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Forming of light-weight gear wheel by plate forging

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ABSTRACT

A forging process is proposed to form light-weight gear wheels for the valve timing system of engine. The cross-sectional shape of the gear has a hollow space at the back of each tooth to reduce the weight by maintaining the rigidity. First, a cup shaped pre-form with a boss is made by upsetting, deep drawing and burring. Then the gear teeth are formed on the side wall by extrusion with a small reduction in area and subsequent axial compression. It is shown by experiment that the proposed process can produce satisfactory products.

1. Introduction

Recently, automobile parts are designed into a shape as light as possible to improve fuel efficiency and to reduce CO_2 emission. Weight reduction of automobile engine parts, especially rotary parts in the driving system, can bring about a notable effect on the fuel efficiency improvement [1].

Fig. 1 shows an illustration of the continuous variable intake valve timing system of engine [2]. The sprocket provides the optimal valve opening/closing timing by changing the phase between the intake cam shaft and the crank shaft according to the engine speed. As shown in Fig. 1, the sprocket has a boss in the center and a gear wheel on the outer periphery. The sprocket should be made to be light and high accuracy to reduce rotary loss, i.e., the wall of the outer periphery is minimized and the boss should be thick to maintain the product rigidity.

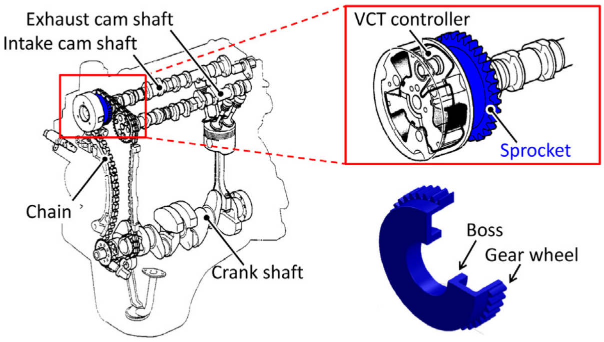


Fig. 1. Function and shape of sprocket in valve timing system [2].

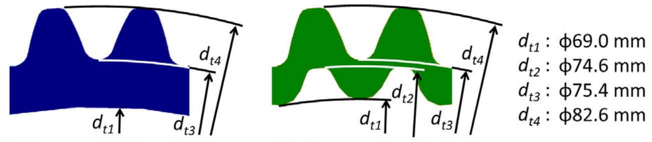
The sprocket is usually made by powder metallurgy [3], but it is considered that plate forging, or sheet-bulk metal forming [4], may be better from the view points of product weight and manufacturing cost. In this paper a new forming method for this sprocket by plate forging is examined because the developed manufacturing method may be applied to quite a few similar products in shape.

2. Proposal of new tooth shape

As shown in Fig. 2(a), the cross-sectional shape of the gear wheel is an involute tooth of 3.6 mm in tooth height and can be simply formed by extrusion from a plate of 6.5 mm in thickness. To obtain a light-weight gear wheel, a new sectional shape of the gear shown in Fig. 2(b) is proposed by referring to the clutch hub made by form rolling of thin walled cup [5]. The proposed tooth shape has an internal depression of a tooth shape at the back of each tooth to reduce the weight to 70% of that of the conventional tooth.

Fig. 3 shows the results of rigidity analysis by a commercial code KS-WAD [6] with an assumption that the bottom surface of the sprocket is fixed. The product material is 0.35%C carbon steel and the applied torque acting perpendicular to the tooth surface at the pitch line is 30 Nm as the maximum value over the common rotation area of engine for safety.

As shown in Fig. 3, the maximum elastic displacements for the conventional and the proposed shapes are almost the same. According to the results of rigidity analysis, rigidity degradation due to the existence of the internal depression is not significant as far as the depth of the internal depression is less than 60% of that



(a) Conventional tooth shape (b) Proposed tooth shape

Fig. 2. Difference of shape between conventional tooth and proposed tooth.

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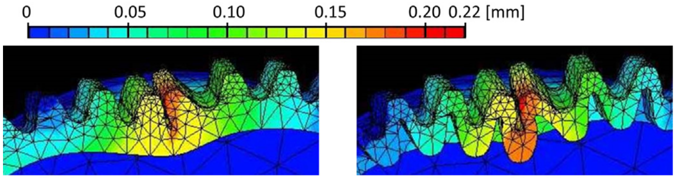


(a) Conventional tooth shape (b) Proposed tooth shape

Fig. 3. Distribution of displacement when maximum torque 30 Nm is applied (displacement is amplified by 20 times).

of the external tooth. Because the proposed tooth shape made by machining shows almost the same performance in the fatigue test as the conventional shape, the forming method of the proposed sprocket is examined by FEM simulation first, and then by experiment.

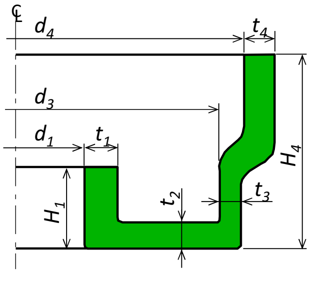
3. Examination of forming method by simulation

A forming sequence to produce the proposed sprocket, which consists of pre-form production from a plate blank and gear extrusion on the pre-form, is proposed. FEM simulation of the method is carried out using a commercial code DEFORM 2D for axi-symmetric deformation and DEFORM 3D for 3D deformation. The blank material is a hot-rolled plate of 0.35%C carbon steel (S35C) and the flow curve of this material is determined by tension test to be $Y = 861(\varepsilon + 0.04)^{0.29}$ MPa. The blank is assumed to be rigid-plastic and the tools are rigid. The friction coefficient is 0.05. The following forming process is the best one among the simulated processes.

