The servo-drives influence on vibration machines

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Abstract

Achieving high-precision surface quality and proper dimension in the shortest possible time is a tend moving the production machines manufacturer forward. In this paper the drive constant adjustments are discussed relate to movement axes of machine tool. The tool tip position, which is given by movement axes, refers to the final dimension of the workpiece, thus its accuracy. This text is primary focused on investigating the transfer functions for differently debugged drives of movement axes. These are then source for determination the limit chip thickness, which depends on the specific cutting resistance and the real part of this transfer function on dynamic compliance. Influence is presented on two-mass system with linear motor

Key words: vibrations; dynamic compliance; limit chip thickness; transfer functions; two-mass system

1. Introduction

Most precision metal parts, whether aluminum, steel or other are produces mostly on the production machines or forming machines. With the growing need for quality demand and products accuracy there is necessary to increase the precision of production machines.

One point of view can include the machine body, which needs to be as stiff as possible, to prevent deformations during the cutting process caused by the cutting forces which are generated by the cutting operation. Also there is necessary to keep in mind that there are many other forces that we have to deal with. For example the gravity. The weight of machines moving parts of cannot over-reach the deformation limit of base parts. So there is always a compromise between stiffness/compliance of the mass of specific production machine.

The whole machine structure is just part of all the reachable quality. The other systems in production machine take their piece for precision. There are the linear guideways, the gears, many bearing, drives and many other mechanical parts, where every single one of them takes part of final compliance.

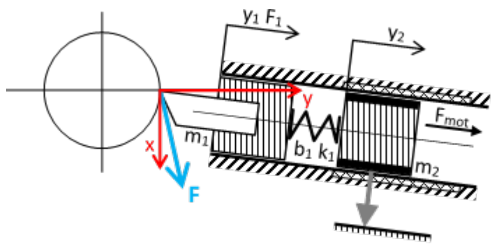

Fig. 1- Two-mass system with linear motor

The final part that takes place in total stiffness is the whole drive controlling system and its setup. There is many optional constants that possibly have serious influence on the final workpiece precision. This is the part of the whole production machine that is discussed and analyzed in following text. For the better understanding and illustration there is used the 2-mass model of machine with linear servo drive to stimulate the whole machine.

2. Two-mass system with linear motor

Example of the two-mass system with linear motor is shown in fig. 1. The system represents simulation of turning operation in general position. The cutting force is labeled F and its projection to the main axix of simulated system is labeled F_1. When the angle between F and x-axis is labeled β and the angle between the main system axis and x-axis is α. Then the the F_1 can be solved as:

$$F_1 = F \cdot \cos(\alpha - \beta) \qquad (1)$$

Considering only two mass on the sides and spring with damping in between, the system can be solved according to the regular equations of motion as following:

$$\boldsymbol{M}\begin{bmatrix}\ddot{y}_1\\ \ddot{y}_2\end{bmatrix} + \boldsymbol{B}\begin{bmatrix}\dot{y}_1\\ \dot{y}_2\end{bmatrix} + \boldsymbol{K}\begin{bmatrix}y_1\\ y_2\end{bmatrix} = \begin{bmatrix}F_1\\ F_{mot}\end{bmatrix} \qquad (2)$$

Where

$$\boldsymbol{M} = \begin{bmatrix}m_1 & 0\\ 0 & m_2\end{bmatrix} \qquad (3)$$

$$\boldsymbol{B} = \begin{bmatrix}b_1 & -b_1\\ -b_1 & b_1\end{bmatrix} \qquad (4)$$

$$\boldsymbol{K} = \begin{bmatrix}k_1 & -k_1\\ -k_1 & k_1\end{bmatrix} \qquad (5)$$

As far as the motor regulation in showed system is considered as closed-loop transfer function with three main loops, see fig. 2. The most inner one for the electric current, labeled *I-reg*, where the requested current is I_r and

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the actual current is I_a. Parental is the speed loop labeled *v-reg*, in which the v_r stands for requested speed and v_a for the actual one. Finally the position loop *y-reg* which refers to the y coordinate in analyzed system, y_r is the requested position and y_a is the actual position measured.

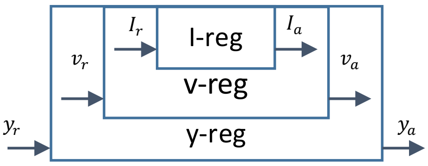

Fig. 2 - Drive regulation

2.1. Complete Simulink model

The system briefly described above has been transferred to the mathematical model in Simulink, see fig. 3. The description is firstly focused on the most inner loop, the current regulation. Input for this loop is in fig. 3 labeled *I_r*. This loop uses the proportional-integral (PI) controller. There has to be two constants set such as current reinforcement constant K_{pix} and current integrating constant T_{nix} those are set by the motor producers, so it is not

