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SUPPLYING SPARE PARTS USING AM TECHNOLOGIES

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Abstract: In order to stay competitive in today's markets corporations are constantly searching for areas of improvement within their products and processes and the available technologies in order to be more efficient and produce products more cost effective. In addition companies try to create distinctions of their products to maintain and gain market share by offering superior products and services. This is not only true for first time parts but also increasingly important for secondary products. These secondary products also called spare parts and their management is becoming a production factor, which is gaining more and more importance. Manufacturers are required to provide spare parts pending on the type of spare parts (consumer products or industrial products) in varying quantities making it more complex for the manufactures to maintain these systems.

This paper is presenting an alternative solution for the growing quantity of product types on the market requiring currently enormous warehouses to keep stock for spare parts, with corresponding high costs and complex logistics. This emerging problem is caused by the continuously decreasing product life time, decreasing time-to-market and increasing regulatory affairs. A solution is foreseen using Additive Manufacturing (AM) technology, enabling economically viable, one-off manufacturing on demand as well as a possibility to create new business models.

1. INTRODUCTION

The competitive corporate world is required to constantly improve its products and processes and find more cost effective solutions to manufacture their products while at the same time offering ever growing possibilities and ways for customers to individualize their products. This is also true for spare parts and the spare parts industry.

Today's spare parts industry can be described as: high volume production with sometimes specialized products, long distance transportation and extensive warehousing, resulting in huge inventory of spare parts that are often scrapped afterwards. As a reaction to this, companies have to try to compete or collaborate with the OEMs, to provide maintenance services and products but are limited with regards to the broadness and flexibility of their service solutions, especially when changes to spare parts (copies or OEM-manufactured) are required.

AM offers completely new manufacturing possibilities which have the potential to change the logistical and business requirements and therefore create room for new business models. Standardization of processes in manufacturing, logistics, product and process management and certification as well as product and business management must be developed. One approach to this development is the work within the EU funded project DIRECTSPARE. The goal is to develop a model which incorporates the old and new requirements of manufacturing and the market demands to assist companies to better compete in the market settings.

2. ADDITITVE MANUFACTURING AND SPARE PARTS MANAGEMENT

2.1 Additive Manufacturing Technologies

AM technologies encompass all technologies used to manufacture a product by adding (placing and bonding) layers of material to each other in a predetermined way. These so called layers are generally speaking 2D-cross-sections of the products 3D-model. AM therefore is creating the geometry as well as the material characteristics during the build. The contour is created in the x-y-direction. The z-direction creates the volume and therefore the 3rd dimension. AM includes the possibility to make optimized products using freedom in design given by this process. Complex shapes and functional parts can be realized by these innovative processes directly from CAD data. Two examples of Selective Laser Sintering (SLS) are shown in figure 1:

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Figure 1: Selective Laser Sintering of integrated robotic gripper and individualized under arm cast © Fraunhofer IPA

In order to hold a finished real product in hand two main process steps need to be performed (Gebhardt, 2007):

- Developing of the cross-sections (layers) of the 3D-model
- Fabrication of the physical product.

These two main process steps either run simultaneously or in sequence depending on the technology. These main process steps can be broken down into a series of steps following a sequence which is shown in figure 2 (Gibson et al, 2010):

