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Measuring components cutting force in chipboards milling

JOANNA ZIELIŃSKA-SZWAJKA [1], JAROSŁAW GÓRSKI[1], KRZYSZTOF SZWAJKA[1]
[1]Faculty of Wood Technology, Warsaw Agriculture University – SGGW

Abstract: Method for measuring forces using a commercial force sensor and a data acquisition system that simultaneously allows the recording of cutting forces and cutting tool position (coordinates X, Y) is presented. The cutting force measurements were carried out by means of a piezoelectric dynamometer, during the milling of chipboard specimens of full thickness and the milling of individual chipboard layers. The measures in the X-Y co-ordinate system cutting forces were vector ally added. Furthermore, the resulting force F was analyzed in the components F_t and F_r.

Keywords: milling, chipboard, cutting force, force sensor

INTRODUCTION

Chipboards are widely used, offering a cheap solution for a broad range of lightweight constructions. Their mechanical properties depend among other parameters on their composition regarding the type and origin of the raw material (wood and glue), as well as the form of the wood particles [Troeger et al. 1998; Troeger et al. 2001].

Chipboard materials are inhomogeneous versus the board thickness. They consist of three easily identifiable layers, two external ones and an intermediate one (Fig. 1).

The top and bottom layers are dense, small grained and stronger than the middle layer, which is large grained and porous and has a lower mechanical strength. Usually, chipboards are coated with a thin hard layer of melamine for decorative purposes. The characteristic chipboard structure affects the occurring cutting forces during their milling. The resulting cutting force divided by the corresponding chipboard width increases in the regions where the dense layer and the melamine removal takes place, as qualitatively shown [Bouzakis et al. 1999; Bouzakis et al. 1998, Bouzakis et al. 2000b]. Milling operations are one of the most common machining operations in industry. It can be used for face finishing, edge finishing, material removal, etc. There are several parameters that influence the forces acting on the cutter. Because of these parameters, the forces may become unpredictable and result in larger dimensional variations when products are produced. Cutting forces are widely recognized as an optimum performance estimator of machining operations. Many authors, compiled in the trend reports by Van Luttervelt et al. [Van Luttervelt, Childs, Jawahir, Klocke 1998] and Ehman et al. [Ehman, Kapoor 1997], have addressed their research work to the prediction and measurement of these forces. Both force modulus and direction are directly related to different aspects of the removal process, with a clear influence on the efficiency of the operation and the quality of the machined part. Thus, cutting force is result of the extreme conditions at the tool-workpiece interface. This interaction can be directly related to the tool wear and, in the worst of the cases, to the failure

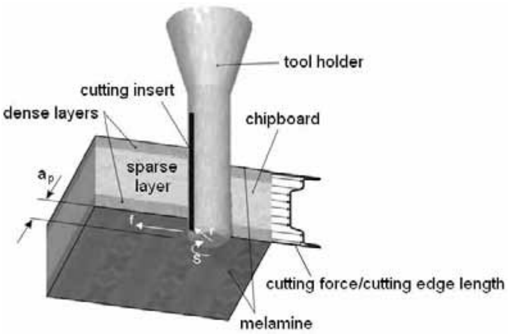

Fig. 1. Characteristic chipboard structure and cutting force distribution on the cutting edge in

of the tool [Lopez de Lacalle, Gutierrez 2000]. Consequently, tool wear and cutting forces are related to each other, although that relationship is different for each different wear mechanism (flank, crater, tool breakage).The most common method to measure cutting forces in machining operations is through table dynamometers. Typical table dynamometers consist of piezoelectric sensors that are clamped between two plates [Gautschi 1971].

CUTTING FORCE EVALUATION IN MILLING

The existing methods for cutting force evaluation in milling consist of two phases. First, the instantaneous cutting force components on an increment of the cutting edge are defined as functions of the cutter rotation angle (Fig. 2). Their value depends on workpiece properties, tool geometry and cutting conditions (instantaneous depth of cut, cutting speed). In the second-phase the force components are integrated along the cutting edge, periods of active cutting are defined because of operation geometry and forces acting on the different teeth are summed, to give the total cutting force.

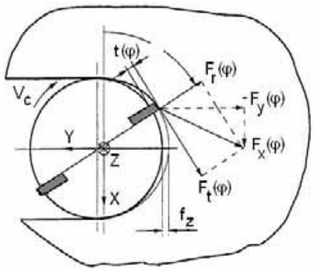

Fig. 2. Cutting forces in milling

The integration and summation phase is identical in all the existing methods, and this part of the problem is considered as solved. Some problems still exist, however, in defining and acquiring the basic expressions and values for the instantaneous (local) cutting force components. The full cut functions may be also expressed in tool coordinates as follows:

$$F_t = F_x \cos\varphi - F_y \sin\varphi \quad (1)$$

$$F_r = -F_x \sin\varphi - F_y \cos\varphi \quad (2)$$

where:
φ-rotation angle, F_t and F_r tangential and radial components of the cutting force, F_x and F_y cutting forces in X-, Y directions.

The forces are oriented as follows: the "tangential force" is oriented along the feeding direction and has its positive versus in the cutting direction; the "radial force" is oriented perpendicularly to the feeding direction and its verse is positive going inside the surface. Both parallel and normal force are in the same horizontal plane.

