ACTIVE MOUNTING OF MACHINE TOOL FEED DRIVES

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Abstract

Contemporary machine tool design is characterized by fix-mounting of feed drives to the machine bed. Thanks to it force shocks are transmitted to the whole machine structure and undesirable eigenfrequency are excited. As a result dynamic properties of the machine tool deteriorate. Partial solution can be spring and damped mounting of the motor. However, this paper deals with extended variant of the problem, when the feed drive is connected with the machine tool by an active element. Intelligent control of the active element significantly decreases the force excitation of the body frame. The feed drive motor is therefore mounted by means of another motor which works as vibroisolation.

Abstrakt

U současných obráběcích strojů jsou pohony pohybových os ukotveny pevně k rámu a tím dochází k přenosu silových rázů do celé konstrukce stroje. To má za následek nežádoucí vybuzování vlastních frekvencí a z toho plynoucí dynamická omezení takového stroje. Částečným řešením je odpružené uložení pohonů, kdy je motor spojen se strojem přes pružinu spolu s tlumičem. Tento příspěvek se však zabývá rozšířenou variantou, kde je spojení aktuátoru s vlastním strojem uskutečněno přes aktivní prvek, jehož inteligentním řízením výrazně snižujeme rázy do konstrukce. Motor pohybové osy tak uložíme pomocí dalšího motoru, který slouží jako vibroizolace.

1. Introduction

In common machine tool there is used classical concept of motion axis. It means, the linear axis is connected to the machine structure by some kind of linear motor. This motor is source of motion force and react equally to machine frame and to the axis. Value of the force signal controls a control system, which have to react to position or velocity change. Because we need high dynamic systems in machine tool field, the system sets force for the motor very quickly with various amplitudes. It causes power shocks which are transmitted to the motion axis and to the machine bed. The main problem of this solution is that the shocks excite wide spectrum of frequencies and if some frequency is equal to eigenfrequeincy of the bed, the machine tool starts to oscillate. Problem is that the oscillations are unfavourable to precise tooling and deteriorate dynamic properties of the machine tool.

The text deals with technique to actively change the frequency spectrum and to decrease amplitude of force signal which apply to the machine structure. The result of this activity is vibroisolated machine tool bed and thereby machine with precise tooling and high-dynamic properties.

2. Feed drives mounting principle

In this chapter is introduced principle of current solution of mounting feed drives and its new active variant with double motor using.

2.1 Fix-mounting

This is common case in machine tool field which was partially described in the chapter 1. As shown in *Fig. 2.1*, the same force reacts to the machine tool bed and motion axis. This simply solution uses linear motor which has primary and secondary part. The primary part is made from steel plates and winding and is closely connected to the motion axis, in this case to the spindle of machine tool. The secondary part consists of permanent magnets and is fix-mounted to the bed of machine tool.

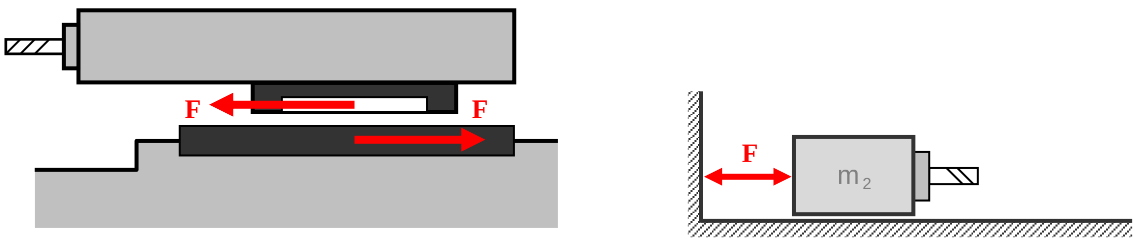

Fig. 2.1 - Contemporary machine tool feed drive mounting

2.2 Spring mounting

More sophisticated method of linear feed drive construction is its spring mounting [Bubák, 2004]. This configuration is shown in *Fig. 2.2* and consists of the same parts as in the previous case. The primary part of the linear motor is closely connected to the motion axis with the spindle. The difference is in mounting of the secondary part. There is used spring to axial connection with the bed.

This configuration allows movement of the secondary part of the motor in range ± 10 mm. For motion stability additional damping of spring connection is very important. In principle a viscose damper solution is used where the efficiently of whole method dependents on the damper setting. The low damping value causes high motion amplitudes and the oscillation tail takes a lot of time, the high damping value deteriorates efficiency of the method (increases shocks to the bed).

