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Influence of thermoelectric junctions on the electrical signals generated by the tool–workpiece thermocouple system in machining

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ABSTRACT

This work investigates the influence of the electrical circuits on *TMF* (total thermoelectromotive force) response signals captured from the rotating workpiece generated by the tool–workpiece thermocouple system in turning process considering four different thermoelectrical circuits – Ec namely: C_1 – bronze pin, C_2 – aluminum pin, C_3 – graphite brush and C_4 – liquid mercury contact. The tests were carried out under different cutting conditions. A multifactorial analysis of variance was performed using the 2^k factorial design, always considering the C_4 as the lower level. In addition, a single factor analysis of variance was performed, keeping the cutting speed, Vc, the feed rate, f, the depth of cut, doc, and the lubri-coolant system, Lub, constants while varying the Ec in order to validate the results found with the factorial design. The results indicated that there was no statistical significant difference in the *TMF* responses of the tool–workpiece thermocouples C_1 and C_4 as well as C_2 and C_4. However, when comparing the *TMF* generated by C_3 and C_4 a significant difference was detected, indicating that graphite brushes is not recommended for such application, while the bronze and aluminum pins can be thought as an advantageous substitute for the laborious liquid mercury system.

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1. Introduction

The action of the cutting tool causes intense plastic deformations on the primary and secondary shear zones of the machined material, whose work is converted almost entirely into heat around the cutting edge of the tool [1–3]. In machining high productivity is always pursued and this is usually achieved increasing the cutting speed and feed rate which in turn increases deformation rates of the work material and hence the cutting temperature, principally when cutting high resistance and high melting point materials [2,4–7].

Among the main problems that high cutting temperatures can cause are tool wear, residual stresses and workpiece distortions [2,8,9] especially in thin-walled workpieces [7]. Measuring the temperature in machining is not an easy task but important in order to study its behavior and effect on the product quality. A method for measuring the cutting temperature that is widely employed to monitor the temperature in the region of the chip–tool interface is the tool–workpiece thermocouple system [10–12].

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A thermocouple signal is generated by the electrical potential difference formed by the movement of electrical charge (*tmf:* thermoelectrical motive forces) between two different materials in contact due to the temperature gradient between its ends [13]. Two main laws govern a thermocouple circuit: (1) A thermoelectric current cannot be sustained in a circuit of a single homogeneous material, however, varying in cross section, by the application of heat alone; and (2) the algebraic sum of the thermoelectrical motive forces in a circuit composed of any number of dissimilar materials is zero if all of the circuits are at a uniform temperature [14].

In machining, the cutting temperature at the chip–tool interface can be determined by a thermoelectrical motive force which is proportional to the temperature in that region [8]. A technique that has provided good results in the acquisition of the *TMF* signal from the tool–workpiece thermocouple in turning processes is the one that uses a mercury bath to provide contact with the rotating workpiece and hence shutting the electrical circuit [5]. However, this method may involve some inconveniences such as environmental contamination if the mercury bath is not hermetically closed or encapsulated because this is a very toxic chemical element; and depending on the setup, it may generate vibrations, particularly under severe cutting conditions.

Another way to capture the voltage signal of the tool–workpiece thermocouple is by using a conducting element such as a graphite brush sliding on the workpiece surface [15]. However, depending on the surface quality and the collection point on the workpiece, it may generate considerable noise in the *TMF*.

The two main difficulties in using a tool–workpiece thermocouple system during machining for acquisition of the *TMF* signal of the tool–workpiece interface are: (i) to acquire the *TMF* signal from the rotating workpiece; (ii) the *TMF* signal measured by the multimeter is actually the algebraic sum of the thermoelectric motive forces (*tmf*) generated by all the junctions that such electrical circuit is comprised of.

The aim of the present work is to compare the simultaneous *TMF* (total Thermoelectrical Motive Force) responses produced by four different circuits (C_1, C_2, C_3 and C_4) used for the tool–workpiece thermocouple system when turning an AA-6263 aluminum alloy. In these circuits there are several thermoelectrical motive junctions (J_i) that allow the passage of electrical current. The pins that make contact with the rotating workpiece of the C_1, C_2 and C_3 circuits are made of different materials (bronze, pure-aluminum and graphite) while C_4 circuit make contact with aluminum-bar by mean of the traditional metallic liquid mercury bath. The TMF_4 response of the C_4 circuit was taken as the reference for the comparisons assigned.

Although liquid mercury is a material of high thermal conductivity and low friction coefficient and hence it normally provides a noiseless electrical circuit of the traditional tool–workpiece thermocouple system, this work aims to look for a possible substitute, in order to simplify the system, as well as eliminate safety risks that the toxic metallic mercury may cause.

Table 1
Chemical composition of the AA-6263 aluminum alloy.

Elements	Al	Si	Cu	Mg
Weights (%)	98	0.40–0.60	0.28	0.70–1.00

Table 2
Properties of the work material (25 °C).

Properties	Density (g/cm^3)	Young modulus (GPa)	Tensile strength (MPa)
Values	2.7	70–80	90

Table 3
Properties of the cutting fluid (Vasco 1000) according to the manufacturer.

Properties	Density (g/cm^3)	Viscosity (mm^2/s)	Flashpoint (°C)
Value	0.95 (20 °C)	56 (40 °C)	180

2. Experimental procedure

2.1. Workpiece material and consumables

In this experiment an AA-6263 aluminum alloy bar ($\sim\varnothing 80 \times 400$ mm) was used as work material with the chemical composition and properties given in Tables 1 and 2, respectively.

In the wet machining condition a base vegetable oil (Vasco 1000 – manufactured by Blaser Swisslube) with the properties given in Table 3, was used at a concentration of 6% (checked with an Atago hand refractometer). It was pumped in the cutting area through a nozzle with a flow rate of 360 L/h.

2.2. Equipment and tools

Turning was carried out on an Imor 520 lathe with 11 kW of power manufactured by Indústrias Romi S.A. A toolholder with ISO specification "DCGT3252-AL/KS05F" and N05 cemented carbide inserts (ISO specification "DCGT11T308-AL KS05F") manufactured by OSG-Tungaloy were used. When an insert is mounted on the toolholder, the following geometry is derived: $\alpha_o = 7°$ (clearance angle); $\gamma_o = 20°$ (rake angle) and $\chi_r = 90°$ (approach angel). The *TMF* on the electrical circuits was measured with an high impedance (1 M Ω) voltmeter, Agilent 34970A (resolution of 0.000001 V).

2.3. Factorial design and analysis of variance

To carry out the experimental investigation a 2^4 factorial design was used with the following input factors: cutting speed, feed rate, lubri/cooling condition and the electrical circuit. The low (-1) and high (+1) levels of the factors were: cutting speed – Vc (73 m/min, 363 m/min); feed rate – f (0.138 mm/rev, 0.388 mm/rev); lubri/cooling condition – Lub (dry, wet) and electrical circuit – Ec (C_1, C_2, C_3, C_4), which has generated the TMF_1, TMF_2, TMF_3 and TMF_4 keeping the depth of cut (doc) constant at 0.5 mm. Since the Ec had four levels, the analysis of variance/significance of the factors

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