SEISMICALY BALLANCED MACHINE TOOL – MODEL AND SIMULATION OF COG MOVEMENT ABSOLUTISATION OF „FLOATING“ AXIS

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Presented contribution describes a seismically balanced machine tool axis with advantages and disadvantages of that kind of concept. After an introductory survey on the seismically balanced machine tool, a system simulation is presented. This system simulation includes a model of the mechanical parts, a model of a synchronous linear motor, and a model of the control circuits. The control algorithm of relative distance (with simulation of relative distance control of two masses) and centre of gravity movement control (absolutisation) is presented. The LQ control algorithm was compared to the heavily used PID control algorithm. The results are shown in the last section of this paper. With these results, optimal design of controller can be achieved.

Keywords
seismically balanced tool machine, simulation, model, control, LQ controller, PID controller

1. Problem definition

The seismically balanced machine tool concept based on "floating" principle brings various problems from the control domain. Fine precision control of a relative distance between the tool and the work-piece is just a half of the control problem. The second half is the problem of COG movement incurred by different friction forces applied on different machine tool masses. Using of modern state MIMO (Multiply Input Multiply Output) controller solves both problems. Classic PID control is shown for comparison. A non floating axis brings interesting control problems as well – precise control of two separate drives in opposite direction.

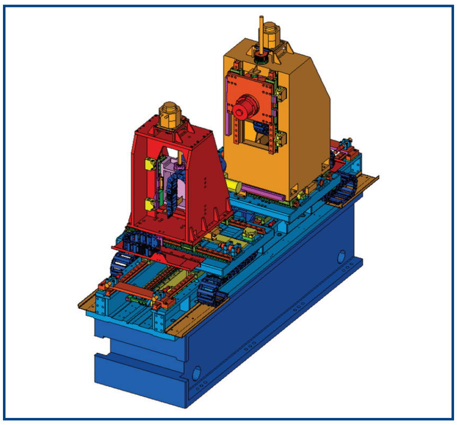

Figure 1. *Stand STD1 build in RCMT as a prototype of seismically balanced tool machine with one floating axis*

2. Seismically balanced machine tool

Stand STD-1 (fig. 1. and schema in fig. 2.) was built in the Research Center of Manufacturing Technology. It is a prototype of seismically balanced machine tool [Bubak 2003] with one floating axis [Novotny 2004] and two balanced axes. The principle is based on eliminating of reaction forces using forces of moving axis drive. Z axis is floating – the schema is in fig. 3. This axis is mechanically balanced. Partial accelerations of tables are defined as

$$a_1 = \frac{F}{m_1} \quad \text{and} \quad a_2 = \frac{F}{m_2}, \tag{1}$$

Where *F* is force and *m* is weight of the table. Overall relative acceleration is defined in equation 2. It is obvious that overall acceleration of floating axis is always higher than on traditional one.

$$a_{12} = a_1 + a_2 = \frac{F}{m_1} + \frac{F}{m_2} = F.\frac{m_1 + m_2}{m_1.m_2} \tag{2}$$

A disadvantage of the floating axis is that due to different non linear friction forces the movement occurs at a lower speed. In that case both tables could "float" from ideal position and thus the center of gravity will not be in one place. Absolutisation drive will be used for correcting error in COG position. Another disadvantage is a more complicated mechanical construction.

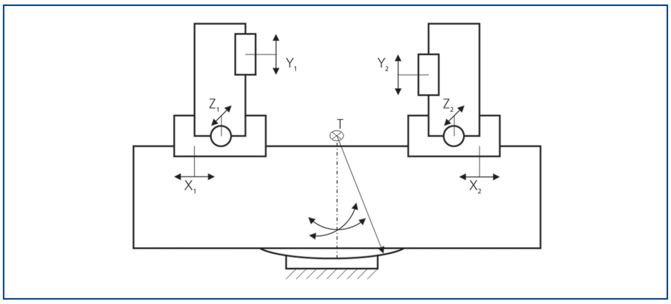

Figure 2. *Overall schema of stand STD1 on spherical base*

Axis *X* and *Y* are constructed of two drives moving in opposite directions. There is no direct mechanical connection so balancing is the problem of control system.

Basic idea of balancing in control system is very simple – the same force is needed to be used in both drives at the same moment. However the solution is complicated due to limitations of control systems and relative distance measurement.

