The sensing system by electric strain gages.

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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 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 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.1.

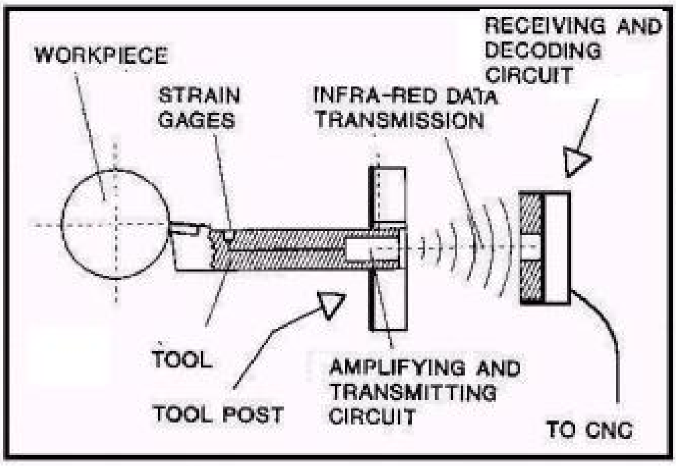

Fig.1 - Schematic view of the sensor integrated tool system.

3. 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.

4. 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).

5. PERFPRMANCG ANALYSIS AND RESULTS

The performance of the system was verified by means of several cutting tests. A PSBNR2525M15 tool and an SNMG150608 insert (P45 ISO grade, coated with TIN and TiC) were used. The workpiece material was AISI 1015 and all the cutting tests were performed with coolant. The data were stored adopting an acquisition frequency of 10 Hz.

In order to make a comparison with a commercial system, the cutting tests were repeated using the same type of tool and insert (without integrated sensor) mounted on a piezo-electric dynamometer for the measurement of the 3 components of the force exerted by the cutting part. The main results obtained from the tests can be summarized as follows:

- tests__with constant_cutting_j3arameiers: The latter test was repeated with worn cutting edges, detecting a variation of the output signal: using a cutting edge with a flank wear having a VB = 0.23 mm, an increase of about 12% of the average value of the signal was measured.
- tests_with change in feed: Output signal obtained by varying the feed stepwise from 0.2
  mm/rev to 0.4 mm/rev.
- tests with change in depth of cut: An example of stepwise changes in depth of cut, from a minimum value of 0.50 mm to a maximum of 1.15 mm. Fig.8 shows the behaviour of the system in the case of a linear variation of the depth of cut, from 2 mm to 1 mm.

The results emphasize that the output obtained by the sensor integrated tool agrees, within acceptable accuracy, with the signal generated by the piezo-electric dynamometer, and produces an output proportional to the linear combination of the 3 components of the force. Within the limits of experimental errors and taking into consideration the geometry of the tool used in the tests, comparison of the diagrams leads to the evaluation of the following influences of the 3 components on the output signal. 69% for cutting force F_c, 23% for feed force Ff, 8% for back force F_p.

The results obtained from the tests also emphasize the following conclusions:

- sensor repeatability: tests made under the same cutting conditions demonstrate that the average signal level always lies within a range of ±3%;
- sensor sensitivity: this is approximately 0.24 mV/N with respect to the cutting force F_c In this regard, shows that the tool is able to measure very low variations in the force: a variation of the depth of cut from 0.50 mm to 0.55 mm generates an increase of the average vaiue of the signal of about 11%;
- disturbance sensitivity: all the tests clearly showed the very low sensitivity of the system (sensor and data transmission device) to environment disturbances, such as coolant or chips.

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.

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