Dynamic Simulation of Crank-Group Driving Mechanism with Clearance

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Abstract: For the crank-group driving mechanism, the assembly clearances can offer the possibility to remove overcoming processing errors. But the clearances inevitably affect the dynamic characteristics of the mechanism. In this paper, the dynamic simulation model of the crank-group driving mechanism is established by NX/Motion Simulation which is based on the mathematical model of planar link mechanism. The comparative analysis is conducted regarding the dynamic characteristics of the mechanism which is influenced by different clearances, different angular velocity, and different damping. The simulation results show that appropriately increasing the angular velocity, increasing stiffness and damping of the components can effectively inhibit the adverse influences of clearance on the dynamic characteristics of the mechanism.

Keywords: Clearance, Crank-group, Driving mechanism, Dynamic simulation, Angular acceleration, Angular velocity, Material damping.

1. INTRODUCTION

In some mechanisms, transmitting small torque, or having a larger center distance, such as packaging machinery, tobacco machinery, using the crank-group driving mechanism instead of common transmission mode such as gears, chains can simplify the structure and cut the cost [1, 2]. The general form of crank-group driving mechanism is shown in Fig. (**1**). Driving crank and driven cranks have the same phase, structure and size, therefore, driving crank, any driven crank and the rod between them can be seen as a parallelogram mechanism. Under ideal conditions (no size error, no stress deformation, and no installation error), each crank carries out rotary movement around its own axis, and the rod moves in translational motion around its own center [3]. The redundant constraints are often transformed into statically indeterminate structure because of the errors and material deformation in processing and installation. The appropriate clearance fit between sizes of the crank pin and rod pin hole is selected to avoid statically indeterminate structure and ensure the feasibility of the mechanism motion [4]. But the mechanism's output parameters are adversely affected by the clearances. The dynamic simulation of the crank-group driving mechanism with clearance can help to grasp the mechanism's dynamic characteristics, evaluate the real motion model of each crank, and design the structure.

2. CLEARANCE MODEL

For simplicity, a schematic diagram of the crank-group driving mechanism based on parallelogram mechanism is shown in Fig. (**2**). A_1B_1 is the drive crank. A_2B_2 and A_3B_3 are the driven cranks, r is the radius of the pin, and R is the radius of the pin hole on B_1. The collision is caused by the clearance between the pin and the pin hole. The non-linear spring-damper model is used to describe the clearance between the pin and the pin hole, that is, the collision force can be shown by formula 1 when two objects come into contact [1, 2, 5].

$$\begin{cases} F_n = k\delta^q + Step(\delta,0,0,\delta_{\max},C_{\max}) & \delta > 0 \\ F_n = 0 & \delta \le 0 \end{cases} \quad (1)$$

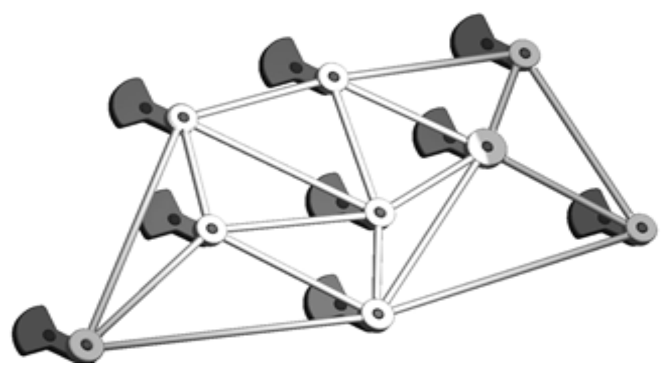

Fig. (1). The general form the crank-group driving mechanism.

In the formula 1, F_n represents the normal force, $q = 1.5$ represents the collision index, δ represents the penetrating amount on the normal direction of the two objects' contact surfaces, k represents equivalent stiffness coefficient [6-8], $k = \frac{4}{3}R^{1/2}E^*$, $1/R = 1/R_1 + 1/R_2$, R_1, R_2 represent the contact radius of two objects, $\frac{1}{E^*} = \frac{1-u_1^2}{E_1} + \frac{1-u_2^2}{E_2}$, u_1, u_2 represent

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respectively the Poisson's ratio of two objects, E_1, E_2 represent respectively the elastic modulus of the two objects, c_{max} represents the maximum damping, δ_{max} represents the maximum penetrating amount on the normal direction of the two objects' contact surfaces, v_τ represents the relative velocity on the tangential direction of the two objects' contact surfaces, and *Step*(*) represents the damping function shown by the formula 2.

