Proposition of Effective Method of Improving Dynamic Stiffness of Joints in Machine Tools

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Abstract

In this paper, the method of improving damping capacity of the joint in jointed structures without reduction of static stiffness is proposed and experimentally examined. As a result, insertion the combination disk spring into the joint improves damping capacity in jointed structures without reduction of the static stiffness. Also, additional damping of the spring element can increase more the damping effect.

1 Introduction

To improve dynamic stiffness of the machine tools, it is necessary to improve the static stiffness and damping of the machine. However, it is well known that since there are many joints in the machine tool, the damping of the machine increases but the static stiffness decreases[1)]. Thus, in order to improve the dynamic stiffness of the machine tools, it is effective to make the damping generated in the joint higher, and to avoid decrease of the static stiffness as much as possible.

Therefore, in this study, we propose the method of improving the damping characteristic without decrease of the static stiffness in the joint, and its effectiveness is considered experimentally.

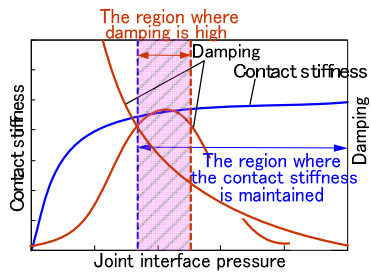


Fig.1 Relationship between joint interface pressure and contact stiffness and damping

2 Proposition of effective method of improving dynamic stiffness of the joint

2.1 Fundamental principle

Fig.1 shows general characteristics of the contact stiffness and damping of the joint for the joint interface pressure. Generally, the contact stiffness of the joint shows the

hard spring characteristic to the interface pressure and become nearly constant at the interface pressure larger than a certain pressure. On the other hand, the damping decreases, or increases and then decreases showing an extreme value, with increase of the interface pressure[2]. By applying these characteristics, if we can reduce the interface pressure as much as possible within the range where the static stiffness does not drop, it seems to be able to increase the damping to the maximum keeping the static stiffness nearly constant.

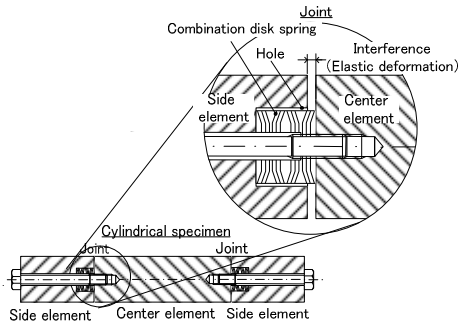


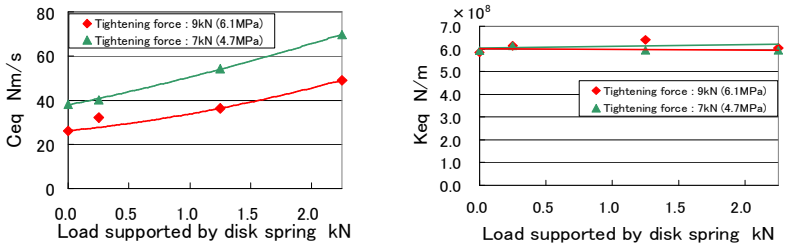
Fig.2 Proposed method for improving dynamic characteristics

2.2 Proposition of specific method for improving dynamic stiffness of the joint

Fig.2 shows a jointed structure embedding the mechanism that is applying the principle stated above. The jointed structure is made up of 3 cylindrical specimens jointed together by bolts, and then has 2 joints. Here, combination disk springs are used to decrease joint interface pressure. As shown in the figure, the disk springs are inserted into a hole provided at the joint and the spring is installed with the required projection. Therefore, before tightening the bolt, gap exists at the joint as shown in the figure. As tightening force increases, the springs deform elastically and the gap gets smaller. When the tightening force is increased furthermore, the gap disappears and the contact is caused at the joint, and the tightening force applied after this point will be supported by the joint interface. Therefore, the tightening force applied until the gap disappears will be the load supported by the disk spring and this supported load will be the amount of reduction of joint interface pressure when tightened by the bolt. Based on the principle stated above, by decreasing the joint interface pressure to its optimum, it is expected that damping could be improved without the decrease of static stiffness.