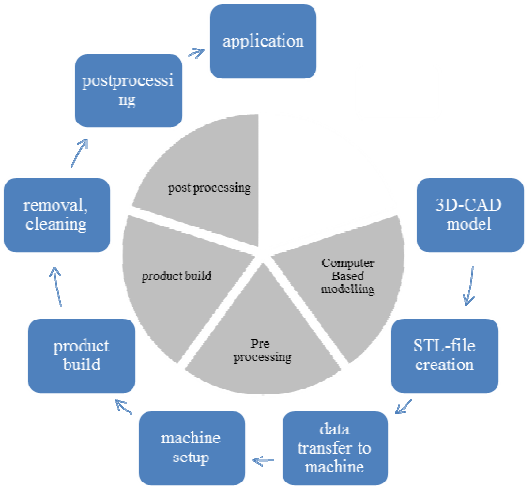

Figure 2: Process Steps of AM

To be accepted as an alternative to conventional manufacturing technologies additive manufactured products have to have the same mechanical and technological characteristics as comparable conventionally manufactured products. This does not equal the fact that its material characteristics have to be exactly the same to the once of conventional technologies. The thinking has to shift from “get exactly the same product and its material characteristics with another technology, so I can compare it” to “get the same performance and functionality of the product regardless of the manufacturing technology” used.

Besides the benefit of using the 3D-model data directly for the manufacturing process of a product exist additional benefits listed below (Gebhardt, 2007; Hopkinson et. al., 2005):

Benefits of AM

Integration of functions, increase in complexity of products and components and including of internal structures for the stability of the product

Manufacturing of products very difficult or not possible to manufacture with traditional/conventional manufacturing technologies (e.g. undercuts …)

Variation of spare products – ability to adopt “local” requirements to the same products and therefore supply local

markets with the product and its expected features, low effort and no true impact on the manufacturing
Customization – two forms of customization are possible - Manufacturer customization (MaCu), and Client customization (CliCu)
No tooling, and reduction in process steps
One-piece or small volume series manufacturing is possible,
Product-on-demand
Alternative logistic strategies based on the current requirements give the AM an enormous flexibility with regards to the strategy of the business model

2.2 Spare Parts Management and Logistics

Spare parts nowadays have become a sales and production factor, especially for any manufacturing company with a highly automated, complex and linked machinery park and production setup. Any production down-time caused by the failure of a component of any equipment within production lines will lead not only to capacity issues but also to monetary losses. These losses may come from (Biedermann, 2008):

- Distribution: sales lost due to products not being manufactured
- Production: unused material, increase in material usage due to reduced capacity, additional over-time for employees to balance the inventory and make up for the lost production, additional maintenance costs of 2-30% of overall production costs
- Purchasing and supply chain: increase in storage for spare parts and costs incurred due to the purchase of spare parts

It is therefore essential to choose the right spare parts strategy to reduce to risk to the business to a minimum by determining the right balance between the minimum inventory and the availability to delivery spare parts in time to prevent production down-time. One aspect on determining this strategy is to define the type of spare parts to be manufactured and supplied. According to DIN 13306 a spare part is an “item intended to replace a corresponding item in order to retain or maintain the original required function of the item”. Biedermann is defining the items in the following way (Biedermann, 2008):

- Spare part: item, group of items or complete products intended to replace damaged, worn-out or missing items, item groups or products
- Reserve/Back-up item: item, which is allocated to one or more machines (anlagen), and therefore not used individually and in disposition and stored for the purpose of maintenance, Back-up items are usually expensive and are characterized by a low inventory level with a high monetary value
- Consumable item: item, which due to its setup will be consumed during use and has no economically sound way of maintenance

Another aspect in determining the strategy is the type of maintenance the company is choosing. There are three basis strategies, of which one is total preventive maintenance (TPM). Total preventive maintenance is characterized by the performance of inspections, maintenance work and replacement of components prior to the failure of the equipment. The second strategy is the scheduled maintenance or reliability centered maintenance. Scheduled maintenance describes a strategy where the replacement of an item is as the term says planned ahead of time. The third strategy is corrective maintenance or repair which is also called risk based maintenance. Corrective maintenance describes a strategy where an item fails and will be replaced in order to convert the installations or equipment back into production mode.

For the determination of which strategy is to be installed at a company, various factors have to be considered. These include failure behavior and failure rate of the item, reliability requirements, level of information available and receivable, back-up solutions, and alternatives amongst others.

The decision on the strategy and the type of spare parts determines the logistics and supply chain model to be chosen and therefore the cost for the logistics portion.

