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A process/shape-decomposition modeling method for deformation force estimation in complex forging processes

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ABSTRACT

The deformation force of a forging is crucial for making high-quality products and for managing the machine's physical condition. Estimating this deformation force is not easy due to the complex forging process and the complex geometric shape of a forging. In this paper, a process/shape-decomposition modeling method is proposed to estimate this deformation force in the complex forging process. The complex forging process is first decomposed into a group of simple sub-processes using system knowledge. Each sub-process represents one kind of system feature, such as the free unsetting stage, the filling cavity stage or the die kissing stage. In each sub-process, the complex geometric shape is then decomposed into many easily modeled sub-units, upon which the deformation force model of each sub-unit is built as the sub-model. All sub-models are further integrated to form a global deformation force model for the whole forging process. The continuities of this global model, between two adjacent sub-units and between two adjacent sub-processes, are also considered and guaranteed. Its unknown parameters are identified using deformation force data, which can be indirectly obtained via the motion model of the hydraulic press machine (HPM). Experiments and simulations finally demonstrate and test the effectiveness of the proposed modeling method.

1. Introduction

Many industry productions must be shaped under forging. A typical forging process is shown in Fig. 1, where a metal forging (also called a work piece) is forged to form a desirable shape in the dies by the driving force from the work plate of the HPM. A high-quality forging usually requires the work plate to have a desirable position and velocity response [1–3]. The control of the position and velocity of the work plate depends entirely on the deformation force model of the forging [3]. This is because the deformation force model reflects the relationship of the deformation of a forging to its deformation force, and this force can determine the required pressure offered by the HPM and, thus, further determine the output of the controller. The more accurate this deformation force model, the easier to control the forging process. Therefore, the deformation force model is crucial in the high-quality forging.

However, as indicated in Fig. 2, the deformation processes are usually very complex due to the following reasons:

1) The forging process is complex [4–8] due to:
   - complex rheological behavior of the metal forging and nonlinear metal flow in all directions;
   - this deformation process is nonlinearly related with material property, stress, stress ratio and temperature;
   - complex boundary constraints from the dies;
   - complex friction behavior between the forging and the dies.
2) The forging has a complex and time-varying geometric shape, which also causes a complex deformation force since the deformation force of the forging depends on its deformation.
3) The deformation force involves many parameters that are difficult to obtain, such as boundary conditions.
4) The deformation force cannot be measured directly in the experiment.

All the aforementioned factors bring a great challenge to modeling of the deformation force, which often makes the deformation process difficult to control.

Many studies have contributed to the modeling of the deformation force by analytical methods and finite element methods. A nonlinear model numerically solved by the finite element method can be used in the design of the HPM [9–11]. However, it must incorporate all boundary conditions and forging conditions, which can be difficult to obtain. It is also difficultly applied to design the controller of the HPM due to their complexity and large computational costs. The analytical modeling methods mainly include the principal stress method [12–14], the slip-line method [15–17], the upper bound method [18–20], and the variational method [21].

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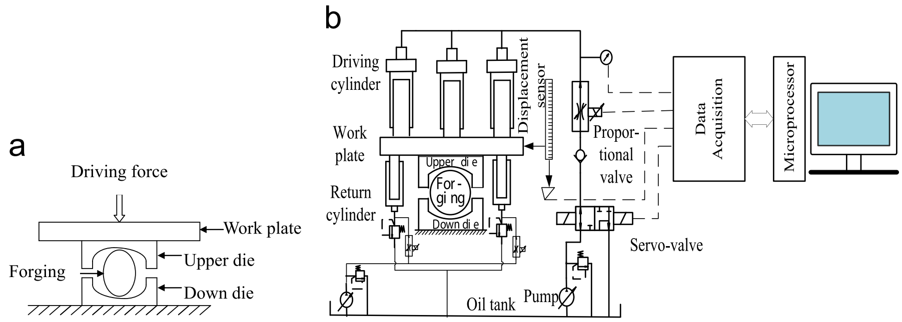

Fig. 1. The diagram of the HPM. (a) Forging process. (b) Simplified driving system and control system.

