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ACCELERATION SIGNAL AS INPUT OF VELOCITY LOOP IN MACHINE TOOL CASCADE CONTROL LOOP

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Summary: *This paper deals with alternative techniques how to get the velocity signal that is needed for the velocity feedback loop. Common implementation of obtaining the velocity signal is for high dynamic machine tools relatively slow, that is why it is extremely important to search new solutions. There are shown in the paper two methods based on acceleration measurement, one of which is closely described and simulated.*

1. Introduction

High-quality of the velocity signal is an important factor for the velocity regulation performance. The velocity signal is generally computed by derivation of the position signal obtained from incremental encoder. Unfortunately calculation of velocity by derivation of the position signal is connected with a time delay and in addition it depends on the incremental step that debases its quality. Because the quality and time delay of the velocity signal are very important factors of the whole regulation quality, it is very useful to search for some new methods of obtaining velocity signal for the velocity control loop.

One possibility is to get velocity by integration of the acceleration signal which is available from the accelerometer fixed on the motion axis. Integration doesn't bring time delay, however some noise superposed on the analog signal of acceleration causes integration deviation of the calculated velocity signal. The noise and integration deviation are the main reasons for non-acceptability of such solution in the machine tool control loop.

Description and use of methods eliminating the integration deviation and processing the acceleration value are the main topics of this paper.

2. Acceleration to velocity conversion principle

Two methods are described in this chapter. Both are based on the integration of the acceleration signal with suppression of the integration deviation. First is based on pure filtration principle and the second one on the reference velocity signal, where both information from the accelerometer and incremental encoder are used.

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2.1. Integration with a pure filtration

The main idea of this conception is to straightly remove the source of the integration deviation that is superposed to the acceleration signal. The integration deviation is caused by low frequency fraction of the noise of the acceleration signal and the aim of this solution is filtering out these low frequencies. As shown in the (Figure 1) the principle is very simple.

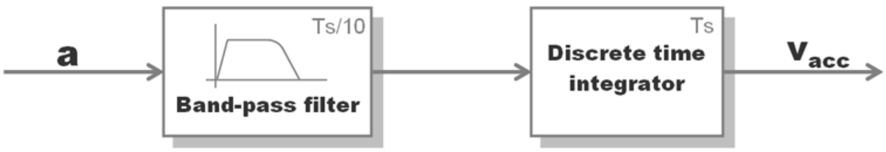

Figure 1 – Block diagram of the integration with the pure filtration

As shown in the (Figure 1) band-pass filter is used as a filtration equipment. It removes the high frequencies (high frequency noise) and the low frequencies (source of the integration deviation) from the acceleration signal. Such filtered signal is integrated by common discrete time integrator and the velocity signal is available in the output in high quality. It is advisable to increase a sampling frequency of the filter (in comparison with the sampling frequency of the control system) because of phase lag and filtration quality.

Main disadvantage of this method is dependence on the filtration quality and non-measurability of low frequency speed. This is the main reason why this method can not be used in the common velocity loop. Otherwise it can by used in vibration suppression activities effectively (Preumont, 1997).

2.2. Integration with a reference velocity signal

Main idea of this method is involvement of the reference velocity signal that is computed from derivation of the position signal obtained from incremental encoder (Hiller, 2003). The final velocity is then computed by combination of the reference velocity signal and signal from the accelerometer. As well as in the previous chapter, high frequency velocity signal is obtained from acceleration. The difference is, that the low frequency velocity is included by using the reference signal.

