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TECHNICAL PAPERS

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Hot Tool Temperature Analysis Though Infrared Images

Textile manufacture occupies a prominent place in the national economy. Because of its importance researches have been made on the development of new materials, equipment and methods used in the production process. The cutting of textiles starts in the basic stage, to be followed by the process of the making of clothes and other articles. In the hot cutting of fabric, one of the variables of great importance in the control of the process is the contact temperature between the tool and the fabric. This work presents a technique for the measurement of the temperature based on the processing of infrared images. With this purpose, it was developed a system which is composed of an infrared camera, a framegrabber PC board and a software which analyses the punctual temperature in the cut area enabling the operator to achieve the necessary control of other variables involved in the process.
Keywords: Cutting of fabric, temperature measurement, infrared images

Introduction

Within the industry the method used for textile cutting constitutes the basic operation from which later processes will be derived. For each type of application, a different cutting process is applied. Today, no process exists that attends all the necessary technical specifications while conserving most of the economic advantages at the same time.

Textile cutting can be classified into three main types: the mechanical cut, the laser cut (Khoury, 1991; Jackson et al., 1995; Yilbas, 1986; Inoue & Okubo, 1989) and the mechanic-thermal cut. This last type consists of the degradation of a narrow strip of fabric through the contact of a warm tool.

In the search for a practical demonstration with reference to a new cutting process, equipment for the hot cutting of textiles was developed in the Laboratory of Machine Tools (LAMAFE) of Mechanical Engineering Department of the São Carlos Engineering School – University of São Paulo. The equipment is composed of an electrically heated vertical mill mounted on a headstock that possesses vertical movement. A coordinate table with horizontal movements in two axes is mounted below it. The equipment can be seen in Figure 1.

In order to avoid combustion of the fabric during the cut, the contact area between the tool and the fabric is covered by a glass campanula or bell shaped cover into the interior of which nitrogen gas N_2 is injected to provide an inert atmosphere. Figure 2 shows both the top and front view of the cutting tool and the bell in the process.

It can be observed the vertical cut along the length of the tool that divides it into two symmetrical parts. At one end the parts are united and at the opposite extremity the parts are linked to the source of the alternating current supplied by a variable transformer to form a small electric circuit.

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The tool possesses a diameter of 2.0 mm and a height of 20 mm in the working area and is appropriate for cutting several layers of fabric up to the total height of the tool; it is also able to generate cuts of complex forms with very accentuated curvatures (Verdério & Ruffino, 2001).

Due to the small area of the cross section of the tool, the high electric resistivity of its material – Nimonic 80A superalloy – and the high value of the electric current in the circuit, the temperature in this area rises due to the heat generated by the Joule effect. The tool performs a rotational movement and the energy generated is used for the degradation of the fabric material as the table advances. The higher the temperature the greater the heat transferred by conduction and radiation to the surrounding material.

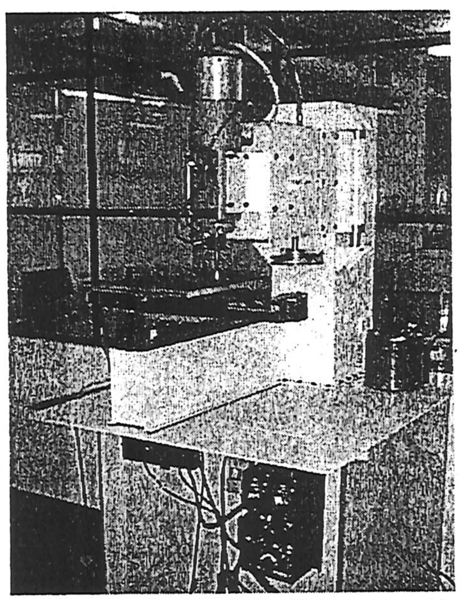

Figure 1. Equipment for the hot cutting of wovem fabric.

