10th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

STUDY OF CUTTING TEMPERATURE IN ORTHOGONAL MILLING

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ABSTRACT
Finite Element Method (FEM) based techniques are available to simulate metal cutting processes and offer several advantages including prediction of tool forces, distribution of stresses, and temperatures, estimation of tool wear, and residual stresses on machined surfaces, optimization of cutting tool geometry, and cutting conditions. However, work material flow stress and friction characteristics at cutting regimes are not always available. The complexity of the phenomena, met within this framework, often limits the approaches to a configuration known as "orthogonal cutting".
In this work we approach in the experimental study, between other aspects, of the measure cutting temperature employing different techniques: pyrometers, thermocouples and a thermographic camera. We began the analysis of an orthogonal milling. These results have to allow us to check the numerical model of the process.
Keywords: orthogonal milling, temperature measurement, FEM

1. INTRODUCTION
Milling process is one of the most widely used processes for material removal in manufacturing industries. Recently the development of precise and reliable milling models has received considerable attention in the academic and industrial fields.
In General, the objectives of the research realized in this area, they have tried to create a model that allows predicting the principal aspects of the process. In 1941, Ernst and Merchant developed the first orthogonal cutting model [1], showing the connection between the geometry of simple cutting operations and the behaviour of the material. Recent research is based on the numerical modelling of the process of chip formation [2].
It is necessary for modelling a process to characterize the influence factors and the laws of behaviour of the machining parameters. In this way, it is possible to relate the input variables: properties of the material to mechanize, tool (geometry, material and coating), conditions and geometry of the cutting process (feed rate, cutting speed and depth of cut) with the output variables: cutting forces, power consumed, distribution of temperatures, tool wear, vibrations and dimensional aspects of the workpiece.

The numerical modelling of chip formation is complementary to the existing methods. It helps diverse sectors related to the machining like: development of cutting tools, optimization of the machining processes or even, development of materials used in the manufacture of products and tools. In addition, it allows the analysis of phenomena that are difficult to observe and understand. It uses experimental essays and real cases, facilitating the comprehension of the material removal process. Besides, it reduces the number of experimental necessary essays.

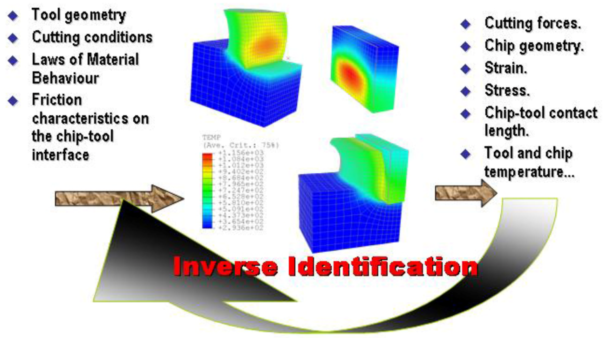

Figure 1. Inverse Identification Process

Some of the most critical aspects to obtain a correct chip formation modelling, they are the use of laws of material behaviour and the chip-tool contact. These features have to be identified in similar machining conditions [2]. This point is solved by means of an adequate recognition of these laws with inverse identification methods, in which the difference between the simulation and empirical results are minimized with techniques that use laws of material behaviour such as Johnson-Cook.

In the minimization process are used input variables that can be studied with the adequate precision in an experimental way [3], for example the temperature. A target function could be the following:

$$\theta = \sqrt{\left(\frac{F_{c\,sim} - F_{c\,exp}}{F_{c\,exp}}\right)^2 + \left(\frac{F_{f\,sim} - F_{f\,exp}}{F_{f\,exp}}\right)^2 + \left(\frac{e_{sim} - e_{exp}}{e_{exp}}\right)^2 + \left(\frac{l_{c\,sim} - l_{c\,exp}}{l_{c\,exp}}\right)^2 + \left(\frac{t_{\max sim} - t_{\max exp}}{t_{\max exp}}\right)^2} \qquad (1)$$

where F_c and F_f are the cutting and feed force respectively, e the chip thickness, l_c the tool-chip contact length and t_{max} the maximum temperature in the zone contact workpiece. The sub-index $_{sim}$ indicates the simulated values and, $_{exp}$ the experimental ones. This equation can be modified assigning a weight in each bracket.

