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Thermal modelling and characteristics analysis of high speed press system

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ABSTRACT

The traditional thermal model of presses neglects the effect of roughness between two contact surfaces on the contact conduction coefficient, which causes the analysis to have a low accuracy. The primary objective of this work is to propose an improved thermal model of the high speed press system with the thermal contact resistance between solid joints and the change of the heat generation power with the temperature of bearings considered to analyze its thermal characteristics. Based on the fractal model and the change of the heat generation power, a complete thermal model for the high speed press system is developed. The temperature histories and the time for reaching thermal equilibrium condition of the high speed press system are explored by the finite element (FE) method. The experimental results demonstrate that the complete model is more accurate than the model without considering the thermal contact resistance and the change of the heat generation power. The thermal expansion of the high speed press system is also investigated, which can provide a theoretical basis for design of structure and intelligent lubrication system to improve its precision.

1. Introduction

The high speed press, as a "less/non-chip finish" highly effective machine tool as well as one of the key pieces of industrial equipment, can manufacture metal parts closer to their final shapes and comply better with the requirements of highly advocated clean and green production. With the development of technology, the manufacturing precision requirements of the high speed press system have boosted dramatically. The main factors that affect the precision of the high speed press system consist of the error from the manufacturing and assembly of the parts, the elastic error of the parts from the working load, and the clearance between joints as well as the thermal error as a result of the temperature change that accounts for about 40–70% of the total errors [1]. With the increase in the speed, the power losses in the mechanical structure of the press system as a result of friction will increase, which causes the lower machining accuracy of the high speed press system. The precision especially dynamic precision is key to the punching and deep drawing process of ultra-thin parts for presses and lower precision will cause such problems as tearing wrinkling and rejection rate of products, higher vibration and noise as well as reduction of mold life. Therefore, it is essential to establish the thermal model to analyze the characteristics of the high speed press system.

There have been a number of thermal or thermo-mechanical models to investigate the thermal and dynamic responses of spindles and machine tools. Bossmanns and Tu [2,3] developed a finite difference model to characterize the heat generation, heat transfer and heat sinks of a high-speed motorized spindle. Lin [4] presented an investigated model with experimental validation and sensitivity analysis for studying various thermo-mechanical-dynamic spindle behaviors at high speeds. Li and Shin [5] developed a more comprehensive integrated thermo-dynamic model for high-speed spindles using the finite element method, which is coupled with the spindle dynamic model through bearing heat generation and thermal expansion of the whole system. They [6] also investigated the effects of bearing configuration on the thermo-dynamic behavior of spindles using the model. They assumed that the temperatures of two contact surfaces were coupled or set an experimental constant value on the resistance for all kinds of joints and the heat generation power was constant. Zhao [7] established the FE model of spindle of NC machine and analyzes its temperature field and thermal deformation. Creighton [8] built the thermal model of milling spindles to simulate the law of its thermal deformation. With the thermal resistance contact

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considered, Xu [9] proposed an improved model for the grinding machine. Hong [10] established the thermal model of gantry processing center set up and explored the temperature field distribution and change. Wang [11] analyzes the thermal field distribution characteristics of spindles of milling machines with the effect of cooling water tank considered. Thermal errors and compensation of different machines are also studied in Refs. [12,13].

The previous thermal models of the press often neglect the effect of the thermal contact resistance between joints and the change of the heat generation power with the temperature of bearings, which causes low precision of its thermal characteristics analysis. In order to analyze the thermal characteristics more accurately, a complete thermal model for the high speed press system is developed in this work, which considers the effect of the thermal contact resistance between joints and the change of the heat generation power with the temperature of bearings. The temperature distribution and the time for reaching thermal equilibrium condition of the high speed press system under a certain working condition are explored by the finite element (FE) method. Furthermore, the effects of the rotation speed on the temperature field and the thermal expansion of the high speed press system are also investigated.

