불평형 질량이 있는 공작물이 부착된 대형 선반 주축시스템의 비틀림 진동해석

Torsional Vibration Analysis of a Spindle System of a Large Scale Lathe with Weight-unbalanced Workpiece

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Key words : Torsional vibration, Unbalancing torque, Crankshaft

1. INTRODUCTION

When the multi-tasking machine tool is machining the large scale workpiece as crankshaft, its spindle system cannot operate in the desired constant rotating speed, because of multiple-gravitational unbalancing torque inevitably arisen in the workpiece. For controlling this unbalancing torque, usually additional control motor is used besides main spindle motor. And geared transmission systems are adopted to transfer driving or control torques from motors to the main spindle and or workpiece. The resulting rotating speed variations in the main spindle or workpiece may cause undesirable or bad effects on machining precision or accuracy.

In this study, we made a 10-DOF lumped parameter model for analyzing torsional vibration of the main spindle system with geared transmission of a large scale machine tool with unbalanced workpiece. We analyzed the torsional vibration of the system using MATLAB and solved the eigenvalue problems of the system using the elementary method. Then, we got the response of the system under the desired input torque and unbalancing torque.

2. THEORETICAL VIBRATION ANALYSIS

From the schematic of the main spindle system with geared transmission as shown in Fig. 1, we made a 10-D.O.F mathematical modeling as shown in Fig. 2. Where J_i represents the mass moment of inertia of i-th equivalent rotor and k_{ij} represents the torsional spring stiffness of the shaft between i-th and j-th equivalent rotor.

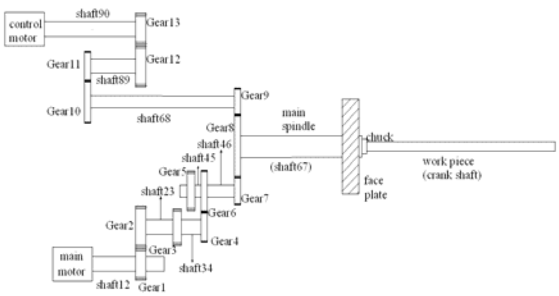

Fig. 1 Schematic of the main spindle system

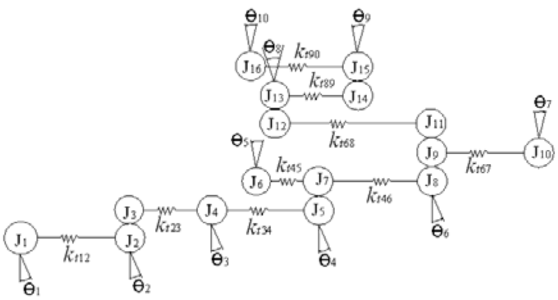

Fig. 2 Mathematical modeling of the main spindle system

In this study, the workpiece is a 6-pin crankshaft. There are three reasons to consist the unbalancing torque arisen in the workpiece; the unbalancing torque of the journals, the misalignment torque of journals and the unbalancing torque of the crankpins.

3-D modeling of a crankshaft, that is workpiece, is shown in Fig. 3. There are 6 pins, which are evenly phased but different unbalance weight each other, in the crankshaft as shown in Fig. 4.

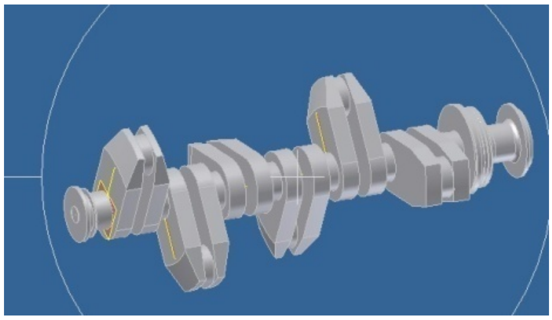

Fig. 3 The 3-D modeling of 6-pins crankshaft

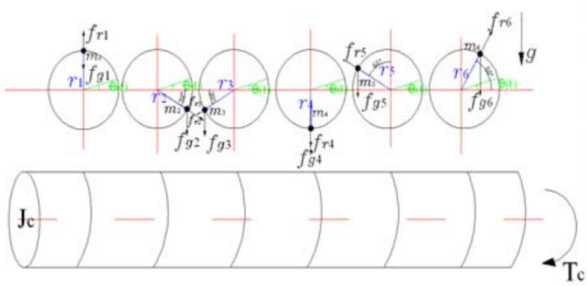

Fig. 4 The phase angle of 6-pins of the crankshaft

The gravitational unbalancing torque of crankpins can be decided as

$$T_{up} = \sum_{i=1} m_i r_i g \cos\left(\phi_i + \theta(t)\right) \tag{1}$$

In this system, the gravitational unbalancing torque of crankpins can be expressed as

$$\begin{aligned} T_{up} &= T_{up1} + T_{up2} + T_{up3} + T_{up4} + T_{up5} + T_{up6} \\ &= r_1 m_1 g \sin\left[\theta(t)\right] - r_2 m_2 g \cos\left[-\phi_0 + \theta(t)\right] \\ &\quad + r_3 m_3 g \cos\left[\phi_0 + \theta(t)\right] - r_4 m_4 g \cdot \sin\left[\theta(t)\right] \\ &\quad + r_5 m_5 g \cos\left[-\phi_0 + \theta(t)\right] - r_6 m_6 g \cos\left[\phi_0 + \theta(t)\right] \end{aligned} \tag{2}$$

Where pin phase angle $\phi_0 = \pi / 6$ in this 6-pin crankshaft.