With the increase in temperature up to a certain limit, the cellulose, the basic material that constitutes the fibers of natural fabrics, presents a decrease in rigidity and resistance to tensile stress. Beyond this limit, the heat degrades the polymer chain of the cellulose in the region of the tool, causing the fabric to lose its mechanical resistance properties, thus favoring its extraction by a mechanical process (Ramiah, 1970; Dollimore & Holt, 1973; Fairbridge et al., 1978; Shafizadeh et al., 1979; Calahorra *et al.* 1989).

Then, the cutting mechanism may be described briefly as the thermal degradation of the material followed by the mechanical removal of the residues by the cutting edges of the moving tool. With the movement of the tool and the retreat of the material degraded by the cutting edges, other zones will be exposed to the thermal effects of the tool. The temperature of the tool is therefore determined by the electric current through it and the condition under which the heat generated is absorbed by the textile material that surrounds it. For high feed rates the heat is more efficiently extracted, lowering the temperature, but the fabric starts to offer mechanical resistance against the tool motion. On the other hand, low feed rates generate a greater tool temperature which results in a greater thickness of the cut strip and thus, in losses in production time. It is interesting for the industry production that the feed rate of the tool is as high as possible.

The feed rate, given by the movement of the table, is a function of the temperature of the tool. This feed should be neither too low that losses are caused in production, nor too high that an increase of the cutting force on the tool are generated. Increase of the cutting force may lead to tool damage.

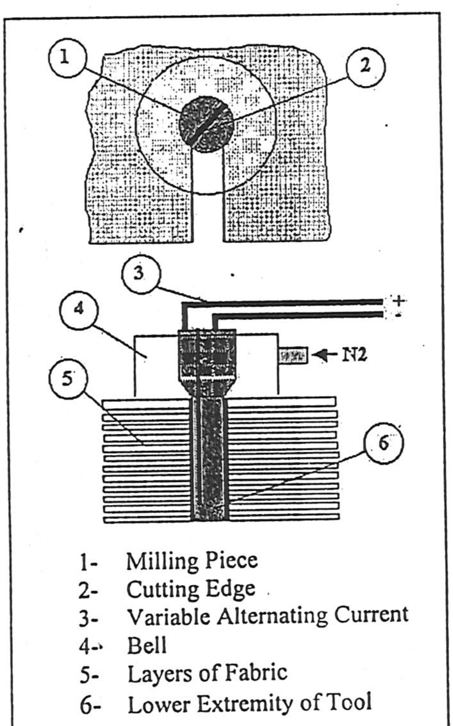

Figure 2. Schematic diagram of the textile cutting processusing an electrically heated vertical mill.

Besides possessing reduced dimensions, the tool is rotating during the operation of the hot cut of fabrics. The table on which the layers of the fabric are to be cut is also in continuous movement in the direction of the coordinates x, y. Such fact makes the necessary measurement of the temperature of the tool in the area of "tool-fabric contact" more difficult. This work proposes a non-invasive method to measure this temperature accurately, based on infrared images. With the information of the temperatures during fabric cutting the supply of the electric current can be controlled. The method will be described without cutting (without operation) and with no rotation of the tool.

Description of Procedure

A system composed of an Infrared Camera, a Framegrabber PC Board and a Software was developed. The software was capable of analyzing the punctual temperature in the cutting area, enabling the operator to make the necessary control over the other variables involved in the process. Figure 3 shows the hot tool without rotating movement.

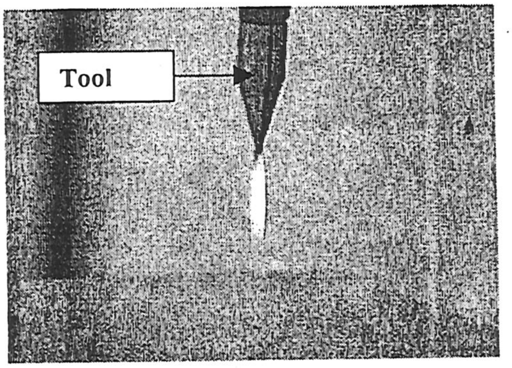

Figure 3. Hot cutting tool without rotation.

The temperature of the tool during the cut was obtained experimentally by the analysis of the luminosity measurement information contained in images captured by the infrared camera.

The infrared image offers a map of tones of gray of the surface over which the cutting process takes place. Each gray tone in the image is associated to a temperature value through an equivalence function.

