A Method of Dynamic Parameter Identification of the Joint Surface based on Acceleration and its Application

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ABSTRACT: The acceleration sensor is easy to install and can be applied to the measurement of complex mechanical structure. In this paper, a new method for the identification of dynamic stiffness and damping of the unit with acceleration is proposed, the experimental verification of the method is correct, and then the effect of the vibration frequency and the normal pressure on the dynamic stiffness and damping of the joint surface is analyzed. Analytical results show that, the vibration frequency has little effect on the dynamic stiffness of the joint surface, but the damping effect on the surface is relatively strong. As the exciting frequency becomes less, the damping value of the excited frequency is smaller with the increase of the excitation frequency, and the combination with the increase of the vibration frequency and the damping value of the combined surface tends to be flat and has a nonlinear point. The influence of surface pressure on the dynamic stiffness of the joint surface is small, and the damping effect on the joint surface is relatively strong. When the surface pressure is very small, the damping value of the surface pressure is decreased fast with the increase of the vibration frequency; when the surface is with large pressure, the damping value of the combined surface tends to be flat with the increase of the vibration frequency.

Keywords: the joint surface; parameter identification; dynamic stiffness; damping

1 INTRODUCTION

The joint surface is the weak link of CNC machine tool. On one hand, the stiffness of the joint surface directly affect the machine tool rigidity; on the other hand, the material damping of machine tool structural component is less which makes the 90% damping of the whole machine tool structure system derive from the joint surface \cite{1}, so there is great significance for the study which combines surface stiffness with damping characteristics to enhance machine performance. With the development of high-end machine, the coupling portion is increasingly prominent and now has become the focus of attention of scholars from various countries \cite{2} to establish binding portion containing a combination of theoretical models based on the sub-structure synthesis and through measurement frequency response function to identify the parameters of the stiffness and damping characteristics of the junction, and the composite beam structure with a system containing a bolt engaging portion of excitation experiments conducted to identify the binding portion of the bolt parameters \cite{3}. The accuracy of the calculation is improved \cite{4} through considering the combined surface layer and binding elastic finite element panel both on the flat-panel joint surface modeling and parameter identification. Base on the equivalent model parameter of identifying composite structure of wavelet transform based, conduct an experimental study on the composite beam of joint part with two bolts to analyze the impacts of the contact surface press and area of joint surface on the characteristics of the composite structure, and to discuss the identified equivalent model parameter \cite{5}. Establish the spring damper model of joint surface and simplify it to two sets of tangential and normal spring damper. Then calculate its stiffness and damping value via matrix. Currently the parameter identification regarding the characteristic of joint surface mainly aims at the concrete structure. Its performance data cannot be zoomed by size because of nonlinearity \cite{6}. So the data of joint surface fail to be applied as general data to analyze the
character of others. In order to better apply it to engineering practice, the basic performance data of unit joint surface are obtained via experiments according to the processing requirement and medium condition of parts, and a method of dynamic parameter identification is proposed.

2 THE THEORETICAL MODEL

The joint surface kinetics model is shown in Figure 1 and the equation is:

\[ m \ddot{x}_i + f_n = f_a \] (1)
\[ f_n = K_n x_n + C_n \dot{x}_n \] (2)

![Figure 1. Dynamic experimental model.](image)

In the equations, \( f_n \) is normal dynamic force of joint surface, \( f_a \) is exciting force, \( x_n \) is normal dynamic displacement of joint surface, and \( m \ddot{x}_i \) is inertia force. \( K_n, C_n \) are respectively normal dynamic stiffness and normal damping of joint surface.

The exciting force above is simple harmonic force. The normal dynamic force and displacement of joint surface can be expressed by the following equations:

\[ f_n = F_n \cos \omega t \] (3)
\[ x_n = X_n \cos (\omega t + \varphi_n) \] (4)
\[ \dot{x}_n = -X_n \omega \sin (\omega t + \varphi_n) \] (5)

And then put equation (3), (4) and (5) into the equation (2), we can get:

\[ F_n \cos \omega t = K_n X_n \cos (\omega t + \varphi_n) - C_n X_n \omega \sin (\omega t + \varphi_n) \]

Calculated by trigonometric function, it can be simplified:

\[ K_n = \frac{F_n \cos \varphi_n}{X_n} \] (6)
\[ C_n = -\frac{F_n \sin \varphi_n}{\omega X_n} \] (7)

Among them, \( F_n \) is a dynamic force amplitude, \( \varphi_n \) is phase difference between the normal dynamic force \( f_n \) and the normal dynamic displacement \( x_n \), \( \omega \) is excitation frequency, and \( X \) is the normal dynamic displacement amplitude.

