MULTI-OBJECTIVE OPTIMIZATION OF A 3D VANELESS DIFFUSER

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The diffuser, an important component in a centrifugal compressor, is absolutely essential for the efficiency and pressure improvement of the system. Experimental research indicates that the kinetic energy of the impeller outlet gas accounts for 20%–50% of the work given by the impeller.

Therefore, the diffuser and other stationary components determine whether high kinetic energy could be converted into pressure energy with high efficiency.

Diffuser performance is limited by its geometry and aerodynamic parameters. Considering the demand of the industry, it is necessary that a direct shape optimization method be developed.

The optimization problem in fluids generally requires the solution of fluid motion equations, so ordinary multidimensional mapping is improper and impractical.

$$c_r \frac{\partial c_r}{\partial r} + \frac{c_u}{r}\frac{\partial c_r}{\partial \theta} + c_z \frac{\partial c_r}{\partial z} - \frac{c_u^2}{r} = -\frac{1}{\rho}\frac{dp}{dr} + F_r;$$

$$c_r \frac{\partial c_u}{\partial r} + \frac{c_u}{r}\frac{\partial c_u}{\partial \theta} + c_z \frac{\partial c_u}{\partial z} + \frac{c_r c_u}{r} = -\frac{1}{\rho}\frac{dp}{d\theta} + F ;$$

$$c_r \frac{\partial c_z}{\partial r} + \frac{c_u}{r}\frac{\partial c_z}{\partial \theta} + c_z \frac{\partial c_z}{\partial z} = -\frac{1}{\rho}\frac{dp}{dz} + F_z;$$

$$\frac{1}{r}\frac{\partial}{\partial r}(r c_r) + \frac{1}{r}\frac{\partial c_u}{\partial \theta} + \frac{\partial c_z}{\partial z}.$$

Of the optimization attempts using computational fluid dynamics, the adjoint method and conjugated gradient method are the most popular. But sometimes the extension of this method is limited.

An optimization model based on fuzzy theory was set up and the corresponding Interactive modified simplex (IMS) method was developed to solve it.

The detailed optimization procedure is described as follows:

(1) The initialization of optimization: the normalization of position vector b and determination of the range of variables;

(2) Diffuser performance calculation: solving of RANS on initial mesh to find the value of the object function;

(3) Optimization with modified simplex: finding the new shroud curve vector;

(4) Convergence check: checking the convergence of the design variables. If the requirements are met, the process is complete. Otherwise, the optimization continues to the next step;

(5) CFD re-grid: defining the new boundary surfaces and smoothing, clustering, and interior grid movement. Return to step (2) for another iteration.

Both static pressure recovery and total pressure loss were considered in the model:

$$\max\left\{U(x)=\left[u_1(x)^{\beta_1}\times u_2(x)^{\beta_2}\right]^{1/\beta_1+\beta_2}\right\},$$

$$\varpi\left(\vec{b}\right)=\frac{p_{3total}-p_{4total}}{p_{3total}-p_{3static}},$$

$$C_p=\frac{p_{4static}-p_{3static}}{p_{3total}-p_{3static}}.$$

Computational fluid dynamics (CFD) method was applied to solve the Reynolds-Averaged Navier-Stokes equation (RANS) and to find flow field distribution to get the value of the object function. After receiving the new shroud curve, grid movement and redrawing technology were adopted to avoid grid-line crossing and negative cells.

The shroud curve was fitted with B-spline. The optimized results concur with the results reported in references. Optimized results indicate that not only diffuser performance is improved but also downstream efficiency is increased because of the change of outlet flow angle.

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