3. NEW PROCESS DESIGN AND BUSINESS MODEL

After a brief introduction and overview of AM Technologies and Spare Parts Management including some detail and its pros and cons, this chapter will introduce the proposed manufacturing ideas and process flow using AM as an alternative

to conventional manufacturing of spare parts. In addition an overview of the main benefits of this new process will be given including a brief outlook on the required future actions.

3.1 Proposed Process Flow

Derived from the limitations and effects of the current supply strategies of spare parts, customer feedback from questionnaires and based on the processes of AM in combination with the product figure 3 illustrates a generic conventional process flow model and figure 4 the proposed preliminary process flow model.

As with standard process models the proposed process flow model covers all the process steps starting with the input from the market in the form of customer orders and customer feedback up until the delivery of the finished product to the customer.

AM technology is becoming more and more an industrial process and because of that, the process model will be in a permanent updating stage. The following figure is showing the currently proposed process model:

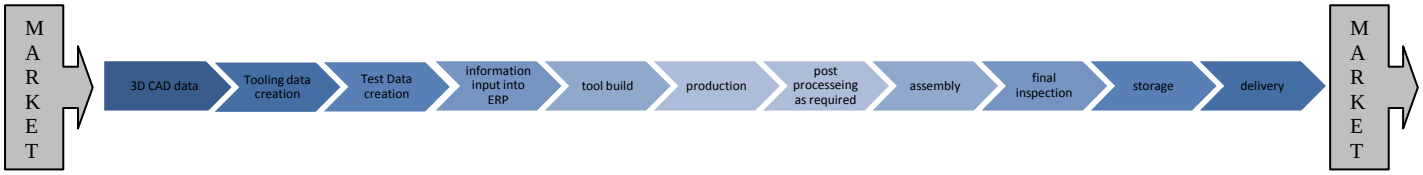

Figure 3: Conventional process flow

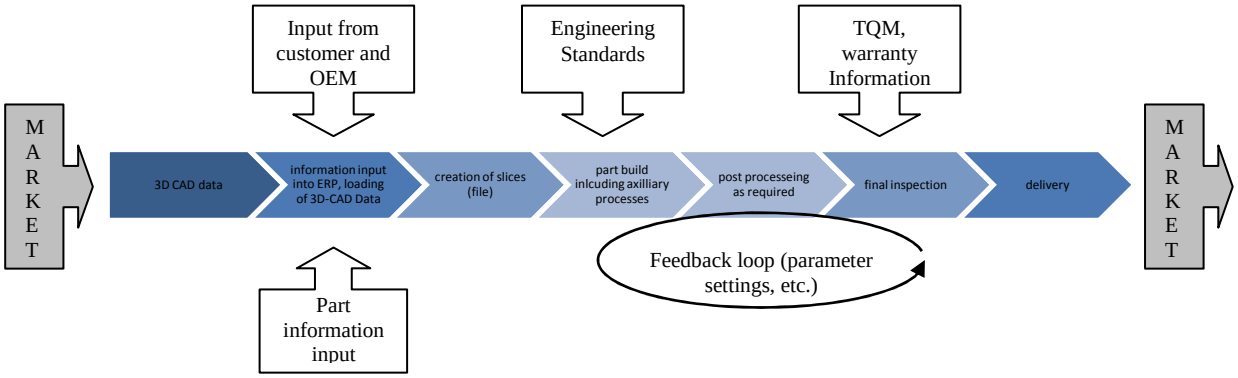

Figure 4: Preliminary Process Model incl. main inputs

Producing parts using AM technologies and the new proposed process flow will have an impact on multiple levels and multiple areas of a business' operation. The main ones are discussed in the following subchapter.

3.2 Impact of AM Technologies on spare parts manufacturing

The impact of using AM technologies to manufacture spare parts will be described in the following subchapter. This chapter presents only an overview of the main benefits.

