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Modeling and simulation of flexible slider-crank mechanism with clearance for a closed high speed press system

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ABSTRACT

The traditional model of a slider-crank mechanism for a closed high speed press system always neglects the flexibility of the crank shaft and considers only one revolute clearance joint between the linkage and the slider. This causes any analysis to have a low accuracy. In this work, a rigid–flexible coupling model of the slider-crank mechanism is described, using the software ADAMS, in which the crank shaft and linkage are treated as flexible bodies, and the effect of the clearance of the joints between the crank shaft and the main linkage, and between the main linkage and the main slider are taken into account. The dynamic response of the mechanism with clearance under no-load and piling conditions is explored for the case of a mechanism with a rigid crank shaft and linkage, and the case with a flexible crank shaft and linkage. The simulation results showed that the dynamic response of the mechanism was greatly influenced by the clearance and the motion of the crank shaft center was characterized by three phases: free flight motion, contact motion and impact motion. The influence of the clearance size, input crank shaft speed, and number of clearance joints on the dynamic response of the mechanism was also investigated.

1. Introduction

The closed high speed press, a "less/non-chip finish" highly effective machine tool, and a key type of industrial equipment when manufacturing pressed metals, can be used to manufacture metal parts closer to their final shapes such that production of these parts complies better to the requirements of clean and green production. The clearance of a slider-crank mechanism for a closed high speed press is mainly caused from manufacturing and assembling errors, and component wear. When the size of the clearance of a joint is small enough, its effect on the dynamic response characteristics can be neglected, however, as a machine continues operating, the size of the clearance of the joint will increase. The presence of clearance inevitably causes the joints of a mechanism to separate and collide, which causes serious vibrations and noise, and degrades the dynamic performance of a mechanism. Moreover, the dynamic response of a mechanism is also affected by the deformation of the flexible components of a mechanism. Therefore, it is important to establish a way to model a rigid–flexible slider-crank mechanism with clearance for use in a closed high speed press system as this will allow us to study the dynamic responses of such systems.

There are a number of publications on the dynamic analysis of slider-crank mechanisms with clearance: Flores et al. have published several papers (e.g., [1–11]) and a book [12] on the dynamics of multi-body systems with imperfect joints. A slider-crank mechanism or a four-bar mechanism is usually used as an example in their investigations, in which a self-developed calculation tool is used. The major objective of Flores et al's work is to determine the influence of different contact force laws [2,3], wear [5], and lubrication [6,7] in the clearance joint on the dynamic behavior of the system. In [8], Flores presents a parametric study that shows the huge impact of the clearance size on the dynamic load and overall system behavior of a slider-crank