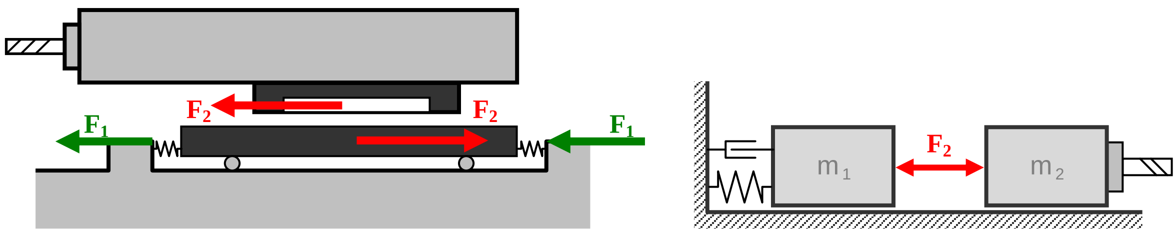

Fig. 2.2 - Spring machine tool feed drive mounting

Main disadvantage of such solution is impossibility to directly and fully control the acting force to the bed, because it is transmitted by damper and spring.

2.3 Active mounting – "motor on motor"

"Motor on motor" is new concept of feed drive construction. As shown in *Fig. 2.3*, compared to spring mounting this variant contains of two independent linear motors. One of them (F_2)

represent common feed drive which makes displacement of motion axis. Second one deals with force transformation (F_1) to the body frame. We can say, that the second one works as vibroisolator and the movement is splitted into two parts [Krabbes et all, 2004].

Main advantage of this solution is possibility to fully control force, which reacts to the tool machine body. In this way we transform this force in an effort to suppress vibration of body structure.

This paper deals with this new concept of feed drive mounting.

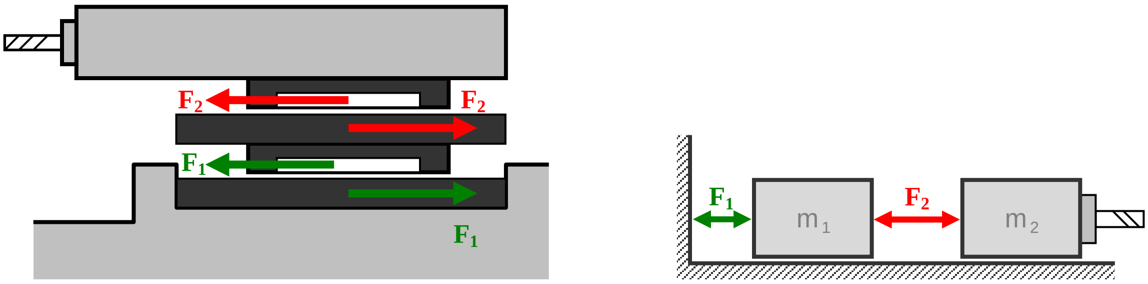

Fig. 2.3 - "Motor on motor"

3. Control principle

When we want to reach high performance tooling, we have to be able to move the motion axis from point to point very quickly. Therefore maximum force in very short time is frequently needed, so-called force step. This shape of force is needed for good quality of regulation, but not for the bed vibration.

In the new feed drive concept the motor (F_2) can be controlled by common cascade loop. Knowledge of sufficiently long NC code is necessary for control of the motor (F_1). The main idea of the control is to react by force (F_1) before NC code sets the setpoint of position. Thus we can prepare better initial condition of motion transmition and profit from dynamic of the moving primary part of the mounting motor.

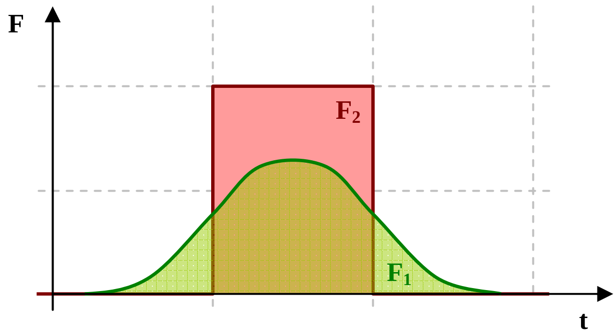

Fig. 3.1 - Time behaviour of force

The time behaviour of forces can look like in *Fig. 3.1*. As shown in *Fig. 3.1*, force which acts to the bed (F_1) has smoother time behaviour and starts earlier than the force (F_2) which reacts to the spindle. The result of this is decrease of the force amplitude which acts to the bed and number of excited frequencies of tool bed is reduced.

