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Research paper

Whole flow field performance prediction by impeller parameters of centrifugal pumps using support vector regression

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ABSTRACT

The relationship of multiple impeller parameters and performance indices is difficult to describe because of some unknown hydrodynamic phenomena. Modeling of performance indices of the whole flow field from impeller parameters often encounters some challenges, especially lower prediction accuracy in relatively small and large flow points, dependence on designers' experience and time-consuming designing process. In this work, the least squares support vector regression (LSSVR) method is proposed to predict multiple pump performance indices of the whole flow field. To describe the performance more completely, the powder, the head, and the efficiency indices are chosen as the model outputs. Additionally, to improve the prediction accuracy and reduce the manufacture difficulty, nine impeller parameters and the flow rate are selected as the model inputs. With the LSSVR model, the complex nonlinearity relationship between multiple impeller parameters and performance indices can be described approximately. Moreover, the LSSVR model and the computational fluid dynamics numerical simulation model are applied to predict the powder, the head, and the efficiency of an actual centrifugal mine pump in the whole flow field. Compared with the performance test results, the superiority of the proposed method is demonstrated in terms of more accurate prediction performance and faster designing process.

1. Introduction

Centrifugal pumps consume huge amounts of energy and play an important role in various industrial applications. The impeller shape of the centrifugal pump has an enormous influence on the hydraulic performance. Optimizing impeller geometric parameters to achieve satisfied pump performance has always been a common way in the engineering designs of centrifugal pumps [1,2]. However, design a group of suitable impeller parameters for further manufacture is still difficult. One main reason is that the relationship of multiple impeller parameters and performance indices in the whole flow field is too complex to describe clearly. Consequently, the performance test is a primary method in acquiring accurate performance indices of the whole flow field to verify the rationality of impeller parameters. Nevertheless, the conduction of experimental studies on samples with different volutes and impeller geometries is very time-consuming and costly.

To shorten the design cycle and reduce the design costs, the traditionally repeated trial and error experiments have been replaced by the computational fluid dynamics (CFD) numerical simulation [3–11]. However, the quality of grid dividing, the setting of boundary condition, and the selection of turbulence model from the designers' experience directly influence calculation results of the CFD numerical simulation [12]. Even for experienced designers, it is an unavoidable problem to improve simulation accuracy with a consequent increase in simulation time and modeling difficulty. Moreover, because of several unknown issues associated with the complete flow pattern in the centrifugal pumps, some hydrodynamic phenomena in relatively small and large flow points, such as tall, reflux, secondary flow and eddy current, have not been exactly described by suitable turbulence models in the CFD software [13]. As a result, the CFD numerical simulation is usually considered to be feasible for performance simulation near the design condition of the centrifugal pump. Nevertheless, it is insufficient for the whole flow field especially for small and large flow points [13]. Therefore, the relationship of multiple impeller parameters and performance indices in the whole flow field needs to be investigated for further simulation, process design and optimization.

Generally, accurate modeling of the performance indices (e.g., the power, the head and the efficiency) using impeller parameters

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is of utmost importance. The problem has been widely studied in academia and industry. Various mechanism models have been developed based on the theory analysis [3–7,14–16] and the orthogonal experiment [8–11]. The accumulated experiences can reduce the design time and costs. However, because of the complex internal flow characteristics and energy loss mechanism of centrifugal pumps, the applications of established models still have several limitations in objects, scopes, and so on. For example, Si et al. [8] pointed out the order of main impeller parameters affecting the efficiency and powder of the multistage pump with low specific speed. For efficiency, the order is the blade inlet angle, the blade number, the outlet angle, the outlet width, the inlet diameter, etc. Until now, none of models can fully and satisfactorily describe the relationship between multiple impeller parameters and performance indices in the whole flow field. Moreover, the common drawbacks of mentioned modeling methods are that the results mainly depend on talented designers. The accuracy of theory analysis mostly depends on designers' experience because many coefficients should be determined in theoretical formula [1,2]. Additionally, the result of the orthogonal experiment always relies on factor levels decided by designers [17].

