Synchronous Behavior Analysis of Two Rotors in Self-synchronization System

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Abstract. Synchronization is widespread in many engineering fields. The double eccentric rotary exciter driven synchronous vibration system can be simplified as a dual-rotor self-synchronizing system. Taking a universal synchronous test bench as the research object, the synchronization characteristics of the self-synchronization system are quantitatively studied in several cases, which fully verifies the ability of the vibration system to self-recover synchronization. Based on the parameters of the experimental platform as a reference, and compared with the measured results, the rationality of the simulation results is proved. Moreover, through experiments and simulations, it is found that when the excitation force is not equal, even if the motor power with larger excitation force is turned off, the system can resume the vibration synchronization state by itself.

1. Introduction

Self-synchronous motion is a special form of coordinated motion: for example, two motors or multiple motor-driven vibrating screens, vibrating conveyors, etc. all have self-synchronizing motion characteristics. In this kind of mechanical system of agriculture, if two eccentric rotors are installed to satisfy the synchronous stability theory, even if the system geometric parameters and initial conditions are not completely symmetrical, the rotational speeds of the two rotors must be the same, and the phase difference angle is a constant value. The most representative results of self-synchronous vibration research are double exciters vibrating screen synchronization theory, near resonance self-synchronization and frequency multiplication synchronization. Someone has studied the problem of double-rotor vibrating screen from kinematics [1,2]. And someone proposed a computer-aided method to calculate the center of mass of the vibrating screen [3-5]. The vibrating screen was studied by an experimental method [3]. However, further research is needed on the self-synchronization of vibrating screens. According to the mathematical model of electromechanical coupling, the variation of parameters of the transition process of the vibration system under different initial conditions and different physical conditions [6-8]. The unified description and expression equation of vibration synchronization and motor coupling are given [9]. In this paper, typical synchronous motor is coupled to a vibration model as a mathematical simulation model dynamic to universal synchronous bench object, using the actual parameters of the synchronous universal test station simulation model of the system dynamics. And the variation law of each system parameter of several typical states of the vibration self-synchronization system is quantitatively studied, and the ability of vibration synchronization and self-recovery synchronization of the vibration system is fully verified. Based on the measurement data of the experimental bench as a reference, and compared with the measured...
results, the simulation and experiment are combined to reproduce the self-synchronizing behavior of the dual-rotor synchronous vibration system.

2. Dynamic Model and Analysis of self-synchronization behavior

A simplified model of a two-motor driven reverse-phase rotary vibration system is shown in Fig. 1. The electromechanical coupling model of the system of the system has been deduced in [5-6] as the dynamic model of the simulation.

The movement track of the synchronous system is the straight-line periodic vibration on the vibration direction. The system parameters are as follows: \( M=148 \text{kg}, \ m_1=m_2=3.5 \text{kg}, \ J=17 \text{kg}\cdot\text{m}^2, \ J_{01}=J_{02}=0.01 \text{kg}\cdot\text{m}^2, \ r_1=r_2=0.08 \text{m}, \ k_y=77600 \text{N/m}, \ k_x=30000 \text{N/m}, \ k_{\psi}=3000 \text{N}\cdot\text{m/rad}, \ c_x=c_y=1000 \text{N}\cdot\text{s/m}, \ c_{\psi}=1000 \text{N}\cdot\text{s/rad}, \ l_1=0.4 \text{m}, \ l_2=0.2 \text{mm}, \ c_1=c_2=0.01 \text{N}\cdot\text{s/rad}. \) Through the system simulation, the transition process from start-up to synchronous vibration motion is obtained when several operating conditions of the dual-rotor self-synchronizing vibration system are obtained. When the initial conditions and geometric parameters of the system are completely symmetrical ideal working conditions, the transition process of system vibration is shown that only the displacement in the vertical \( y \) direction changes, and finally, in a reciprocating motion of a certain period, no vibration occurs in the horizontal and torsional directions. When the phase difference between the two eccentric rotors is constant to zero, the phase synchronization is at this time, and the system realizes self-synchronization.