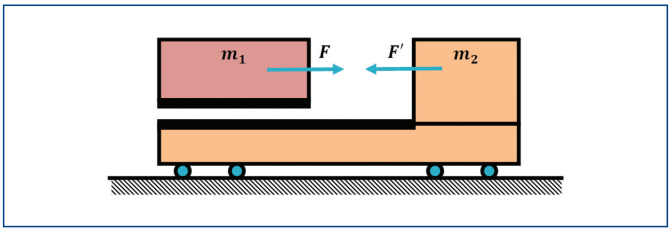

Figure 3. *Scheme of "floating" axis*

3. Simulation results

The Model of the "floating" machine tool axis is shown in fig. 4.For the simulation and for described model was used Matlab® and Simulink® environment described. The model is composed of two mechanically connected masses. The relative distance change could be done by force (proportional to current) developed by a drive between masses. Due to different friction forces overhung masses are moving along the machine base frame. Friction forces are modelled as simple linear functions (fig. 5).To compensate this undesirable effect the movement of both masses is needed. This movement is controlled by a second (absolutisation) drive.

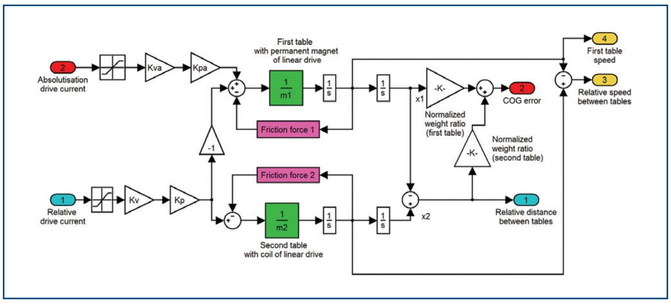

Figure 4. Simulink model of floating axis

The inputs of the model are the forces for each motor. Relative distance of two masses, the distance of the COG from ideal position and velocities of the masses are the outputs. The distance of the COG from ideal position and velocities of the masses are added information for state regulation.

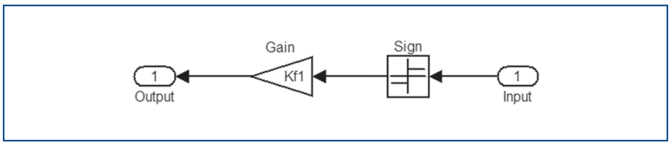

Figure 5. Friction force block

The overall regulation scheme is shown in fig. 6. Two masses (1000 kg and 500 kg) are accelerated by relative distance drive and drifting from the COG ideal position is compensated by the absolutisation drive. Two PID controllers or one state controller (REG) is connected to a model of two masses overhung connected to the base frame. The state controller is a LQ based controller extended by a Kalman filter, model of a noise signal and it is extended by reference [Stecha 1996]. Optimal control parameters are computed by Matlab® and used in the control scheme. The PID controller's parameters are empirically obtained using the Ziegler–Nichols method.

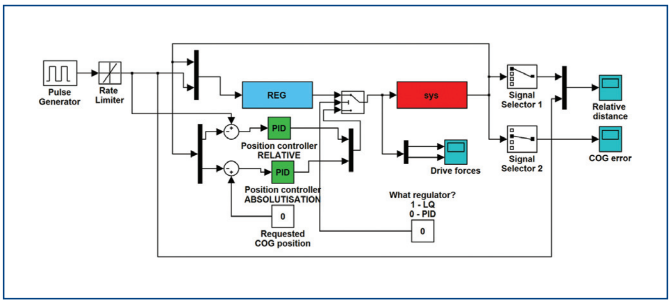

Figure 6. Overall regulation scheme for absolutisation

3. Simulation model for one "floating" machine tool axis

A couple of controllers were designed and simulated for the concrete model parameters and the concrete machine properties; one classical PID controller, whose parameters were empirically obtained using the Ziegler–Nichols method and one LQ state regulator (extended by a Kalman filter, model of noise and reference).

The system response of step input signal on desired relative distance between masses is shown in fig. 7. The PID controller shows an overshoot which is unwanted in the machine tools domain. To get rid of this overshoot the PID parameters should be even more lowered. That makes the model control more imprecise. The LQ controller is more accurate and reacts faster on change of inputs than the PID controller.