Recently, data-driven empirical modeling methods have been increasingly employed to optimize impeller parameters. Data-driven empirical modeling methods do not require substantial understanding of the mechanism. Additionally, the model development process is more straightforward rather than relying on designers' experience. Popular methods are genetic algorithm (GA) [18–23] and neural networks (NN) [18,21,24,25]. GA can deal with global optimization problems. NN is a nonlinear modeling method. However, for a complex modeling task, the convergence rate of GA and NN are relatively slow. The parameters of GA should be carefully chosen. Additionally, the determination of network topology for NN models is not easy. Due to their disadvantages, most previous studies only optimized three to five pump parameters to guarantee a performance index at the rated point based on GA and NN model [18–25]. However, only using three to five impeller parameters are inadequate for the description of an impeller shape and the prediction of the power, the head, and the efficiency, especially for the whole flow field [1,2]. Additionally, it is difficult for pump engineering manufacture with insufficient impeller parameters. In practice, the description of multiple performance indices in the whole flow field is more attractive. For example, in the design of centrifugal mine pumps, it is necessary to know the power, the head, and the efficiency at all flow points for safety.

To overcome these problems, the least squares support vector regression (LSSVR) algorithm is proposed to predict multiple pump performance indices from multiple impeller parameters. LSSVR has been adopted to predict complex behavior in nonlinear processes with limited training samples [26–32]. Different from abovementioned GA and NN models, the LSSVR model can be trained more efficiently. For its insensitivity to the dimension of input variables, the LSSVR model can improve prediction precision and reduce impeller design difficulty by increasing the quantity of impeller parameters. Moreover, the complex nonlinearity relationship between multiple impeller parameters and pump performance indices in the whole flow field can be approximately captured, not needing the complete description of pump mechanism. These properties make LSSVR more suitable as an empirical model for performance indices of the whole flow field using impeller parameters.

The remainder of this paper is structured as follows. Section 2 describes the main method. In Section 3, the proposed LSSVR model is applied to predict the performance of the D82-19-2 centrifugal mine pump for the whole flow field. Then the common CFD numerical simulation is used to simulate the D82-19-2 performance. Furthermore, the D82-19-2 performance is tested by the performance test method. The results are compared and discussed to show the advantage of the LSSVR model in Section 4. Finally, Section 5 summarizes the work.

2. Materials and methods

2.1. Experiment object

The D82-19-2 centrifugal mine pump, as the experiment object, was applied to evaluate the LSSVR prediction model. In practice, it is necessary to obtain the powder, the head, and the efficiency in the whole flow field to prevent motor damage. The flow, the speed, the power, the head, and the efficiency of the D82-19-2 at the rated condition are 82m^3/h, 1475n/min, 15 kW, 19 m, and 75%, respectively. The hydraulic design diagrams of the impeller and guide vane are shown in Figs. 1 and 2 [33], respectively. The material objects of the D82-19-2 impeller and pump are shown in Figs. 3 and 4 [33], respectively.

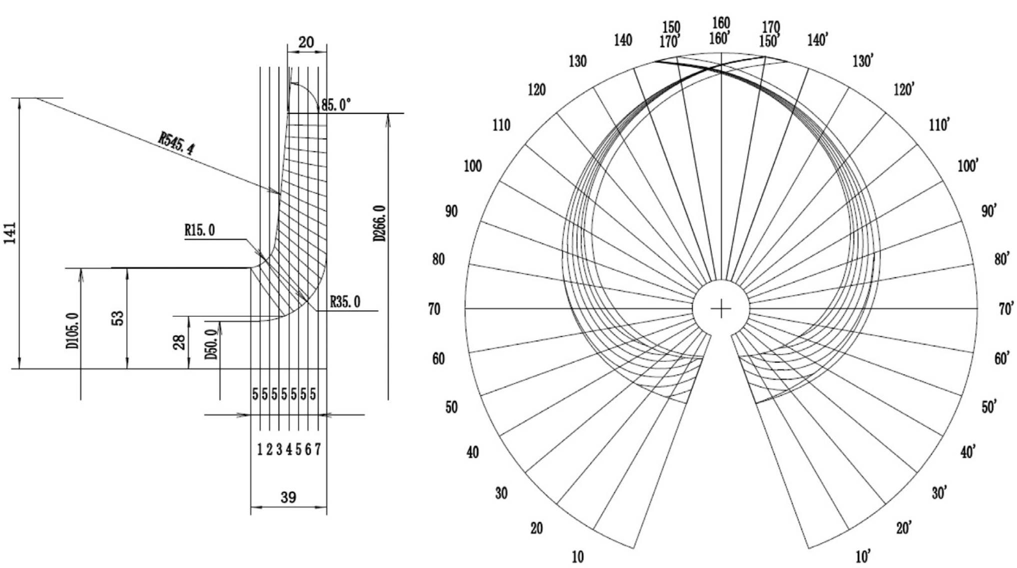

Fig. 1. Impeller hydraulic design diagram of the D82-19-2 centrifugal mine pump.

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