![Fig.1 The self-synchronous process under the small-different motor parameter conditions](image1)

![Figure 2 Self-synchronization behavior when differences parameters motor](image2)
of transitioning from startup to synchronization is shown in Fig. 1. Due to the difference of the initial phase, there is no significant change in the vertical \( y \) direction and the ideal state. The horizontal and torsional direction and phase difference have sharp vibrations after starting, but eventually decay to zero. In the horizontal direction, the torsional direction and phase difference have sharp vibrations after starting, but eventually decay to zero. The phase is synchronized and the system realizes self-synchronizing vibration.

When the initial parameters of the two motors are slightly different, the system resumes its own self-synchronization behavior as shown in Fig.2. In the above two typical cases, the vibration in all directions occurs with the constant change of the phase difference. When the phase difference angle of these two states is not zero, but a constant value, the vibration in the horizontal direction and the torsional direction will not completely attenuate to zero, and finally there is a small stable vibration. The phase difference is eventually a constant value and the system self-synchronizes itself.

3. Research on synchronous test bench

The universal synchronous test bench is a fully functional device that can fully simulate multi-form, multi-state vibration synchronization behavior. The universal synchronous test bench is shown in Fig. 5. When the universal synchronous test bench only has two motors on both sides to perform the excitation input, and the middle motor does not supply power, the system is a double-rotor self-synchronizing vibration system. This causes the two rotors to operate in the direction of the simplified model, which is the inverted vibration state. In this state form, the acceleration test of the test bed starts transition process and the steady state motion state is performed. The sampling frequency of this test is 65536 Hz.

The stable state of the vibration system is to perform the reverse synchronous stable motion when the operating frequency of the system is 16 Hz. It can be observed from Fig.5 that during the starting process, the motor torque and the rotational speeds of the two rotors also change, and there is a small periodic fluctuation, but the rotational speeds of both rotors tend to be stable. The vibration frequency of the vibrating body in the \( x \) direction and the \( y \) direction is equal to the rotation frequency of the rotor, that is, the operating frequency of the motor (16 Hz). In the collected data, both vibration directions have acceleration generated, and the sharp and significant changes in the starting are not synchronized. After a short time, the acceleration in the two directions of the system reaches the stable vibration amplitude, and the system synchronously stabilizes the vibration.

Through the comparison of the experimental results and the simulation data, the simulation shows that in the ideal state, the amplitude of the horizontal direction is zero after the system is synchronized, but in the experiment, the system parameters are not completely symmetrical, and there are interference and measurement errors. The experiment measured that the system vibrates in both the \( x \) and \( y \) directions, and has amplitude at the multiplier. The experimental data of the actual amplitude at the operating frequency is consistent with the results of the simulated data, and this is very close to the measured data of the system. After the system reaches the synchronous steady state, the power supply at one end is disconnected, and the system is still in a stable vibration state. Only the system has a small amplitude of stable amplitude vibration in both the \( x \) directions and \( y \) directions at the operating frequency, and will slightly increase in amplitude compared to when the power is not turned off.

Data acquisition is performed when the magnitude of the two excitation forces is not equal. In the test, the magnitude of the exciting force was changed by changing the scale marked on the two eccentric rotors on the exciter. When the eccentric rotor excitation force is increased, the measurement results and simulation data of the vibration process are shown that the system is displaced in both \( x \) and \( y \) directions due to the increased total excitation force of the system. And the magnitude of the displacement increases slightly when the magnitude of the displacement at the operating frequency is equal to the excitation force. The system is still in a stable state.

It has been found through experiments that even if the excitation force is not equal to the synchronous state, even if the motor power supply with high excitation force is turned off, the amplitude at the operating frequency is slightly higher than the amplitude of the power supply that is
not turned off. The system can still recover the vibration synchronization status by itself. This is because the system can still meet the self-synchronization stability condition at this time, so the system will still perform self-synchronous stable motion. The motion trajectory of the system changes when the exciting force is equal, and the linear motion in the vertical $y$ direction becomes an approximate circular motion in which both the $x$ direction and the $y$ direction are displaced, and a motion in the torsional direction perpendicular to the $xy$ plane is generated.