3.2.1 Reduction or Elimination of Tooling

Conventional manufacturing processes require various tooling in order to fabricate a product from start to finish. One example would be injection molding tools. This need of tooling results not only in costs for the tool build and tooling

material, but also in time for the tool build, setup procedures during production periods and maintenance activities in order to keep the tools and therefore production running. Additionally tooling often has to be stored for a defined time after the end of production (EOP) to be able to produce spare parts when needed.

There are two possible alternatives to the conventional way of manufacturing spare parts being proposed: one being the fabrication of products including its spare parts strictly using AM technologies from the start, thus eliminating tooling completely. In order to proceed this way AM technologies and its requirements must be the main focus of the product and process development activities including TQM methods in order to secure production capabilities and therefore reduce the risk of downtime due to production issues. This also requires knowledge about AM, its possibilities and limitations.

The other alternative is to manufacture primary products using conventional technologies including tooling but manufacturing spare parts using AM technologies.

In order to make a decision which alternative is to be preferred we suggest to perform a detailed analysis of the spare part characteristics, spare part quantity requirements as well as production requirements with the focus on the potentials and risks of using AM technologies. As a result new manufacturing opportunities, significant monetary savings as well as the reduction in time, thus presenting the possibility to be faster on the market can be an outcome of the analysis. Depending on the spare parts type and the chosen strategy the following benefits can be achieved:

- Reduction or elimination of tooling
- Freeing up storage space for not needed tooling
- Freeing up storage space for already produced products
- Reduction in costs for logistics
- Freeing up production time for not required products to be made ahead of time after EOP
- Reductions of obsolete or excessive spare parts being produced at EOP and being disposed if not required.

In the case of spare parts an additional benefit is that product failures causing the need for spare parts can be examined and corrective actions can be implemented into the product design without the need to also change or update tooling data, tooling and processes.

It is important to note that not all tooling can be reduced or eliminated at the current state of the AM technology maturity level. Tooling for inspection processes is typically still required unless on-line one-step inspections can be performed during the building process and the required surface and appearance characteristics is already achieved during the build.

3.2.2 Reducing complexity

The manufacturing of spare parts directly from 3D CAD data presents a significant reduction of the complexity in the whole organizational and operational processes. On the one hand the number and sequence of administrative, planning and production processes can be vastly reduced, e.g. reduction of data transfers and conversion for the various tools and equipment.

On the other hand, handling of data is much more convenient than handling of real parts, but also required a secured loop in order to assure the correct data handling and storage. Within the mega trend of customization / individualization of products it is very easy to produce lots of different versions and personalized products with very little additional effort short-term and long-term. Data handling of all the versions will be the limitation.

Price and capacity calculations and estimates to provide a quote for the needed spare parts will become obsolete as well as the need for platform product strategies introduced to control the overall number of different versions. Continuous work in the area of reducing the complexity of the spare part management is required.

3.2.3 Manufacturing “on demand” and “on location”

The main feature of AM as a production process for spare parts is the possibility to produce parts on demand. Two alternative models of this process are possible. First model is that the spare parts will be kept on stock in very small numbers and the customer demand will trigger the delivery of the parts from the stock and the immediate production of the desired number of parts to refill the stock. This results in very small remaining stock that has to be calculated and in a very fast response time. The second version is to eliminate the stock and produce directly the number and version of parts that the customer demands. The result will be an a little bit longer response time but no tied capital. In this case there is a higher risk of getting into trouble because of problems with production e.g. no free capacities, raw material shortage and bad quality of parts from service providers.

Another big advantage is the production on location, meaning that in the near future it will be possible to send around not the parts but only the 3D CAD data with additional information regarding building process, materials and tolerances. The production will be made in independent or dependent production facilities that have clearly defined and certified AM capacities. This model could have a large impact on the logistics that will be evaluated. Fraunhofer IPA is currently working on strategies for the certification of manufacturing processes and service providers to assure the required quality level of the products.

