10th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

THE STUDY OF DYNAMIC STABILITY TO HIGH SPEED MACHINING MILLING

Petru A. Pop, Petru Ungur, Mircea T. Pop
University of Oradea
1 University Str, 410087, Oradea
Romania

ABSTRACT

This paper presents a modality for study the dynamic stability of high speeds machining milling. The dynamic stability of milling machine is complex operations which suppose to use a dynamic installation to analyze the milling cutting process. The experimental installation can measured the vibration and cutting forces in milling process.

Keywords: actuator, dynamic stability, eigenfrequency, modal analyse.

1. INTRODUCTION

The strong development of machine tools, toolholders, cutting materials, controls, and especially CAD/CAM features and equipment is required to find new machining solutions. High speed machining (HSM) is one of the modern techniques [4,5] that in comparison with conventional machining ensure to improve the accuracy, efficiency, quality of workpieces and to reduce costs. There are many ways to define HSM, such as:

- High cutting speed machining;
- High spindle speed machining;
- High speed and feed machining;
- High productive machining.

HSM is applied to a wide range of metallic and non-metallic materials, including the production of components with specific surface topography requirements and hard materials machining. The industry is an important market which deals with machining aluminium to produce automotive components, small computer parts and medical devices. This sector needs fast metal removal because the technological process involves many machining operation. A great area of HSM is represented by milling of electrodes in graphite and cooper. Graphite can be machining in a great productivity with Ti(C, N), diamond coated solid carbide endmills. Another big category is air craft industry involves machining of long aluminium parts often with thin walls. The third category is the die mould industry which requires dealing with finishing of hard materials. Injection moulds and blow moulds are also suitable for HSM because of their small sizes.

The combination of higher spindle speed and greater depth of cut could appear great vibrations, which could reduce the life of the machines and increase the need of frequent maintenance services with interruption of the working activity .The vibrations are the main causes of troubles on the spindles for HSM. So, the main objective being vibrations suppress to machine-tools using different techniques of vibration control: active and passive damping of vibrations, and adaptive control techniques.

2. DYNAMIC INVESTIGATION

The problems of dynamic stability to machine tools can be resolved with techniques of dynamic investigations of elastic structure of machine [4], which means a complex mode to analysis the system. For this can be used the modal analyses which compares the analytical modal with experimental model.

Experimental modal analysis must to identify the dynamic parameters of machine tools by using excitation of impulse hammer and considering a limited number of measurement points with accelerometers. The firs result is determination the eigenfrequencies, and then the dynamic equivalent parameters. Analytical modal and model simulation can confirms or no the mechanical model and determinate the stability diagram of system. If appears a great difference of eigenfrequencies between the values obtained by analytical modal and simulation with experimental modal it's required to re-design and re-analysis the mechanical model and the dynamic parameters.

Higher spindle speeds and machine federates, combined with a great depth of cut rise the metal remove rate and the productivity. All of these make chatter a far more significant concern. So it's important to study the dynamic cutting process behaviour to find the best speed for achieving the highest productivity. Every system composed by spindle-toolholder-tool has one or more optimum spindle speeds called "*sweet spots*", which are the spindle speeds where the cut is so stable that the axial depth of cut can be doubled or tripled in comparison to other speeds [1,4]. In time of milling process at these high speeds can appeared a great deflexion between cutter and workpiece. When the cutter tooth enters into the cut, the system spindle-toolholder-tool will be deformed, due to the applied cutting forces. When the forces are released by the tooth exiting the cut, the system will vibrate with its eigenfrequency. This vibration leaves on the surface workpiece a little waviness (fig.1). The unfavourably condition is when the vibration from the cutting edges moves and the mirror image of the surface waviness is 180^o out of phase. In this case appears the chatter.

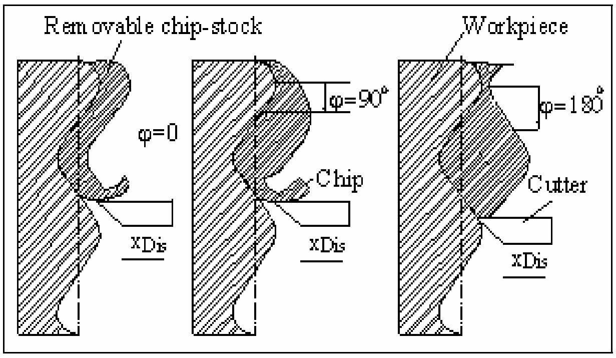

Figure 1. Variation of chip thickness of tool-workpiece.

