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# Strain gauge based sensing hydraulic fixtures

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ABSTRACT

Clamping errors in workpiece positioning decrease the outcome of machine tools. To avoid rejects, which occur due to failures in the clamping, a sensory clamping system is being investigated at the Institute of Production Engineering and Machine Tools (IFW). The aim is to provide hydraulic clamping elements with sensory capabilities to enable condition and process monitoring of the clamping system inside the harsh environment of a machine tool.

Firstly, this paper gives a general survey of the targeted application and the concept to achieve a sensory clamping system for the industrial use in series production. Then it focuses on the integration of strain gauges into the exemplary chosen hydraulic swing clamp. Hereby, it shows the qualification of strain gauges for the estimation of different objectives, like hydraulic pressure, piston position, and external loads. Therefore, methods for the identification of suitable positions for the strain gauge integration into the clamping element are being discussed on the basis of experimental results and simulations. Furthermore, a method to achieve higher sensor sensitivity by 71% to the detriment of the compliance by 1.3% is presented.



## 1. Introduction

Clamping systems hold the workpiece in a defined position in the working space of a machine tool. Hence, positioning errors directly influence process behavior and machining results. Approximately 40% of rejects arise due to dimensioning errors that are attributed to poor fixture design [1].

The design and fabrication of fixtures take up to 20% of the total manufacturing cost [1–3]. Their quality often relies on the designers experience and is based on his understanding of the product. To reduce this dependency, but still provide a reliable clamping, much research effort has been focused on computer aided manufacturing. A broad survey of recent research and trends in computer-aided fixture planning (CAFP) and design (CAFD) are given in [1,3,4]. Most of the CAFP/CAFD methods have the aim to determine accessible and collision free locations of fixture points that ensure part immobility under the application of external forces and moments. Boyle et al. conclude, that many of the CAFD approaches have been tested for simple workpieces, which are not representative for those encountered in industry. Thus, the effectiveness of the developed techniques cannot be stated with confidence [4]. On this account, despite the accurate effort in the phase of fixture planning and designing, malfunction or failure during machining cannot be excluded.

Nevertheless, to ensure a reliable and sustainable manufacturing, different developments were done to enable machine components to monitor the machining processes [5–7] and to interact with manufacturing processes by using mechatronic systems [8]. Nee et al. [9] present an intelligent fixture prototype, which is capable of improving machined workpiece quality by controlling the clamping intensity. For the measurement of the clamping force, a direct sensing method with piezo-electrical force sensors was used. The direct monitoring methods can achieve a high accuracy, but due to numerous practical limitations, e.g. missing robustness against lubrication, these are characterized as laboratory oriented techniques [10]. To enable suchlike applications in industrial environment, sensor systems are needed, that are more suitable for practical applications at machine shop level.

An advantageous approach is presented by Litwinski [11] by integrating an intelligent sensor system into already existing components of a machine tool. Hereby, a modular clamping system is being investigated within the Collaborative Research Centre 653[1] in the project N1. The system determines the potential use and performance of a manual sensory clamping fixture for machine tools. Being a prototype of a basic research project and regarding the robustness it is not suitable for industrial use yet. The system is

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[1] www.sfb653.uni-hannover.de.

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characterized by integrated sensors for measuring cutting forces as well as accelerations and temperatures. The collected information allow assessing the current process state and the detection of process faults. The use for process monitoring offers outstanding performance. Therefore, the system is being transferred from research to industry within the transfer project T02 of the Collaborative Research Centre 653.

The aim is to develop a hydraulic clamping system, which is typically used in series production, with sensing capabilities in cooperation with two partners from industry, a clamping technology manufacturer and a fixture construction service provider. Error conditions such as wear, overload, incorrect setting, and improper use should be recognized to enable process and condition monitoring. In addition, the sensor integration, high system robustness, power and data transfer to rotating systems, and the consideration of cost aspects set special requirements to the application in an industrial environment.

Chapter Section 2 of this paper gives an overview of the overall concept to realize a sensory clamping system. Then it focuses in chapter Section 3 on the integration of strain gauges into hydraulic swing clamps to provide the fixture with sensing capabilities and ends with a conclusion in chapter Section 4.

## 2. Concept of the sensing fixture

The development of the sensory clamping system is carried out on the basis of a representative application scenario. It deals with the hydraulic clamping for multi-axis machining of cast casing covers. The simplified system structure is shown in Fig. 1a. The exemplary hydraulic clamping fixture (see Fig. 1b) is an assembly, which consists of a fixture plate, three hydraulic swing clamps with appropriate supports, and one hydraulic work support. The supply of oil for the hydraulic clamping elements within the fixture is realized by drilled hydraulic lines inside the fixture plate.

