State of steel products in industrial production processes

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Abstract

Requirements of external and internal customers towards the quality of steel products are continuously rising. To fulfill these requirements, production processes are becoming more complex and need more information about the individual product. This is especially true for production networks where different companies work together on a single product.

The goal of this paper is to propose a first definition of the term “state of a product” as a combination of different relevant state characteristics of a product at a specific point during the production process. The idea is that the state ideally provides all necessary information to all stakeholders at any time before, during and after the industrial production process. Additionally, the question of which state characteristics are relevant defining product state and how they can be identified will be examined.

Subsequently, an industrial example will show how the product state of a highly stressed steel product can be described during the production step of machining by a selection of relevant state characteristics. Concluding, an outlook on further research and chances of an information management based on a state oriented view on products will be presented.

Keywords: product state; production process; information management; state characteristics

1. Introduction

The German economy evolved in an engine of growth within the European Union [1]. A large part of this success is built on the strong industrial basis, especially the showcase sector of mechanical engineering. German engineering products are exported worldwide and have the reputation of advanced technology and premium quality [2]. This reputation as high quality products is a key factor of success considering the global competition. At the same time, the customer’s requirements towards quality of products and services increase steadily [3], leaving the companies with the constant need to improve. Many companies focus on their core competencies and work together in collaborations to satisfy the customers’ requirements and gain sustained competitive advantage [4]. All these developments lead to an increasing complexity that companies have to deal with. Taking into consideration that business success of every company is based on the quality of its business processes [5], it can be said, that business success of a collaborative network is based on the quality of business processes of every collaboration partner.

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1. Introduction

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Looking at industrial companies, production processes play an important role through the direct value adding to products. The outcome of this is that the quality of a product is directly influenced by the quality of the production processes [6].

The trend of today’s products becoming more and more optimized leads to a consistent exploitation of achievable product properties. At the same time, it has to be secured that these desired product properties can be achieved through the production processes. Therefore, a detailed understanding of the production processes and their influence on products becomes increasingly important. Thus, continuous improvement of the industrial production processes can be a way to stay ahead of competition. It is necessary to take a closer look at what impact the increased overall complexity in the global business environment of mechanical engineering companies has on collaborative production processes. One important factor is the rapidly increasing need for information exchange between companies with all the pitfalls, which among other things include: communication problems, security issues, interface problems of IT systems and, of course, the sheer amount of information to process.

One approach to handle this challenge is to base the information exchange on information which is not interpretable. Describing the product itself and connecting this information directly to the physical product will allow all partners in a collaborative production process to access the information when needed and use them individually. So the current process step owner can extract the relevant information for its use. This is not only important for production and manufacturing itself but for a successful supply chain management in total.

In this paper, a definition of the product state will be given as one approach to describe a product by attaching information and data directly to an individual product. Following, in more detail, the question of how to determine the individually relevant state characteristics will be examined. This approach will be made more tangible through an example of a highly stressed steel product and how it can be described during the process step of machining. Concluding, an outlook on planned activities towards product state related information systems will be given.

2. State as a method to describe a product

In this paper, the term product is used comprehensively to describe an artefact over various stages of its product-life-cycle replacing the more technically accurate terms e.g. component or work-piece during production. This is due to, on the one side, reducing complexity and, on the other side, to distinguish that the focus lies on one individual product over different stages of the product-life-cycle. In the end, describing a product can be done in various ways. Most likely the manner of describing an industrial product, e.g. gear made of steel, will be different from the description-style of a design product, e.g. a plastic rear mirror. At the same time, the individual describing an artefact influences the description based on, among other things, its own background, knowledge and experience. Therefore, the approach of describing it through its product state will help to align the descriptions in a commonly understood manner as well as increase transferability and usability of accompanying information by the addressees.

At the moment, the term state itself is not sufficiently defined for the use in industrial production processes in combination with a product. Looking at literature, the term state is frequently used in various areas like physics, chemistry, medicine or even philosophy. However, the transfer and usability of these existing definitions to the context of industrial production processes is not easily achievable. Nevertheless, understanding what stands behind different definitions and what the major differences are is important for the definition of product state in industrial production processes. One of the oldest and most common used definitions is the state of aggregation, which describes the simplified classification of material as solid, fluid and gaseous [7]. The example of the state of aggregation of water can help to understand two aspects which are universal over most state definition and will be important for the definition of product state at a later point. First, the state is time-dependent. Water can be at the point in time $t=0$ in a liquid state and at $t=1$ in a solid one (see Figure 1).