3 Experimental setup and method

Fig.3 shows the outline of an experimental setup. This is composed of the impulse hammer for exciting the jointed structure, the acceleration pick up for detection of the response of the structure, FFT analyzer that imports signal of excitation force and response and calculates the transfer function, and PC for reading out the analyzed results. Evaluation is carried out by dynamic characteristic parameters such as equivalent viscous damping coefficient and equivalent stiffness, and the dynamic



(a) Damping coefficient **(b) Equivalent stiffness**

Fig.4 Effect of inserting disk spring at the joint

Characteristic parameters are identified based on the transfer function and the free damped vibration waveform.

4 Experimental results

4.1 Effect of improvement of damping by inserting disk spring

Fig.4 shows the equivalent viscous damping coefficient and the equivalent stiffness when changing the load supported by the disk spring under constant tightening force (9kN, 7kN). As seen from Fig.4 (a), the damping is improved by increasing the load supported by the disk spring, that is, by decreasing the load applied on the joint interface. Also as seen from fig.4 (b), the equivalent stiffness is kept nearly constant.

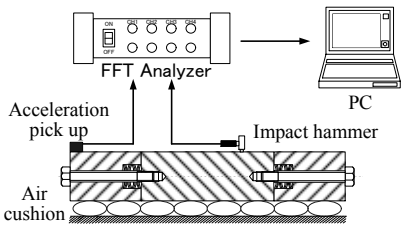


Fig.3 Outline of experimental setup

Therefore, it can be said that the joint interface pressure is adjusted adequately and the damping is improved keeping the equivalent stiffness constant.

4.2 Contribution of disk spring itself to the improvement of damping

Fig.5 shows equivalent viscous damping coefficient when changing the load supported by the disk spring under constant joint interface pressure (6.1, 4.4, 3.4Mpa). Compared with the case where the disk spring does not support the load of the tightening force, the damping is greater in the case where the disk spring supports the load. Since the joint interface pressure is constant, the damping generated at the joint interface is considered to be the same independently of the supporting load of disk spring. Therefore, it can be said that this increase of the damping is due to the damping property of the disk spring itself. In addition, the damping shows an extreme value with respect to the amount of load supported by the disk spring and then there is a suitable value for the load that the disk spring supports.

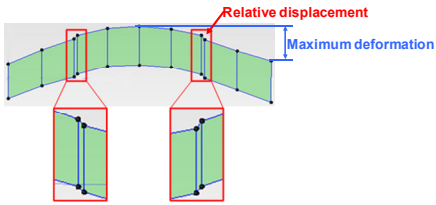


Fig.6 1st vibration mode of the specimen

4.3 The mechanism of damping generated at the joint

Fig.6 shows the 1st mode of vibration of the jointed structure when excited. The sections surrounded with rectangle mark shows the relative displacement at the joint.

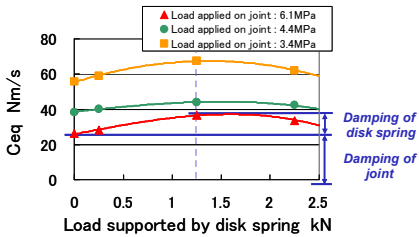


Fig.5 Damping of the disk spring

Table 1 shows the relationship between relative displacement and maximum deformation. When the tightening force is small and the damping is large, the relative displacement at the joint is large and therefore the damping occurs at the joint, resulting in small maximum deformation. On the other hand, when the tightening force is large and the damping is small, the relative displacement at the joint is small, resulting in large maximum deformation. Therefore, the damping of the jointed structure is considered to be mainly generated by the contribution of micro-slip at the joint.

Table 1 Relationship between relative displacement and maximum deformation

Tightening force (kN)	Relative displacement (disp/N)	Maximum deformation (disp/N)
4	3.724E−03	2.770E−02
10	1.818E−03	7.680E−02

Summarizing the results mentioned above, in order to improve dynamic characteristics of the joint effectively, first of all, we need to understand the damping characteristics of the joint and determine the optimum joint interface pressure for improving dynamic characteristics. Secondly, we need to understand the supporting load of the disk spring that maximizes the damping of the disk spring itself, and then adjust the joint interface pressure to its optimum value with the supporting load.

5 Conclusions

In this research, the method for improving damping without decrease of the static stiffness in the joint has been proposed and considered experimentally. As the result, the followings are clarified.

1) By inserting the spring element into the joint and supporting a part of tightening force, the damping in the joint effectively increase with keeping of the static stiffness of the joint under the specified tightening force.
2) Adding the damping of the inserted spring element can increase more the damping effect.
3) The damping is mainly generated by the contribution of micro-slip at the joint interface.

References:

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