Measurement 45 (2012) 1380–1386

Contents lists available at SciVerse ScienceDirect

Measurement

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

Decomposition of process damping ratios and verification of process damping model for chatter vibration

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ARTICLE INFO

Article history:
Received 21 October 2011
Received in revised form 24 February 2012
Accepted 20 March 2012
Available online 29 March 2012

Keywords:
Cutting tests
Workpieces materials
Model verification

ABSTRACT

In the previous study, by the same authors, titled "A new process damping model (PDM) for chatter vibration (Measurement, 44 (8) (2011) 1342–1348)", a new approach has been presented for obtaining process damping ratios (PDRs). This PDM has been constituted on the basis of the shear angle (φ) oscillations of the cutting tool and the alteration of the penetration forces when they penetrate into the wavy surface. Variation and quantity of PDR are predicted by reverse running analytical calculation procedure of traditional Stability Lobe Diagrams (SLDs). In this study, firstly, how the PDM in previous study results with different materials such as AISI-1050 and Al-7075 are examined. Then, two problems are solved: how much of the total PDR of cutting system is caused by the tool penetration and how much is caused by (φ) oscillation? Finally, verification of PDR values and PDM are performed by energy equations.

1. Introduction

To obtain the final shapes of mechanical parts by turning operations are very important in present-day manufacturing. Examples of this metal cutting process can be found in the automotive, aerospace, and the mold and die industries [1]. However, one of the main factors limiting productivity in milling is the vibration of the system machine tool, spindle, tool holder, and tool, mainly due to a lack of dynamic stiffness. Regenerative chatter, a self excited vibration in operations where the tool cuts a previously machined surface, is the most common problem. The consequences are poor surface quality, inaccuracy, loud noise, excessive tool wear, machine tool damage, increased costs in terms of time, materials, and energy, and the environmental and economic impact of sanding marks, dumping non-valid final parts or repeating the metal removal operation [2].

Early research on chatter started with Taylor [3], Arnold [4] and Hahn [5] in the early part of the 20th century. Chatter was thought by some to be negative damping in the machining process [6] whilst others have more recently claimed that in the case of titanium milling the oscillation in forces as the result of segmented chip formation can initiate chatter [7], but is widely understood to be a function of the system dynamics and the cutting parameters [6,8].

A simple way to avoid regenerative chatter in machining is to select stable cutting conditions. A stability map can be generated, to show the combinations of width of cut and cutting speed where stable cutting conditions are found. Another successful strategy involves mitigation of chatter at lower surface speeds, utilizing process damping by tool–workpiece contact [9]. Most machining operations are conducted in low speeds (typically less than 300 m/min) range for hard materials, for instance titanium and nickel alloys. Certain operations take place in this range for softer materials also, e.g. grooving for

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http://dx.doi.org/10.1016/j.measurement.2012.03.028

carbon steels. When the tool or workpiece vibrates during cutting, waves are generated on the workpiece surface as a result [10].

Process damping force occurs in a section between tool cutting edge and wavy surface during the dynamic cutting. However, as it is not linear, the modeling of the process is still arduous and the basic subject matter has not fully been comprehended though it is recognized why and how this force is produced. The main subject of analytical calculation of process damping for chatter vibration is to research how and why the process damping occurs in chatter vibrations under low cutting speed conditions. Answers to those questions could not be found in the former research available in literature [11–14]. Since how the process damping affects the orthogonal cutting is not clearly understood, the additional effect of the process damping to the cutting system's structural damping could not be determined as well. In our previous study [15], a complex dynamic system is modeled prior to the orthogonal cutting which forms a mechanical cutting basis for all cutting processes in general. The complex dynamic system consists of dynamic cutting system force model which is based on the shear angle (φ) oscillations and the penetration forces which are caused by the tool flank contact with the wavy surface. Static and Dynamic Cutting Force Coefficients (DCFCs) are obtained by using the dynamic cutting force model. Using these coefficients in the motion equations derived for the stability analysis increased the total PDR of the system. The complex PDM is developed through considering that it is derived from the shear angle (φ) oscillations of dynamic cutting system and the penetration of tool to the wavy surface. PDR of the available cutting system are can be obtained by this complex PDM for different workpiece materials and cutting tools. Obtaining of the PDR values is achieved for the stability analysis in turning and milling conversely. Additionally the verification of PDM is analyzed after having found the total PDR with this procedure and how much is caused by tool penetration and how much by the alteration of cutting angle is found [15,16]. In this study, primarily the results of PDM with diversified materials such as AISI-1050 and Al-7075. The reason is to investigate according to what features of workpiece material the PDR changes.