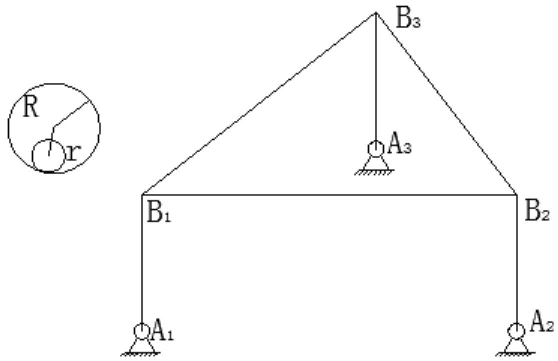


Fig. (2). A diagram of the crank-group driving mechanism.

$$Step(\delta,0,0,\delta_{max},C_{max}) = \begin{cases} 0 & \delta \le 0 \\ C_{max}[\frac{\delta}{\delta_{max}}]^2 + [3-2\frac{\delta}{\delta_{max}}] & 0 \le \delta \le \delta_{max} \\ C_{max} & \delta \ge \delta_{max} \end{cases} \quad (2)$$

3. SIMULATION MODEL OF CRANK-GROUP DRIVING MECHANISM WITH CLEARANCE

The simulation model shown in Fig. (**3**) of crank-group driving mechanism with clearance is built on its diagram shown in Fig. (**2**). A_1B_1, A_2B_2, A_3B_3 all represent the crank length, and their value is 300 mm. B_1B_2, B_2B_3, B_1B_3 all represent the rod length, and their values are respectively 600 mm, 527 mm and 592 mm. The density of all parts is 7830 kg/m^3. The nominal diameter of the pin and pin hole is $\varphi 20$. In order to simplify the model, only the clearance at point B_1 associated with the drive crank A_1B_1 is considered, and the clearance fit is φ20H8/h7, that is, the clearance maximum is 0.054 mm.

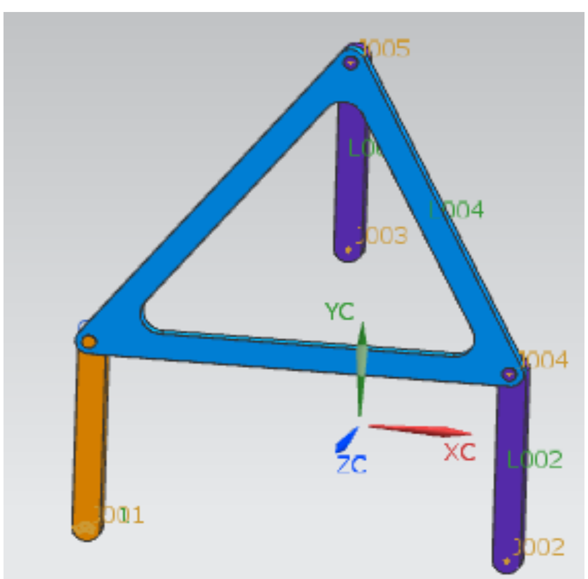


Fig. (3). Simulation model of crank-group driving mechanism with clearance.

4. SIMULATION RESULTS AND ANALYSIS

4.1. The Influence of the Clearance on the Angular Acceleration of the Driven Crank

The angular acceleration curves of the driven crank are shown in Fig. (**4**) when the clearance between the pin and pin hole are taken as 0.054 mm and 0.027 mm. From Fig. (**4**), it is evident that when the drive crank angular velocity is 600 r/min and other conditions unchanged [9-11], the maximum amplitude of the driven crank angular acceleration when the clearance is 0.054 mm and is much larger than that when the clearance is 0.027 mm.

4.2. The Influence of the Angular Velocity of Drive Crank on the Angular Acceleration of the Driven Crank

The angular acceleration curves of the driven crank are taken as 300 r/min and 600 r/min. When the clearance is 0.054 mm and other conditions unchanged, the maximum amplitude of the driven crank angular acceleration when the angular velocity of drive crank is 600 r/min and is much larger than that when the angular velocity is 300 r/min.

