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Manufacturing and use of novel sensoric fasteners for monitoring forming processes

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ABSTRACT

This paper presents sensoric fasteners which are produced by metal forming. Sensoric fasteners enable the monitoring of pretensioning forces and operating loads in mechanical connections between components. For the gathering of combined force and torque sensor signals in individual spatial directions the sensor unit has to provide the capability to transmit loads in all directions of space. The elementary sensors are integrated into the metallic fasteners structure during manufacture. This results in an assembly of supporting structure and sensor which shows a highly reproductive and sensitive interaction between its mechanical and electrical properties. In order to evaluate this interaction calibration measurements are carried out.

With the help of examinations of both stationary and transient running manufacturing processes it can be shown, that the new fasteners provide the mechanical connection between tools and machine as well as the possibility to monitor operating loads. The latter allows monitoring and analysis of process forces acting within the mechanical connections.

1. The demand for novel sensors in mechanical engineering

In fields of mechanical engineering, bolted connections play the most important role beneath all detachable connections. Due to the fact that loads acting on the joint can be multidimensional, the design of the bolted connection can be critical. This is complicated by the circumstance, that the possibilities to investigate the actual conditions in the bolt are very limited. On the other hand, a measurement location in screws would open up the possibility to efficiently detect reaction forces and -torques in the interface of components. Because of the standardized sizes and standardized joining conditions, bolted connections allow the establishment of an universal measurement equipment based on sensoric fasteners.

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1.1. Novel sensors in manufacturing processes

To fulfill the requirements of this measuring task a multi-axis sensor concept is needed. In the fields of research, there are several proposals for the design of sensors ranging in size from some hundred millimeters [1] (Fig. 1a) down to less than 10 mm [2] (Fig. 1b). In this context, examples of a common concept based on plate-beams with applied strain gauges for a six-axis force/torque sensor is introduced by Kim et al. [3] (Fig. 1c) and Tibrewala et al. [4].

The common disadvantages of the proposed sensors are the non-capsulated architecture and unstandardized sizes and measurement ranges. Especially these characteristics prevent a wide and industrial use of such measurement technology in the fields of mechanical engineering. Conclusively, there is a distinct demand for sensor assemblies, which can also be used in unfavorable production environments.

These sensors, according to Doege et al. [5], have the ability to equip monitoring systems that provide a signal

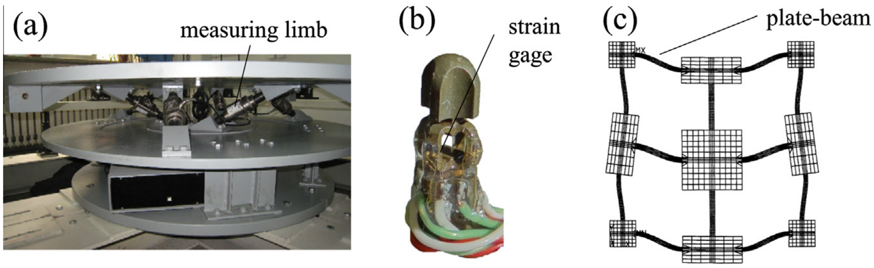

Fig. 1. Concepts for multi-axial force/torque sensors: (a) statically indeterminate sensor based on a modified stewart platform [1], (b) miniature tri-axial force sensor [2] and (c) six-component force/torque sensor based on plate beams [3].

analysis on the basis of suitable sensors in machine or tool. This allows reliable statements about the manufacturing process as well as the machine and tool condition. By observing recorded error conditions, it is possible to initiate a subsequent action at an earlier stage, resulting in the production of fewer defective parts [6]. A further benefit of monitoring is the increase of machine readiness by predictive diagnosis, which is for example proposed by Spiewak et al. [7].

An example for the use of process monitoring in a transient process is given by Li et al. [8] in conjunction with a steel ball forming process. The authors investigate different scenarios affecting the forming quality, including bad sized or misaligned semi-finished products, which lead to defect products. Within this research a novel force sensor needed to be integrated in the existing machinery. Fig. 2 shows the sensor (a) which is adapted to the cross section of the tool (b).

Further new development was needed for the example of the monitoring of a stationary process. Nyahumwa [9] proposed a cantilever sensor for cold rolling of sheet metal. The introduced sensor is capable to accurately measure normal and frictional forces acting at the roll-billet interface.

Besides the monitoring of forces, novel sensors are also used for structural health monitoring of bolted connections. Here the vibration based test method for example is used for the detection of bolt load loss [10]. Park et al. [11] propose the self-repairing of joints by employing shape memory alloy actuators which is shown in Fig. 3.

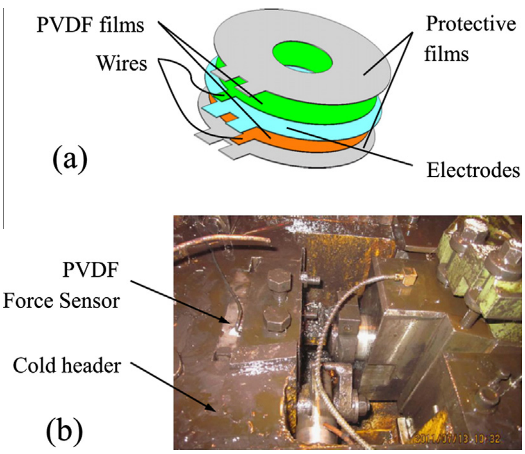

Fig. 2. The novel sensor (a) and which is adapted to the cross section of the tool (b) [8].

1.2. Integration of functional material into load-carrying structures

A key factor for any kind of monitoring is sensor integration. The parallel interaction among sensors enables a contemporary detection of occurring loads [12]. A novel approach is provided by smart structures, which are highly integrated systems consisting of functional material with sensory and/or actuatory capabilities and a load-carrying structure. Those structures enclose the susceptible functional material and seal it from harsh environments. Piezoelectric composite laminates for example are being used in aeronautic and aerospace structures [13]. Drossel et al. [14] investigate the fabrication of multi-layer composites with sensor and actuator functionality as well as their further processing in forming process. Those laminates with embedded sensors also found application in civil engineering in connection with load-carrying structures made of concrete [15] (see Fig. 4).

The fusion of carrying structure and smart materials with actuatory and sensory capabilities, proposed by Brenneis and Groche [16], enables new product architectures and the possibility of a cost-effective production by a joining operation which takes place simultaneously to the forming process.

Fig. 5 shows the test setup for the used infeed rotary swaging process. The assembly parts are loaded by rotary swaging dies and supported by an inner mandrel [17]. In order to protect the edges of the piezoceramics rings from high mechanical loading, protective end caps are used.

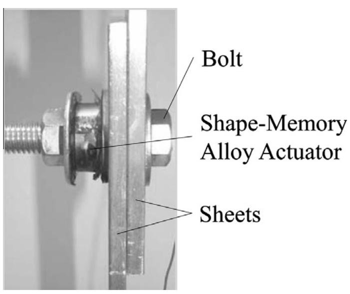

Fig. 3. Setup for self-repairing bolted joints [11].