Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

AGGRESSIVE TURNING FOR ENHANCED PRODUCTIVITY

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Abstract *Manufacturing of low rigidity components still remains a challenge for aeronautical industry where aircraft components must vanish new restrictive conditions what leads to conservative cutting parameters with the consequent loss of productivity. The following study faces the problem of maximizing the mass removal rate (MMR) in medium turning by means of two different approaches. The first part of the study involves the stability prediction by means of the frequency-domain method applied to a flexible part to detect the maximum productivity stable zones. The benefits from using this model are found through validation tests. A second approach to the problem involves the investigation of a relatively new process, namely turn-milling, to maximize the MMR. This technique is investigated through tool life test series.*

Key words: *turning, flexible parts, stability, turn-milling*

1. INTRODUCTION

Minimizing production time is a key objective in every machining process. Due to the high cost of the NC integrated into the machining centre, a productive approach to the process is required in order to obtain the payback in a reasonable time. This need of optimizing the cutting values is even more important in rough machining where the high chip evacuation rate increases the opportunities for time and cost savings (Meng et al., 2000). Concerning stability prediction models, Tlusty and Polacek (Tlusty & Polacek), used an approximate solution reducing the dynamics problem into a 1D case. Although this can be valid for plunge turning or straight turning where the inclination angle and the nose radius are neglected, it may not be accurate for multidimensional cutting processes or dynamics. This paper presents two different approaches to optimize productivity in medium turning. The first approach predicts the stable cutting parameters using the frequency-domain method based on the model from Altintas and Budak (Altintas & Budak, 1995) which is then contrasted with validation tests. The second one is based on a relatively new alternative, turn-milling, which allows for high feed speeds and increased depths of cut. This process is preliminary investigated by means of tool life testing.

2. STABILITY PREDICTION IN TURNING

The following model is based on the frequency-domain method proposed by Budak and Ozlu (Budak & Ozlu, 2007) which discretizes the tool radius to enhance the accuracy of the stability plot. In this case, unlike the previous one, the method is applied to different cutting depths with global coefficients which account for the total cutting energy put into play.

2.1 Stability model

The most significant assumptions of the model are:

- Single DOF in radial direction
- Flexible workpiece-rigid tool
- Cutting coefficients dependents of the depth of cut
- Side cutting edge angles defined from the depth of cut average of the corresponding element

The force model uses a simple linear dependency between the chip thickness and the cutting force. Thus, the effect of the friction is absorbed by the pure cutting. Fig. 1 shows the model scheme associated with a simple turning operation. The steady-state force in radial direction is expressed as shown in Eq. 1:

$$F_x = K_x(x)\cdot b\cdot h = K_x(x)\cdot f\cdot a_p \qquad (1)$$

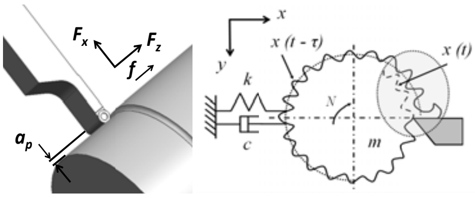

Fig. 1. Turning operation and 1DOF model scheme

For dynamic analysis, only the variable force is considered:

$$\Delta F_x = -a_p\cdot K_r\,\frac{\cos\kappa}{\sin\kappa}\cdot\Delta x = a_p\cdot A_0\cdot\Delta x \qquad (2)$$

The vibration vector, difference between the actual and the previous periods, can be expressed using the transfer function matrix $\mathbf{G}_{xx}(\omega_c)$ in X direction:

$$\Delta x = x(t) - x(t-\tau) = (1-e^{-i\omega_c\tau})\mathbf{G}_{xx}(\omega_c)\mathbf{F}e^{i\omega_c t} \qquad (3)$$

Introducing Eq. 3 in the dynamic force equation (Eq. 2), it results the final expression for the study of the system stability:

$$\mathbf{F}e^{i\omega_c t} = a_p(1-e^{-i\omega_c\tau})A_0\mathbf{G}_{xx}(\omega_c)\mathbf{F}e^{i\omega_c t} \qquad (4)$$

This is an eigenvalue problem which solutions represent the stability boundary limits. The proposed method uses global cutting coefficients obtained from cutting tests at different depths of cut: from 0.5 to 2 mm with variable cutting speeds from 200 to 600 m/min (f=0.4 mm/rev). Tab. 1. shows the specific forces for two different depths of cut obtained as continuous functions of the cutting speed by means of a second degree polynomial.

ap [mm]	Kcy [N/mm^2] (Vc [m/min])
1	$-0.00207\cdot Vc^2 + 2.061\cdot Vc + 885.75$
1.5	$0.00305\cdot Vc^2 - 1.3880\cdot Vc + 1150.77$