We assume that the unbalance of the journals, u_j, is 1%; the error in radius of gyration of journals, $e_{j,}$ is 3.5 %.

By assumption, the gravitational unbalancing torque of journals can be expressed as

$$T_{u1}(t) = m_{uj} r_{uj} g \cos\theta(t) = (u_j m_j) r_{uj} g \cos\theta(t) \tag{3}$$

The misalignment torque of journals can be expressed as

$$T_{u2}(t) = m_J r_{mj} g \cos\theta(t) = m_J (e_j d_j) g \cos\theta(t) \tag{4}$$

So the unbalancing torque of crankshaft in this system can be e xpressed as

$$T_u(t) = T_{u1}(t) + T_{u2}(t) + T_{up} \tag{5}$$

The equation of motion of the system can be expressed as (6),

$$[J]\{\ddot{\theta}\} + [K_t]\{\theta\} = \{T\} \tag{6}$$

Here, $[J]$ is the mass moment of inertia of the equivalent rotor; {T} is the input torque of the system; $[K_t]$ is the torsional spring stiffness of the shaft.

3. VIBRATION ANALYSIS RESULT

3.1 Eigenvalue problem

By using MATLAB, we got the eigenvalues as listed in the Table 1.

Table 1 Calculated eigenvalues of the system

Mode number	Natural frequency (Hz)
1	199
2	253
3	390
4	430
5	606
6	697
7	1548
8	10086
9	18967

3.2 The Response of the System

Simulated the system by MATLAB, and we can get response of the workpiece as shown in Fig. 7 under the input main torque (as shown in the Fig. 5)and the unbalanced torque. And then, we got the effect caused by the unbalancing torque during machining as shown in Fig. 8.

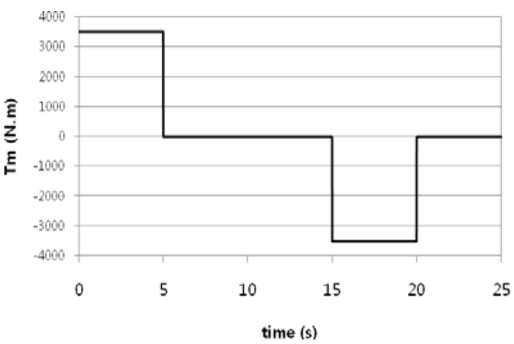

Fig. 5 The input torque of the main motor

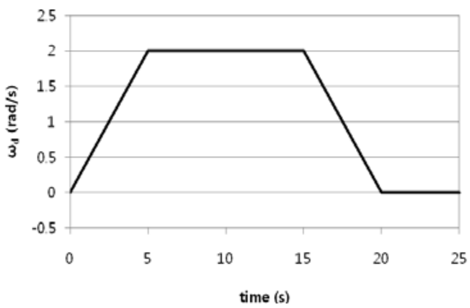

Fig. 7 The desired angular velocity curve

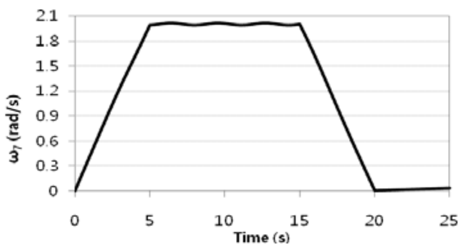

Fig. 8 The angular velocity response at the face plate center

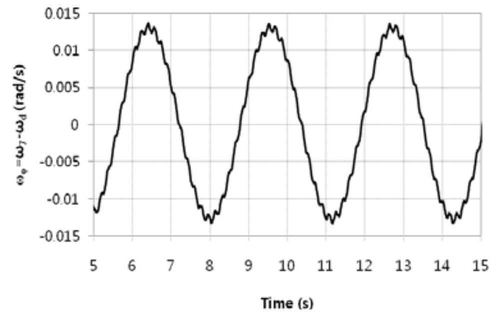

Fig. 9 The effect caused by the unbalancing torque during machining

4. CONCLUSION

This paper analyzed the torsional vibration of a spindle system of the multi-tasking machine tool with unbalanced workpiece by modeling it as a 10-D.O.F lumped parameter model mathematically. We solved the eigenvalue problem of the system and got the response of the workpiece. Finally we got that the rotating velocity of the workpiece cannot be constant during machining caused by unbalancing torque. It will affect the accuracy of the machining.

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