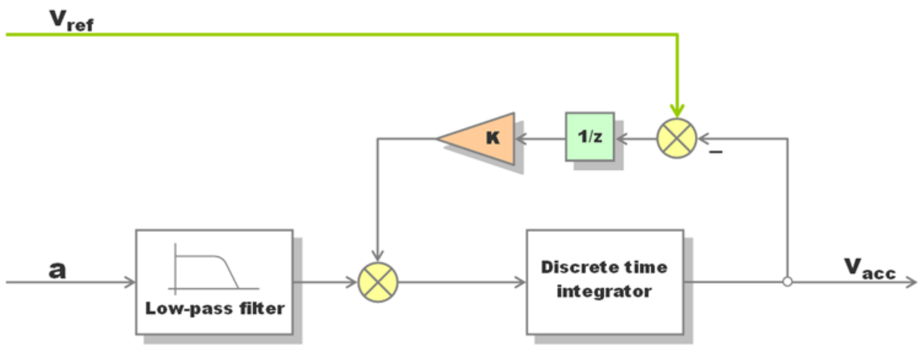

Figure 2 – Block diagram of the integration with the reference signal

The block diagram of the integration with the reference signal is shown in the (Figure 2). As shown in the diagram, some acceleration correction is added to the “dirty” acceleration signal because of suppression of the integration deviation. The correction signal is proportional to the velocity difference by gain *K*.

To explain this scheme we have to write the block diagram as an equation in Laplace domain (Valášek, 1995):

$$v_{acc} = \frac{a - K \cdot \left(v_{acc} - v_{ref}\right)}{s} \tag{1}$$

where *a* is so called “dirty” acceleration signal from the accelerometer, connected with low frequency noise and v_{ref} is the reference velocity signal. We obtain relation for the final velocity by simple modification of the equation (1)

$$v_{acc} = \frac{a}{s+K} + \frac{v_{ref}}{\frac{s}{K}+1} \tag{2}$$

where

$$a = v \cdot s \tag{3}$$

First part in equation (2) represents velocity high-pass filter and the second one velocity low-pass filter, both with corner frequency *K*. It means, the final velocity consists of low frequency contribution from reference velocity and of high frequency contribution from velocity obtained from acceleration. Thereby the integration deviation is removed. The principle is shown in (Figure 3).

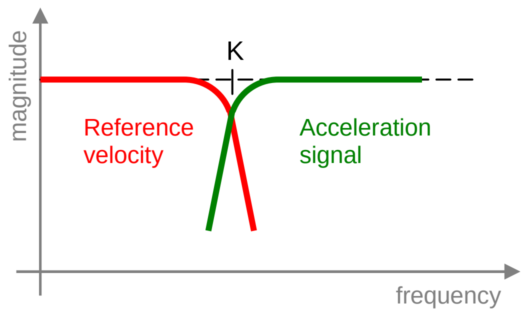

Figure 3 – Frequency contributions of the velocity signal

As shown in the (Figure 3) the velocity signal is available for each frequency and without integration deviation, thereby it can be used in common cascade loop as a regular velocity signal.

The gain value (filter corner frequency) must be tuned carefully because of the method efficiency. For low gain value, the integration deviation can occur. Second part of equation (2) can be neglected and velocity is mainly computed from acceleration signal. Otherwise for high gain value, the advantage of low time delay is lost. First part of equation (2) can be neglected and the final velocity signal is fully computed from the slow reference signal.

As shown in block diagram in (Figure 2), at first the acceleration signal is filtrated by low-pass filter because of removing high frequency noise. Next, the feedback loop must be equipped with unit delay block because of time causality.

In the end, velocity signal obtained by using this methodology is not connected with the time delay and is resistant to the integration deviation.

3. Simulation experiment

Simulation experiment was made on two-mass model of machine tool (Figure 4). Integration with the reference velocity signal was chosen as the integration method. The reason is full substitution of common velocity signal.

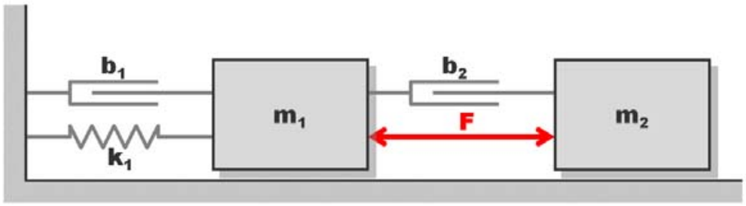

Figure 4 – Two-mass model of machine tool

As shown in the (Figure 4) the first mass represents machine tool body with some damping and stiffness. The second one represents spindle head whose weight is significantly less than the first machine tool mass. Between both masses reacts machine tool feed drive and some damping that simply simulates properties of linear guideways.