The determination of the equivalence function is obtained experimentally by the calibration of the infrared camera. The resulting curve is called the calibration curve.

Calibration of the Infrared Camera

For the measurement of the temperature by means of the infrared radiation measurement it is necessary to consider parameters such as the emissivity of the object, the distance of the object to the infrared camera, relative humidity, room temperature, temperature reflected by the atmosphere, (Ay & Yang, 1997), as well as characteristics of the surface of the object itself (Soloman, 1998).

Borelli *et al.* (2000)a,b,c, determined curves of the infrared camera for different materials: tool, chips and workpiece. The calibration curves were obtained for the calculation of the temperature in the contact area between the workpiece and the tool during a machining process. In this work, calibration of an infrared camera for cutting tool material was performed. A sketch of the system can be seen in Figure 4.

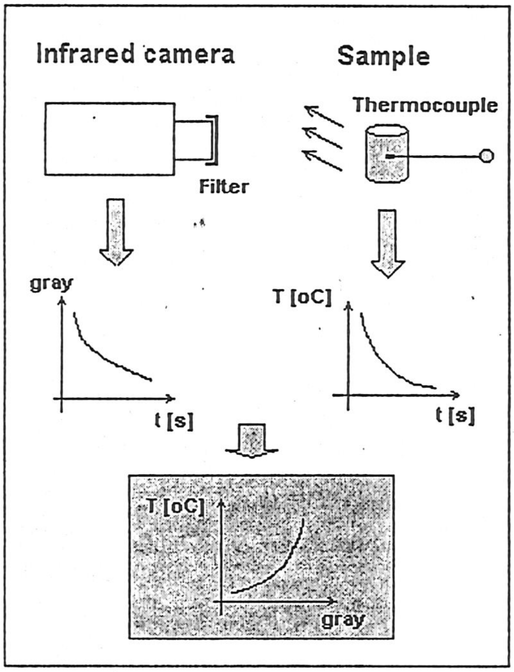

Figure 4. Sketch of camera calibration technique.

For calibration of the infrared camera for the tool material (Nimonic 80A), the same conditions as those met by the camera, the fabric and the tool during the cutting operation were reproduced. A sample of the material was warmed and the temperature cooling curve was then plotted as a function of time.

For the heating of the sample, an electric oven as shown in Figure 5 was used.

In order to measure the temperature during cooling, a probe was made of a sample of the material of the tool and connected to a thermocouple. This apparatus was linked to a data acquisition system. The infrared camera was used to capture the images of the sample as it cooled in air, accompanied by the acquisition system, as seen in Figure 6.

The images were digitalized later and grayscale plots were obtained for each corresponding sample cooling time.

By processing the pictures of these images, it was possible to trace the curves of gray tones as a function of the temperature for each sample.

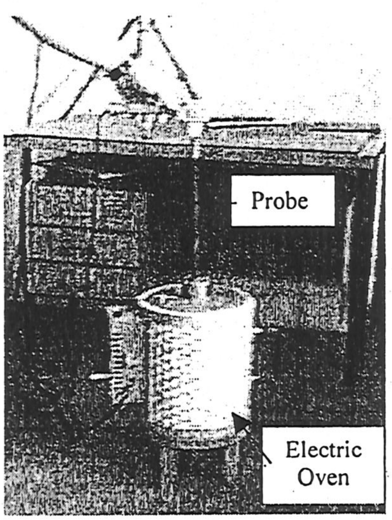

Figure 5. Electric oven for heating the samples.

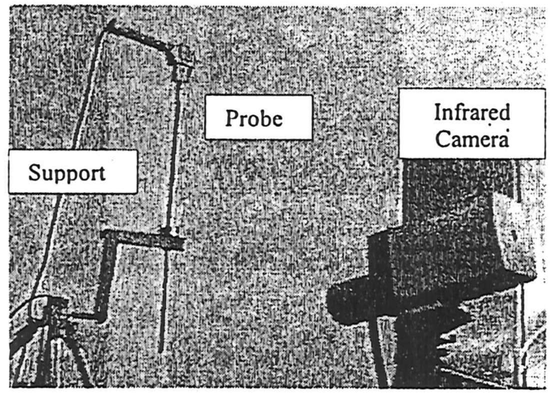

Figure 6. Cooling of the sample.