4. Optimization

The right shape of the force (F_1) dependents on many facts, therefore it is necessary to use some mathematical method for its obtaining [Valášek, 1995]. Here is used the genetic algorithm for searching minimum of target function (1). The target function looks:

$$tf = c_1 \cdot \sum_{i=1}^{n} F_i^2 + c_2 \cdot \max_{0 \to t}\left(x_1^2\right) + c_3 \cdot \sum_{i=1}^{n-1} \left(F_{i+1} - F_i\right)^2 - c_4 \cdot x_2^2 \tag{1}$$

The output of this solution has many results which are shown in *Fig. 4.1*. Each point in the figure represents one solution of the target function and from our point of view are interesting solutions lying on the red line. This line represents pareto-set, where both criterions are minimal. It means, by reducing value of the one criterion, the second one is increasing.

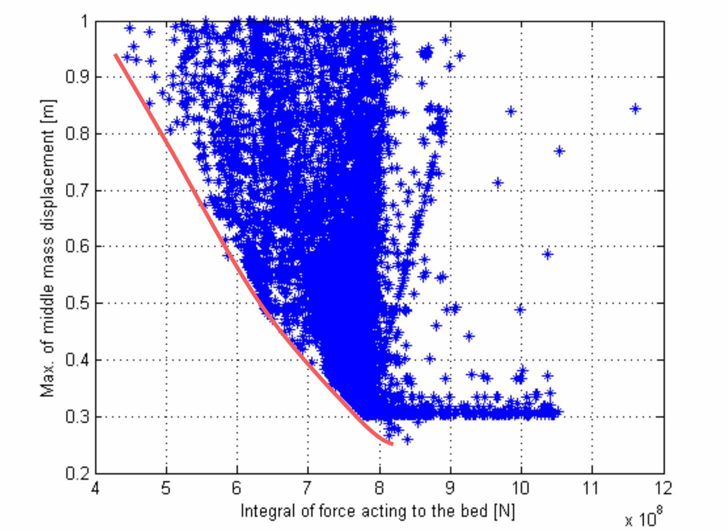

Fig. 4.1 – Optimization result

As the final result of the optimization, one point of the pareto-set is chosen. The characteristic force time behaviour for this point is shown in *Fig. 4.2*.

As shown in the *Fig. 4.2*, the time behaviour of the force which reacts to the bed is similar to the time behaviour shown in *Fig. 3.1*. It starts to react before detection step of spindle force (F_2) and has smaller amplitude than it. It means in this case the force which acts to the bed is less than the force in the variant with fix-mounted motor (contemporary feed drive construction). In *Fig. 4.2* are shown properties of variant with springy secondary part of motor too, so-called spring mounting. The force amplitude of this construction type has very high value and is connected with oscillation.

It would by very difficult and time consuming to find the time behaviour of optimization force in continuous form. Based on this the time behavour is splitted into time steps in which the optimization force is constant. By this it is possible to find results in reasonable time. The problem is the shape of the force, it looks like steps and the frequency spectrum of the signal isn't useful. As shown in the *Fig. 4.2* on the right side, this profile of optimization force is interpolated by cubic spline in each time interval. Such time behaviour is useful and can by used in the simulations.