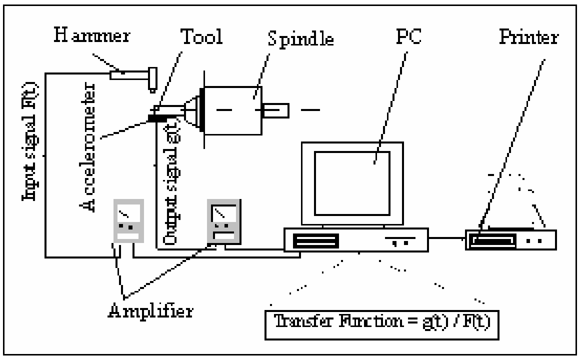

Figure 2. Experimental installation.

The ideal condition is when the surface waviness and cutting vibration are in phase. At this speed is a constant chip thickness, the cut is smooth and the tool gets inside much deeper cut without negative effects, could appear "sweet spots". These are computed by using two approaches. One of them is to find the mode shape and eigenfrequencies system, and the second method is to perform cutting test.

An experimental installation (fig.2) was used for determine the chatter free speeds spindle. A piezoelectric hammer is used to apply a short force pulse to the system and an accelerometer measures the vibration displacement caused by hammer. The transfer function is than computed and used to calculate the sweet spots for a certain workpiece material and cutting condition. All of them are realized by the actuators, which command the optimal speeds for obtained the "sweet spots".

For HSM the maximum metal removal rate (MMRR) is an important parameter of machining, being limited by some factors including the onset of machining instabilities that are dependence by vibration modes from machine and tool. An alternative approach used an active control system to alter the system dynamics. This active control systems is composed by actuators, sensors, PC and software replace mechanical components to provide the desired dynamic response characteristic.

An active control of milling machine was realized to Milling Machine Ingersoll Co. [2].The vibration is sensed at the root of a rotating tool by strain gages that are arranged in half bridge configurations to sense bending in two lateral directions. A telemetric system is used to transmit strain data from rotating spindle to stationary receivers. Strain is measured in a coordinate system that rotate with the shaft (x,y,z), however actuation occurs in a coordinate system that is stationary with the machine (X,Y,Z). The change of angular position to stationary coordinates is made by decoder. Decoder and strain-gage-bridge voltages are fed into anti-aliasing filters, analogue and digital converters (A/D) and a processor for the computation of this transformation. All of them compose by the controller, which is a hardware component with the ability to capture voltage signals, combine them in accordance with a mathematical relationship, and output the result as another set of voltage signals. Control laws were designed to absorb energy from rotating tool, reducing entrapped energy. This energy absorption enhances the stability of cutting process and the MMRR. Three voltage signals are fed into the controller, two signals from the receiver and one from the decoder (fig.3). These signals are passed through anti-aliasing filters and being then sampled. So, this transformed the rotating coordinates (x,y,z*)* in stationary coordinate system (X,Y,Z) [2,4].

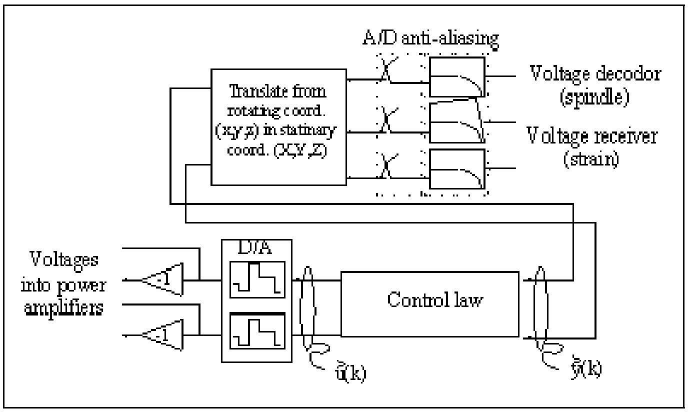

Figure 3. Diagram block of controller.