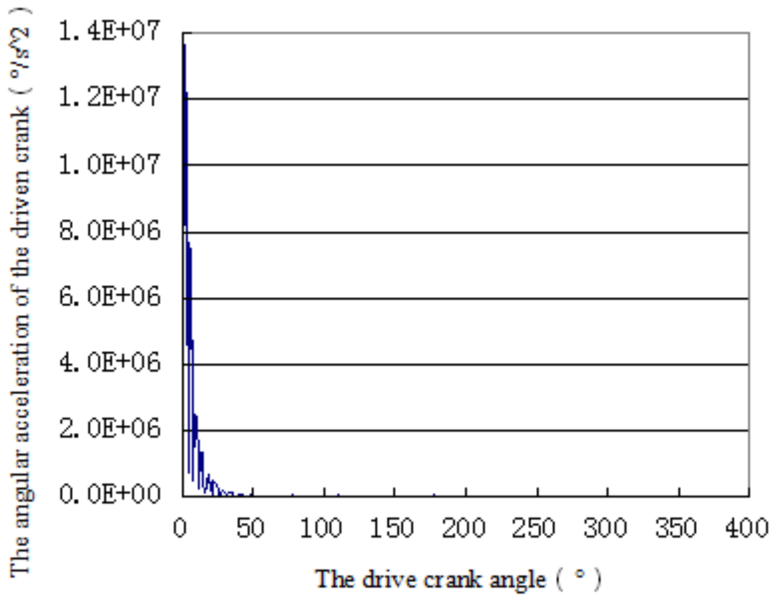
4.3. The Influence of the Material Damping on the Angular Acceleration of the Driven Crank

The material dampings are taken as 10 N-s/mm and 15 N-s/mm. When the clearance is 0.027 mm and other conditions unchanged, increasing the material damping can significantly reduce the magnitude of the angular acceleration of the driven crank.

CONCLUSION

1) The impact caused by the clearance is mainly in the initial phase of the movement, and the influence of the clearance on the angular acceleration of the driven crank is great. But the movement is stable when crank turns to 50°.
2) Increasing angular velocity increases the magnitude of the angular acceleration of the driven crank in the initial phase of the movement, but angular acceleration is relatively stable when the movement is stable.
3) Increasing the material damping not only can effectively reduce the angular acceleration magnitude of driven crank in the initial movement, but can further reduce the impact caused by the clearance in the steady phase of the movement.
4) The simulation of the crank-group driving mechanism with clearance based on NX/Motion Simulation can

(**a**) The material damping is 10 N-s/mm



(**b**) The material damping is 15 N-s/mm

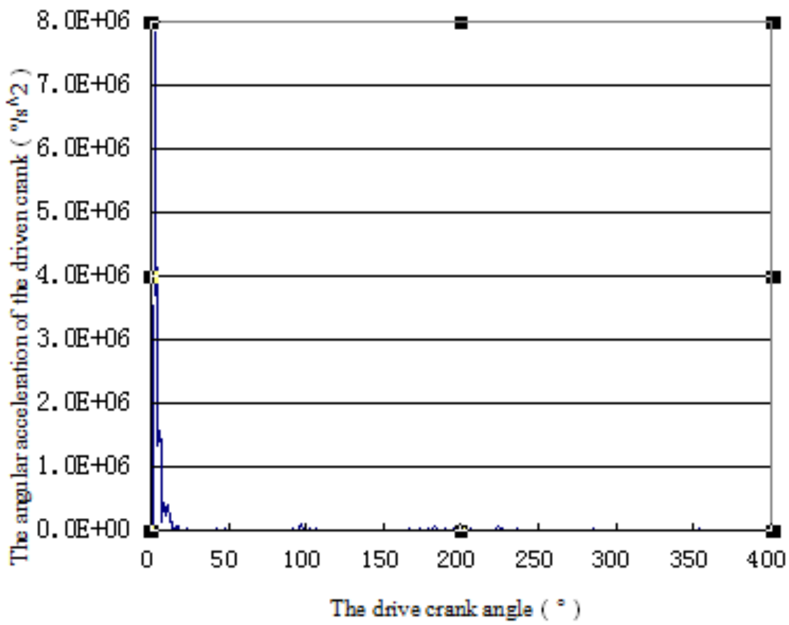


Fig. (4). The angular acceleration curve of the driven crank in different material damping.

avoid a lot of programming. In the simulation platform, modifying the simulation parameters can achieve the purpose of understanding the movement of the crank-group driving mechanism with clearances.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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