Wear 350-351 (2016) 27–34

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Advances on indirect methods to evaluate tool wear for Radiata pine solid wood molding

A. Aguilera [a,*], P.J. Méausoone [b], A. Rolleri [a], J.L. Barros [c], F. Burgos [a], C. Aguilar [d]

[a] *Forest Products Laboratory, Universidad Austral de Chile, Valdivia, Chile*
[b] *LERMAB, Laboratoire d'Études et de Recherche sur le Matériau Bois, Lorraine University, Epinal, France*
[c] *Acoustic Institute, Universidad Austral de Chile, Valdivia, Chile*
[d] *Department of Metallurgical Engineering and Materials, Universidad Técnica Federico Santa María, Valparaíso, Chile*

ARTICLE INFO

Article history:
Received 18 September 2015
Received in revised form
24 December 2015
Accepted 27 December 2015
Available online 7 January 2016

Keywords:
Radiata pine
Sound pressure
Electrical current
Tool wear
Molding

ABSTRACT

The final quality of solid wood molding depends on several factors, where the choice of cutting conditions and consequently the tool performance are key points when processing this type of material because tool wear affects physical–chemical and thermodynamic behavior of the surface submitted to coating. One of the main problems at the production line is to achieve an adequate monitoring system of the cutting process to prevent and detect operational problems or loss of productivity. The objective of this research is to evaluate results from two different control process methods, such as sound pressure and electrical current measurement submitted during different cutting conditions and to determine the cutting distance increase, as innovative methods to estimate tool wear when appearance grade products are being produced.

1. Introduction

Currently, added value wood based products such as the appearance grade of decorative moldings, reach increasingly demanding markets. These wood products are not free from defects, produced either from raw material or as a result of mismatches in the production process. Several processing variables can produce these defects, the most important being surface quality.

In the industrial context of molding production, comprehensive selection and classification controls of raw material are applied, using infrared scanning technology and X-ray vision [26,27], coupled to highly efficient and accurate analysis. The twain system prevents raw material losses that may compromise process efficiency. Quality appreciation is undergone by machine operators but this process lacks sensors that evaluate processed wood quality. Surface quality influences the coating or the adhesion between surfaces, where the evolution of tool wear will affect to some extent these properties. In this sense, when cutting distance is regularly increased with production, we observe a gradual increase of cutting power and a progressive deterioration of surface quality. Tool wear phenomena may raise production costs because of the loss of raw material and ultimately the loss of markets and lack of consumer confidence, with the principal reason being the late replacement of the cutting tool. Although, tool wear estimation is essential for online process control and optimization: in fact, many technicians eliminate the used tool, in fear of producing damaged surfaces.

Tool wear prediction methods have been extensively studied in metal machining [28,29] but not as much for wood machining. Therefore metal research has used, for example, tool life models like Taylor's equation and also temperature based equations. These are considered as a function of input cutting parameters and tool wear rate models as a function of output state variables (cutting temperature and speed, normal stress, etc.) using Takeyama and Murata's [1] wear model or Usui's wear model [2], both based on physical considerations such as abrasive and diffusion phenomena. Tool life is primarily affected by edge wear until the point of cutting refusal. It is well known that the limiting factor is the dimensional accuracy of the machine piece, the roughness or when the tool wear is such that the edge is no longer reliable. From the mechanical point of view, tool life comes to its end when the edge breaks [3] or once it has met a defined value. It is necessary to set up strong definitions to identify when the cutting edge is worn out by different operations, criteria and tools. Clearly, if a cutting edge does not produce the required finish or if it does not maintain certain tolerances, it can no longer be used for the operation. The risk of rupture increases with the level of edge wear, mainly once it exceeds a certain value.

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[*] Corresponding author. Tel.: +56 632221717; fax: +56 632221224.
E-mail address: aguilera@uach.cl (A. Aguilera).

http://dx.doi.org/10.1016/j.wear.2015.12.011
0043-1648/

The cutting tool is constantly submitted to stress and temperature rises due to forces exerted at the cutting edge that generate progressive wear at both faces: rake and clearance, rapidly modifying the edge radius, and hence the cutting geometry [4]. Many wood machining processing controls are essentially of a reactive nature, i.e., only when a problem appears, an action is taken. There is no on-line monitoring control system to constantly evaluate and quantify the process line. Therefore, since control is based on the operator's experience, the process is subject to a degree of uncertainty and uncontrolled qualitative type.

