A STUDY ON CREATING STABILITY LOBE DIAGRAM BASED ON TOOL TIP DYNAMICS

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ABSTRACT

Creating stability lobe diagram has an important role in optimizing the maximum depth of cut at the highest available spindle speed without chatter. Thus, this study was carried out to determine the stability lobe diagram of a milling machine tool. Firstly, the dynamics of tool tip were investigated by impact tests that applied impulse loads and the signals then were obtained by using Metalmax^{TM}. The TXF^{TM} was utilized to achieve the modal parameters by using modal fit. Finally, a simulation was accomplished by using a Matlab^{R} program to carry out the stability lobe diagram with Fourier series approach. The result obtained from simulation agrees with that comes from the software.

Keywords: *Chatter, stability lobe diagram, tool tip dynamics, machining dynamics*

INTRODUCTION

Machine tool chatter is a self-excited vibration that causes machining instability, it results in poor surface roughness, and increasing tool wear in machining [1, 2]. Therefore, this phenomenon should be avoided during the mechining processes to improve the productivity. In general, a stability lobe diagram based on regenerative chatter theory is a simple and useful way to predict and control chatter, the diagram represents the relationship between critical chip width and spindle speed [1-3]. It has two regions, stable and unstable zones, which are separated by a boundary created by a series of intersected stability lobes. Thus, higher depth of cut and material removal rates can be achieved by using this method [4-6]. Investigation ofthe dynamics of the tool tip is required for creating the stability lobe diagram, and it could be measured using impact tests and modal analysis [7].

In this study, the impact tests are used to determine mode shapes and natural frequencies of an end milling. The model parameters and stability lobe diagram were obtained by using the Metalmax^{TM}. Another stability lobe diagram was obtained by using a Matlab^{R} program with Fourier series approach, a comparison of both approaches will be done to analysis the factor that effect on the machining stability.

EXPERIMENTAL SETUP

In this work, the tool tip dynamics will be determined by applying the impulse load at the tip of tool. The arrangement is shown in Fig. 1(a). The tests are achieved using a carbide end mill cutter, the tool's parameters and its setup are shown in table 1.

The frequency response function (FRF) of the tool-holder-spindle assembly in x and y directions can be obtained by Eq. (1).

$$G_{xx}(\omega)=\frac{X(\omega)}{F_x(\omega)};\ G_{yy}(\omega)=\frac{Y(\omega)}{F_y(\omega)} \tag{1}$$

where $X(\omega)$ and $Y(\omega)$are the measured response in the frequency domain in x and y directions, respectively; and $F_{x,y}(\omega)$are the impulse load applied on the tool. The impulse loads has been impacted by impulse hammer having sensitivity 1.24 mV/N and the corresponding displacement at the tool tip is measured by the accelerometer (352C23) having sensitivity 5.29 mV/G. The FRF in x and y directions can be achieved from the output of TXF^{TM} software shown in Figure 1(b).