Common cascade loop (Marek, 2006; Souček, 2004) is implemented at first because of comparison with new method described above. Its block diagram is shown in the (Figure 5).

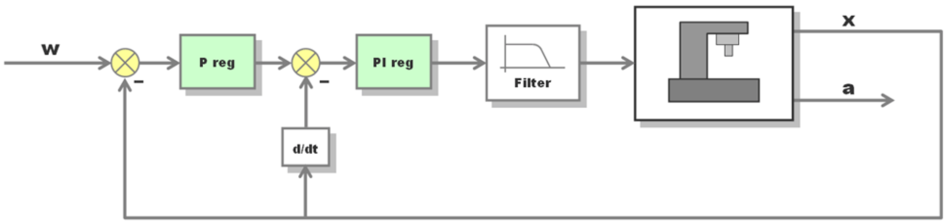

Figure 5 – Common cascade loop block diagram

Modified cascade loop that uses acceleration signal and reference velocity signal is shown in the (Figure 6).

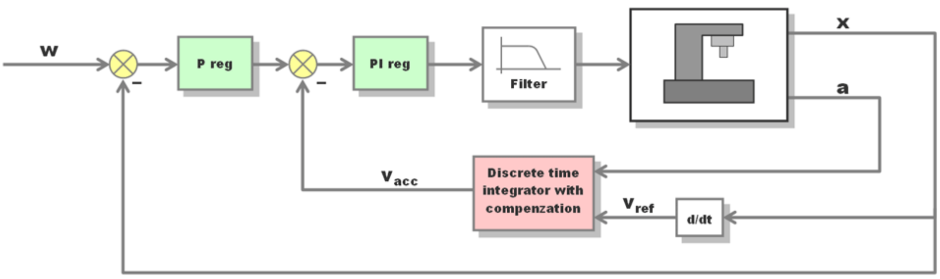

Figure 6 – Modified cascade loop block diagram with the integration with the reference signal

Low-pass filter in the feedback loop substitutes function of the current regulation, that has limited frequency bandwidth.

Velocity step response of the simulated model with cascade control loop is shown in the (Figure 7). It is evident from the simulation that the common integration is connected with some integration deviation caused by low frequency noise. The integration with reference velocity signal appears to be resistant to the integration deviation and visualizes the actual velocity with smaller time delay than in the case with velocity obtained from position derivation.

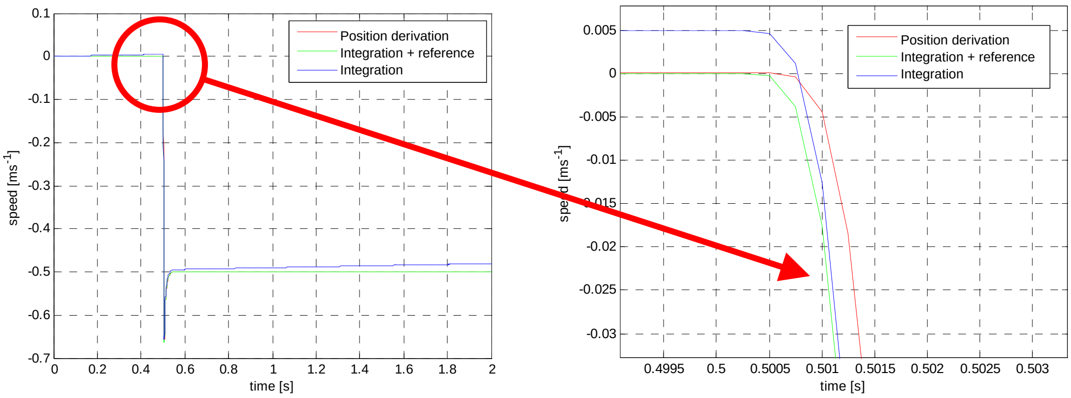

Figure 7 – Velocity step response

Regulation quality comparison as a velocity step response is shown in the (Figure 8). The shown time behaviour is for the one velocity loop with two different velocity signals. The velocity loop with velocity signal obtained from acceleration is characterized by smaller overshoot than the loop with common velocity signal. Consequently it is possible to tune up K_{pv} gain and improve regulation quality and dynamic in that way.