Finite element modelling of machining enables temperature distribution to be determined and these are shown to be similar in form to Fig. 2 in workpiece and chip during orthogonal cutting.

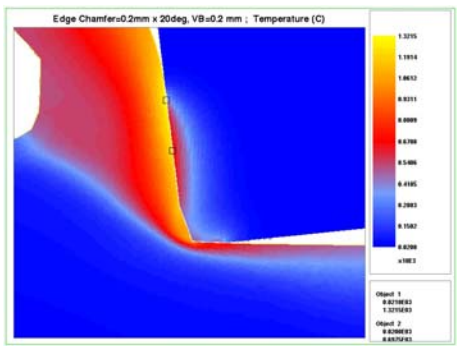

Figure 2. Temperature distribution in orthogonal cutting – FEM

Nevertheless this analysis in milling turns out to be more complex, for it the experimental study of orthogonal milling is developed in this paper, with the purpose of obtaining information to be used in the adjustment of the numerical modelling. The object of this work is the study of temperature distribution in workpiece and cutting tool.

2. EXPERIMENTAL PROCEDURE

The difficulties in calculating the temperatures and gradients of temperatures in the cutting zone, even for simple conditions, emphasise the practical methods for measuring temperatures, also in milling process [4].

Some of these methods only make it possible for the average cutting temperatures to be determined, but effective methods are available for determining temperature distribution in workpiece, chip, and tool near the cutting edge.

For obtaining the chip we realized essays in orthogonal milling conditions (slot milling), with a two-dimensional system of forces. The material mechanized was steel Thyrotherm F-5318, with dimensions 150x60x3 mm, placed on a clamping system (Fig.3).

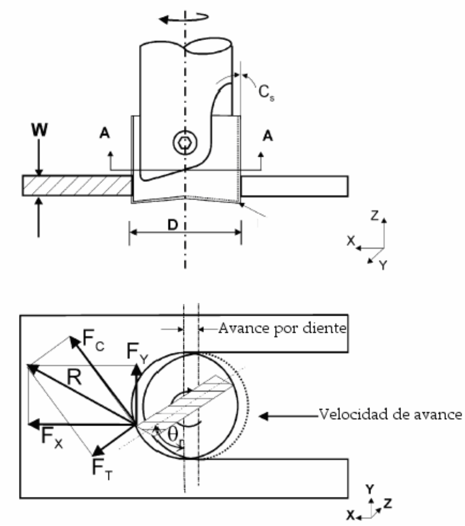

Figure 3. Orthogonal milling conditions

The diameter of the tool was 20 mm, with an only tool insert (Helistar serie, Iscar) with the geometry TPKN 1603 PPTR-42 (IC328) and the following angles: cutting angle 90º, main rake angle 0º, axial rake angle 0º and radial rake angle 0º.

Images as the showed ones in Fig. 4, can be obtained by means of a system of infrared thermography (VarioTHERM Research 270 of Jenoptik). This system includes a high resolution sensor (256x256 pixels). One of the main problems of this technique is the dependency on the results with the materials emissivity. The different materials of the workpiece and the tool appear in the image, also the emissivity changes with the temperature and with the oxidation processes in the zone near to the cutting. Thermography shows how the highest temperature is reached in the tool and in the chip, nevertheless the information about the workpiece does not turn out to be so clear.

In order to have estimation both qualitative and quantitative of the thermal behaviour of the process, we have chosen to use several methodes: thermographic camera, pyrometers and thermocouples.

