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Detailed contact surface evaluation based on electric field potentials

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Abstract

This paper presents a novel method for the evaluation of the contact between opposing faces of machine parts. In high speed machining, modal damping of the machine-tool-workpiece loop plays a key role in the stability of the process. Due to prior experiences, the majority of structural damping originates in dry friction. The presented method maps the contact patch among opposing faces based on measured electric field potentials, hence providing reliable fundamentals for friction models. A neural network was trained on a data set generated by a finite element software, and the numerically predicted contact patterns were validated by measurement results.

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1. Introduction

The proper modeling of machining processes requires the accurate measurement of various system parameters. Unfortunately, if a structure is composed of several parts, the interactions at the joints are difficult to evaluate – however, they have a major influence on the modal parameters. In the present paper a method is proposed for the reliable evaluation of the mechanical contact between metallic machine parts.

Besides the natural frequencies of the machine-tool-workpiece system, the damping properties play a key role in the stability of cutting processes [1,2], where the so-called regenerative effect makes the stability calculations non-trivial.

The damping properties of materials and structures are related to various physical phenomena [3]. In engineering structures or machines, the material damping of metals is usually negligible compared to the so-called structural damping [4]. Structural damping is strongly related to the relative motion between structural elements, thus, the corresponding models are mostly based on the well-known Coulomb friction model [5].

Although the Coulomb friction force is primarily related to the normal force between the bodies, the distribution of the pressure may have a large influence on the natural frequencies and damping properties of the structure. Several models were introduced in the scientific literature in order to describe the contact of solid bodies and the unavoidable friction between them.

Elastic contact problems were rigorously solved by Hertz [6], and his results still provide a reliable base for the estimation of contact stress if smooth surfaces touch each other. However, macroscopically smooth surfaces are rough on finer scales and – as it was pointed out by Bowden and Tabor [7] – the real contact area is only a small fraction of the apparent area. Several models were coined since then for the description of the distribution of the contact pressure. The multi-scale or fractal models of contact can be traced back to Archard [8], while Greenwood and Williamson [9] developed a very successful model that is based on the height distribution of asperities. Despite the popularity of their approach, it turned out that certain assumptions of the model must be revised [10]. Nevertheless, they pointed out that the real contact areas are sometimes evenly distributed, while clustering can be observed in other cases. Thus, the evaluation of the contact pattern or contact patch has significance in the characterization of the contact.

As the computational capacity of computers reached a sufficiently high level, researchers started to use numerical simulation for the calculation of the dependence of contact properties on normal force, based on measured or generated

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surface topography and the theories of elasticity and plasticity [11].

It is worth to mention that the interaction of contacting bodies can be described on an atomic or molecular level, too (see e.g. [12,13]). However, for the application of the contact theories in the engineering practice, one must choose a proper macroscopic scale for the characterization of the contact. On a large scale, even the application of machinist's blue (soft liquid or hard paint) can reveal the contacting areas or highlight the points of excessive wear.

In case of well-machined surfaces – e.g., the mating surfaces of the tool-holder and the main spindle in milling machines – a more refined method needs to be developed that can provide information about the actual contact, i.e., when the parts are not separated. This is especially important if the damping properties are to be characterized, since the friction force was found to increase in time [14].

2. Principles of the method

Our method is based on the dependence of electrical contact resistance on the normal force or pressure. This relationship was examined by several authors, see e.g. [9,15,16]. The connection between these two physical quantities is often exploited for the evaluation or design of the contact resistance, based on mechanical properties. This problem is especially important during the design of electric switches or arc-welding processes [17]. However, the inverse problem – evaluation of mechanical contact based on measured electrical resistance – is not examined in the scientific literature. For the application of the proposed method, the nominal contact area must be partitioned into a discrete number of smaller regions. The physical characteristics of the contact (electrical resistance, contact pressure and stress) can be defined according to the resolution of the partition. By keeping the electrical current constant and measuring the electric voltage between several pairs of points on the two bodies in the vicinity of the contact, the electrical resistance can be characterized on each region. The variation of the measured voltage values along the perimeter of the contact area provides information about the mechanical contact pattern. For the calibration of the obtained discrete contact pressure distribution, the equilibrium of forces and the results of additional electrical resistance measurements can be used.

2.1. Quantifying contact resistance

In order to quantify the contact resistance, a sufficiently thin layer of virtual material is assumed between the contact surfaces. The electric resistance of this layer, R_c can be calculated such that

$$R_c = \delta \rho_0 \frac{t}{A}, \tag{1}$$

where ρ_0 is the specific resistivity of the reference material in the contact; δ is the relative specific resistivity, t is the thickness and A is the area of the virtually added layer. Let us introduce a new parameter,

$$\lambda = \delta t \,. \tag{2}$$

As a consequence,

$$R_c = \rho_0 \frac{\lambda}{A}, \tag{3}$$

hereby λ represents an equivalent thickness of the mating materials that has the same resistivity as the virtually added layer.

As discussed in Sect. 1, we follow the assumption that the majority of contact force is transmitted through a number of domains with high contact pressure, yet the greater part of the surfaces is subjected to relatively small or even no pressure. With respect to this, dimensionless conductivity, c is used instead of λ, defined as

$$c = \frac{L}{\lambda}, \tag{4}$$

where L is a characteristic linear dimension. The advantage of using a conductivity-like quantity instead of a resistivity-like one is that the no pressure zones will be characterized by $c = 0$ instead of $\lambda = \infty$, hence providing more favourable range of numerical values for the analysis.

2.2. Measuring contact resistance

Pressure vs. contact resistance can be directly measured in case of quasi uniform pressure distribution on a large scale. But in case of varying contact resistance only indirect measurement methods are available. In order to avoid singularities and to eliminate the contact resistance of the electrodes itself. The current is generated by a current source between points A and D, while voltage is measured between B and C, as shown in Fig. 1.

Dividing U_{BC} voltage by the current I_{AD} is not equal to the contact resistance, even in the hypothetical case of measuring voltages just on the edges.

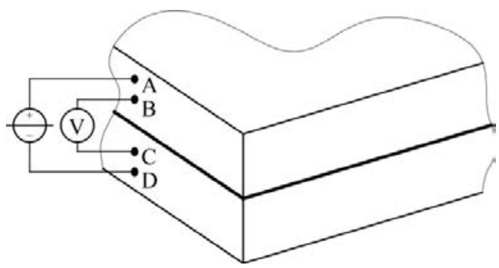

Fig. 1. Current is generated between A and D, voltage measurement is realized at the in-between points, B and C.

In the present paper, we are dealing with the one-dimensional problem as a first approximation, i.e. the