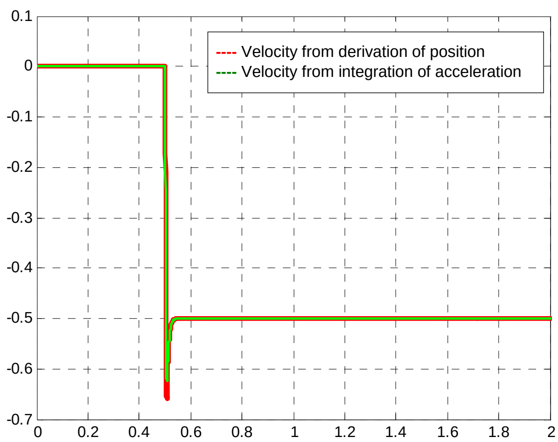

Figure 8 – Velocity step response – regulation quality

Dynamical stiffness is improved by using of velocity obtained from acceleration too. As shown in (Figure 9), disturbance force step causes small axis displacement that is compensated by control loop. Slight reduction of this displacement is brought by simple using of velocity feedback with the velocity obtained from acceleration. The axis regulation displacement can be more eliminated by tuning up the regulator constant K_{pv}. As shown in the (Figure 9) the regulation displacement can be suppressed up to 40%. This additional K_{pv} constant tuning and regulation displacement improving is possible because of using the velocity signal with smaller time delay.