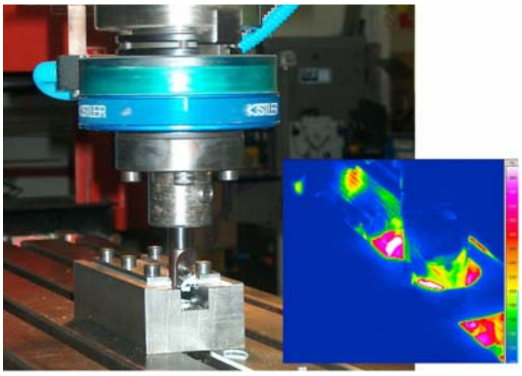
Figure 4. Termographic image of orthogonal milling

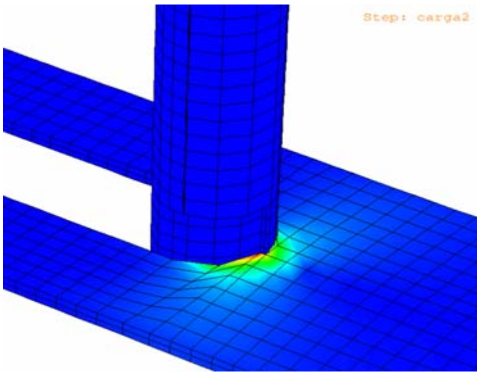

Figure 5. First model by ABAQUS V. 6.5

Using thermocouples of small diameter, it is possible to obtain good results in relation to the temperature gradients in the turning tool by means of many small holes in different positions. But this is impossible in milling conditions. A series of superficial measurements of the workpiece has been captured (with a disposition as showed in Fig. 6) in order to use the information in two senses: to obtain a reference to the measurements with the camera and the pyrometer and to obtain the punctual temperature in the cutting.

When the material is cut the contact happens between the thermocouple and the chip; we can obtain the first approach by means of a fast system of data capture (Agilent 34980A - Multifunction Switch/Measure Unit).
The technique of temperature measuring by the measurement of radiation is sometimes very useful in obtaining the surface temperature of the workpiece, the chip and the tool. This method gives information only about the temperature on exposed surfaces, although some experimental techniques attempted to measure the temperature distribution on the flank or the rake face of the tool through small holes in the workpiece [5]. Basically the method consists of measuring the temperature on the machined surface just below the cutting edge (Fig 7). The temperature may be measured at different positions below the cutting and then the results are used to extrapolate to the cutting edge (Fig 5).

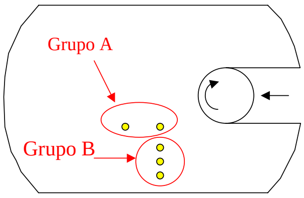

Figure 6. Superficial temperature measurement by means of thermocouples.

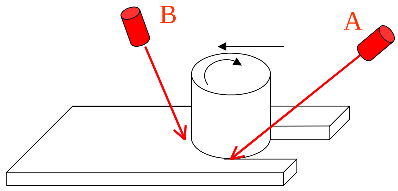

Figure 7. Assembly for using the radiation pyrometer.

3. CONCLUSIONS

The main signals that can be measured in a metal cutting operation are force, surface roughness, chip dimensions, strain, tool wear and temperature. Among these, the temperature is the most difficult to measure, which explains the numbers of different methods used over the years in the literature.

Particularly, the measurement of the temperature distribution in the zone of contact in milling process turns out to be complex for the dynamics of the process. The important gradients, the movement of tool and the changeable conditions determine the precision of the results and they disable the application of the methods used in turning processes. At this point, we have some general results about the problem but it is necessary to employ complementary techniques in order to obtain significances values.

The infrared method gives a good indication of the maximum temperature of the workpiece and may be possible to employ these results in order to the feeding of the inverse identification process, necessary to obtain the laws of material behavior. Also the application of a cutting fluid to the system adds more difficulty to the problem of measuring temperature.

4. ACKNOWLEDGEMENTS

The Ministry of Science and Technology of Spain and FEDER have financially supported this Project DPI2003-09676-C02-02, in the frame of the National Program of Design and Industrial Production.

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