This paper is organized as follows: In Section 2, the structure and working principle of the high speed press system is described briefly. In Section 3, the dynamic analysis of the mechanism is implemented. In Section 4, the thermal model of the high speed press is established. In Section 5, the thermal characteristics of the high speed press are analyzed and discussed, and the validity of the thermal model is verified. Section 6 summarizes the proposed thermal model and the conclusions as well as future work.

2. Physical description

The physical figure of the high speed press, as shown in Fig. 1, consists of the frame, base, motor, crank shaft, linkage, slider, flywheel, bearings, etc. The solid model of the high speed press system and locations of the measured points on the press structure (numbers 1, 2, 3, …,12) are shown in Fig. 2. The motion of the motor is passed through the belt to the crank shaft. The linkage connects with the crank shaft as well as the slider, which can translate rotary movement of crank shaft into linear reciprocating motion of slider. The upper mold is installed on the slider while lower mold on the working plate. When the sheet metal is put between the upper and lower dies, blanking or other operation techniques can be carried out by the press system. The slider of the press can move or stop optionally as a result of the clutch and brake. The working time of the press under load is short throughout the work cycle and majority of the time is for empty trip without load. The flywheel of the press is used to get the motor to work under uniform load and make use of energy with high efficiency. In order to ensure forming accuracy, the pneumatic device is designed as dynamic balance components.

With the development of the high speed machining, the thermal characteristics of the high speed press system have been considered, which include the thermal field, thermal balance time, thermal deformation and the thermal geometric accuracy and affect the performance of the press system. The thermal characteristics are mainly influenced by such heat sources as friction heat between the ball and the groove of bearings, between the slider and the pillar as well as heat from the motor. These heat sources produce the non-uniform temperature field of press components that expand with heat and contact with cold. They eventually cause low machining accuracy of the high speed press system.

Fig. 1. Physical figure of the high speed press system.

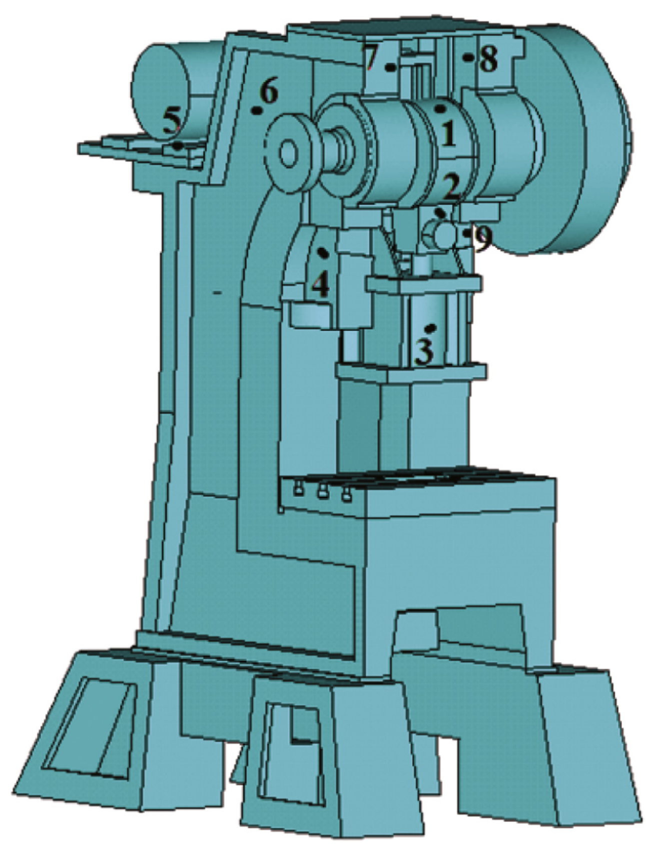

Fig. 2. Model of the high speed press system. 1 – upper part of linkage, 2 – lower part of linkage, 3 – middle part of slider, 4 – left part of rail, 5 – motor, 6 – upper part of press frame, 7 – upper part of left bearing, 8 – upper part of right bearing, 9 – right part of rail.

3. Dynamic analysis of the mechanism for the high speed press system

The pneumatic balancing device of the high speed press system connects with the slider through stud. In practice, it is assumed