![State is time-dependent](image-url)
Another aspect is the descriptive character of state. Within the research field of Information and Communication Technology (ICT) the term state is used, for example, in Unified Modelling Language (UML) to describe a constraint of an object during the life-cycle [8, 9]. The state is then active when the constraint becomes true. Another way of using state in ICT is with finite-state machines. Within this theory, a new state (t=1) depends always on an original state (t=0) and an input. Again, the time-dependency of the state occurs, plus the dependency of state on external input or change.

The descriptive character of common state definitions is also pointed out within the field of thermodynamics in which the term state is clearly defined. In thermodynamics, the state of a system describes a situation in which all variables of the system can be allocated with a clear numerical value. These variables are called state variables. The number of state variables, which is necessary for a definite determination of state, depends on the inner structure and complexity of the system [10]. This definition introduces variables with attributed certain numerical values. It also implies that the number of variables needed depends on the situation. In other definitions or descriptions of state, these variables are also known as properties, parameters, attributes, factors or characteristics. Within this paper, the term characteristics will be used from now on as a descriptive element of state. Looking at the thermodynamic literature on how characteristics can be defined, one can find them described as qualitatively definable and quantitatively measureable physical quantities [10]. Other fields take a more uncommitted approach and view characteristics as a qualitative describable value or appearance without being able to quantify it [11]. For the product state in industrial production processes, a combination of quantitative and qualitative characteristics will be used.

Based on elements of the above definitions combined with the requirements of industrial production, product state can be defined as follows:

The product state describes a product at a certain time during the production process or after through a combination of state characteristics. State characteristics are definable and ascertainable measures, which can be described in a quantitative or qualitative way, e.g. weight or chemical composition of the material. The product state changes due to external influence, for example machining or corrosion from t=0 to t=1 when at least one descriptive state characteristic changes (see Figure 2).

Fig 2. Product state changes over time when state characteristics change due to external influence

The change of state can happen on different levels. To illustrate, during a production process the state changes to a certain degree with every process step as value is added. This change is intentional, but it also involves the repercussion of unintentional changes. For example, when cutting a steel pipe the intension is to reduce the length to a certain degree. However, wanted or not, at the same time the weight of the pipe will be reduced due to the cutting of material. This is a simplified example. In reality many more characteristics change with every process step in industrial production processes. A more complex example also emphasizing the importance of looking at a production process as a whole is the straightening of steel bars after heat treatment in the steel mill. The changed
geometry of steel bars due to distortion is often straightened out before delivery to customers. There are many reasons for this, such as ease of transportation, continued processing or simply the look and feel of the product. The main purpose is to clear the bending of the steel bars. Nevertheless, at the same time residual stress is caused which can lead to problems at a later stage of the production process, e.g. after the final heat treatment. For this reason, it is important to think of what characteristics have to be known to describe the product state. This will be highlighted in the following chapter.

3. Identifying relevant state characteristics

In this chapter, the first paragraph will point out reasons for the need to identify a selection of relevant state characteristics out of all the theoretically available ones. Following, a selection of influencing parameters for selecting relevant state characteristics, such as intended later application area, will be introduced.

Theoretically all thinkable characteristics could be included for a complete description of product state. However, this is neither reasonable nor practical. There are many reasons which can be clustered in three groups:

- **Technical reasons:** for example, some characteristics cannot be measured without destroying the product (e.g. tensile testing of maximum elongation).
- **Economical reasons:** for example, measuring characteristics within the process with limited or no known influence on e.g. final product quality slows down lead time and requires extra funding for personnel/machinery.
- **Knowledge reasons:** for example, some characteristics of product state might just not yet be discovered.

Due to these reasons, it is necessary to describe the product state based on an individual selection of relevant state characteristics. The accentuation is on individual because relevant state characteristics cannot be identified over all products and processes once and for all [6]. Even for a batch, it is not guaranteed that little variations will not influence certain state characteristics, e.g. temperature or lubricants. There are many parameters influencing the relevance of state characteristics during a production step, such as type of product, type of material, type of production process, machinery used, application area of the product (e.g. low-cost or high-quality) and many more. The relevance has to be given not only for a single task or production process but over the whole product-life-cycle.