In the measured results, there is still a small vibration in the vertical direction of the vibrating body, which is about an order of magnitude different from the amplitude of the main vibration represented by the simulation result, which is mainly caused by factors such as incomplete symmetry of the system parameters and external disturbances. Similarly, in the double-vibration motor self-synchronous drag system, when the vibration motor foot bolt is loose, step distortion occurs, and significant lateral vibration occurs. The existence of low frequency and double frequency is caused by loose installation of equipment, insufficient excitation force or incomplete structure of the two motors. At the same time, the installation method of the motor is similar to that of the cantilever beam. The vibration of the motor itself generates noise, and there is strong interference. In the process of measurement, the base of the equipment shows obvious slippage during the start-up and shutdown process, which makes all the errors of the experimental measurement results and the simulation data.

4. Conclusion

In this paper, the universal synchronization test bench is taken as the object, and the actual dynamic parameters of the universal synchronous test bench are used to simulate the previously established system dynamics model. The variation characteristics of each system parameter in the typical state of the electromagnetic vibration self-synchronization system are studied. The synchronization motion characteristics of the vibration system and the self-recovery synchronization are fully verified. The formation process and development process of self-synchronous vibration in several state cases are reproduced by mathematical simulation. Taking the measured data of a self-synchronizing vibration test bench as a reference, the rationality of the simulation calculation results is proved. And through experiments, it is found that when the excitation force is not equal, even if the power of the motor with large excitation force is turned off, the system has the ability to recover the vibration by itself, and its amplitude is slightly larger than when it is not turned off. This is because the system can still satisfy the self-synchronization stability condition in this state.

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References

[1] Senator, M.. Synchronization of two coupled escapement-driven pendulum clocks. Journal of Sound & Vibration, 2006, 291(3), 566-603.
[2] Jovanovic V , Koshkin S . Synchronization of Huygens' clocks and the Poincare method. Journal of Sound & Vibration, 2012, 331(12):2887-2900.
[3] Banerjee, T., Biswas, D., & Sarkar, B. C.. Anticipatory, complete and lag synchronization of chaos and hyperchaos in a nonlinear delay-coupled time-delayed system. Nonlinear Dynamics, 2012, 72(1-2), 321-332.
[4] Blekhman I. I., Fradkov, A. L., Tomchina, O. P., & Bogdanov, D. E.. Self-synchronization and controlled synchronization: general definition and example design. Mathematics and Computers in Simulation, 2002, 58(4-6), 367-384.
[5] Xiong W. l., Wen B.C., Duan Z.S. Mechanism of electromechanical-coupling on self-synchronous vibration and vibratory synchronization transmission. Journal of Vibration Engineering, 2000, 13(3): 325-331. (in Chinese)
[6] Kandah, M., & Meunier, J. Theoretical and experimental study on synchronization of the two homodromy exciters in a non-resonant vibrating system. Shock & Vibration, 2015, 20(2), 327-340.

[7] Hou Y.J., Yan G.X. Electromechanical-coupling mechanism of self-synchronous vibrating system with three-motor-driving. Journal of Vibration Engineering, 2006, 19(3): 354-358. (in Chinese)

[8] José M. Balthazara, Jorge L., Palacios Felix. Some comments on the numerical simulation of self-synchronization of four non-ideal exciters. Applied Mathematics and Computation, vol 164 (2005) 615–625.

[9] Kibirkštis E, Pauliukaitis D, Miliūnas, Valdas, et al. Synchronization of pneumatic vibroexciters operating on air cushion with feeding pulsatile pressure under autovibration regime[J]. Journal of Mechanical Science and Technology, 2018, 32(1):81-89.