The following picture (fig. 8) from simulation shows the result of optimal design of the LQ controller. For our set of simulation parameters is COG drift lower by 2/3 for the LQ controller than for

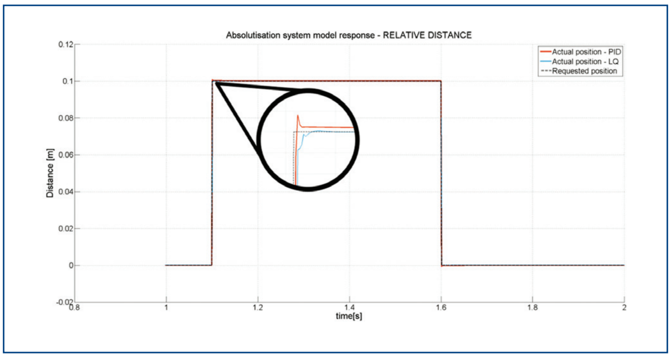

Figure 7. Step response for relative movement request

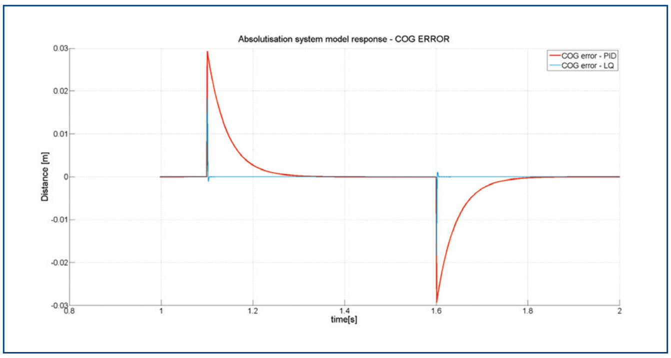

Figure 8. Error of COG ideal position

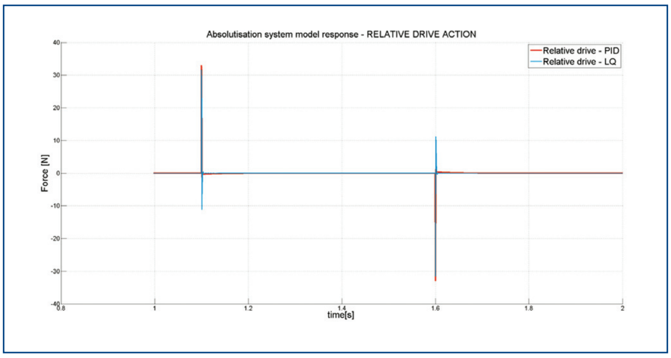

Figure 9. Action force of relative drive

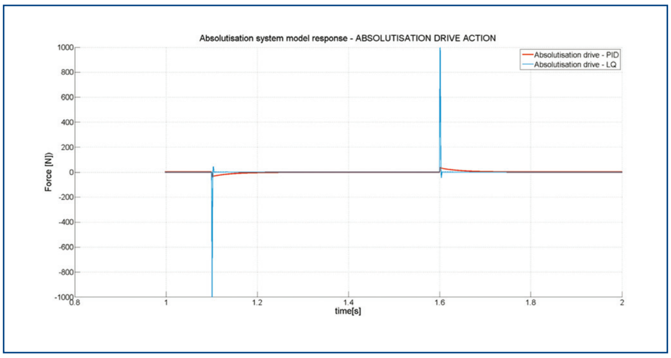

Figure 10. Action force of absolute drive

the PID controller. This is the most important parameter for choosing of controller in our case. This precise control is possible due to tuning of the LQ controller parameters by math computing. For any change of model parameters (weight, friction forces) new precise LQ controller could be computed. The action of particular drives can be found in fig. 9. and 10.

4. Conclusion

The seismically balanced machine tool brings a new fresh concept into the design of machines tools. It brings new requirements as well as advantages compared to the former classic concept. Some of the related problems and solutions were described in this paper. Simulation results show the possibility of using enhanced controllers to achieve significantly better results for drift of the centre of gravity (COG) elimination problem. Lower COG position error enables construction of seismically balanced machine tools and achieves quick manufacturing with high speeds and precision. Next level of research should be adaptive absolutisation algorithms as well as absolutisation algorithm of mechanically disconnected balanced masses. A possible solution of the control problem has also been outlined. The results shown in this paper open a large area of research for more advanced mechatronic systems to be used in machine tools.

References

[Bubak 2003] Bubak, A. et al. New principles for design of highly dynamic machine tools. *Proceedings of the International Conference ICPR-17* (Ed Deisenroth M. P.), Blacksburg, Virginia, USA, 3-7 August 2003, (Virginia Polytechnic Institut and State University). ISBN 0-9721257-3-6

[Novotny 2004] Novotny, L. Horizontal Milling Centre with Floating NC Axis. *MATAR Prague 2004,* Society for machine tools, 2004, ISBN 80-903421-3-2

[Stecha 1996] Stecha, J., Havlena, V. *Modern Control Theory,* textbook CTU, (in Czech), Prague, Czech Technical University, 1996

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