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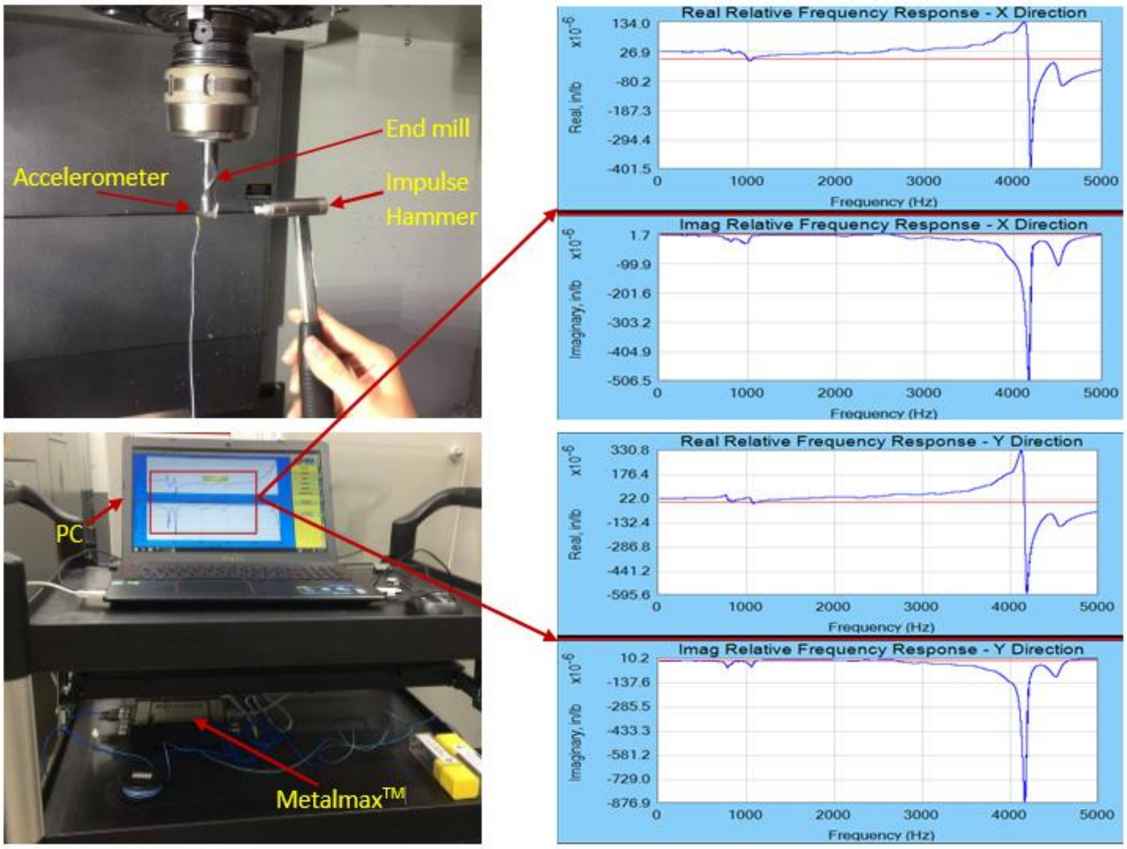


(a) **(b)**

Fig.1. *Experimental modal analysis set-up (a), output of TXF^{TM} -FRF in x and y directions (b)*

Table 1. *Cutting tool's parameters*

Cutting Tool	Diameter *(mm)*	Cutting edges	Cutting edge length *(mm)*	Stickout length *(mm)*
Carbide End Mill	12	2	30	40

MODE SHAPES

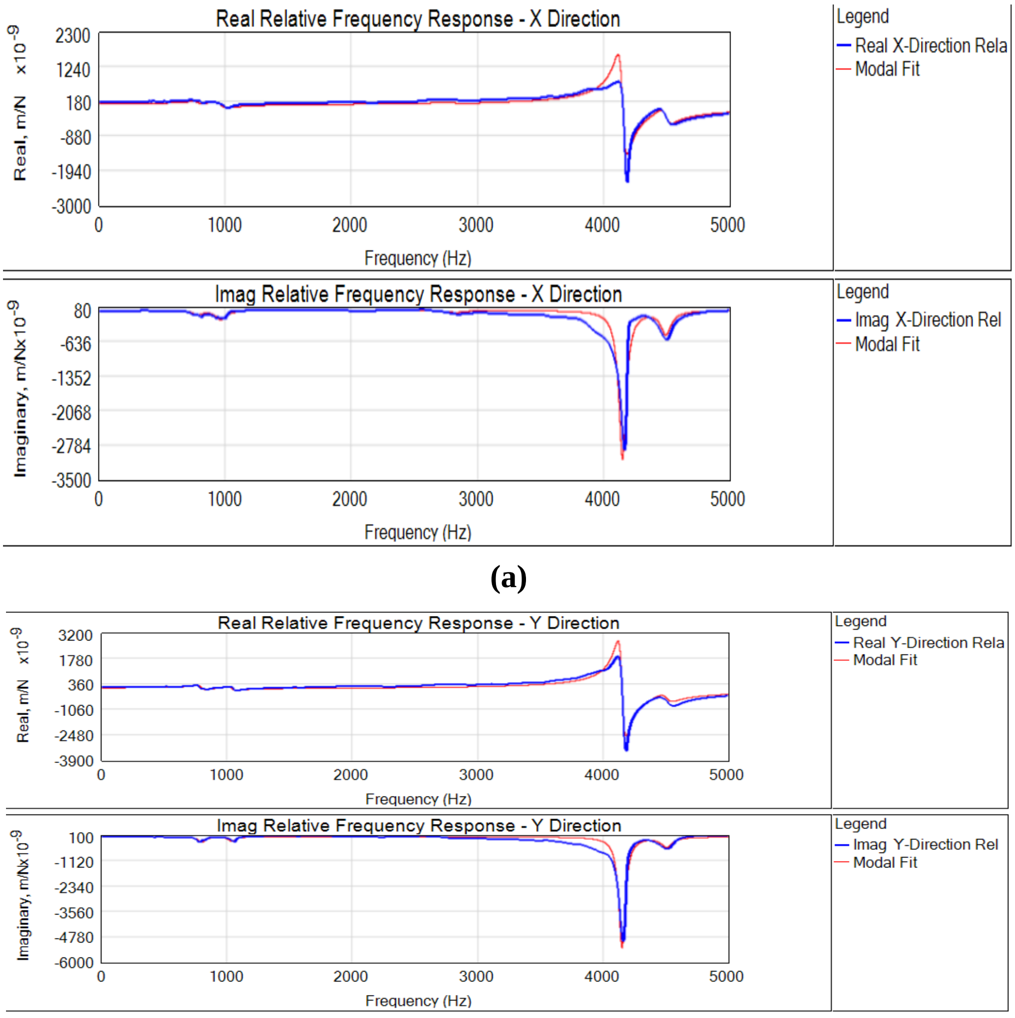
$$\zeta_{qi} = \frac{\omega_{real\,min\,i} - \omega_{real\,max\,i}}{2\omega_{ni}} \tag{2}$$