2. Process damping investigation from experimental results

In this study, a system of orthogonal cutting was dealt with as a SDOF. Analytical modeling of this system and investigation of its stability were conducted in two different forms. The movement of the tool in dominant direction for SDOF system was considered because the natural frequency of the tool in another direction was very low in relation to the dominant direction. For this reason, it was accepted that the movement in this direction had no effect on stability limit of orthogonal cutting. Some simplifications were made in order to obtain a useful system model.

Values of natural frequency, stiffness coefficient and structural damping ratio (ω_n, k, ζ_{str}) respectively are obtained by the modal analysis measurements and values of chatter frequency and stability maximum axial depth ($\omega_c, a_{\lim}$) respectively are obtained by cutting tests as given in Table 1. Modal parameters were determined by using a modal test, CutPro®MalTF software and CutPro®Modal software. These modal analysis measurements and cutting tests have been performed for AISI-1050 and Al-7075 workpiece materials whose diameter is 60 mm and tool attach lengths $L = 70, 90, 110$ mm the attach lengths of tool. The workpiece is cut by Kennametal (SDJR-2525M11 NA3) inserts on universal lathe TOS SN50C. Tool holder dimensions are $(b \times h \times l) = (25 \times 25 \times 110)$ mm. The modal analysis measurements are performed for measurement transfer functions of cutting systems. Measurement of transfer functions uses an impact hammer instrumented with a force transducer and an accelerometer attached to a machine tool structure (see Figs. 1 and 2). Diameter of the workpieces during the cutting tests has been reduced from 60 mm to 35 mm.

Measurement of transfer functions of cutting systems have been performed for different available spindle speed [rpm] on machine tool and tool attach lengths (L). Feed rate

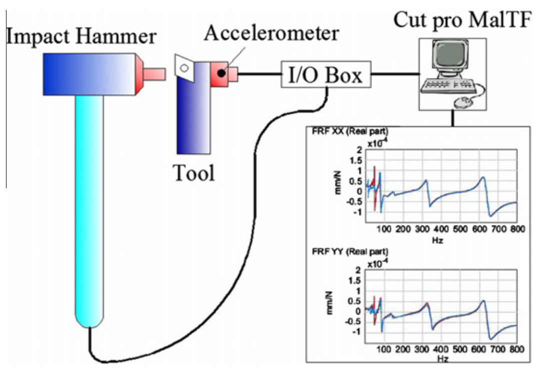

Fig. 1. Experimental setup for frequency response function (FRF) measurement.

Table 1
Modal analysis and chatter frequency values for AISI-1050 and Al-7075 materials.

Tool length, L (mm)	Material	Natural frequency, ω_n (Hz)	Stiffness, k (N/m)	Damping ratio, ζ (%)	Chatter frequency, ω_c (Hz)
70	AISI-1050	1696	2.15×10^7	1.92×10^{-2}	1700
	Al-7075	1520	2.28×10^7	3.83×10^{-2}	1640
90	AISI-1050	944.6	5.71×10^6	4.15×10^{-2}	1035
	Al-7075	973.6	6.60×10^6	2.77×10^{-2}	1020
110	AISI-1050	768.5	4.50×10^6	3.90×10^{-2}	900
	Al-7075	732.5	4.53×10^6	1.43×10^{-2}	750