Another possible future approach is it to use raw material from the location where the parts are build and therefore form a cooperation setup. This could present additional logistical benefits. The impact of a production on demand, on location and with local material is recapped in the following list:

On demand	**On location**	**Local material**
No more warehousing for spare parts including space, building maintenance, energy for climate control, workers…	Worldwide service without limitations	Reaction on local requirements
No more logistics of scrapping unused old spare parts	No more logistics for end products	Environmental friendly
No more time limitations for spare parts support	Faster response time over long distances	Much less raw material logistics
		Social benefits of job creation in the local area
		Cultural adaption

3.2.4 Business Model Opportunities

Staying competitive using traditional business model concepts is becoming more and more difficult. Customization and the response time to customer needs are two critical factors of being successful. 21st century companies have to focus on moving physical products as well as their information quickly through retail, distribution, assembly, manufacture and supply in a timely and cost-effective manner. This is part of the value proposition manufacturing and service providers offer to their customers. Using AM technologies can provide a significant competitive advantage to a company.

New business models will be developed which consist of a deeper cooperation between suppliers and receivers of on-demand parts, taking into account the roles of original equipment manufacturers, “traditional” component suppliers, product manufacturers using AM technologies, possible virtual networks all members including providers of part data (geometrical and material models) products and end-users. Examples of the setup of such business models are illustrated in figure 5:

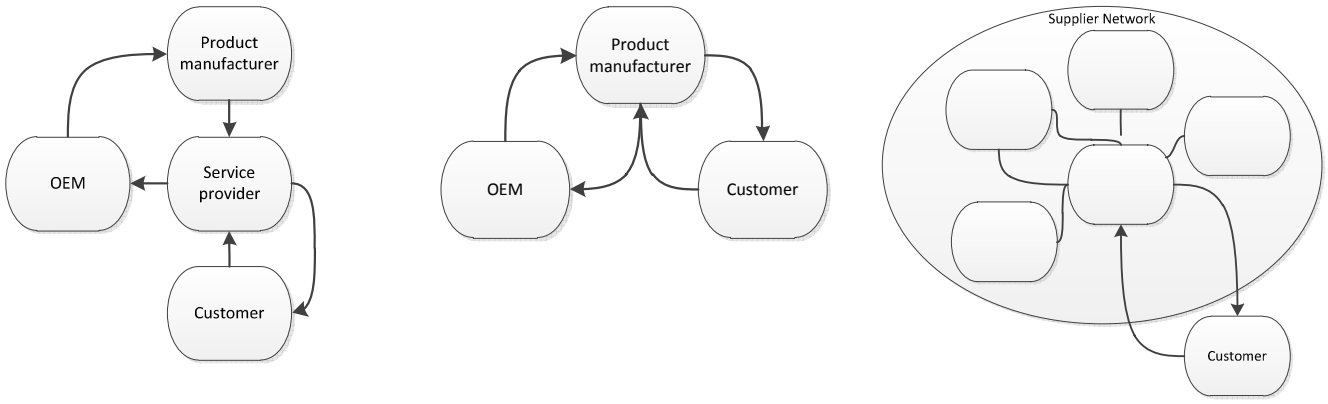

Figure 5. Three possible Business Model Constellations

Depending on the business model each player has a different level of involvement and therefore a different level of value creation he adds to the overall product.

4. CONCLUSIONS AND OUTLOOK

Implementing and using AM in order to manufacture spare parts offers a viable option not only to familiarize one with a new emerging manufacturing technology but also presents opportunities to offer products and services to the customer which fit their desire and requirements regarding time and cost effective delivery as well as customizing spare parts and components perfectly to the needs. It is however important to take in account that AM has also its limitations like size, surface finish quality and the production volume (number of parts), which however will become less dominant with the future development of these technologies. AM and their benefits have the potential of an enormous economic impact by reducing inventory levels to an absolute minimum as well as reducing logistics cost significantly. In addition ecological impacts are also able to be achieved by reducing the use of resources to the amount of truly required spare part quantities.

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