$$k_{qi} = \frac{-1}{\min\left(\mathrm{Im}\left[FRF_i\right]\right)2\zeta_{qi}} \tag{3}$$

$$m_{qi} = \frac{k_{qi}}{\omega_{ni}^2} \tag{4}$$

$$c_{qi} = 2\zeta_{qi}\sqrt{k_{qi}m_{qi}} \tag{5}$$

In this section, the modal parameters will be determined. Once, the FRF in *x* and *y* directions were measured, a model are defined by performing a modal fit to the measured data. To identify the modal parameters, fitting approach will be a peak-picking method where we use the real and imaginary parts of the system FRFs. This work was done on TXF^{TM} software and the model fit results are shown in figure 2 in which five modes are selected in *x* direction and four modes in *y* direction. Picking the peak values of real/imaginary parts and the corresponding values of frequencies in *x* and *y* directions are shown in Table 2 and Table 3, respectively.



(a)

(b)

Fig. 2. *FRFs_Real and their model fit in x and y directions*

Table 2. *Pick the peak values of imaginary parts and the corresponding values of frequencies for each mode in x direction*

X direction	**Re(FRF)_max**		**Re(FRF)_min**		**Im(FRF)_min**	
	Value *(m/N)*	**Frequency *(Hz)***	**Value *(m/N)***	**Frequency *(Hz)***	**Value *(m/N)***	**Frequency *(Hz)***
Mode 1	1.659e-7	751	9.455e-8	817	-1.045e7	787
Mode 2	1.485e-7	920	-3.245e-8	1023	-1.957e7	970
Mode 3	1.314e-7	2769	9.752e-8	2887	-4.607e8	2830
Mode 4	1.603e-6	4113	-1.441e-6	4185	-3.068e6	4149
Mode 5	-1.140e-7	4452	-5.068e-7	4537	-5.103e7	4493

Table 3. *Pick the peak values of imaginary parts and the corresponding values of frequencies for each mode in y direction*

Y direction	**Re(FRF)_max**		**Re(FRF)_min**		**Im(FRF)_min**	
	Value *(m/N)*	**Frequency *(Hz)***	**Value *(m/N)***	**Frequency *(Hz)***	**Value *(m/N)***	**Frequency *(Hz)***
Mode 1	2.544e-7	770	1.510e-8	837	-2.512e7	804
Mode 2	1.485e-7	920	-3.245e-8	1023	-1.957e7	970
Mode 3	1.603e-6	4113	-1.441e-6	4185	-3.068e6	4149
Mode 4	-1.140e-7	4452	-5.068e-7	4537	-5.103e7	4493

