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Dynamic analysis of a planar slider-crank mechanism with clearance for a high speed and heavy load press system

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ABSTRACT

In dynamic analysis of a slider-crank mechanical with clearance for a closed high speed and heavy load press, elements are generally assumed to be rigid. The dynamic response is considerably changed as joint clearance and flexibility are introduced. Considering the actual features such as clearance, flexibility and friction, a rigid–flexible model is developed into ADAMS. With energy loss taken into account, the IMPACT function is employed by the contact–impact model to describe the contact response between the journal and bearing. The acceleration experiments of the slider-crank at different driving speeds are carried out. We conduct the dynamic simulations of the slider-crank mechanism and compare the numerical results with experimental data. The results reveal that the rigid-flexible coupling model, compared with the rigid model, is more effective to reflect the dynamic response of the mechanical. Meanwhile, the occurrence of motions can be divided into three types: a free flight, a continuous contact motion, and an impact motion. Furthermore, influence of the linkages flexibility, size of joint clearance, and driving speed of crank shaft on the dynamic behavior of the mechanism are studied.

1. Introduction

The press machine is a highly effective manufacturing system with the features of high speed and heavy load. Sometimes, there is an additional requirement on the adaptability to different work pieces. Because of these features, wear and shaking are common operating phenomena, and they further cause the large clearance and deformation of the link. Therefore, for the closed press machines, the mechanism structure should be as simple as possible. The mechanism concerned in this paper is a slider-crank mechanism in press machines. In order to obtain a consistent performance, it is essential to investigate the dynamic behavior of the slider-crank mechanism for the press machine, as the dynamic behavior can easily deviate from its desired one due to the joint clearance and link flexibility. This paper presents a study on modeling and simulation of the slider-crank mechanism in the context of press machinery, with consideration of the joint clearance and link flexibility. The mechanism has further features of high speed and heavy load [1–6].

Modeling and simulation of the slider-crank mechanism is obviously not new, as the slider-crank mechanism is a very popular mechanism used in many different types of machinery. Dubowsky [7–8] investigated the dynamic force response with an increase of the joint clearance for planar mechanisms including the slider-crank mechanism. The link flexibility was taken in the account by Moening [9], the results showed the mitigating effects of link flexibility on impact forces. The dynamic modeling method was presented for robotic manipulators by Kakizaki and Deck [10]. Although they built the dynamic modeling with the flexible links and joint clearances, the slider-crank mechanism was studied in the light workload condition. Based on the equations of motion

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for a multibody system, Ravn [11] presented a continuous analysis method to calculate a slider-crank mechanism with joint clearances. The experimental results verified that the method is available. Rogers [12] and Flores et al. [13–15] estimated the effects of clearance on dynamic behavior of a slider-crank mechanism with contact force, which can provide information on their application range and accuracy in different contact situations. Yang [16] applied the finite element method to investigate the characteristics of the four-bar mechanism, which provided a simpler and more practical numerical solution method for convenient analysis. Bai and Zhao [17] also studied the dynamics of a four-bar mechanical with revolute clearance. The contact model in clearance joint was established by a hybrid nonlinear contact force model, which could effectively describe the dynamic behavior of planar mechanical system.

In general, the Hertz contact theory cannot give an accurate description of the overall nonlinear nature of the contact process due to its simplicity. Many researchers focused on the effects of clearance on dynamic behavior of mechanisms considering contact–impact models. Khemili and Romdhane [18] studied the effect of joint clearances on the dynamic behavior for a slider-crank mechanism by the impact–function model and confirmed that the method could be accurate described by experiment. Flores [19–21] developed a methodology for studying and quantifying the wear phenomenon in revolute clearance joints. The results drew that the contact between the joint elements was wider and more frequent in some specific regions. Bai and Zhao [22–23] used a hybrid contact force model to predict the dynamic behavior of planar mechanical system with clearance in revolute joints. It was indicated that many factors might have effects on the selection of the contact force, for example, restitution coefficients and contact velocity. Gummer and Sauer [24] investigated a methodology for modeling a slider-crank with clearance in RecurDyn. The results demonstrated that the approach was suitable for calculating a slider-crank mechanism.

Due to small of clearance in actual revolute joint and the complexity of the physical phenomenon of friction, Hertz theory does not always satisfy the actual condition. Consequently, researchers developed studies of friction in the kinematic joints of mechanical system, which included static friction and stick–slip friction. The best known contact force model with hysteresis damping function was proposed by Lankarani and Nikravesh [25], which was widely used for different problems. Schwab and Meijaard [26] achieved a dynamic analysis of rigid and elastic mechanical systems considering the friction force. The results demonstrated that the friction coefficient had a significant influence on the contact–impact problem. Flores [27–28] discussed effects of friction on planar multibody systems based on the elastic Hertz theory and classical Coulomb's friction law, which indicated that the dynamic behavior of contacting solids strongly depended on the selection of the contact force model. Also, Muvengei et al. [29] investigated dynamic characteristics of multibody systems with clearance joints by LuGre friction law. Recently, another dynamic model considering friction and Hertz contact force proposed by Reis et al. [30] could be applied in the case of soft and hard contacts.

In the most previous simulations of a mechanism with clearance for press machine, the rigid model cannot describe the influences of clearance and links flexibility on the system response. Although Zhang and Zhou [31] modeled the dynamic of the closed high speed presses with consideration of both flexible links and joint clearances, the slider mechanism considered in their study was with light slider (less than 5000 kg). However, the mass of main slider in most press machines are usually very heavy, so the rigid–flexible model cannot satisfy the high speed and heavy load press system. Moreover, the dynamic analysis of the press machine only relies on the simulations, which has not been compared with experimental test. Thus, it is essential to investigate the influence of clearance and links flexibility on the dynamic response for the high speed and heavy load press system.

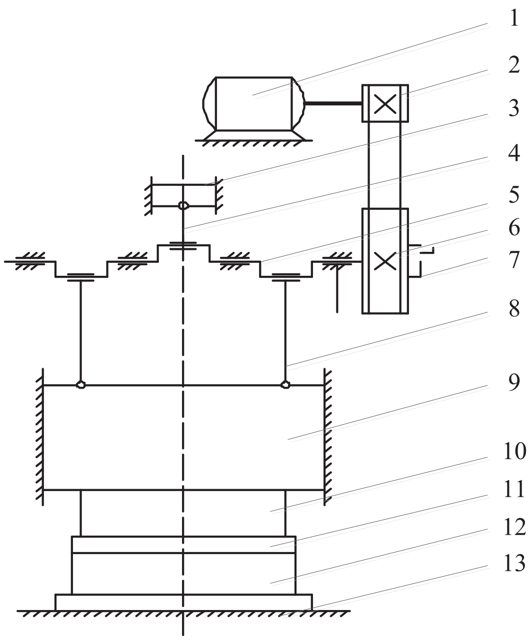

Fig. 1. Composition and principle sketch of press 1. Motor; 2. Motor wheel; 3. Counterweight slider; 4. Addition linkage (flexibile part); 5. Crank shaft; 6. Fly wheel; 7. Clutch; 8. Main linkage (flexibile part); 9. Slider; 10. Upper die; 11. Lower die; 12. Worktable; 13. Foundation.