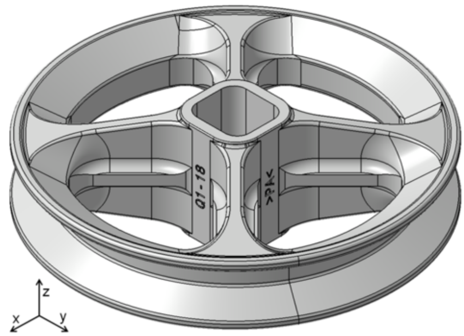

Figure 8. Suggestion of a component optimization.

Based on the FEA simulation, component optimization can also be carried out, for example with the help of the automatic optimization modules integrated in CAD-Systems, which allows further material savings. Figure 8 shows a suggestion of how the V-belt pulley might look after a stress-related component optimization. However, this variant has been created manually and still needs to be verified by FEA. When comparing this component with the previously adapted V-belt pulley from Figure 7, it can be seen that the component geometry can change significantly as part of a stress-related optimization.

4. Conclusions and Outlook

Additive manufacturing processes are increasingly establishing themselves in the industrial production of functional components and end products [4]. Especially with the powder bed processes treated here, plastic components can be produced which are suitable for long-term use as a functional component [18].

The basis of the developed concept for CAD model adaptation in context of a change from injection molding to additive manufacturing are the process-specific restrictions as well as the material properties. These informations are the influencing factors for the later model adaption recommendations [21].

The process-specific restrictions are assigned to the respective manufacturing processes. It is shown that the part design of injection molded parts is strongly influenced and limited by demolding and mold filling [16]. However, at the design of additive manufactured components, the component orientation in space of the machine and the powder removal must be considered.

With regard to the limitations of both methods, it can be stated that the maximum component size of AM components is significantly lower compared to injection-molded components and that the producible surface quality is also considerably rougher. The problems of component distortion and the formation of voids or sink marks in additive manufacturing, unlike injection molding, can be circumvented by the formation of voids in the component [15]. With regard to the material properties, it should be noted that the variety of different processable plastics offered by the injection molding process is not given in additive manufacturing processes, especially in the case of amorphous plastics [18].

In addition, the mechanical properties of additively processed plastics are axis-dependent. In particular, the elongation at break of AM plastics along the Z-axis is usually far lower than with comparable injection-molded plastics [19][20]. Other features that need to be individually checked and compared are temperature properties, media attack resistance, optical properties and many other certifications.

The developed concept for CAD model adaptation in context of a change from injection molding to additive manufacturing consists of a catalog of design elements that are frequently used in injection molding [22]. For each individual element, it is first examined which influencing factors play a role in injection molding. Subsequently, it is examined which of these factors disappear in case of a change of procedure and which new influencing factors may be added. Based on this study, individual customization recommendations are defined.

The conceptional procedure envisages that in case of a change from injection molding to additive manufacturing, a substitute material will first be selected for the affected component. Subsequently, the model is analized resulting in a list of all design elements contained. For this list, the required adaptations in the catalog are researched and an adaptation plan is created, which is then processed [22]. Finally, it is validated whether an additive manufacturing of the component is possible after the model adaptations made.

The exemplary application of the concept shows that a CAD model adaptation can be necessary in a process change. The component considered here could have been made additively without adjustments, but could not fulfill its function due to the failing snap connections.

It could be shown that many design elements, which typically occur on injection molded components, are also suitable for additive manufacturing after minor adaptations. It should be noted that the complexity of implementing the developed concept is component-specific and, moreover, it is influenced by the designer's approach when creating the CAD model [23][24]. Therefore, CAD models that have been built to a consistent design methodology will cause fewer complications in the application of the concept.

Finally, it can be stated that the developed concept enables additive manufacturing of components that were originally designed for the injection molding process. However, a change from injection molding to additive manufacturing involves a comprehensive expansion of design freedom in parts design [25][26]. Therefore, it is also spoken of a change away from the processing-oriented to the stress-related design of plastic components [18].

To fully exploit this freedom of design, however, functional components with high component utilization require more in-depth model analysis using FEA calculations and CA-optimization tools. Only with the results of these simulations and calculations, a complete component optimization in the sense of a stress-oriented design can be done and, thus, the advantages of additive manufacturing processes can be fully exploited [25].

Finally, additive manufacturing imposes more options in the selection of the location for manufacturing facility [27]. Subsequently, one-a-kind manufacturing by additive manufacturing goes global. To practice additive manufacturing in a globalized context, the applied concept should be tailored to the degrees of novelty and interdependence [28].

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