![Fig 3. Influencing parameters for selection of relevant state characteristics to define product state](image)

A first attempt to identify relevant state characteristics can be based on the input needed of each production process step. The next chapter will present an exemplary selection of relevant state characteristics that can be used to describe the product state of a highly stressed steel product during the process step of machining.
4. Product state of a highly stressed steel product during machining

To make the theoretical construct introduced in the previous chapters more feasible, an exemplary description of some relevant state characteristics that can be used to describe the state of a highly stressed steel product will be presented. This example is based on a production process following [12] which consists of the following process steps: (1) Primary shaping; (2) Forging; (3) Machining; (4) Heat Treatment.

As mentioned above, to describe the product state, an individual selection of state characteristics has to be executed based on various parameters. As this industrial production process was not conducted to produce a to-be-sold product, some parameters that would influence the selection of relevant state characteristics, such as later application area or customer needs, cannot be taken fully into account. Furthermore, at this point, a full description of all relevant state characteristics for this individual product and process will go beyond the scope of this paper.

Table 1 depicts a selection of state characteristics. The scope is to highlight a wide variation of possible state characteristics, incorporating not just material data but also aesthetic characteristics such as e.g. color of the product. The first column names the state characteristic. The second column answers the question of whether or not the value or appearance of this specific characteristic will change during the process step of machining. For example, the value of state characteristic of weight will change as material is taken off during the process step. In the following column, the relevance of the state characteristic for the process before the start of machining (t=0) is evaluated. In this case, the question is, does the value or appearance of this characteristic have an influence on how to adjust the parameters of the process step of machining? Does the state characteristic skin hardness, for example, influence the chosen cutting insert? The last column answers the question of relevance for the process after the process step of machining (t=1). Here the importance of the value or appearance of the state characteristic is questioned when following production process steps such as heat treatment or the later usage phase. Taking the example of the state characteristic color after machining, the appearance might be important depending if the following process steps change this state characteristic again or if the color will be set until delivery to the final customer.

Table 1. Individual selection of relevant state characteristics of a highly stressed steel product during the production process step machining

<table>
<thead>
<tr>
<th>Description of characteristic</th>
<th>Change during process step</th>
<th>Point in time of relevance for process t=0</th>
<th>Point in time of relevance for process t=1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Diameter</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Marginal zone characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface hardness</td>
<td>maybe</td>
<td>yes</td>
<td>maybe</td>
</tr>
<tr>
<td>Surface roughness</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Material characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual stress allocation</td>
<td>maybe</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Aesthetic characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>yes</td>
<td>yes</td>
<td>maybe</td>
</tr>
</tbody>
</table>

As mentioned before, this is just a small selection of the possible relevant state characteristics needed to satisfyingly describe the product state. Identifying state characteristics involves an in-depth understanding of the whole production process, the product, the surroundings and the interdependencies.

5. Conclusion and Outlook

This paper introduced the product state as a means to describe a work piece, component or product along the product life cycle, especially during the phase of the industrial production process through an individual selection of relevant state characteristics. State characteristics are definable and ascertainable measures, which can be described...
in a quantitative or qualitative way. This view on products allows creating information and data in a rather unbiased and un-interpreted manner. This is considered especially helpful when managing interface and security challenges along company boarders within a distributed production process with different partners/business units involved. The idea for describing a product by its state is largely based on results and experiences from works of the subproject B5 “Product and Process Design for Distortion Control” within the CRC 570 “Distortion Engineering”. Within this project, the product state observed through the complete production process was the basis to examine methods and tools to anticipate distortion potential and distortion of a highly stressed steel product [12, 13, 14].

In a next step the state of a steel product including relevant characteristics over a whole collaborative industrial production process will be examined. A special focus will then be put on describing and analyzing implications of interdependencies between state characteristics over company or business unit boarders. Understanding these interdependencies allows for the identification of more influencing relevant state characteristics to describe the state more accurately. In the end, this deeper understanding helps to understand the effect of influencing factors and process parameters on the process output, e.g. the final products quality. On this basis, the potential for developing an information management system that allows the tracking of the product state over the whole production process, e.g. development of a digital “resume” of the product for quality assessment, will be will be explored in order to increase overall process quality as well as reduce scrap and rework.

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References