By eliminating the time variable, it was possible to obtain the resulting graphs relating the gray tones to the temperatures. These graphs were used to trace the calibration curve of the camera for the sample of the tool material.

A group of filters of neutral density were placed in the lens of the infrared camera to avoid saturation of the images it has furnished. Saturation occurs when the temperature of the material exceeds the maximum limit of the camera.

The data acquisition system used to measure the cooling rate was a "Quenchometer" manufactured by the FAC company. According to Curi (1995), the system captures variations of temperature of the probe as a function of the cooling time of the samples, stores the data in a system database, allowing, then, the plot of the cooling curves.

To trace the curve of the gray tones as a function of the cooling time, a software that analyzes the images captured by the infrared camera, supplying the curves of gray tones as a function of the cooling time of the sample, was developed. The interface that can be seen in Figure 7 shows the already digitalized image captured by the camera as it was shown in the video. The vertical white strip is the image of the hot tool for a prescribed time.

The interface possesses a graphic window within which the images obtained by the infrared camera are visualized. On the left side above the interface, images of the probe obtained during cooling can be seen. Each image was obtained with a interval of 1/30 s. A point at the center of the tool was chosen for calibration (with the coordinates x = 460 y = 402 as may be seen in the figure). This point corresponds to a pixel of the screen. Others eight pixels of the screen in its neighborhood were taken (two in each direction: above, below, left and right) to calculate the average values of the gray tones. The interface still allows verification of the punctual dynamics of the gray tones on the sample, besides supplying the vector of gray tones as a function of time (right side top). With the vector of gray tones as a function of time, the graph of gray tones can also be traced as a function of time. Eliminating the time variable in the two graphs described above: temperature as a function of time and, gray tones as a function of time, the graph of temperature as a function of the gray tones, which is the calibration curve of the infrared camera for the tool material, is obtained.