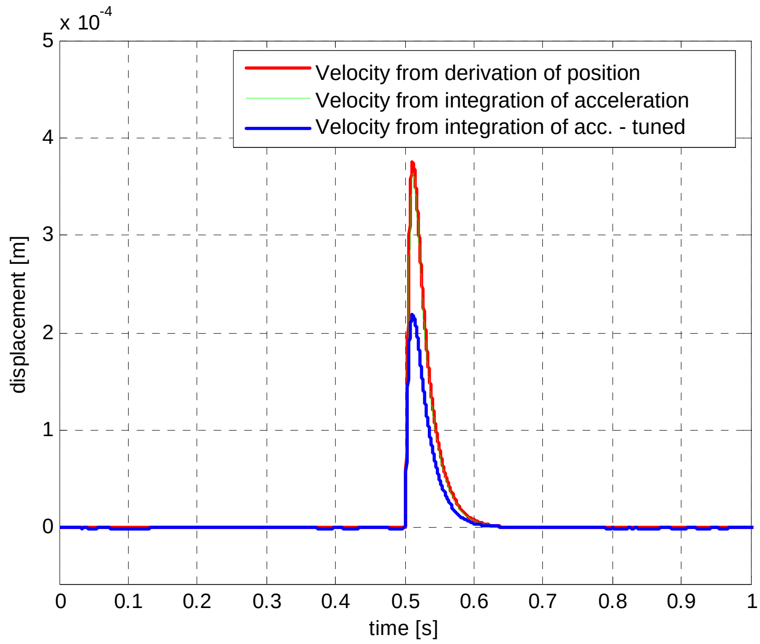

Figure 9 – Disturbance force step response – dynamical stiffness

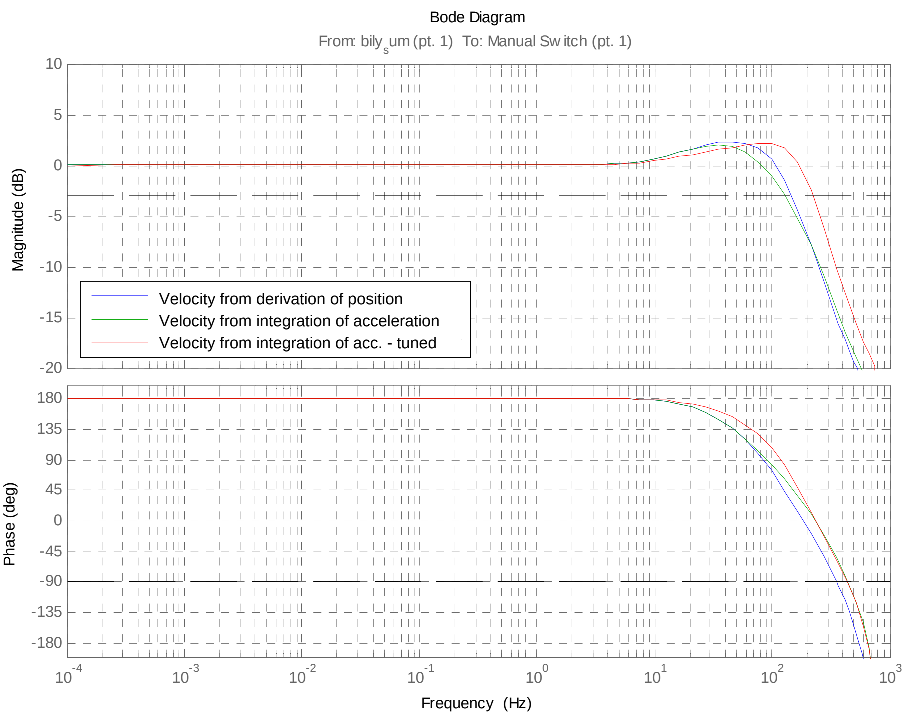

Figure 10 – Velocity loop transfer function

The velocity loop transfer function is shown in (Figure 10). As shown in the picture, frequency band-width of velocity loop is extended. Transfer function overshoot is suppressed because of using the velocity from accelerometer and thereby we can tune up the velocity regulator as well as in the previous paragraph. The frequency band-width of the velocity loop in our simulation model is increased by 75 Hz in magnitude (from 147 Hz to 222 Hz) and by 78 Hz in phase.

4. Testing bed

As shown in the (Figure 11) a testing bed was designed. The bed was equipped by the acceleration sensor based on the Ferraris principle (Hiller, 2003) and the incremental encoder. This sensors are necessary for testing the above described method. At this time the testing bed is under construction and real experiments will be done as soon as the bed will be finished.

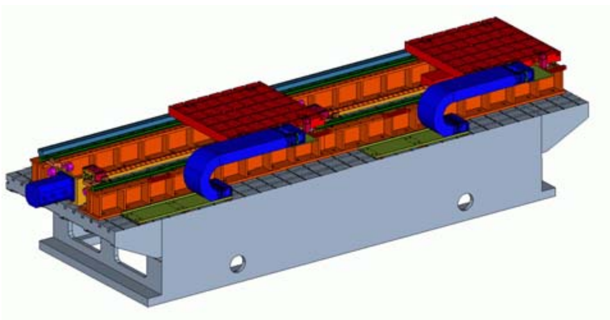

Figure 11 – Testing bed

5. Conclusion

Described velocity loop principle with the reference signal appears like useful solution. Obtained velocity is not connected with large time delay as in the common case with velocity computed from incremental encoder and the shape of such signal is much more smoother. Proportional gain of the velocity loop can by increased because of using this method and thereby the dynamical stiffness and frequency band-width can be improved.

The other mentioned principle with pure filtration is useful when the reference signal is not available. Disadvantage of this solution is non-measurability of low frequencies. This is the main reason why this method can not be used in the common velocity loop. This principle can by used in vibration suppression activities effectively.

In conclusion the acceleration signal as an input of velocity feedback looks like a perspective solution for modern machine tools. Simulation results will be verified on designed testing bed.

6. Acknowledgement

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7. References

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