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Non-circular belt transmission design of mechanical press

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A B S T R A C T

The quality of parts manufactured by metal forming operations depends on the kinematics of the mechanical press in a large degree. Non-circular belt transmission with a rotational angle-dependent speed ratio in the press drive mechanism offers a new way to obtain optimum stroke-time behaviors for specific metal forming operations in terms of manufacturing. In this work, the mathematical model for mechanical press driven by non-circular belt transmission is established with the concept of polar coordinate equation for tangent curves introduced, and a general design method of non-circular belt pulley pitch curves and slack for transmission system is proposed. Compared with traditional crank-slider press, numerical simulation results demonstrate that mechanical press with non-circular belt transmission has a lower speed under deep drawing operation and a quick-return characteristic under non-loading stage, which is suitable for blanking and deep drawing products that are made of poor plasticity and embrittlement material. Furthermore, the slack of non-circular belt transmission for mechanical press is calculated under operation, which can provide a theoretical basis for the design of take-up mechanism.

1. Introduction

The mechanical press, as “less/non-chip finish” high-effective machine tool as well as one of the key industrial equipment, can manufacture metal parts closer to their final shapes and comply better with the requirements of highly advocated clean and green production. Traditional mechanical press commonly consists of belt transmission and crank-slider mechanisms, which are used to transmit the rotary motion of electrical machine into translational movement of slider so as to realize stamping operation. As the conventional belt transmission ratio is constant, the motion law of the slider is sine shape [1] and cannot meet the requirements of blanking and deep stamping products that are made of poor plasticity and embrittlement material. Therefore, to overcome this problem, a type of non-circular belt transmission with variable velocity ratio should be designed and a specific output motion law of slider for mechanical press should be generated, which includes a low speed under loading stage and a high speed under non-loading stage.

Many researchers have studied majority kinds of transmission with variable velocity ratio for the special law of motion. The application of non-circular gears in function generating mechanism has been proposed and discussed [2,3]. By designing a pair of non-circular gears, which are able to perform a proper gear ratio function, the output member of a mechanism can be effectively forced to move according to a prescribed law of motion when operated at a constant input velocity [4,5]. For the special law of motion obtained by a pair of meshing elliptical gears, a design solution was given by Wunderlich W and Zenow P [6]. F.S Li and X.T Wu [7–9] proposed the use of non-circular gears to achieve the non-uniform transmission ratio. The use of non-circular gears in the drive of mechanical press offers a new way of meeting the demands on the kinematics. Investigations at the Institute for Metal

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Forming and Metal Forming Machine Tools of Hanover University have shown that in this simple manner all the relevant uninterrupted motions of the ram can be achieved for various forming processes [10]. E Doege and M Hindersmann [11] also came up with the non-circular gears to achieve the optimized kinematics of press, but the specific method of design was not given. For application of cam-follower mechanisms, these devices can also reproduce almost any characteristics of the follower's motion and their manufacturing costs as well as the number and dimensions of moving parts are rather limited [12,13]. F Freudenstein and C.K Chen [14] developed a new mechanical component: variable ratio chain drives with noncircular sprockets and minimum slack, and illustrate applications to the design of an optimum bicycle configuration and a harmonic-motion generator. X.L Cao and J Liu [15] designed a type of chain transmission with a variable velocity ratio and outlined that two spans of a chain are never simultaneous in tension, and the chain slack can undergo moderate periodical changes while the transmission runs. Based on the results [15], J Liu and L.P Feng [16,17] studied the algorithmic computation of Non-circular chain transmission. Carlo Innocenti and Davide Paganelli [18] presented a new procedure to design a two-pulley synchronous belt transmission connecting, with no belt tensioner, two parallel-axis shafts with a variable velocity ratio. The procedure takes into account the limited number of choices for pitch and length of off-the-shelf synchronous belts. Hellmuth Stachel [19] treated the geometry of tooth profiles and pulleys and their algorithmic computation as well as the relation between tooth profiles and 'strict' cases without take-up pulley. A geometric solution was proposed by Hoschek J [20], who pointed out that some tangents to the pulley contours were determined through an iterative procedure, and the envelope of these tangents was approximated by a sequence of Bezier splines.

