Gentelligent Components: Closing the Gap between Components and Information

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Summary: The field of intelligent products is on the advance. Nowadays, products are still generally considered in terms of function and design. Thereby it is neglected that enhanced capabilities of products initiate a rethinking of conventional approaches for production or supply chain control, fault detection, lifecycle monitoring or part authentication and protection against counterfeit products. In the future, products, parts and components will instead actively participate in their production processes, transport, maintenance or redesign. This paper focuses on beyond-state-of-the-art technologies which fundamental idea is to abolish the naturally existing gap of the physical component and its corresponding virtual information about its design, production process or lifecycle for example. With products taking an active part during their production or lifecycle, autonomous decision and control systems as well as new strategies e. g. for load sensoring or maintenance become feasible. The continuous development of integrated sensors and embedded systems leads to further available information about the current product condition, its usage and environment. An overview is provided considering the future possibilities and technologies for novel, gentelligent components which are characterised by genetic and intelligent attributes.

Keywords: Sensorial Materials, Condition Monitoring, Intelligent Products, Product Lifecycle.

1. Challenges in production technology

Market-driven developments force production companies to continuously adapt their product portfolio and resources in an innovative manner in order to keep pace. Several trends can be observed which strongly impact the actual competitiveness of companies in production technology and require new measures and technologies.

Continuously, companies identify new market niches, launch further product variants and establish globalised supply networks in order to serve prospective customers around the world. Referring to the trend of further customisation an average increase about 50% of the amount of offered models within the automotive market could be identified (e.g. [1]). A higher product variety leads in turn to an individualised design, an increased production variety with higher requirements for the inventory management regarding product identification and traceability. Referring to the usage of the products, a higher heterogeneity of lifecycles results requiring new maintenance measures. Information becomes a critical issue: In order to improve the product or component design, engineering departments depend on reliable data like experienced loads or deformations from the product's lifecycle. Within the production, locating parts, setting up machines for specific products or identifying if parts fit together and can be assembled are vital information for adaptive control strategies. Another critical issue in terms of market competitiveness is the increasing amount of counterfeit and pirate products which have led to tremendous losses and represent a major risk for the customers due to unexpected failures or breakages [2, 3].

Along with the mentioned market developments, information technology has reached a new level of miniaturisation, data storage, processing and transmission ability. The established operations for product identification like the ubiquitous stamped serial numbers in metal components or barcodes do no longer keep up with the requirements from nowadays production technology. Instead, products need to be provided with further partial intelligence and functionality.

2. Augmenting the inherent capabilities of a component

2.1. Changing perspectives

The emergence of information technology as a measure for further productivity can be traced back to the 1990th. During this period, Computer Integrated Manufacturing (CIM) represented a significant approach in which product design steps or the coordination and control of machine tools, robots or handling systems have been further computerised [4]. Nonetheless, several shortcomings of CIM-systems have been discovered in the past leading to new approaches for production control [5]. One major drawback of the CIM strategy is that information is stored in local databases and systems are hierarchically controlled in a central manner. Reflecting the challenges mentioned in chapter 1, it is apparent that this approach requires a revisit and alternatives. With each component requiring a specific treatment based on individual customer preferences, the higher variety of products and the globalised production networks, a centralised approach reaches its limits. New approaches emerged, for example agent-based systems with the capabilities that agents, e. g. a defined object within the production, gain autonomous and intelligent behaviour [6]. The result is an increased production flexibility.