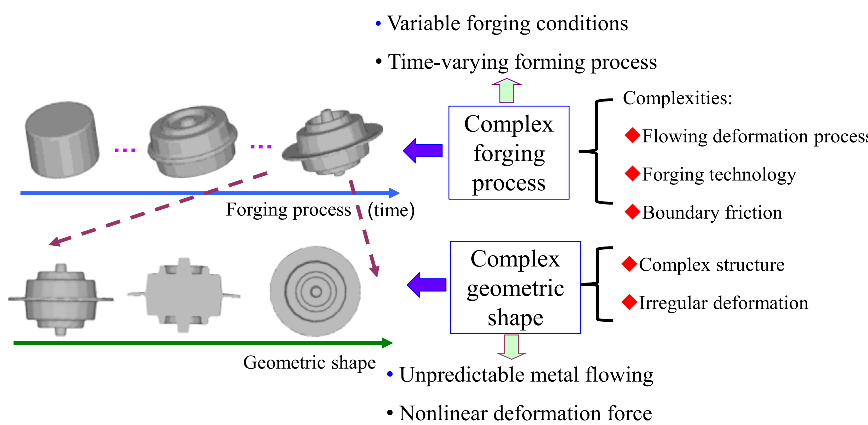

Fig. 2. Complex forging process.

These methods must know all conditions of the forging process, including the material parameters, shape parameters and boundary conditions. However, obtaining all these conditions is often difficult. Moreover, they paid less attention to the complex forging process with the complex geometric shape of the forging. Furthermore, in the design of the controller, this deformation force is often represented by a linear model produced through simulation or the experience of the experts [22,23]. The linear model is often coarse due to neglect of the nonlinear dynamics, especially when the production requires a large-scale forging. Thus, an effective modeling method is still necessary to be developed for the deformation force estimation in a complex forging process.

In this paper, a process/shape-decomposition modeling method is proposed for the deformation force estimation in a complex forging process. This paper is organized as follows. A novel process/shape-decomposition modeling method is presented in Section 2. Section 3 presents the implementation of the proposed method for the deformation force estimation. Section 4 contains the simulation and experimental results, while conclusions are drawn in Section 5.

2. Novel process/shape-decomposition modeling method

This paper proposes a novel process/shape-decomposition modeling method to estimate the deformation force in the complex time-varying forging process, as indicated in Fig. 3 with several key points. It first decomposes the whole forging process into many sub-processes, upon which the complex geometric shape in each sub-process is then decomposed into many easily modeled sub-units. The global deformation force model of the whole forging process is further derived by integrating all sub-unit models. The continuities of this global model, between two adjacent sub-units and between two adjacent sub-processes, are also considered and guaranteed. Finally, unknown parameters in this global model are identified by using data of forging process.

A detailed configuration of the proposed method is shown in Fig. 4. It involves the following key points:

- Process decomposition: The complex forging process is decomposed into a group of simple sub-processes using system knowledge. Each sub-process represents one kind of system feature, such as the free unsetting stage, the filling cavity stage or the die kissing stage. In this way, the complex modeling task of the original forging process is decomposed into a series of simple and easily realized sub-modeling tasks.
- Geometric shape decomposition based sub-process modeling: In each sub-process, the complex geometric shape of the work piece is then decomposed into many easily modeled units, such as the planar rectangular element and the axisymmetric element, as shown in Fig. 4(b). The deformation force model of each sub-unit is then built. Finally, the model structure of this sub-process is determined by integrating the deformation forces of all sub-units. The continuity between two adjacent sub-units in each sub-process is also considered and guaranteed.
- Model integration: The models of all sub-processes are integrated with consideration of the continuity condition between two adjacent sub-processes to construct a global deformation force model.
- Parameter identification: In simulation, the deformation force data can directly used to identify unknown parameters in the global model. While in the practical forging, since the deformation force data cannot be measured directly, the global model is inserted into the motion model of the HPM, upon which its unknown parameters are identified online using deformation force data that are indirectly derived from the motion model.