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Tuning of position control loop of machine tools based on experimentally identified mechanical model

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Feedback control of machine tool feed drive axes is highly demanding in the accuracy point of view. Overshot only micrometers can worse machined surface with impact on workpiece, for example on mould surface. Surface quality is not only reason for demands on smooth and accurate movement. There are other aims like productivity of machining and ability to track highly curvature shapes. It illustrates the wide field for complex views on machine tool cascade servo control.

Desired input for position control, or position setpoint, is derived from the workpiece dimension and desired machining speed (given for example by technology and workpiece material). But no machine is capable to ideally track the desired inputs. One significant influence that limits the tracking accuracy are vibrations caused by interaction of flexible machine mechanics with the machine feedback control system [1]. Manufacturers of commercial control systems implement to their product some tools which enables to supress unwanted vibrations. Such functions are for example current and speed filters. Thus beside the setting of P and PI controllers in feedback loops there are an extended possibilities to increase the loop gain and consequently to reach higher dynamic stiffness and wider bandwidth in frequency response.

Optimization via these functions is usually done in the level of speed and position feedback. However, resulting vibrations can also be lowered by shaping the input command. This can be easily done by setting the value of jerk [1]. Higher values of jerk tends to excite higher oscillations. But from the pure kinematical point of view higher values of jerk enables to reach acceleration in shorter time and hence higher curvature can be machined. That indicates requirement on finding its proper value. Finding the appropriate value of jerk together with the setting of position controller gain known as Kv factor is the key task in the optimizing position feedback loop of machine tool axis.

This article is focused on the automatic tuning of position control loop. Kv factor and jerk value are taken into consideration. Tests were carried out on the experimentally identified mechanical model of machine tool feed drive axis. The inner velocity control loop was set to suitable dynamics and this setting was held during the experiments with position control. The model order of mechanics was set to accurate describe mechanics in high as well as low frequencies.

The influence of jerk and Kv factor on the accuracy will be evaluated on the shape of position error. Its steady state part has a zero mean due to the active velocity feedforward and transient part is nonzero due to the limited dynamical stiffness. Two criteria were used as a measurement for the evaluation of position error. Maximal overshot of position error Δ and ITAEn integral criteria with the enhanced meaning of time. First criteria is the natural measure of maximal deflection from the desired trajectory. This criteria does not catch time duration or settling time of the overshot. The second one evaluate the surface of position error with strong emphasis on its time progress. For this reason time exponent n = 5 was chosen.

$$ITAEn = min \int_0^\infty t^n |\Delta(t)|\, dt, \qquad n = 5$$

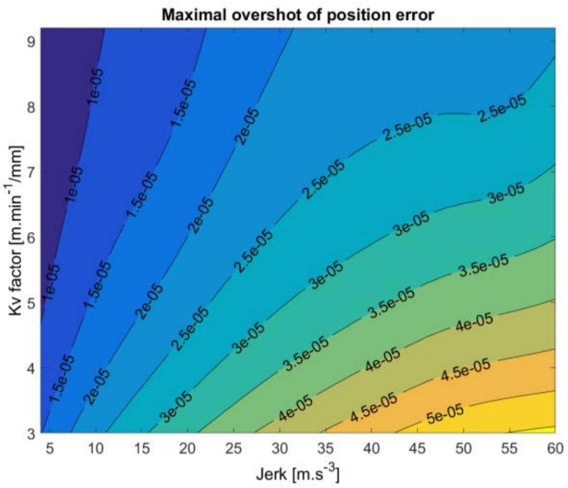

Fig. 1. Maximal overshot of position error

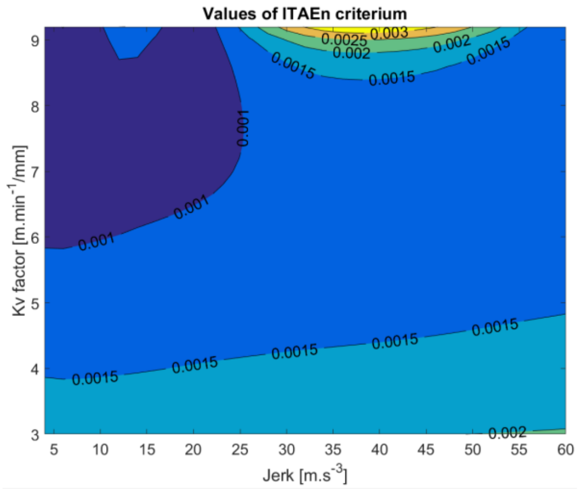

Fig. 2. Values of ITAEn criteria

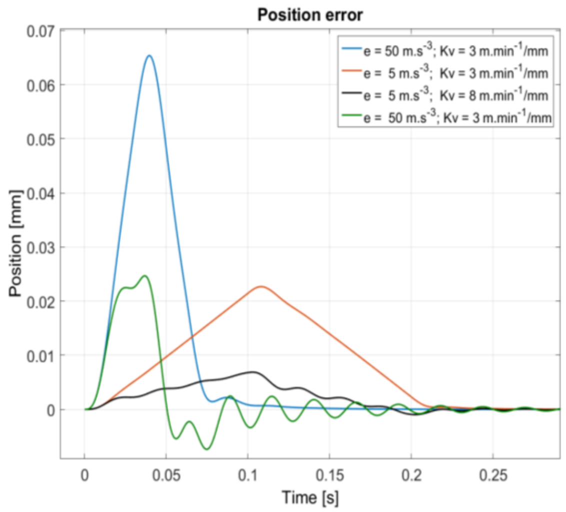

Fig. 3. Overshots in position error

Simulations were carried out in Matlab-Simulink environment. Values of both criteria for several combinations of jerk and Kv factors are shown in Fig. 1 and Fig. 2. Dark blue regions distinguishes areas with the low overshot and also with low ITAEn criteria. Such regions are defined by low position error and are valid for higher Kv factor and lower jerk. Fig. 3 shows that lower Kv factor and higher jerk can result in higher overshot but without oscillations, case e = 50 $m.s^{-3}$ and Kv = 3 $m.min^{-1}/mm$, whilst higher Kv factor with higher jerk, case e = 50 $m.s^{-3}$ and Kv = 8 $m.min^{-1}/mm$, have both criteria low but significant number of unwanted oscillating periods are present.

We can conclude that the low value of integral criteria and low overshot in position deviation at the same time need necessarily not lead to satisfactory behaviour of feed drive axis. Higher number of oscillating periods can decrease the machining accuracy and surface smoothness. Computer simulations can be carry out for finding the appropriate values of jerk and Kv factor. When adjusting the machine in practice, it is necessary to be careful with possible transfer of parameters into the control system. Some effects such as friction are not included in the model so real oscillations may differ from the modelled ones.

References

[1] Souček, P., Servomechanisms, CTU, Prague, 2004. (in Czech)