Table 4. *Model parameters in x direction*

X	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
ω_i*(rad/s)*	4945	6095	17781	26069	28230
ξ_{qi}	0.0419	0.0531	0.0208	0.0087	0.0095
$k_{qi}*10^8$*(N/m)*	1.1411	0.4812	5.2058	0.1878	1.0358
m_{qi}*(kg)*	4.6667	1.2955	1.6465	0.0276	0.1300
c_{qi}*(N.s/m)*	1935.2	838.4	1220.7	12.5	69.4

Table 5. *Model parameters in y direction*

Y	Mode 1	Mode 2	Mode 3	Mode 4
ω_i*(rad/s)*	5052	6095	26069	28230
ξ_{qi}	0.0417	0.0531	0.0087	0.0095
k_{qi}*(N/m)*	$0.4777*10^8$	$0.4812*10^8$	$0.1878*10^8$	$1.0358*10^8$
m_{qi}*(kg)*	1.8719	1.2955	0.0276	0.1300
c_{qi}*(N.s/m)*	788.0331	838.4122	12.5032	69.4158

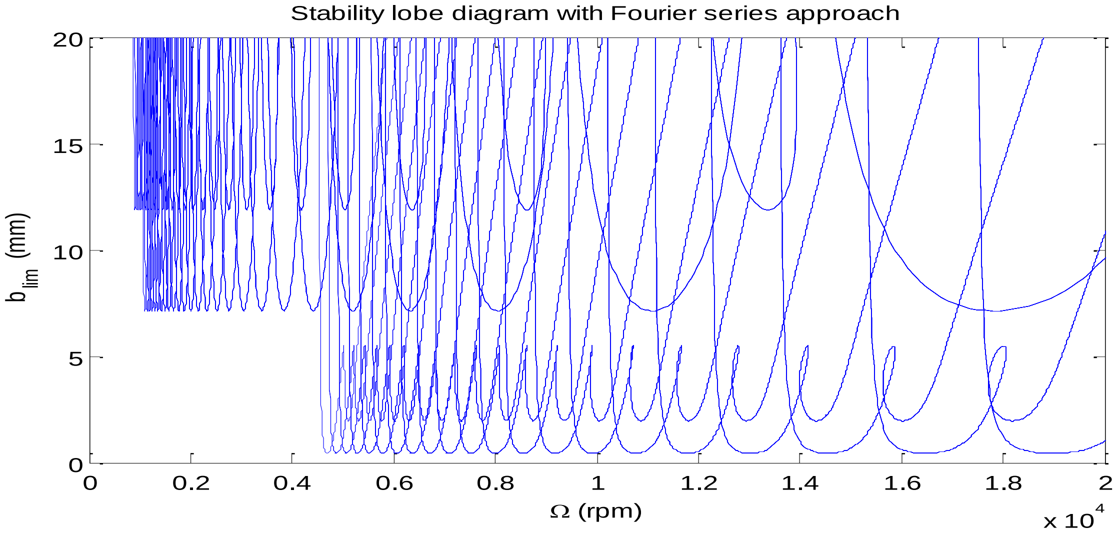


Fig. 3. *The stability lobe diagram from Simulation*

In addition, from peak picking modal fit, the model parameters can be calculated by using equations from (2) to (5). These model parameters in x and y directions are represented in Table 4 and 5, respectively.

RESULTS AND DISCUSSIONS

The direct FRF in x and y directions can be reconstructed by using model parametersobtained by peak picking modal fit that have been presented in [1]. In this present work, the slot milling on a block of Aluminum 7050-T7H51 were supposed, for the force angle β = 65.91°, and the specific cutting force coefficient K_s = 800 N/mm2. A stability lobe diagram then was obtained by using Fourier series approach [3] shown in Figure 3. Figure 4 represents the stability lobe diagram that obtained from TXF^{TM} software. In general, the simulation results are quite close to that of the software.

Especially, as the range of spindle speed Ω> 4200 rpm, the limitation of stabilities are 0.41 mm and 0.26 mm at Ω = 11800 rpm in Figure 3 and 4, respectively. When the rage of spindle speed Ω< 4200 rpm, the limit stabilities are 7.01 mm and 4.9 mm at Ω = 1600 rpm in Figure 3 and 4, respectively. It can be seen that the most different thing between two results is in which the TXF^{TM} software consider process damping with process damping wavelength of 0.6 mm. whereas simulation results (Figure 3) does not consider that. This lead to in Figure 4, the stability lobes gradually move up at lower spindle speed, but this phenomenon does not happen in the Figure 3.