Still, information breaks remain, for example between the producers, who can barely gain information about the product lifecycle and thus a feedback of information from the product usage, if desired, is not feasible. Thus, it is necessary that the component itself becomes an active part of the system and contributes in order to improve functional designs, determine maintenance intervals or enable a unique identification and a fast, individualised production. With each component being able to carry information about its design, production, usage or recycling, the required information is always available on-side where needed. Hence, production processes can quickly be adapted and changes in production processes can be additionally stored at the component. Furthermore, components are equipped with a unique, secure and durable identification as a strong measure against counterfeit products. This allows a complete traceability of products within production during its lifecycle if desired. During the lifecycle, further information can be gathered and stored for example if a component has been replaced, changed or reconditioned. The capabilities of the products need to be augmented with corresponding technologies

2.2. Enabling technologies

Nowadays, the number of sensor systems as well as their diversity of application permanently increase [7]. The technology of Radio Frequency Identification (RFID) thereby currently experiences a tremendous growth and represents a key enabling technology to enhance a product capability in industrial application. RFID has already been successfully applied in production, transportation or for monitoring of components and leads to new possibilities in production engineering [8].

The increasing demand for RFID in production companies represents a first step to close the gap between the physical flow of materials and the corresponding information. Being attached on a product, a unique identification of the component becomes possible, information about the past production processes combined with corresponding quality results can be stored on the part and the communication between components, machines and infrastructure becomes feasible. During the production, the variety of products can be exactly differentiated and the product can communicate to the next production process which operations need to be carried out. The conventional centralised control is enhanced by new active objects within the supply chain. Simultaneously, new sensor technologies are being developed and further minimised enabling new strategies for condition monitoring and process control. Resistance strain gauges are for example a widespread measure to detect deformations in structural components. The evolution of components referring to their enhanced capabilities is depicted in Figure 1 referring to [9].

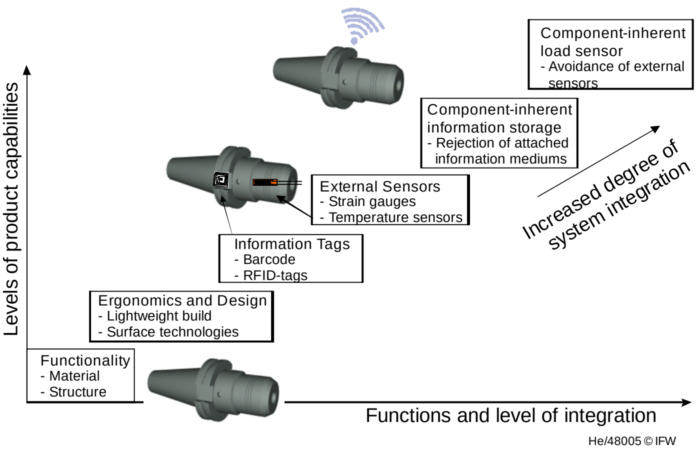

Figure 1. Enhanced component's capabilities.

By further integrating sensor capabilities into a product, the component is not only able to store and communicate information, but also to gather data about its current condition referring to temperature, load or pressure. The next step in this evolution is to integrate enhanced capabilities into a component for component-inherent data storage and load sensors. Several reasons can be mentioned: For example, sensors and RFID tags are usually limited by the geometry of the component. In addition, transmission problems have been encountered in combination with metallic components. Still, RFID-tags and external sensors can detach from the component, e. g. in aggressive machining conditions or during the subsequent treatment. Furthermore, as RFID-tags usually remain within the particular production facility, the further application of the component or the applied loads during its lifecycle remain inaccessible to the producer and thus to its design department.

3. The approach of gentelligent components

Thinking beyond conventional approaches to enhance the capability of components leads over to the next generation of components which do not only carry external sensors and identification tags but become an inherent sensor and data storage device itself. During its design and production, a component is equipped with these new capabilities. Comparable to the genetic evolution of nature, each generation of components will then share their lifecycle information in order to improve the successive generation. This leads over to the term of "gentelligent components". The expression itself consists of two concepts: Genetics and Intelligence [10]. Thus, a component is gaining "intelligence" in terms of additional sensorial capabilities and "genetic" capabilities referring to the possibility to store information about its re-/production inherently within itself. Thereby, production technologies provide promising possibilities. Exemplarily, selected technologies and corresponding regions of the component are depicted in Figure 2.