Tab. 1. Specific cutting force: polynomial approach

2.2 Experimental validation

The operations were carried out in a CMZ TC25BTY turning centre with a FANUC 31iT HVi numeric control. A test part made of AISI 1045 (*D* = 150 mm and *L* = 150 mm) was machined with a round carbide insert (RCMT 08 03 MO 4225 by Sandvik) for medium turning. Tool holder is placed with the minimum length to sustain the rigid tool assumption. During the characterization of the inserts as well as in chatter tests, the cutting forces were measured using a 9257B Kistler dynamometer. The signals are then amplified towards an OROS multi-channel analyzer and processed with Matlab9. The modal parameters of the workpiece were proved to remain practically constant during each chatter test but variable from one test to another. Tab. 2. shows the main values used for two of the simulations (ap=1 and 1.5 mm). The FRF values were obtained through impact hammer tests before each chatter test. Here, the discretization of the tool radius has been achieved with 4 elements (n=4) with 0.5 mm width (ap from 0 to 2 mm). Each depth of cut considered corresponds with a global cutting coefficient averaged in the range of study (Vc from 200 to 600 m/min). One important feature when using tool discretization models, even more for round inserts due to a nonlinear geometry of the edge, lies on the estimation of the effective side cutting edge angle acting at each depth of cut studied. In this case, the side cutting edge angle is defined at each element's mean depth of cut (see Eq. 5.):

$$\kappa_{a_p} = \cos^{-1}\left(\frac{r - 0.5\cdot a_p}{r}\right) \tag{5}$$

ap	FRF modal parameters			Kcy (avg.)	κ
[mm]	f [Hz]	ξ	k [N/m]	[N/mm2]	[º]
1.00	160.3	9.80e-3	5.88e+7	1553.6	28.96
1.50	139.7	4.22e-2	2.98e+7	1282.2	35.66

Tab. 2. Modal parameters, global specific cutting forces and side cutting edge angles

Fig.2. and Fig. 3. represent the stability lobe diagrams and their match with the experimental tests conducted for ap=1 and ap=1.5 mm.

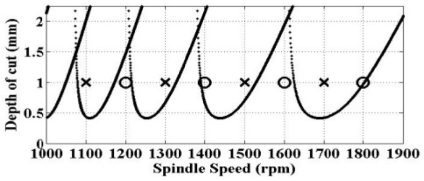

Fig. 2. Stability diagram and chatter test at ap=1 mm

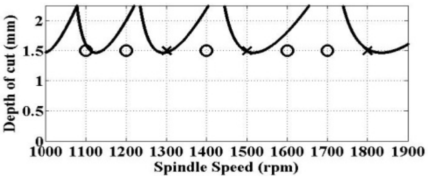

Fig. 3. Stability diagram and chatter test at ap=1.5 mm

3. A NEW ALTERNATIVE: TURN-MILLING

3.1 Introduction to turn-milling

The kinematics of the turn-milling process is based on a simultaneous rotation of the pair tool-workpiece, appearing in multi-task machines of 4 to 5 axes. This technique can be categorized as coaxial or orthogonal depending on the spatial position of the rotation axes. It is called coaxial when the axis of rotation of the tool and the piece are parallel to each other. This option is suitable for both external and internal machining. On the other hand, it is called orthogonal when the axis of rotation of the tool is perpendicular to the piece, which is only applicable for external machining. The application of this technique offers great opportunities increasing productivity compared with conventional turning or milling operations (Choudhury & Bajpai, 2005) due to its flexibility. This aspect eliminates transition times and reduces the number of tools. From the point of view of the determination of the optimal cutting conditions, the estimation of the tool life and cutting forces with an acceptable degree of accuracy is essential due to their strong effect on the main restrictions imposed to the part.

3.2 Tool life analysis

The experiment was anew conducted in the CMZ turning machine with four degrees of freedom using the orthogonal strategy. The test part is a cylinder of AISI 1045, with initial diameter D=152 mm and L=160 mm of working length. Tool wear is studied in carbide inserts with four cutting edges (RCKT M0) with D=50 mm. In order to control the wear of the inserts during the cutting tests, systematic measurements were carried at different machining lengths (each 480 mm). The values obtained for the four cutters were averaged to plot the wear curve shown in Fig. 5.

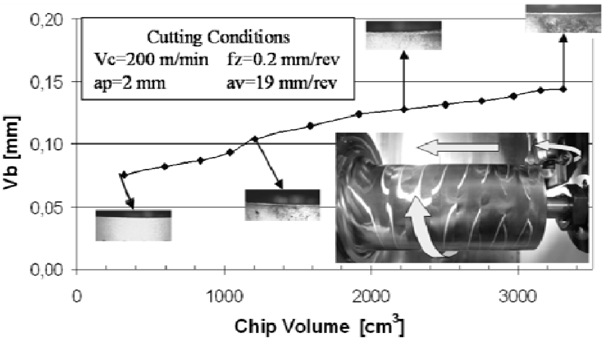

Fig. 4. Tool flank wear vs removed chip volume

4. CONCLUSIONS

When it comes to part manufacturing and production, it is a key issue to define optimized cutting conditions before their introduction to the process chain. In this sense, the study proposes, on one hand, an analytical approach for the stability prediction with successful degree of matching between simulations and experimental results what allows to fix stronger cutting conditions. Future research will focus on one hand on exploring the benefits of such a model not only for the assumption of flexible workpiece but for flexible tool as well as the possibility of using new mathematical algorithms which allow to introduce variable coefficients (with the depth of cut and with the cutting speed) as well as more reliable side cutting edge angles. On the other hand, turn-milling is preliminary studied by means of the evolution of the tool wear resulting in controlled values with the simultaneous aim of stronger conditions but safeguarding the life of the tool. Future plans include a force model to predict the cutting forces and a surface roughness prediction model.

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