3.1. Forming method of pre-form

Fig. 4 shows the dimensions of the pre-form. The blank thickness of 4.0 mm is chosen from the standard thickness values by taking account of the thicknesses t_1, t_2, t_3 and t_4. A combined process by three stages of upsetting, deep drawing, burring and re-striking is proposed after the following considerations.

(1) To ensure the material volume in the inside part to become the boss (t_1 and H_1), the bottom part is compressed to squeeze the material to inside, and thus the original plate thickness should be larger than the bottom thickness (t_2).
(2) The boss is made by burring and subsequent axial compression to ensure the boss thickness (t_1).
(3) The stepped outer wall (t_3 and t_4) is formed by deep drawing with a stepped die.

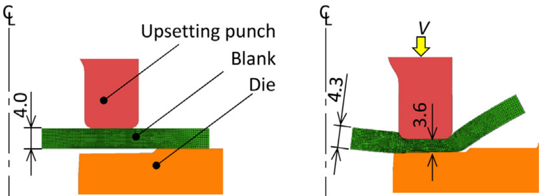


d_1 : ϕ34.0 mm
d_3 : ϕ69.1 mm
d_4 : ϕ75.8 mm
H_1 : 10.0 mm
H_4 : 26.6 mm
t_1 : 4.5 mm
t_2 : 3.6 mm
t_3 : 3.0 mm
t_4 : 4.2 mm

Fig. 4. Dimensions of pre-form.

3.1.1. Upsetting stage

Upsetting is carried out to reduce the thickness of the product bottom to 3.6 mm from the blank thickness of 4.0 mm. As shown in Fig. 5, by setting a difference in height on the die surface, the plate at both outside and inside of the punch is promoted to be bent suitably for the subsequent stage. The thickness of the inside part to be burred is increased to 4.3 mm by upsetting [7].

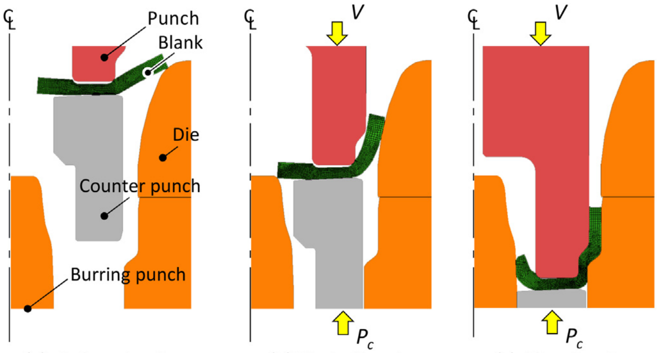


(a) Before upsetting (Tool layout) (b) After upsetting (Tool motion)

Fig. 5. Upsetting stage.

3.1.2. Deep drawing and burring stage [8]

As shown in Fig. 6, the punch moves downward with a constant velocity and the blank is drawn by the die and then is burred by the burring punch while a constant load is applied to the bottom of the cup by the counter punch. Fig. 6(b) gives the shape of the blank at the punch stroke that the blank begins to contact with the burring punch. Fig. 6(c) shows the final shape of the blank. The outline is almost finished except for the boss part.



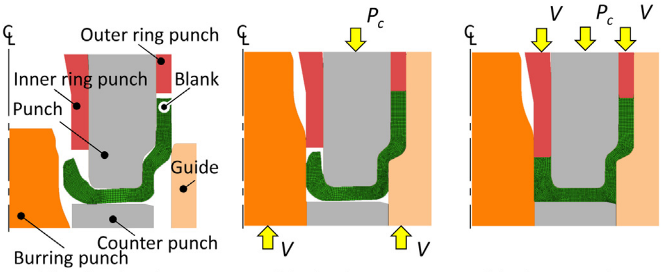
(a) Before drawing (Tool layout) (b) Start of burring (Tool motion) (c) After drawing (Tool motion)

Fig. 6. Drawing and burring stage.

3.1.3. Burring and re-striking stage

As shown in Fig. 7(a), the blank is first held between the punch and the counter punch. The punch motion is controlled by a load larger than the burring load and the counter punch is kept stationary. The burring punch and the guide move upwards and the burring process is finished as shown in Fig. 7(b). After burring, a constant load is added to the burring punch and the guide to keep their positions. In Fig. 7(c), the inner and outer ring punches move downwards and the top edge of the drawn cup is pressed and thus the material is provided to the unfilled parts and the boss is completed. During processing, the punch load is kept constant.

As shown in Fig. 7(c), production of the pre-form is finished by re-striking the inner boss and outer wall to the axial direction.



(a) Before burring (Tool layout) (b) After burring (Tool motion) (c) After re-striking (Tool motion)

Fig. 7. Burring and re-striking stage.

3.2. Forming method of tooth shape

To form the gear part, extrusion is employed. As shown in Fig. 8, the ideal pre-form may be a ring that has the same sectional area as that of the product tooth and deformation mode is folding or bending in plane. But by this deformation mode, the tooth shape is hardly filled. As shown in Fig. 8(c), a pre-form with somewhat excess material that is extruded out from the section by backward extrusion is used to ensure the precise tooth shape. The pressing area of the punch is designed into almost the same cross-sectional profile as the product tooth shape to prevent excessive supply of material to the gear part.

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