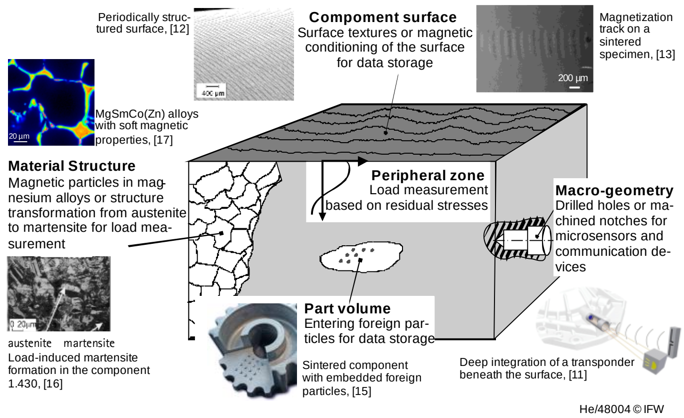

Figure 2. Alternative regions of a component and exemplary approaches for data storage or load measurement.

Within the component, several regions offer potential for augmenting the product capability in terms of data storage and sensorial characteristics: The component surface, material structure, part volume, peripheral zone and macro-geometry. Approaching from the outside, the surface offers different possibility to enhance the product's capabilities. The macro-geometry of the part, especially holes or notches can be used to integrate transponder deep into a component leading to a further integration of component and information [11].

Referring to the micro geometry and outer surface layer, information storage can be realised based on micro patterns entered during a machining processes (e. g. turning or milling) using a piezo-actuated tool [12]. A piezo-electric driven tool performs a motion in the direction of depth setting. The data in the surface can then be read out optically. Following a different approach, data can be written using an inductive magnetic writing head which moves above a specially sintered component and generates a magnetic data track within the surface region. For read-out, the magneto-optical Kerr effect (MOKE) is used [13].

Referring to the peripheral zone, the influence of load and fatigue on the subsurface properties, e.g. residual stresses, can be used to draw conclusions on the load history of a component and to predict the remaining life-span [14]. Referring to the inner region of a component, different approaches are currently under development. In sintering processes for example, it is possible to insert foreign particles or powder into a component at a specific position within the volume of the part. This enables data storage within the component. Since the foreign particles are located inside the component, the markings are not visible from the outside and can be read-out non-destructively and contactless using X-ray devices [15].

Referring to the material of the component, other effects offer possibilities for gentelligent components: In the material structure of metastable austenitic steels (1.4301 (X5CrNi18-10)), mechanical strain can render a transformation from austenite to martensite. By means of stamping during the production process, the initial martensite content can be locally set leading to an increased growth rate of martensite under further load. The martensite content can be measured using eddy current testing methods and conclusions concerning the load during the component's lifecycle can be drawn [16]. Another promising approach referring to the material is the production of defined magnesium alloys with magnetic particles leading to concentrated precipitation of magnetic intermetallic phases within the structure. This leads to magnesium materials with ferromagnetic characteristics which, in combination with eddy-current measurements for readout, can be used as inherent load sensors for the detection of component strains like for example elastic deformations [17].

4. Conclusion and outlook

By avoiding the physical separation between product and information and by understanding the capability of components to become inherent information carriers and sensors, companies can gain further competitive advantages in the future. In contrast to conventional approaches like for example RFID-tags, the approach of gentelligent components goes beyond the attachment of external sensors or data storage systems to a component. For a defined application, the implementation thereby depends on the components characteristics, the specific material and the available production processes. By further integrating these functions into a component, the risk of losing information by detaching external labels, tags or sensors is eliminated. Furthermore, information about the lifecycle of a component can be gathered by the component itself and is always available on-site. This will tremendously improve the design of the next generation of components, increase the amount of available information and contribute to production sustainability. In the future, it is planned to further develop the gentelligent components and combine these in systems, e. g. for machine tool or automotive structure monitoring.

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