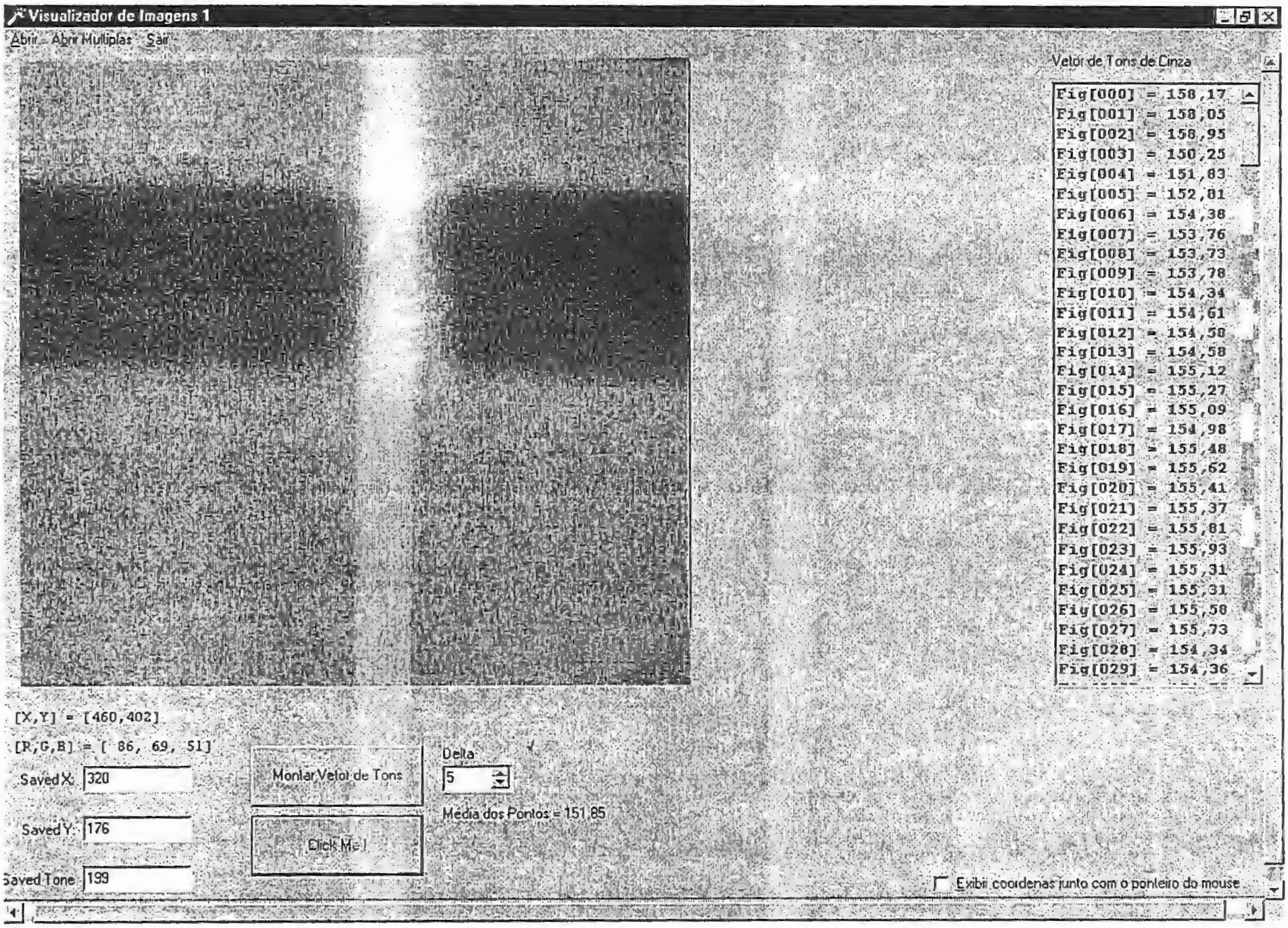

Figure 7. Interface for calibration of the infrared camera.

Experimental Results and Discussion

The graph with the results of the measurements supplied by the data acquisition system is presented in Figure 8.

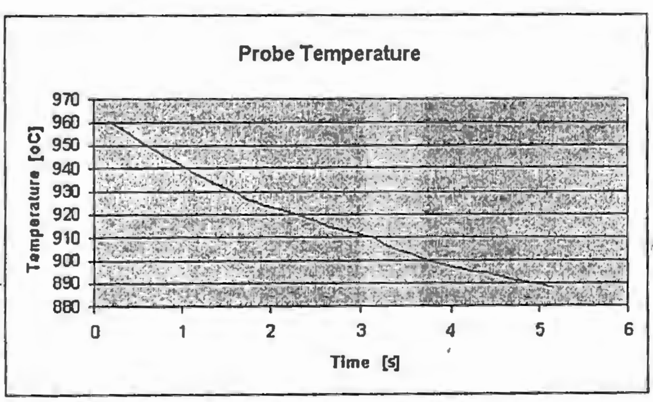

Figure 8. Temperature of the probe sample. (temperature as a function of time – thermocouple).

The graph with the results of the analysis of the gray tones as a function of time (as supplied by the software) is shown in Figure 9.

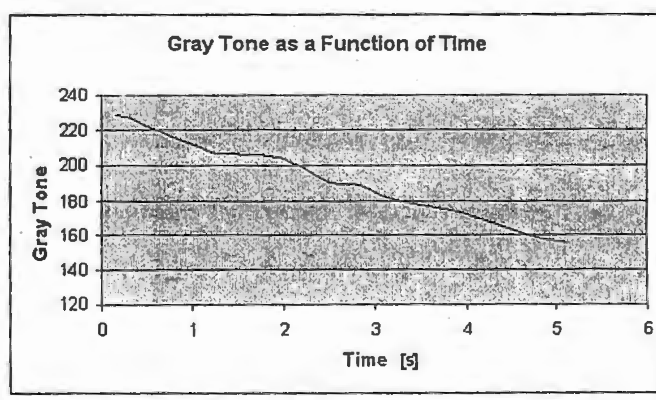

Figure 9. Gray Tone as a function of time. (infrared image).

