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Cold orbital forging of gear rack

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ABSTRACT

At present, gear rack is manufactured mainly by cutting method while its precision plastic forming method has not been reported. This paper proposes an innovative cold orbital forging method for manufacturing gear rack, in which the complicated teeth of gear rack are forged by the highly dynamic rocking tool under straight line path. Firstly, a universal method for designing the rocking tool under straight line path is proposed according to the forming mode and contacting mode between the rocking tool and component, i.e., one side of the component is ultimately overall formed by the overall contact (it is achieved by the incremental deformation) between the corresponding side of the rocking tool and component. Based on this universal method, the rocking tool in cold orbital forging of gear rack is accurately designed. Secondly, the mathematical model and method for interference examinations between the rocking tool and gear rack are developed and the interference amount and interference zone are calculated. Thirdly, to eliminate the interference between the rocking tool and gear rack so as to guarantee the forming accuracy of gear rack, a dynamic envelope forming principle is proposed and an innovative forming mode of gear rack is correspondingly developed, i.e., all the time-varying interference zones in the rocking tool are cut one by one and the ultimate tooth surface (planar) of gear rack is incrementally formed by the local contact between a series of modified surfaces (nonplanar) of the rocking tool and tooth surface of gear rack. Based on this proposed dynamic envelope forming principle, the mathematical model and method for modifying the rocking tool are developed and the dynamic envelope forming of gear rack is achieved successfully. The FE simulations and experiments of cold orbital forging of gear rack are conducted. The results demonstrate that the proposed cold orbital forging method for manufacturing gear rack in this paper is effective and cold orbital forging shows great potential in manufacturing gear rack.

1. Introduction

In cold orbital forging, the rocking tool is designed to be conical and it contacts components locally. Therefore, the contacting zones between them become much smaller compared with that in traditional forging. This allows for cold orbital forging deformation in local zones and thus provides a more efficient (smaller force is needed) method for material deformation while obtaining excellent mechanical properties. As an advanced incremental plastic forming technology, cold orbital forging is adopted to manufacture complicated components with high quality and high added value.

Since orbital forging was invented, lots of researchers have focused on studying and developing this technology. In terms of orbital forging machine, a mechanism with dual eccentric rings was invented by Marciniak and four types of rocking tool paths, i.e., circular, straight line, spiral and planetary, can be achieved [1]. According to the Euler angle of revolution, an advanced orbital forging machine was developed by Standring [2]. The design principles of novel spherical hydrostatic bearings for orbital forging machine were proposed by Yuan and Zhou [3]. In terms of plastic deformation theory, lots of researches have been carried out on energy consumption [4–7], interface behavior [8–10], forging defects [11,12] and metal flow [13–19] in cold orbital forging of cylinder and ring billets. In terms of process and technology, more attentions were payed to process and technological design methods for manufacturing some complicated components, such as flanges and gears [20–25]. Cold orbital forging was also utilized to riveting assembly [26–28]. Recently, some new cold orbital forging processes have been developed. Nowak et al. [29] proposed a new orbital forging method through putting some anvils between the rocking tool and billet. Merklein et al. [30,31] proposed sheet-bulk metal forming by cold orbital forging. Han et al. [32] proposed the technological design methods for cold orbital forging of non-rotary components. In a word, the above researches have three common points. The first one is that the components in

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cold orbital forging are circular or approximately circular. The second one is that most of the adopted rocking tool path is a circle. The third one is that the highly dynamic rocking tool is adopted to forge the simpler surfaces of components while the lower tool which does not rock is adopted to forge the more complicated surfaces of components.