From equation (6) and (7) we can get the method of identifying the dynamic stiffness and damping of the bolt’s joint surface based on displacement. Thereinto, the joint surface dynamic force amplitude can be calculated by exciting force and inertia force by cosine.

\[ F_n = \sqrt{f_n^2 + (m \ddot{x}_i)^2 - 2 f_n m \ddot{x}_i \cos (\ddot{x}_i, f_a)} \] (8)

In the formula, \( \cos (\ddot{x}_i, f_a) \) is the phase difference of the acceleration relative to the exciting force.

3 THE METHOD OF IDENTIFYING THE DAMPING AND STIFFNESS OF THE JOINT SURFACE BASED ON ACCELERATION

In the general harmonic vibration, the relationship between displacement and the corresponding acceleration can be expressed as:

\[ \frac{x}{\ddot{x}} = -\frac{1}{\omega^2} \] (9)

Put equation (9) into equation (6) and (7) respectively, and it can be obtained:

\[ K_n = -\frac{\omega^2 F_n \cos \varphi_n}{A_n} \] (10)
\[ C_n = -\frac{\omega F_n \sin \varphi_n}{A_n} \] (11)

Wherein, \( A_n \) is acceleration value of the joint surface. Formulas (10) and (11) are the method of identifying the dynamic stiffness and damping of the bolt’s joint surface based on displacement. In the experiment, the data that can be measured directly is up and down acceleration values \( A_1, A_2 \) and their phase differences \( \varphi(\ddot{A_1}, A_n), \varphi(\ddot{A_2}, f_n) \) relative to excitation force. Thereinto, the joint surface dynamic force can be obtained by equation (8), and the phase differences \( \varphi(A_1, A_n) \) of acceleration \( A_1 \) and \( A_2 \) can be expressed as follow:

\[ \varphi(A_1, A_2) = \varphi(A_2, f_n) - \varphi(A_1, f_n) \] (12)

The acceleration of joint surface \( A_n \) via vector calculation can be expressed as:

\[ A_n = \sqrt{A_1^2 + A_2^2 - 2A_1A_2 \cos \varphi(A_1, A_2)} \] (13)
Due to $\varphi_n$ is a dynamic combination of surface displacement $x_n$ relative to dynamic force of the joint surface $f_n$ of phase, can be defined $\varphi(A_n, f_n)$ dynamic acceleration expressed as a combination of surface $A_n$ relative to the dynamic force of the joint surface $f_n$ phase. Therefore, the relationship can be expressed as:

$$\varphi_n = \varphi(x_n, f_n) = \varphi(A_n, f_n) - 180^\circ$$ (14)

Phase $\varphi(A_n, f_n)$ can be expressed as:

$$\varphi(A_n, f_n) = \varphi(A_n, A_1) - \varphi(f_n, A_1)$$ (15)

In equation (15), $\varphi(A_n, A_1)$ is the phase of the joint surface acceleration relative to the acceleration $A_1$, and $\varphi(f_n, A_1)$ is the phase of the joint surface dynamic force relative to the acceleration $A_1$.

It can be obtained from the vector relationship among the inertia force, the dynamic force of the joint surface and the exciting force, and among the $A_1$ and $A_n$ vector and $A_2$:

$$\sin \varphi(A_1, A_n) = -\frac{A_1 \sin \varphi(A_1, A_n)}{A_n}$$ (16)

$$\sin \varphi(f_n, A_1) = \frac{F \sin \varphi(A_n, f_n)}{F_n}$$ (17)

Thus, if the acceleration $A_1$, $A_2$ and the phases $\varphi(A_n, f_n)$, $\varphi(A_2, f_n)$ relative to the exciting force can be measured, the dynamic stiffness and damping of the bolt’s joint surface can be identified. That realizes that the dynamic stiffness and damping of the joint surface can be identified just by acceleration sensor.