Eliminating the time variable from the graphs shown in Figures 8 and 9 we have the graph of the temperature as a function of the gray tone, as shown in Figure 10.

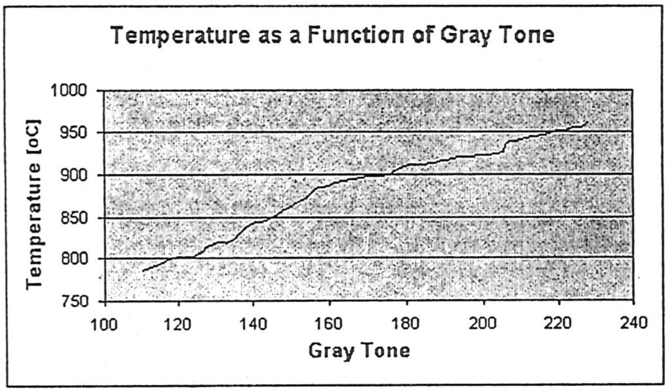

Figure 10. Temperature as a function of gray tone. (Calibration curve of the infrared camera for the sample material).

The curve of gray tones as a function of the electric current is shown in Figure 11.

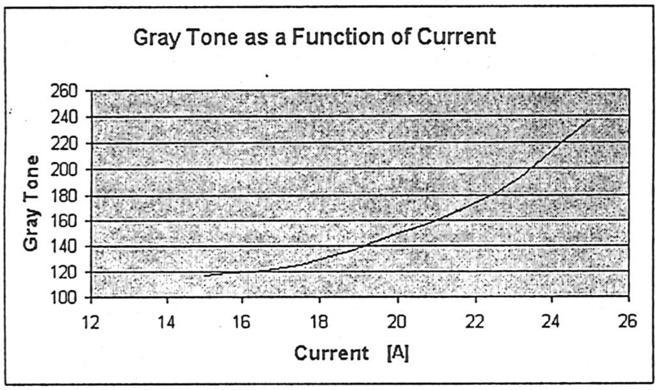

Figure 11. Gray Tone as a function of the electric current.

Interpolating the points produces the curve of temperatures as a function of the electric current in the circuit as shown in Figure 12.

The use of the calibration curve obtained in Figure 11 will permit to obtain the electric currents which will regulate the mill cutting temperature between 850 and 900 °C to the various cutting conditions such as cut velocity, thickness of superpose layers and types of fabric by means of this process of temperature measurement in further experiments. Figure 12 shows that in order to maintain the temperature within these limits under the "without operation" condition the electric current must be between 19.7 and 22 A.

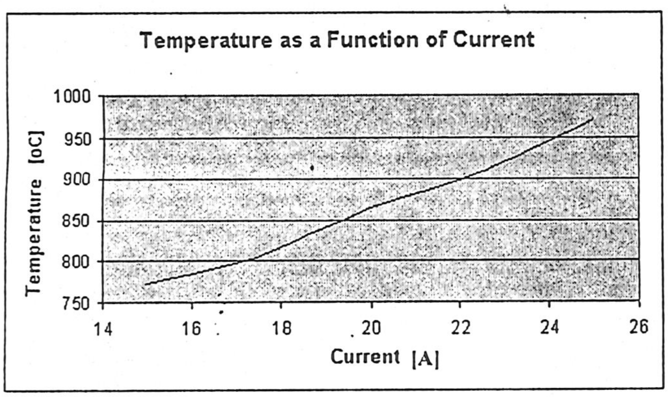

Figure 12. Temperature as a function of the electric current.

Holding the mill within these temperature limits provides a good combination of mechanical properties of the tool material and degradation conditions in the textile, allowing a better efficiency of the cut. This provides reliability in the process while allowing the control and adjustment of the speed of the table to provide feed rates that guarantees an uniform high performance cut without risk of damage. Using the appropriate temperature, the cutting forces on the tool are minimized.

Conclusions

The method of temperature measurement used is non-invasive and offers support for the implementation of control systems and the automation of the cutting operation. It is adequate to situations where the use of thermocouples, as in metal cutting process for example, is difficult.

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