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THE MEASUREMENT OF FORCES IN TURNING OPERATIONS

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Abstract: *This paperdescribes the development of a new concept of cutting tools using strain gages for the measurement of forces in turning operations. The report describes the development of a new way of production remote control and long-range diagnostics of the controlled subsystems with orientation on the data communication. The basic idea is the integration of the sensor within the tool shank, in order to obtain a system which is easy to use, easy to install and capable of transmitting data to the CNC through wireless equipment. In particular, the output signal of the measurement bridge is amplified and sent to an external data acquisition system by infra-red transmission.*

Keywords: *Tool Condition Monitoring, Turning, Cutting Force Measurement.*

1. INTRODUCTION

Since no exact and reliable mathematical models exist for the cutting process which are able to predict tool wear, tool breakage, surface quality, cutting temperature, forces and power, the development of monitoring systems for tools and machine tools has always been highly requested by industry, especially in recent years. The last review CIRP has clearly outlined the evolution of this research topic: from the study of the, working principles of sensors to their inclusion in a sensing system. In this regard, it can be pointed out that cutting force is a good indicator of cutting conditions.

2. DESCRIPTION OF THE STRAIN GAGE

When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur. For a uniform distribution of internal resisting forces, stress can be calculated (Fig. 1) by dividing the force (F) applied by the unit area (A): Stress(σ)=F/A

Strain is defined as the amount of deformation per unit length of an object when a load is applied. Strain is calculated by dividing the total deformation of the original length by the original length (L): Strain (ε)=(ΔL)/L

Fundamentally, all strain gages are designed to convert mechanical motion into an electronic signal. A change in capacitance, inductance, or resistance is proportional to the strain experienced by the sensor. If a wire is held under tension, it gets slightly longer and its cross-sectional area is reduced. This changes its resistance (R) in proportion to the strain sensitivity (S) of the wire's resistance. When a strain is introduced, the strain sensitivity, which is also called the gage factor (GF), is given by:

$$GF = (\Delta R/R)/(\Delta L/L) = (\Delta R/R)/Strain$$

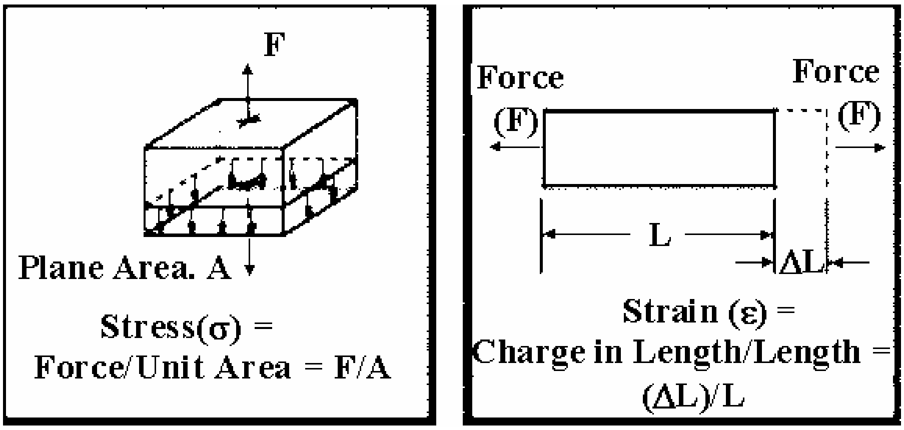

Fig. 1 Definitions of Stress & Strain.

Bonded Resistance Gages

These devices represent a popular method of measuring strain. The gage consists of a grid of very fine metallic wire, foil, or semiconductor material bonded to the strained surface or carrier matrix by a thin insulated layer of epoxy (Fig. 2). When the carrier matrix is strained, the strain is transmitted to the grid material through the adhesive. The variations in the electrical resistance of the grid are measured as an indication of strain. The grid shape is designed to provide maximum gage resistance while keeping both the length and width of the gage to a minimum. Bonded resistance strain gages have a good reputation. They are relatively inexpensive, can achieve overall accuracy of better than +/-0.10%, are available in a short gage length, are only moderately affected by temperature changes, have small physical size and low mass, and are highly sensitive. Bonded resistance strain gages can be used to measure both static and dynamic strain.

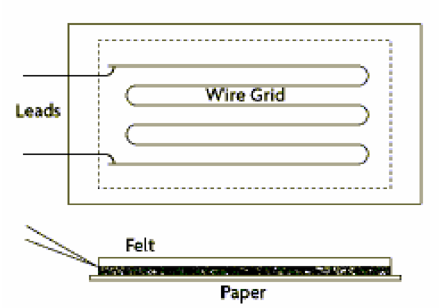

Fig. 2 Bonded Resistance Strain Gage Construction.