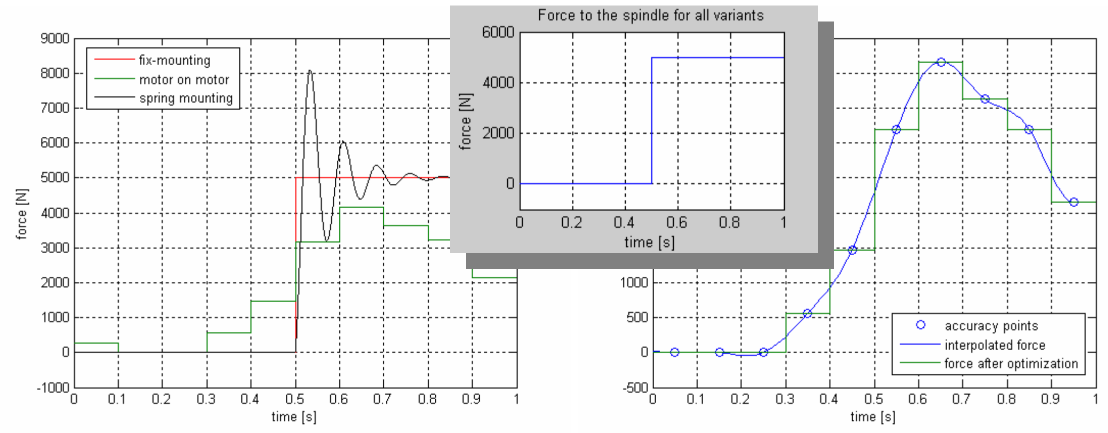

Fig. 4.2 – Time behaviour of force that reacts to the bed and its interpolation

The important issue which give us information about quality of used method is power spectral density of force signal. In the *Fig. 4.3* is shown comparison of power spectral density of fix-mounting, spring mounting and motor on motor principle. We can see many excited frequencies by fix-mounting principle in the figure. It is due to sharp profile of the time behaviour of the force which reacts to the bed. Better situation is by using spring mounting variation, time behaviour of this force isn't so sharp and there is lower number of excited frequencies. The best solution is by using "motor on motor" construction. As shown in *Fig. 4.3*, course of the power spectral density of such signal is the best of all, number of excited frequencies is minimal and its value is lower then by spring mounting and fix-mounting construction.

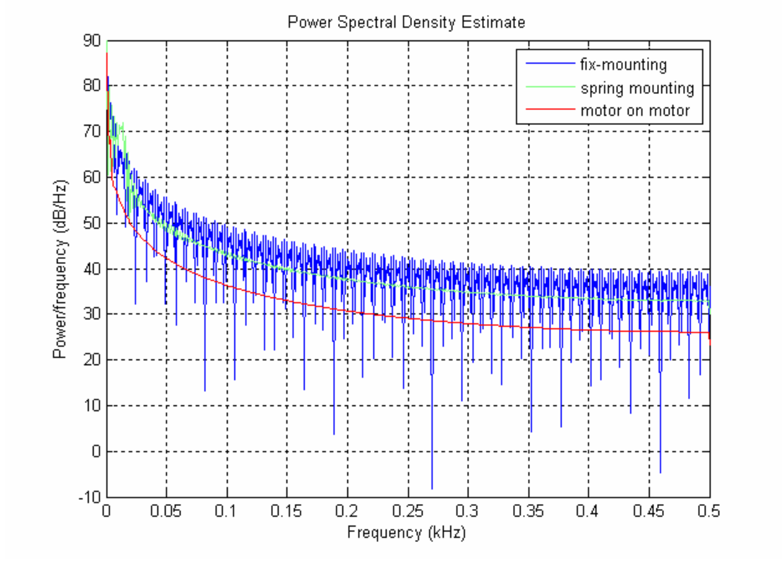

Fig. 4.3 – Power spectral density comparison

5. Testing bed

It is designed a testing stand for validation of control algorithm. As shown in *Fig. 5.1*, the stand consists of two parts. First is bed with linear motor and ball screw and the second one is equipped with tubular motor and is connected to the axis with linear motor. At this time the testing stand is under construction.

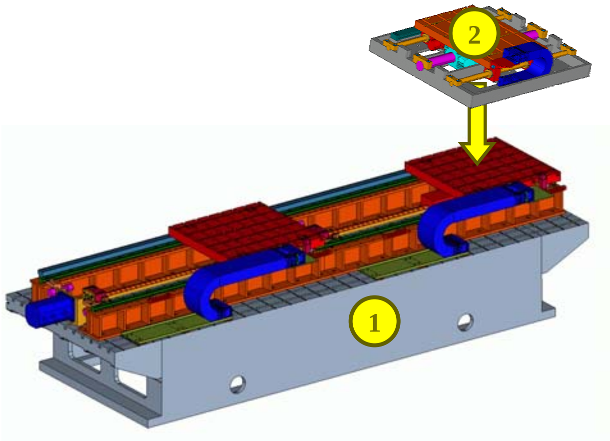

Fig. 5.1 – Testing bed

6. Conclusion

The mentioned concept of feed drive construction brings new level of control and dynamic. By using this construction we can reduce forces reacting to the machine tool bed and number of excited frequencies. Such machine tool is better protected from bed vibration and thereby it can reach better dynamic properties.

The advantage of this new solution is possibility to fully modify the force which reacts to the testing bed. In such case we can profitably use methods for improving machine properties based on input shaping.

Main object of the paper is introduction of the method and demonstration of its benefits. Designed optimized solution is only for specific case and for real application in machine tool it is necessary to develop some universal control scheme which can be used for all working situations in machine tool field. This task is the aim of the following work.

As described in chapter 5, it was developed testing stand which will be used for the method validation.

References

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