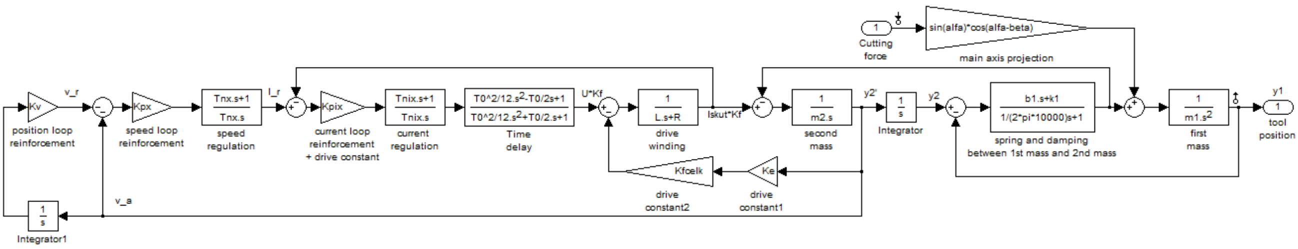

Fig. 3 - System simulink model

recomended to tune them. The actual motor is described in the drive winding block which reflects the motors resistance and inductance. The system time delay is simulated by the second order of Padé approximant.

For the speed loop there is also used the PI-controller where two constants are set by the user. Integrating speed constant is T_{nx} and the reinforcement is K_{px}. Please note that in case of presented model this constant is given in Ns/m, it imply the speed loop reinforcement and also the motor constant K_{Fcompl} in one.

Position loop contains only one K_v constant, insomuch as there is used only the proportional (P) controller.

This simulation also considering the speed feedback, which is integrated to get the position. This type of feedback is called indirect measuring system. The second option of looping the system can be direct measuring system, where the loop closing path will connect input to K_v with tool position.

3. Process stability

Main reason to reach the optimal settings is to get the most precious workpiece in shortest time. Goal is to avoid any type of vibration causing no-go components. The productivity is set by the combination of cutting speed and chip thickness that is removed. Those parameters can be set to its limits. This study is focused on the chip thickness. According to the [1] the limit chip thickness b_{lim} is defined as:

$$b_{lim} = \frac{1}{2C_0 |Re_{neg} G_y(j\omega)|} \qquad (6)$$

Where C_0 is specific cutting resistance, based on the type of machined material and tool material. The $Re_{neg} G_y(j\omega)$ is real part of dynamic compliance transfer function. This is for investigated case defined:

$$G_y(j\omega) = \frac{y_1(j\omega)}{F_1(j\omega)} \qquad (7)$$

To proof the process stability there is usual to plot the Nyquist plot (Real part to imaginary part) of the (7) transfer function. The stability is ensured only for the diagram part that is located on the left side of imaginary axis. That is why there is Re_{neg} In the (6) equation. In graphs showed bellow the focus is aimed only on the negative part of dynamic compliance real part.

Overall it can be stated that when cutting over the limit chip thickness the vibrations can be possibly observed.

4. Simulink model simulation

Used parameters for the current regulation are assumed the same as in the x-axis drive in the Tajmac ZPS vertical milling machine MCFV5050LN [2].

$$T_{nix} = 2ms, K_{pix} = 70\,V/A\,, L = 18mH, R = 1{,}8\Omega,$$
$$f_0 = \frac{1}{T_0} = 4kHz, K_{FX} = 63\,N/A\,, K_{Fcompl} = 1{,}5K_{FX},$$
$$K_e = 63\,Vs/m$$

The mechanic two-mass part with spring and dumping between, specific cutting resistance and general in-space position is simulated by the following parameters:

$$\alpha = 90°, \beta = 20°, m_1 = 20kg, m_2 = 80kg,$$
$$C_0 = 1 \cdot 10^9\,N/m^2\;\; k_1 = 1{,}5 \cdot 10^6\,N/m,$$
$$b_1 = 547{,}7\,Ns/m\,, K_v = 40/s$$

Tracing process stability and finally the limit chip thickness is the most noticeable when tuning the speed regulation constants. There have been investigated 3 cases for the certain K_{px} and T_{nx} combination:

4.1. First case setup

$K_{px} = 10\,000 \;\; Ns/m$
$T_{nx} = 1{,}9 \; ms$

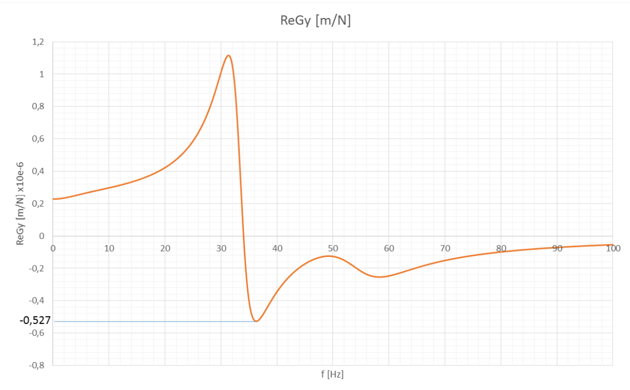

Fig. 4 - 1st settings

In the first case the optimal settings are not reached. The setup appears as very sharp. From the real part of transfer function of dynamic compliance is deducted:

$$Re_{neg}G_y(j\omega) = -0{,}527$$

Then the limit chip thickness can be solved according to (6) as:

