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Observations of surface acoustic wave strain and resistive strain measurements on broaching tools for process monitoring

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Abstract

The monitoring of high end material removal processes continues to develop to greater levels of technical sophistication which in turn enable greater levels of insight into the process phenomena occurring at the tool-chip interface. The broaching process is a traditional machining process which is used extensively in the manufacture of some of the most expensive components of the aero engine. As a relatively slow cutting process with low degrees of freedom, broaching could be a target for strain based monitoring. It is well known that strain gauges provide a rich source of data when installed close to the cutting process. This research provides insight into the resistive strain gauge measurements during broaching. The paper also specifically focuses on the use of surface acoustic wave based strain measurement and provides some initial observations on the strain data available during tooth loading and cutting scenarios in broaching.

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Keywords: broaching tooth; strain field; monitoring

1. Background

The topic area of sensors and monitoring in machining processes has been recently reviewed by Teti et al[1] providing a comprehensive body of information on the state of the art ranging from sensor systems to signal processing and decision making algorithms. However the use of monitoring in broaching processes is a relatively limited despite the critical nature of the broaching of aero engine components such as fir-tree slots. Monitoring of aero engine manufacturing processes has received renewed attention in recent years by researchers such as Klocke et al[2] and Veselovac[3] who have strong collaborations with aero engine component manufacturers.

Axinte et al[4] also carried out significant research on the monitoring of broaching processes where a variety of sensors were applied to a servo-hydraulic broaching machine including acoustic emission, vibration, cutting forces and hydraulic pressure. The authors demonstrated good correlation between defects in the broaching process and acoustic emission, vibration and cutting forces and ranked the sensors in order of the ability to detect tool condition with combinations of time and frequency analysis of the sensor signals.

Of particular interest in broaching is measurement of cutting forces and this has involved the development of special purpose workpiece fixtures that have been combined with various force sensor systems [2]. The platform provides essential data for validation of models of forces in broaching such as the work reported by Vogtel et al[5]. With the renewed interest in the modeling of the broaching process [5-7] there is a requirement for novel approaches for the validation of the models with accurate measurements.

Up to this time there has been relatively little focus on the strains and forces experienced on the tool side of the broaching process. Axinte et al[8] investigated the monitoring of various broaching tool profiles with forces, vibration and acoustic emission, but the focus was on the workpiece. Monitoring forces and strain on the tool side is challenging due to the motion of the broaching tool, limited access to the

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broaching tooth, and the complex tooth profiles. This research paper proposes an approach for strain based measurement on the tool side using both wired resistive strain gauges as a reference, and novel wireless Surface Acoustic Wave (SAW) based strain sensors.

Figure 1 below illustrates the SAW sensor concept. An incident short duration RF signal is transduced into a surface acoustic wave which propagates along the surface of the device setting up a standing wave and causing the device to resonate at a so-called centre frequency. Mechanical strain modulates this centre frequency. An RF interrogator is used to supply both the energizing RF pulse and detect the change in the resonant frequency of the SAW device.

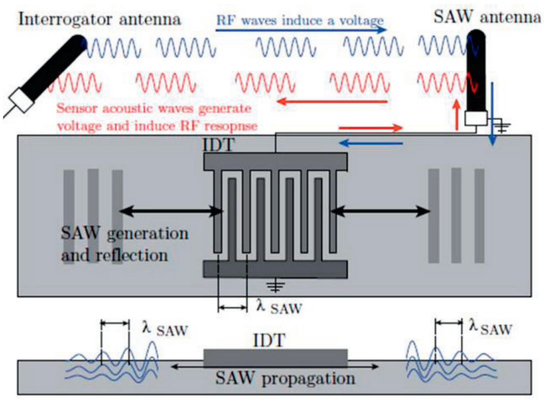

Fig. 1. Typical SAW sensor layout showing concept [9].

In the past there have been limitations with integrating SAW sensors into applications, primarily due to a lack of commercially available interrogation systems. However commercial off-the-shelf solutions for temperature monitoring in high end applications such as turbine blade are now available. Up to now strain measurement using SAW devices has been largely confined to the research domain possibly approaching TRL 6 to 7.

Recently work by Stoney et al[9] demonstrated the principle that surface acoustic wave strain based monitoring of turning processes is possible. Further work demonstrated real time measurement of strain up to 240Hz [10].

Through appropriate miniaturisation and integration SAW sensors can be positioned close to the cutting action in order to wirelessly measure strain. Monitoring of the cutting process in broaching has the potential to detect critical tool conditions that may cause issues with workpiece sub surface integrity leading to potential failures of the part in service. Wired strain measurement solutions have limitations and disadvantages in the industrial implementation due to specialist effort to protect and route cables in the harsh environment of broaching. This paper reports on the first work using wireless SAW strain sensors in the broaching process aimed at overcoming the drawback of wired sensing solutions.

2. Experimental approach and setup

A broaching analogous process was set up in order to facilitate measurement using a Kistler dynamometer type as shown below.

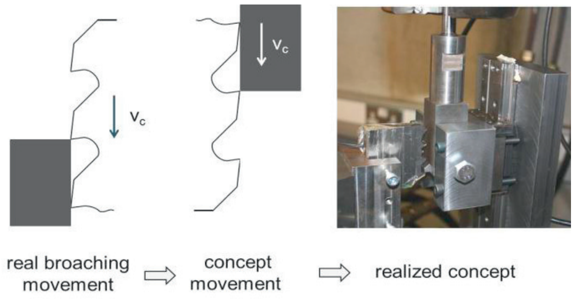

Fig. 2. Broaching analogous process for measurement of force and strain during broaching.

It can be seen that the analogy involved the movement of the workpiece sample relative to a stationary broaching tool in order to facilitate measurement of forces experienced by the broaching tool. An Instron 8874 multiaxis servo-hydraulic loading machine type was used to provide the force and movement in the vertical axis. Rigid tool and workpiece clamps and precision linear guideways were manufactured for the test scenario.

A generic measurement chain for high speed data acquisition was reconfigured for the purpose of monitoring sensors signals from the Kistler dynamometer, the resistive strain gauges, and the SAW strain sensors. Figure 3 shows the measurement chain for the experimental setup using National instruments C-DAQ hardware.

The Kistler type 9263 dynamometer was connected via charge amplifiers to the analogue input card type C-DAQ 9239. The wireless SAW sensors were connected through an interrogator and sampled at 45Hz with one additional option for higher sampling at 5kHz through an analogue input channel.

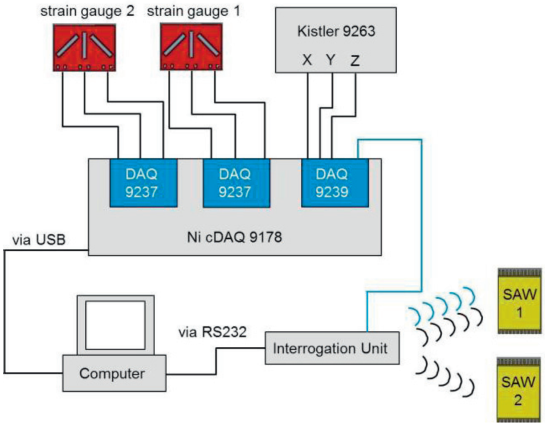

Fig. 3. Schematic of the measurement chain showing Kistler, Strain and wireless channels.