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mechanism. A comparison of simulation results to experimental data is presented in [11]. Using the lubrication model introduced, B.J. Alshaer [13] built a dynamic model of the slider-crank mechanism with clearance and studied its dynamic response using a numerical simulation method. Compared to the dry friction model, the simulation results show the lubrication model increases damping and stiffness, and is more consistent with the actual state. Based on both the spring-damping model and the collision model, Saad Mukras [14,15] has established a dynamic model of the slider-crank mechanism with clearance, using the Archard model to explore the effect of the wear on the mechanism. The numerical results demonstrate that the dynamic response of the mechanism is similar under two situations, but the difference in the abrasion level was large. Farahanchi and Shaw [16] have studied the influence of clearance size, friction and crank speed on dynamic response and observed chaotic and periodic response. Based on a continuous contact model, Fang Jia [17] treated the clearance of joints as a rigid linkage without mass and studied the dynamic errors of the slider-crank mechanism for closed high speed press. In order to stabilize the slider-crank mechanism with a revolute joint between the slider and the connecting rod and overcome its chaotic behavior, Olyaei et al. [18] present a control mechanism based on the Pyragas method. Here, the joint contact loss is eliminated and the modified mechanism exhibits periodic motion under small perturbations. Muvengei et al. [19] have investigated the parametric effects of differently located frictionless revolute joints on the dynamic characteristics of a planar slider-crank mechanism. The simulation results demonstrate that different joints in a multi-body system have different sensitivities to clearance size and a one clearance revolute joint should be avoided in the general case for a mechanical system. Gummer and Sauer have developed a methodology to calculate a slider-crank mechanism with a revolute clearance joint using the commercial MBS tool RecurDyn [20]. This methodology chooses appropriate contact, damping and friction force models from a wide range of approaches available in the literature. The results, compared with results in other papers showed the validity of the methodology. Megahed and Haroun present a model for a slider-crank mechanism with multiple clearance joints in Solidworks/CosmosMotion, which has an embedded ADAMS engine for conducting the simulation [21]. Bauchau O.A. [22] has established the dynamic equations of flexible multi-body system with clearance based on the nonlinear dynamic theory. Then, using a slider-crank mechanism taken as numerical example, they studied the effect of clearance and flexibility on the dynamic response of the mechanism. Imed Khemili [23] built a rigid–flexible coupling model of a flexible slider-crank mechanism with clearance, and the connecting rod considered to be a flexible body, and studied its dynamic response. Considering the effect of length of crank, translational joint clearance and the impact of joints, Mihai Dupac [24] discretized the connecting rod into several rods and investigated the dynamic response of the flexible slider-crank mechanism with clearance and analyzed its stability using Lyapunov equations. Schwab et al. [25] have analyzed the dynamic behavior characteristics of a slider-crank mechanism when the coupler is rigid or flexible. The simulation results show that the flexibility of the connecting rod has a smoothing effect on its dynamic responses and acts as a suspension for the mechanism when compared to the rigid case. Gu et al. [26] investigated the dynamic response of the flexible slider-crank mechanism with clearance and confirmed the chaotic and the periodic motion of the mechanism using numerical and experimental methods. In order to consider the elasticity of the connecting links in mechanisms with clearance joints [27,28], Tian et al. implemented all absolute nodal coordinate formulation based on Lankarani and Nikravesh's continuous force law and Coulomb's friction law.

Previous dynamic models of a mechanism with clearance for closed high speed presses have always neglected the flexibility of the crank shaft and only considered one revolute clearance joint, which leads to a low precision dynamic analysis. The primary objective of this work reported here was to analyze the dynamic behavior of a mechanism with clearance for a closed high speed press in a more reasonable and accurate way. In this work, which is based on the nonlinear spring-damping model taken from Hertz contact theory and the modified Coulomb friction model, a multibody rigid-flexible coupling dynamic model of the slider-crank mechanism with clearance for closed high speed press is proposed using ADAMS software. In the model, the crank shaft and linkage are considered to be flexible elements and the clearance of the joints between the crank shaft and the main linkage, and between the main linkage and the main slider are taken into account. The dynamic response of a mechanism with clearance for closed high speed press is explored under the case of a mechanism with rigid crank shaft and linkage, and a case of a mechanism with flexible crank shaft and linkage.

This paper is organized as follows: the physical structure and principle of the mechanism with clearance for closed high speed press is described briefly in Section 2. The dynamic model of the mechanism with clearance is established in Section 3. Numerical simulations of the dynamic model are described and discussed in Section 4. The presented rigid–flexible coupling model for the slider-crank mechanism of a closed high speed press system is summarized in Section 5 and the conclusions are also presented in this section.

2. Description of a mechanism with clearance for a closed high speed press system

The working principle of the mechanism for a closed high speed press system is shown in Fig. 1. Motion and energy from the motor are transmitted to a slider through a transmission system, which can manufacture the metal parts closer to their final shapes. The belt transmits the motion of the motor from the small pulley to the big pulley, then the motion is transmitted to the crankshaft from the big pulley. The upper end of the main linkage is connected to the crankshaft and the lower end is connected to the slider, which converts the rotary motion of the crankshaft into a straight reciprocating motion. In order to balance the inertia force, additional weight is added at the other end of crankshaft. To meet the needs of the production process, the slider is alternately in motion and motionless so the press must have a brake and clutch. Such presses often have a fly wheel to keep the load-bearing requirements on the motor uniform and to make the press more energy efficient.