The existing approaches mainly apply non-circular gears transmission, belt transmission, chain transmission and cam-follower mechanism to generate specific motion law. Only non-circular gears transmission has been applied to mechanical press in order to optimize its kinematics and meet specific machine requirement. Although non-circular gears have the advantage of lower weight-to-strength ratios and absence of gross separation or decoupling of moving parts [4], non-circular belt transmission is more attractive than gear transmissions if the center distance is relevant or if lubrication is unavailable as well as if the cost of design and manufacture is concerned. Therefore, it is important to design non-circular belt transmission for mechanical press so as to obtain optimized kinematics and improve its manufacturing flexibility.

The primary contribution of this work is to design non-circular belt transmission for mechanical press in order to obtain optimized kinematics and meet the machine requirement of deep drawing. Based on the polar equation for tangent curves, the pitch curve of non-circular pulley is designed. Compared with traditional crank-slider press, numerical simulation results demonstrate that mechanical press with non-circular belt transmission has a lower speed under deep drawing operation and a quick-return characteristic under non-loading stage, which is suitable for blanking and deep drawing products that are made of poor plasticity and embrittlement material. Furthermore, the slack of non-circular belt transmission for mechanical press is calculated under operation, which can provide a theoretical basis for the design of take-up mechanism.

This paper is organized as follows: in Section 2, the physical structure and machine requirements of mechanical press are described briefly. In Section 3, the pitch curve of non-circular pulley is designed and slack of belt transmission is obtained. In Section 4, numerical example is simulated and comparative analysis is performed. Section 5 summarizes the design of non-circular belt transmission for mechanical press and the conclusions.

2. Physical description and press machine requirements

The physical figure of mechanical press is shown in Fig. 1 and the working principal sketch of press is shown in Fig. 2: Motor (1) passes the movement on to pulley (10) through the belt and then passes motion on to crankshaft by gears (2, 3). The rod (11) connects with crankshaft on the top and with the slider (6) on the bottom, which can translate rotary movement of crankshaft into linear reciprocating motion of slider. The upper die (10) is installed on the slider and lower die (7) on the plate (9). When the sheet metal is put between the upper and lower dies, Press can carry out blanking or other deformation techniques. In order to meet the manufacturing process needs, press is equipped with clutch (4) and brake (12) that can sometimes get the slider to move or stop. The press's working time under load is short throughout the work cycle and most of the time is for empty trip of no-load. In order that motor works under uniform load and makes use of energy with high efficiency, crank-slider press often installs flywheel. As Fig. 2 shows, the big pulley (13) serves as flywheel.

One manufacturing cycle, which corresponds to one stroke of the mechanical press, goes through three stages: loading, forming and removing the part. Instead of the loading and removal stages we often find feeding the sheet, especially in sheer cutting. For this, the press slider must have a minimum height for a certain time. During the forming period the slider should have a particular velocity curve, which will be gone into below. The transitions between the periods should take place as quickly as possible to ensure short cycle time.

In deep drawing operations, the velocity of impact should be as low as possible to avoid the impact when striking the sheet. On the one hand, velocity must be sufficient for lubrication during forming. On the other hand, we have to consider the rise in the strain rate which creates greater forces and may cause fractures at the transition from the punch radius to the side wall of the part.

3. Design formulation for non-circular belt transmission

In typical arrangements for mechanical press shown in Fig. 3, a pair of non-circular pulleys is used to drive a crank-slider mechanism, so that the slider is forced to move according to a specific law of motion. The design of this mechanism consists of two phases, namely the synthesis of the pitch curves, starting from the requested law of motion, and the computation of slack.