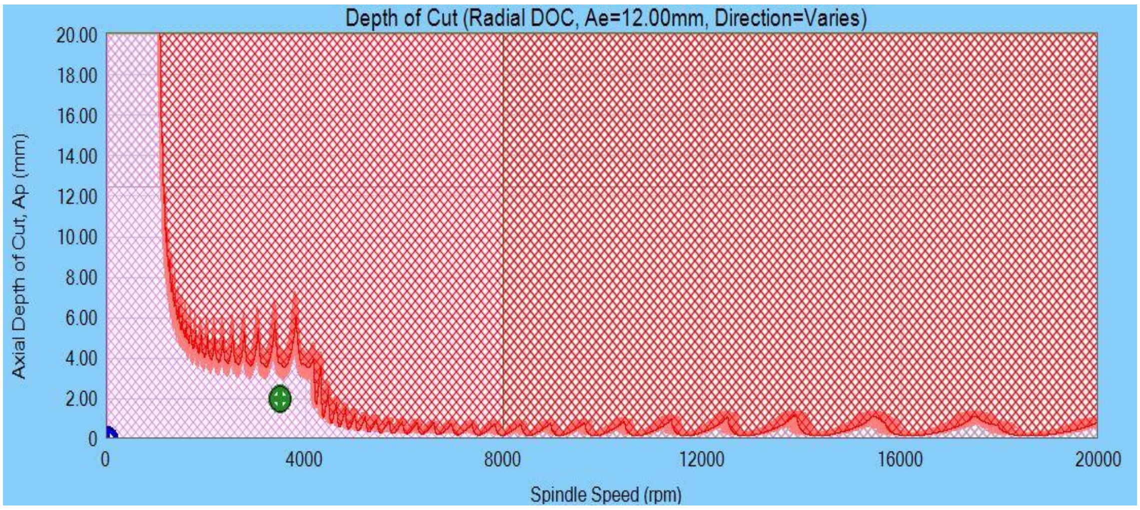


Fig. 4. *The stability lobe diagram from TXF^{TM}*

CONCLUSIONS

In this study, the impact tests with impulse loads were used to determine mode shapes and natural frequencies of an end milling. The model parameters and stability lobe diagram were obtained by using the Metalmax^{TM}. Another stability lobe diagram was obtained by using a Matlab^{R} program with Fourier series approach. A comparison of both approaches was done and shown that the simulation result is very close to that of the software.Thispresent work also contributes to a better understanding to create the stability lobe diagram.

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TÓM TẮT

NGHIÊN CỨU XÂY DỰNG BIỂU ĐỒ ỔN ĐỊNH GIA CÔNG PHAY DỰA VÀO ĐỘNG LỰC HỌC CỦA MŨI DAO

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Xây dựng biểu đồ ổn định gia công có vai trò quan trọng trong việc tối ưu hóa chiều sâu cắt cực đại và tốc độ cắt lớn nhất của máy mà không xảy ra hiện tượng tự rung. Vì vậy, nghiên cứu này trình bày một cách tiếp cận nhằm xác định biểu đồ ổn định gia công cho quá trình phay. Trước tiên, động lực học của mũi dao phay sẽ được xác định dựa vào các thí nghiệm va đập mà ở đó các lực va đập từ búa và các tín hiệu rung của đầu dao phay được ghi lại thông qua hệ thống Metalmax^{TM}. Phần mềm TXF^{TM} sau đó được sử dụng nhằm xác định các thông số động lực học của mũi dao phay. Cuối cùng, thông qua một chương trình mô phỏng trên Matlab^{R}, biểu đồ ổn định gia công đã được xây dựng sử dụng phương pháp chuỗi Fourier. Kết quả mô phỏng thu được phù hợp với các kết quả từ phần mềm TXF^{TM}.

Từ khóa: *Tự rung trong gia công, Biểu đồ ổn định gia công, Động lực học mũi dao phay, Động lực học quá trình cắt*

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