Stationary strain data at sample time k is given in vector form:

$$\vec{y}(k)=\begin{bmatrix}\delta_x(k)\\ \delta_Y(k)\end{bmatrix} \tag{1}$$

Where: $\delta_X(k)$ and $\delta_Y(k)$ is sampled, stationary, strain data in planes X and Y, this vector control law to compute the controller outputs. The control law takes the form:

$$\vec{x}_C(k+1)=A_C\vec{x}(k)+B_C\vec{u}(k) \tag{2}$$

$$u(k)=C_C\vec{x}_C(k) \tag{3}$$

Where: A_C is the controller state matrix, B_C is the controller input matrix and C_C is the controller output matrix. Choosing a controller state, input and output matrix that will damp tool motion, a mathematical realization (plant) of dynamics from $\vec{u}(k)$ to $\vec{y}(k)$ must be produced. The algorithm used is the Eigensystem Realization Algorithm with Direct Correlations [3] and produced a plant:

$$\vec{x}(k+1)=A\vec{x}(k)+B\vec{u}(k) \tag{4}$$

$$\vec{y}(k)=C\vec{x}(k) \tag{5}$$

Initially a Linear Quadratic Gaussian (LOG) approach was used to determinate the state, input and output matrices of the control low (fig.4). From the Nyquist diagram can be saw that at 450 Hz is an eigenfrequency, which is tool mode. Considering symmetry and neglecting cross coupling the plant is:

$$H(s)=C(Is-A)^{-1}B=\begin{bmatrix}\Omega(s) & 0\\ 0 & \Omega(s)\end{bmatrix} \tag{6}$$

$$\Omega(s)=\frac{\phi(s)K_s}{s^2+2\zeta\omega_n s+\omega_n^2} \tag{7}$$

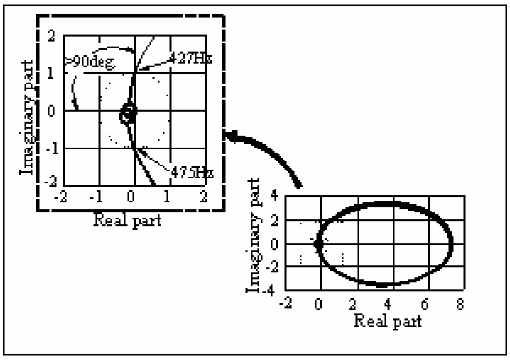

Figure 4. Nyquist diagram of loop gain

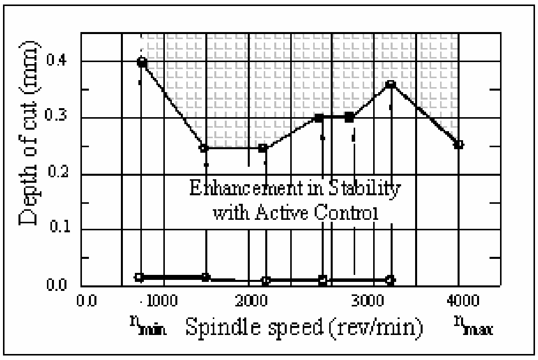

Figure 5. The stability diagram of milling machine.

$|\phi(s)| = 1$, and s is the Laplace transform variable. So, the *LOQ* approach produced controllers that can be approximated:

$$G(s) = C_c (Is - A_c)^{-1} B_c = \begin{bmatrix} \Psi(s) & 0 \\ 0 & \Psi(s) \end{bmatrix} \tag{8}$$

$$\Psi(s) = \frac{K_c s + \alpha}{s^2 + 2\zeta\omega_c s + \omega_c^2} \tag{9}$$

For $\omega \approx \omega_c$ and moderate values of K_S and K_C the loop gain $\Psi(s)\ \Omega(s)$ is greater that 1.0 only for frequencies near to ω. The Nyquist diagram contains a single lob that occurs near the fundamental frequency of the tool. The magnitude and rotation of this lob is controlled by the parameters K_C, ζ_C and α. Chatter instabilities occur during cutting due to dynamic feedback between tool inserts. This interaction creates a dynamic feedback path between successive cuts, can lead to instability.

At spindle speeds n_{min} and n_{max} can appear the *"sweet spots"* or instability regions which can influence the MMRR. Using the active control at milling machine can realized a grown of stability and rise the depth of cut and MMRR, improving the dynamic performance of milling machine for n_{min} = 700 rev/min and n_{max} = 4000 rev/min., which is show in diagram by fig.5, where can be see that depth of cut is rise more that double by active control.

3. CONCLUSIONS

The high speed machining is a very dynamic development in machining technology improving the quality of surface workpiece and great productivity. For that is necessary to increase the dynamic stability of system using adaptive control system, which can avoid the great vibration in time of cutting process by control the cutting forces. Using an active control at HSM assumed new charge and experienced employers, but the results are spectacular, that developed new software and manufacturing technology.

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