$$b_{lim} = 0{,}9 \; mm$$

4.2. Second case setup

$K_{px} = 14\,500 \;\; Ns/m$
$T_{nx} = 4 \; ms$

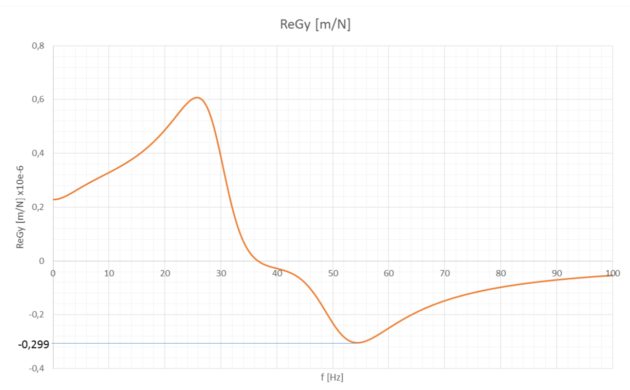

Fig. 5 - 2nd settings

The second settings give much better results compare to the first one. The real part of transfer function of dynamic compliance is:

$$Re_{neg}G_y(j\omega) = -0{,}299$$

The chip limit thickness is than:

$$b_{lim} = 1{,}7 \; mm$$

4.3. Third case setup

$K_{px} = 19\,000 \;\; Ns/m$
$T_{nx} = 8 \; ms$

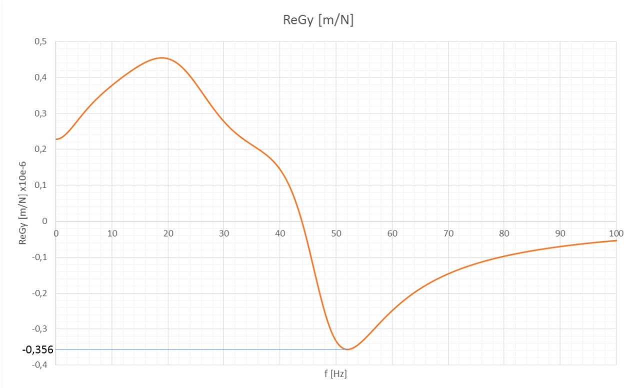

Fig. 6 - 3rd settings

The third case is more like an example that if the constants are rising, no better results are obtained. In this setting, the system is slow and there are no acceptable values obtained. The real part of transfer function of dynamic compliance is:

$$Re_{neg}G_y(j\omega) = -0{,}356$$

The chip limit thickness is than:

$$b_{lim} = 1{,}4 \; mm$$

5. Conclusion

In this paper the influence of setting the drive constants on cutting stability is presented. The investigation is focused on solving the limit chip thickness. That is the critical axial depth of cut. If the cutting depth will be below this limit, the process can be considered as stable. There is also possibility to achieve stability above this limit, more in [3].

Based on the simulation there is significant change in the limit chip thickness based on changing the integrating speed constant T_{nx} and the reinforcement constant K_{px}. The optimal constellation is found for $K_{px} = 14\,500 \;\; Ns/m$ and $T_{nx} = 4 \; ms$, where the maximum chip limit thickness is reached - $b_{lim} = 1{,}7 \; mm$. For the sharpest settings, where $K_{px} = 10\,000 \;\; Ns/m$ and $T_{nx} = 1{,}9 \; ms$ the chip limit thickness is dropping to $b_{lim} = 0{,}9 \; mm$ and on the other side for the slowest settings, where $K_{px} = 19\,000 \;\; Ns/m$ and $T_{nx} = 8 \; ms$ the drop in limit chip thickness is obvious also.

Nomenclature

Symbols

C_0	Specific cutting resistance $[N/m^2]$
F_1	Projected cutting force to main system axis $[N]$
F_{mot}	Force generated by the motor $[N]$
$G_y(j\omega)$	transfer function of dynamic compliance
I_a	Actual current$[A]$
I_r	Requested current $[A]$
K_{FX}	Motor force constant $[N/A]$
K_e	Motor voltage constant $[Vs/m]$
K_{pix}	Current reinforcement $[V/A]$
K_{px}	Speed reinforcement $[Ns/m]$
K_v	Position reinforcement $[1/s]$
T_0	PWM period $[s]$
T_{nix}	Current integrating constant $[ms]$
T_{nx}	Speed integrating constant $[ms]$
b_1	Damping between mass 1 and mass 2 $[Ns/m]$
b_{lim}	Limit chip thickness $[mm]$
f_0	PWM frequency $[kHz]$
k_1	Rigidity between mass 1 and mass 2 $[N/m]$
m_1	Mass 1 $[kg]$
m_2	Mass 2 $[kg]$
v_a	Actual speed $[m/s]$
v_r	Requested speed $[m/s]$
y_1	Position of mass 1 $[m]$
y_2	Position of mass 2 $[m]$
y_a	Actual position$[m]$
y_r	Requested position $[m]$
F	Cutting force $[N]$
L	Motor inductance $[mH]$
R	Motor resistance $[\Omega]$
x	x-axis
y	y-axis

Greek symbols

α	x-axis and main system angle [°]
β	Cutting force and main system angle [°]

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