4 THE EXPERIMENTAL VERIFICATION

The experimental apparatus is shown in Figure 2, screw the exciting rod 1, exert some static force on the specimen base 9 to maintain the joint surface under a certain surface pressure, and the static state force sensor 11 is used to detect the preload. The data acquisition instrument through the software output sinusoidal voltage signals, which act on the test specimen via exciter after increased by the power amplifier and the dynamic force sensor 4 can measure the signals of dynamic force in real time. Due to the function of force, the joint surface vibrates, which makes the Edy current displacement sensor 5 detect the displacement signals. As the displacement sensor is fixed on the upper part of the specimen, the tested displacement is the normal vibration displacement of the top test specimen relative to the bottom one which is the relative displacement of normal dynamic force of the joint surface. Then use M+P dynamic analysis software system for constant displacement control, to get the dynamic characteristic parameters of the joint surface under the different vibration amplitude. The accelerometer 10 detects the acceleration signal of the test specimen. The symmetrical arrangement of displacement sensor and accelerometer can guarantee the symmetry of structure and quality.

The collected data are used to calculate respectively the damping value by the identification method based on displacement and acceleration, and the results are shown in Table 1. The maximum error of two methods is 6.55%, which proves it is feasible.

<table>
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<tr>
<th>Identification method</th>
<th>29Hz</th>
<th>47Hz</th>
<th>300Hz</th>
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<td>Calculation of damping value based on displacement</td>
<td>41570.3</td>
<td>62735.1</td>
<td>9401.4</td>
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<tr>
<td>Calculation of damping value based on acceleration</td>
<td>44059.4</td>
<td>58625.5</td>
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<td>Error</td>
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<td>6.55%</td>
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5 ANALYSIS OF EXPERIMENTAL RESULTS

5.1 Effect of vibration frequency on the dynamic stiffness and damping of the joint surface

(1) The influence of vibration frequency on the dynamic stiffness of the joint surface
Figure 3 shows the matching materials 45 steel of 45 steel of the joint surface adopt dry contact form at the vibration amplitude of 25nm, to get the normal dynamic stiffness and vibration frequency of the joint surface under the condition of different normal surface pressure Pn. We can see that, under that condition, the dynamic stiffness changes little with the increasing vibration frequency.

(2) Effects of the vibration frequency on the damping of the joint surface

Figure 4 shows the matching materials 45 steel of 45 steel of the joint surface adopt dry contact form at the vibration amplitude of 25nm, to get the normal damping and vibration frequency of the joint surface under the condition of different normal surface pressure Pn. We can see that, under that condition, the vibration frequency has great influence on the joint surface damping with strong nonlinearity. The damping declines quickly at low frequency, while it declines slowly or even keeps unchanging at high frequency.

5.2 Effect of surface pressure on the dynamic stiffness and damping of the joint surface

(1) Effects of the normal pressure on the normal dynamic stiffness of the joint surface

Figure 5. Effects of the normal surface pressure on the stiffness of the joint surface.
Figure 5 shows the matching materials 45 steel of 45 steel of the joint surface adopt dry contact form at the vibration amplitude of 25nm, to get the relation between the normal dynamic stiffness and surface press.

From the image above, it can be concluded that at the vibration amplitude of 25nm, the normal dynamic stiffness is increasing with the increasing of the normal surface pressure, which is consistent with the change law of the static stiffness.

(2) Effects of the normal pressure on the normal damping of the joint surface

Figure 6 the matching materials 45 steel of 45 steel of the joint surface adopt dry contact form at the vibration amplitude of 25nm, to get the relation between the normal damping and surface press.

From the image above, it can be concluded that at low surface pressure and under the condition of low surface pressure and the vibration amplitude of 25nm, the normal damping is increasing with the increasing of the normal surface pressure. This is because, under the low normal surface pressure, micro-convex between mutual contacts of joint surfaces is smaller and the consumed energy is less. With the increasing of the normal surface pressure, micro-convex is enlarging and the consumed energy is increasing, which makes the normal damping coefficient increase.

REFERENCES