THE 5TH ASIAN COMPUTATIONAL FLUID DYNAMICS
BUSAN, KOREA, OCTOBER 27~30, 2003

The application of Large Eddy Simulation in designing the impellers of double-flow-conduits-sewage pump

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ABSTRACT

In this paper, Gauss filter function is used to filter the N-S equation and the subgrid-scale Reynold stresses model is introduced to deduce the practical form of LES equation for 2-D case for flow calculation of hydraulic machine. Then the LES equation and its discrete form in computational field are obtained in the body-fitted coordinate system and the numerical calculation program is built. The incompressible turbulent flow in double-flow-conduits-sewage pump impeller is computed by using the abovementioned program, and then the distribution rules of velocity and pressure in flow field are obtained. Based on this, the designs of double-flow-conduits-sewage pump impeller are optimized.

INTRODUCTION

Because double-flow-conduits-sewage pumps not only have the character of no jam but also the flow passage is symmetry and operation is steadily, so it is widely used. The advantages and disadvantages of its hydraulic performance is being attention. Because the distribution state of flow speed and pressure in flow passage (especially the distribution of flow field in impeller) exert a great influence on efficiency, So only after grasping its inside distribution law of speed and pressure, Could we put forward the corresponding measure for improving the complete machine performance of the pump.

At first, the LES (Large Eddy Simulation) method is put forward to against the three-dimensional question most, but if we use it to deal with actual three-dimensional turbulence flows, we will meet enormous difficulties. Firstly, the general eddy model needs intensive node, so the huge computer that has the ability of storing enormous data is needed. Secondly, the computer must have the ability of high-speed to deal with enormous data and the non-liner partial differential equation. Thirdly, very considerable calculation time and funds are needed. Thus, the application of the method is limited.

Because of the need of the subject and to avoiding above-mentioned difficulties, we simplify the LES equation for 3-D case to 2-D case, and use it to calculate the inside flow field of double-flow-conduits-sewage pump and optimize design the double-flow-conduits-sewage pump. Thus, not only the main advantage of the LES method is maintained, but also we can predict the state of 2-D turbulence flow under the common calculation conditions.

THE SIMPLIFICATION AND DEDUCTION OF 2-D LES EQUATION

According to two-dimensional incompressible flow control equation, Gauss filter function is used to filter the N-S equation and the subgrid-scale Reynold stresses model is introduced to deduce the practical form of LES equation for 2-D case. We can see the detail process in the reference [1].

THE 2-D LES EQUATION AND ITS DISCRETE FORM ON COMPUTATIONAL FIELD

In the numerical simulation of internal flow field of runner machine, the boundary of physical field is not regulation. If we use the finite difference method in Cartesian coordinate directly, we will need complex method of interpolation to deal with the boundary conditions. Because the boundary conditions have great influence on calculating the inside nodes, the boundary value that is obtained by interpolation will affect the precision. So we adopt the body-fitted coordinate system. Thus, the numerical calculation is very convenient and efficient and the numerical solution also has high accuracy[2].

According to the above equation on physical field, the body-fitted coordinate system is introduced to deduce the 2-D LES equation on computational field. And the discrete form of the 2-D LES equation on computational field is get by using difference method. The computational programme is built based on the following set of equations.

$$\left\{\left[-\rho\frac{\left(x_\eta^2+y_\eta^2\right)}{A_p^u}\frac{\Delta\eta}{\delta\xi}\right]_e+\left[-\rho\frac{\left(x_\eta^2+y_\eta^2\right)}{A_p^u}\frac{\Delta\eta}{\delta\xi}\right]_w+\left[-\rho\frac{\left(x_\xi^2+y_\xi^2\right)}{A_p^v}\frac{\Delta\xi}{\delta\eta}\right]_n+\left[-\rho\frac{\left(x_\xi^2+y_\xi^2\right)}{A_p^v}\frac{\Delta\xi}{\delta\eta}\right]_s\right\}P_p'=$$
$$\left[-\rho\frac{\left(x_\eta^2+y_\eta^2\right)}{A_p^u}\frac{\Delta\eta}{\delta\xi}\right]_e P_E'+\left[-\rho\frac{\left(x_\eta^2+y_\eta^2\right)}{A_p^u}\frac{\Delta\eta}{\delta\xi}\right]_w P_W'+\left[-\rho\frac{\left(x_\xi^2+y_\xi^2\right)}{A_p^v}\frac{\Delta\xi}{\delta\eta}\right]_n P_N'+$$
$$\left[-\rho\frac{\left(x_\xi^2+y_\xi^2\right)}{A_p^v}\frac{\Delta\xi}{\delta\eta}\right]_s P_S'+(\rho U*\Delta\eta)_e-(\rho U*\Delta\eta)_w+(\rho V*\Delta\xi)_n-(\rho V*\Delta\xi)_s \qquad (1)$$

$$U_p'=\left(-\frac{y_\eta^2}{A_P^u}+\frac{y_\eta x_\eta}{A_P^u}\right)p_\xi' \qquad (2)$$

$$V_p'=\left(-\frac{x_\xi^2}{A_P^v}+\frac{y_\xi x_\xi}{A_P^v}\right)p_\eta' \qquad (3)$$

PROGRAM CONSTRUCT

(1) Suppose the pressure field and initial flow field.
(2) Use momentum equation to calculate initial velocity (u*, v*) and the corresponding value on computational plane (U*, V*).
(3) Calculate pressure correction value.
(4) Calculate velocity correction value (u, v) and the corresponding value on computational plane (U, V).
(5) Update the coefficient of the discrete momentum equation and correct the pressure field.
(6) Repeat the step 2-5, until convergence[3][4].

GENERATE GRIDS IN BODY-FITTED COORDINATE SYSTEM

For the flow passage of double-flow-conduits-sewage pump is symmetry, we only need to calculate one of the two flow passages. In this paper, we use the method of solving biharmonic equation to generate the body-fitted coordinate grids on the region [2].

CALCULATE INSIDE FLOW FIELD OF DOUBLE-FLOW-CONDUITS-SEWAGE PUMP AND ANALYZE THE RESULT

(1) Define the boundary condition:

Inlet: According to the experiment data of full developed turbulence flow, the average velocity $\bar{u}$ and υ_{SGS} are given.

Outlet: velocity uses zero grads condition.

Walls: non-slippage condition[1].

(2) Define the initial condition:

Give the average velocity at the inlet of impeller through experiment. Give the random pulse velocity field by programme.

(3) Result:

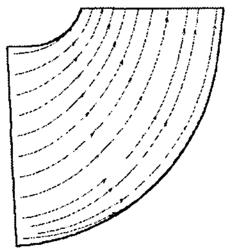

FIG1. Velocity trace

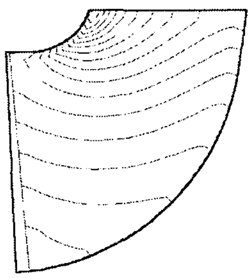

FIG2. Isoline of pressure

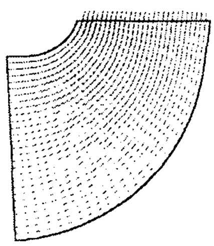

FIG3. Velocity vector

CONCLUSION

1. We optimize the design of double-flow-conduit-sewage-pump by using the result and get satisfying hydraulic model. It shows that the program is successful.
2. It is helpful to deeply understand the nature of flow by using the LES to get the detail of flow. Thus, the performance of fluid machinery is improved.
3. Because we simplify the real medium to single-phase viscosity medium, this may bring error to result of simulation.

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