In bonding strain gage elements to a strained surface, it is important that the gage experience the same strain as the object. With an adhesive material inserted between the sensors and the strained surface, the installation is sensitive to creep due to degradation of the bond, temperature influences, and hysteresis caused by thermoelastic strain. Because many glues and epoxy resins are prone to creep, it is important to use resins designed specifically for strain gages. The bonded resistance strain gage is suitable for a wide variety of environmental conditions.

3. DESCRIPTION OF THE SYSTEM

The design of the system has been based on the following main technical specifications a conventional tool for turning operations is used, the parameter measured on-line is the force exerted by the cutting part, the signal should be transmitted to a receiver installed outside the operating area of the machine tool, maintenance should be minimal (periodical battery change), the working principle and the installed devices should be implemented with acceptable costs (comparable to two or three times the cost of a conventional tool without sensors). These requirements have been satisfied by the system illustrated in Fig. 3.

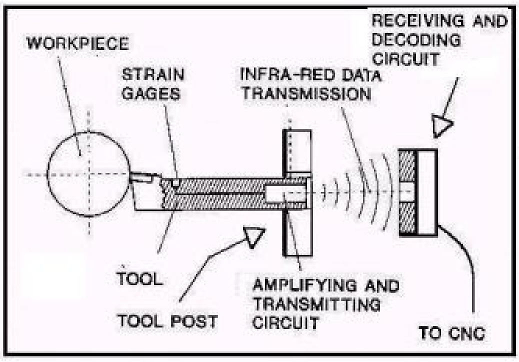

Fig. 3 Schematic view of the sensor integrated tool system.

4. THE SENSING SYSTEM

The choice of electric strain gages for measuring cutting forces was suggested following these considerations.

- the sensitivity which allows a stress to be detected without leading to a decrease in stiffness,
- the possibility to be directly applied to the tool with the minimum modification of shape and size;
- relatively simple signal conditioning.

Severe thermal transients are expected in the region near the insert due to the heat generated during cutting. In order to avoid the use of special strain gages and cements and to increase sensitivity, a location was selected as far as possible from the tool tip, while still being within the overhang area of the tool. Due to the relatively high stiffness, the strain induced by the cutting force is small and temperature compensation is necessary For this reason, two 90° stacked rosettes were applied in a full Wheatstone bridge arrangement. Preliminary tests were performed on a servo-hydraulic testing machine. The results showed good linearity and near absence of hysteresis.

5. THE SIGNAL PROCESSING CIRCUITS

The signal processing is performed in 2 stages:

- an amplifying and transmitting stage,
- a receiving and decoding stage.

The signal of the Wheatstone bridge is processed by a CMOS chopper-stabilized amplifier having a very low variation of offset voltage with temperature and a gain of 200. The amplified signal is converted by a voltage-to-frequency integrated circuit and sent to an infra-red emitter diode placed in the rear side of the tool. Optical transmission was preferred since:

- it can be shielded from light sources with different wave length and from electro-magnetic disturbances;

- it can be easily positioned within the tool shank.

The receiving and decoding circuit has been placed outside the working area of the lathe, on the axis of the emitter diode. The signal is received by a photodiode, amplified and sent to a frequency-to-voltage converter. At this point the signal is formed of two separate elements:

- an offset voltage, deriving from the power supply system of the transmitter, the initial unbalancing of the measurement bridge, thermal effects, etc. Before sending to the CMC, the offset component is eliminated, evaluating its amount as an average value of the output signal when the tool is not cutting. Preliminary tests, performed on the electronic circuit, have shown the following main characteristics: » maximum allowed transmission distance: 380 mm;
- maximum allowed misalignment of transmitter and receiver axes: 60 mm (measured at a transmission distance of 270 mm):
- average output drift[1] 12.6 mV/h (measured at room temperature), 13.6 mV/h (measured at 40°C).

6. CONCLUSIONS

This research has led to the development of a first prototype of 3 sensor integrated tool for force monitoring in turning operations.

In addition to the typical advantages of a sensor integrated within the tool (force measurement close to the machining point, no modification of the machine tool), the proposed solution shows further interesting aspects:

- negligible reduction in the static and dynamic stiffness of the tool;
- no modification of the external dimensions of the tool,
- quick and easy installation on the machine tool;
- adaptability to workshop conditions,
- acceptable costs.

The cutting tests demonstrated the capability of the system to correctly monitor the force exerted by the cutting part under different conditions. Future developments will mainly concern the improvement of the sensor, in order to separately measure the force components, and of the control circuit, in order to reduce its dimensions and integrate the battery within the tool shank.

7. REFERENCES

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