Gear rack is a type of critical fundamental mechanical component which is used to transfer movement and force. It has some great advantages in transmitting mechanisms, such as large bearing capacity, long transmitting travel, high transmitting accuracy and efficiency. These advantages make gear rack have wide applications in steering devices, precision machine tools, risers and so on. At present, gear rack is manufactured mainly by cutting method, which can not satisfy the manufacturing requirements of gear rack with high performance. Therefore, a precision plastic forming method for manufacturing gear rack has to be developed. Cold orbital forging is one of the advanced precision plastic forming methods for manufacturing gear components with high performance. Different from circular components mentioned above, gear rack belongs to long rod component. For cold orbital forging of such long rod component, the circle, helical line and rose line paths of the rocking tool are not suitable and the straight line path has to be selected. Obviously, the technological design methods and plastic deformation mechanisms in cold orbital forging of long rod components under straight line path of the rocking tool are absolutely different from the relatively matured ones in cold orbital forging of circular components under circle path of the rocking tool. By now, the researches on cold orbital forging of gear rack with long rod characteristic under straight line path of the rocking tool have not been reported. Therefore, this paper proposes an innovative cold orbital forging method for manufacturing gear rack, in which the complicated teeth of gear rack are forged by the highly dynamic rocking tool under straight line path. Firstly, a universal method for designing the rocking tool under straight line path is proposed according to the forming mode and contacting mode between the rocking tool and component. Based on this universal method, the rocking tool in cold orbital forging of gear rack is accurately designed. Secondly, the mathematical model and method for interference examinations between the rocking tool and gear rack are developed and the interference amount and interference zone are calculated. Thirdly, to eliminate the interference between the rocking tool and gear rack so as to guarantee the forming accuracy of gear rack, a dynamic envelope forming principle is proposed and an innovative forming mode of gear rack is correspondingly developed. Based on this proposed dynamic envelope forming principle, the mathematical model and method for modifying the rocking tool are developed and the dynamic envelope forming of gear rack is achieved successfully. The FE simulations and experiments are carried out to test the effectiveness of the proposed cold orbital forging method for manufacturing gear rack in this paper.

2. Fundamental technological conditions in cold orbital forging of gear rack

The research objective in this paper is a cylindrical gear rack. Before researching the cold orbital forging process of gear rack, its fundamental technological conditions have to be addressed.

(1) In cold orbital forging of gear rack, only the teeth need to be deformed while other parts are not expected to deform. Therefore, the billet in cold orbital forging of gear rack is designed to be a cylindrical rod whose diameter and length are equal to that of gear rack, respectively.
(2) Gear rack belongs to long rod component and thus the straight line path of the rocking tool in cold orbital forging is selected.
(3) The highly dynamic rocking tool, but not the lower tool which does not rock, is adopted to forge the complicated teeth of gear rack. There are three main reasons for this special technological design. The first one is that the contacting zones between the rocking tool and billet are smaller than that between the lower tool and billet. In such a case, the contacting pressures between the rocking tool and billet become much higher. Therefore, the metals contacting the rocking tool are easier to flow into the rocking tool to form the teeth. Inversely, if the teeth are forged by the lower tool, the deformation is mainly concentrated on the tooth back which contacts the rocking tool (In fact, the tooth back is not expected to deform), while the metals contacting the lower tool are difficult to flow into the lower tool to form the teeth. The second one is that it is in favor of fixed position of the billet because the cylindrical billet and lower tool with a semi-circular groove can match perfectly, as shown in Fig. 1. Inversely, if the cylindrical billet is directly put in the lower tool with teeth, it is much difficult for the fixed position. The third one is that because the cylindrical billet and lower tool with a semi-circular groove keep perfect matching all the time, the forged gear rack can keep straight so that the forming accuracy can be guaranteed. Inversely, if the teeth are forged by the lower tool, the two ends of the cylindrical billet are always suspended and thus the forged gear rack may bend under the action of the rocking tool.

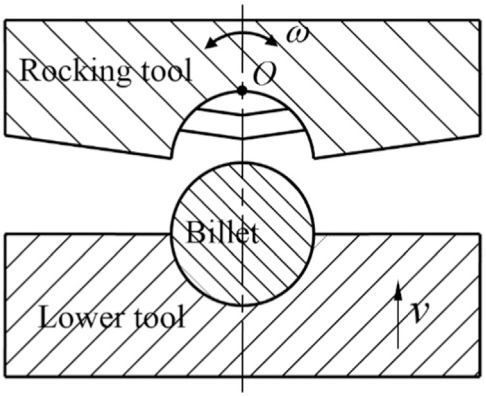

Fig. 1. Schematic diagram of cold orbital forging of gear rack under straight line path.

3. Method for designing the rocking tool in cold orbital forging of gear rack

In cold orbital forging, there usually are four types of typical rocking tool paths, i.e., circular, straight line, spiral and planetary. Because the straight line path is obviously different from other three types of paths in motion mode, contacting mode and forming mode, the method for designing the rocking tool under straight line path is obviously different from the relatively matured one under other three types of paths.

Under straight line path, the rocking tool performs a rocking motion (rotating back and forth) around one fixed axis, i.e., the straight line path of the rocking tool is vertical to this fixed axis. When the rocking tool rocks to one side, it has to accurately match one side of the component. Likewise, when the rocking tool rocks to the other side, it has to accurately match the other side of the component. This indicates that, at the final forming moment, one side of the conical rocking tool completely (overall) contacts the corresponding side of the component. That is to say, one side of the component is ultimately overall formed by the overall contact