The evolution of tool wear [5] when processing solid wood can be noted on various response parameters [6], becoming evident mainly with the gradual increase of cutting forces and power. Cutting edge recession gradually increase when both the time and distance of the processed material increase. Moreover, the relationship between cutting speed (*Vc*) and feed (*Vf*), cutting circle, depth and width of the cut, determine chip thickness parameters and feed per knife or bite (*fz*), both related to cutting energy and surface quality [7,8].

1.1. Monitoring wood machining processes

It is important to monitor wood machining process, because an efficient survey provides an early alert to the operator in order to shut-off the machine before critical conditions of cutting kinematics (cutting speed or feed) are reached. Different methods may be applied for monitoring a tool's cutting performance and to detect changes occurring in the process line at early stages (Table 1).

The interesting relationship between cutting forces and electrical current makes these methods promising to assess cutting performances of wood material [7]. Since the 1980s, researches have focused on the implementation of noninvasive monitoring methods using acoustic emission [14]. Both the implementation of touch sensors, such as accelerometers, and non-contact sensors, such as microphones or laser, require that the acquired signal effectively corresponds to what it wants to measure.

Therefore, the response parameters of sound pressure and electrical current became interesting aids to control and survey tool wear. Consequently, the use of some means to monitor the cutting process, such as sound pressure, seek to improve performance by decreasing delays in the production line, maintaining the quality standards of wood machining operations. For this reason, the research objective involves testing a new and innovative online monitoring system developed for early detection of changes in cutting conditions, based on an electrical current and sound pressure monitoring process technique, when appearance grade products are being produced for Radiata pine solid wood molding.

2. Materials and methods

2.1. Materials

Kiln dried and free of defects (knots and resin pockets) Radiata pine wood were machined in a 4 kW single-spindle shaper machine with computer controlled cutting speed and feed. The average specific gravity of raw material was 0.42 g/cm^3, with a moisture content of 10%. The samples had a length of 214 cm and a section of 40 mm, the radial face of samples was exposed to machining (Fig. 1a). The cutter head was a 6 knives hydro-tool, 177 mm of cutting circle diameter, having as cutting geometry 25° of rake angle (Fig. 1b), 26° clearance angle and 39° of sharpness angle. High Steel (HSS) freshly sharpened corrugated knives (Fig. 1c) without jointing were used in the test. The machining conditions were: conventional cutting mode [24]; cutting width 40 mm; depth of cut 1 mm; feed speed from 4 to 38 m/min; cutting speed 56 m/s.

The cutting conditions were defined considering chip thickness (mm) as a parameter that explains both the cutting power and surface quality [24,8]. As the knives have a rotational movement, the produced chip varies constantly. Therefore, it was more appropriate to work with mean chip thickness [25]. The mean chip thickness (e_m) is related directly to the feed per tooth or bite (*fz*) and depth of cut (*ap*), but inversely to the cutting circle diameter, as shown in the following expression (1) for planning heads. Feed per tooth is directly related with feed speed (*Vf*) and indirectly with the number of knives (*Z*) and rotational speed (*N*).

$$e_m = \left(\frac{Vf}{N*Z}\right)\sqrt{\frac{ap}{D}}\,(\mathrm{mm}) \tag{1}$$

In order to study the cutting process behavior, two main response variables were evaluated: electrical current (amperage) and sound pressure (RMS). Both were evaluated systematically, each 1500 m of cut distance from 0 to 10,000 m of processed wood; the analysis included the behavior according to chip thickness and feed speed variation at different cutting distances. A knife characterization is also included in order to have knowledge about microstructural characterization, hardness and composition of steel. Finally, a cutting process survey was performed at an industrial mill facility where sound pressure was monitored on a molder in one shift.

Table 1
Methods to survey cutting performances.

Methods	References	Highlights
Power consumption of motor-spindle	[9,10]	The results are not accurate enough because the output signal is a low-pass filter type, due to inertial effects of the motor-spindle system.
Tool wear process	[4,10–13]	– Use of dynamometers, mounted between the spindle and the feed table. – Difficulties to use the system as an on-line monitoring system.
Sound emissions	[15,16]	Contact sensors avoid crosstalk effects/for a microphone, the measured sound source must be insulated.
	[17–20]	The use of acoustic emissions provides guidelines for monitoring tool wear/cutting conditions/surface roughness.
	[21]	– Electroacoustic system coupled with computer software as a non-invasive method of monitoring molder machine tools. – Linear relationship between sound pressure RMS (root mean square) and feed speed during the cutting process.
Electrical current	[22]	The cutting power behavior to feed rate a work piece depends on the section being processed and the action performing a specific cutter head.
	[23]	– Increase of wood density and cutting depth showed a continuous increase of the cutting power requirements, with a clear surface deterioration when increasing feed rate. – Wood density influences directly the cutting power with a constant level of chip thickness.