The realization of a sensing clamping fixture will be achieved by the sensor integration into the hydraulic clamping elements. Intended measurement quantities are strains, accelerations, and temperatures. Every sensory clamping element possesses an embedded micro-controller based hardware for signal-preprocessing. This serves several purposes: the shortening of susceptible analog transmission paths by digitalization close to the sensors, and the connection to a common fieldbus to enable communication abilities. In this way, it is possible to expand the fixture by additional sensory clamping elements with little effort. The transfer of the sensor information to an industrial PC for central data processing is established by an additional fieldbus participant via radio link. For the communication with the PLC of the machine-tool, e.g. to send status information, the industrial PC is provided with a PROFIBUS-interface.

To enable the multi-axis machining the fixture has to be mounted on a rotary table. Therefore, a hybrid rotary coupling is used to supply the fixture with electric and hydraulic energy. This unit is a combination of a rotary coupling for hydraulic oil and induction coils for contactless energy transfer. A typical voltage of 24 V DC is used and converted into AC voltage for the primary induction coil by an embedded circuit board.

## 3. Sensor integration

This chapter deals with the sensor integration. First the monitoring objectives and error conditions are described in Section 3.1. After that, the concept for the sensor integration is shown in Section 3.2. In Section 3.3 the result of preliminary experimental analysis are discussed, which led to the development of the methods for signal improvement that are described in Section 3.4.

### 3.1. Monitoring objectives and error conditions

The main task of hydraulic clamping elements is to convert hydraulic energy into mechanical clamping force. Hence, the actual present oil pressure inside the clamping chamber influences it directly. This principle is well known and used in hydraulic clamping systems for setting the clamping force by controlling the operating pressure at the hydraulic pump to a desired level. During the period of use different error conditions, e.g. leakages at hydraulic

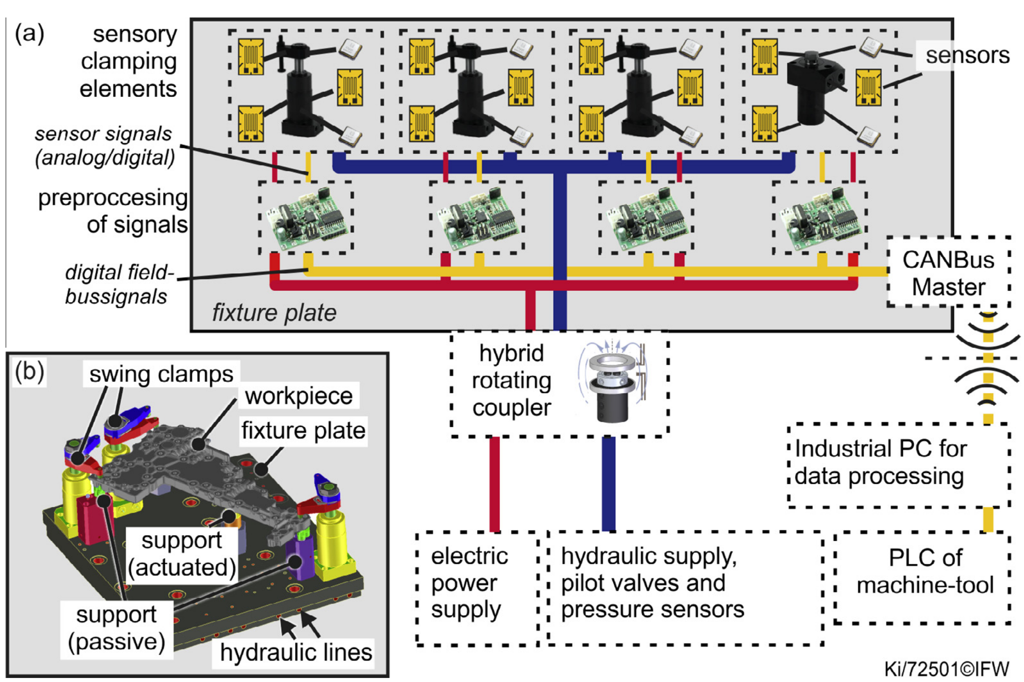


**Fig. 1.** (a) System overview and (b) hydraulic clamping fixture.