CUTTING FORCES MEACUREMENT AND ACQUISITION

The measurement of cutting forces milling a routing process is a quite complicate operation because of the high frequency and the periodical solicitation that excite the system to vibrate according to its natural frequency. Moreover a machine with more axis produce lots of vibrations affecting the signal. For this reason we reduced as much as possible the mass handing over the platform. The measuring system is a tri-axial dynamometric piezoelectric platform, connected to three charge amplifiers switched to “long” modality. We measured cutting forces along the tree axes, therefore only two of them (X and Y) are analyzed in this paper. Data have been collected, stored and analyzed by an acquisition board and the means of the computer analysis. The set-up is reported in Table 1. In Table there are milling parameters.

Table 1. Acquisition system set-up for the test and milling parameters

Measuring system	Tri-axial dynamometric piezoelectric platform	Wood species	chipboard
Platform cut-off frequency	2500 Hz	Milling machine	Buselatto JET 100
Acquisition device	Computer board	Feeding speed	4.5m/min
Anti alias filter	Mechanical	Inserts material	DIMAR ϕ12 HW
Sampling frequency	50 kHz	Cutting depth	18mm

CUTTING FORCES ANALYSIS

The measurement of cutting forces milling processing is always difficult, because of the interferences brought by all the vibrations affecting the system. The signal is often difficult to analyse, and to retrieve cutting forces is a really complicate operation. For this reason it has been necessary to operate an important filtering. By a side filtering very much would affect the data, but at the same time would clean them from useless noise. Even if filtered data do not represent exactly cutting forces, they are easy to analyse and to process and not far from real cutting forces (anyway closer than with noise). For this reason a filter type Butterworth of 4th order set as low-pass at 550Hz, has been used to clean the data from noise. Considering that 550 Hz is bigger than cutting frequency (500Hz) we should not significantly affect the signal, and the embedded data Fig. 3.). The cutting conditions are reported in Table 2.

Table 2. Acquisition system set-up for the test

Cutting revolution frequency	250Hz
Time to make a revolution	0,004sec
Cutting frequency (2 edges)	500 Hz
Time between two chips	0,002sec
Filter Frequency	550Hz
Order	4^{th}
Type	Low-pass

As shown in Fig. 4, two kinds of fluctuation can be observed in the measured cutting force signals; the higher and the lower frequency fluctuation. The latter corresponds to the rotational frequency of the tool holder, multiplied by the number of its cutting inserts, resulting from the successive entries of the cutting inserts into the workpiece material.

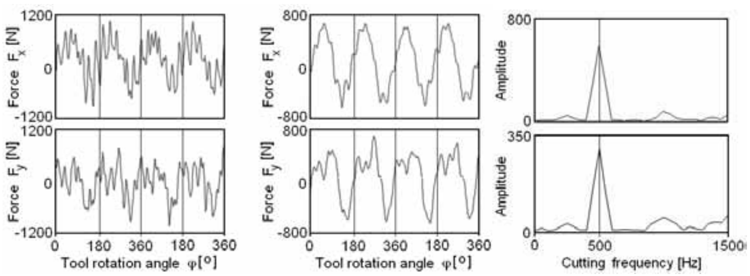

Fig. 3. Cutting forces signal in *X*-, *Y* directions before and after filtering

The higher frequency fluctuation of the registered cutting force signal does not occur due to either the dynamic response of the workpiece, its holder or the machine tool used.

The cutting force measurements were carried out by means of a piezoelectric dynamometer (Fig. 4), during the milling of chipboard specimens of full thickness. The measures in the *X*-*Y* co-ordinate system cutting forces were vectorially added.

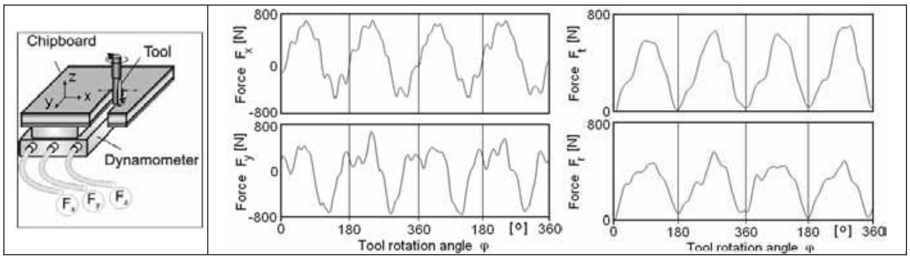

Fig. 4. Characteristic cutting force distribution on the cutting edge in chipboard milling

CONCLUSIONS

The sensor allows for precise measurement of cutting force components. Can be determined the components (tangential and radial force) of cutting force on the basis of milling forces in the directions *X* and *Y*. Determination of cutting force components allow the correct design of machine tools.

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Streszczenie: *Pomiar składowych siły skrawania przy frezowaniu płyty wiórowej*. W artykule zaprezentowano metodę pomiaru sił za pomocą komercyjnego czujnika sił skrawania oraz akwizycji danych, które jednocześnie pozwala na rejestrację sił skrawania i oraz pozycji narzędzia (współrzędne X, Y). Pomiary sił przeprowadzono za pomocą siłomierza piezoelektrycznego podczas frezowania płyty wiórowej. Na podstawie zarejestrowanych sygnałów sił we współrzędnych XY postanowiono określić rzeczywistą siłę cięcia oraz siłę promieniową występującą podczas frezowania.

Corresponding author:

Joanna Zielińska-Szwajka,
Warsaw University of Life Sciences,
Faculty of Wood Technology,
02-776 Warsaw
Nowoursynowska 159 str. Poland
e-mail: jzielinska@poczta.onet.pl