Side Entry Using Multi-Island Genetic Algorithm / Study on Optimization of Outlet Shape

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Abstrat: Physical model tests or numerical simulations are generally used to study the hydraulic characteristics of the set shape of hydraulic structures, and then studies are carried out to adjust the shape according to unfavorable hydraulic indicators until a satisfactory better shape is obtained. This is the traditional practice. Lateral inlet under two-way flow / Optimization of outlet shape can be regarded as a multi-objective optimization problem. In this paper, the weighted head loss coefficient is set as the objective function, and the non-uniform coefficient of flow velocity in the orifice cross-section and the non-uniform coefficient of flow volume between orifices are taken as the constraint conditions. The multi-objective optimization is converted into single-objective optimization, and the multi-island genetic algorithm is used to optimize the outlet shape of / to obtain the optimal shape. In addition, the application of parametric modeling method and response surface model based on CFD accelerates the speed of modeling and numerical simulation and improves the optimization efficiency. Taking the outlet of / of a lower reservoir as an example, compared with the original body, the recommended body type obtained according to the method in this paper has the following characteristics: the total head loss coefficient of / outflow is reduced by 3.35%, the flow velocity nonuniformity coefficient is reduced by 14.50%, and the flow nonuniformity coefficient of / inflow is less than "20% 。 This research method provides a convenient way to optimize the shape of hydraulic structures.
Keywords: side inlet / outlet; Two-way flow; Shape optimization; Parametric modeling; Multi-Island Genetic Algorithm

Research background

The outlet of the intake / of the pumped storage power station has the characteristics of two-way flow. Its body design should consider the hydraulic characteristics of both intake and outlet conditions, including uniform diffusion of water flow during outlet, avoidance of reverse flow velocity at the cross section of the trash rack, and reduction as much as possible during intake and outlet of /.
[1]
Head loss, etc.

For the lateral inlet / outlet of pumped storage power station, domestic scholars have made a comprehensive analysis through physical model tests and numerical simulation methods.

The distribution of orifice velocity due to the shape change of the diffusion section at the outlet of the inlet / is analyzed.

head loss

Traffic Distribution The influence of such, the rule is

The optimization of the shape of the outlet of the inlet / has laid the foundation. For example, higher education is equal. It is pointed out that the lateral inlet / outlet diffusion section affects the head loss and orifice flow.

State plays a decisive role. The influence of shape parameters of diffusion section on flow distribution between orifices is studied. Zhang Landing

By adjusting the diffusion section body, etc.

The model analyzes the problems of uneven velocity distribution and large head loss coefficient when the lateral inlet / outlet flows out. Cai Fulin et al. Through hydraulic model According to the model test, it is pointed out that the distribution of flow velocity is affected by the arrangement of diversion piers in the diffusion section. Yang Xiaoting, etc

Summarize the existing model test data.

It is pointed out that the diffusion angle, velocity distribution and discharge distribution of each orifice of the top plate in the diffusion section have an important influence on the head loss. Sha Haifei et al

The optimization of diffusion section by numerical simulation has improved the phenomena such as large nonuniform coefficient of flow velocity at the outlet of /. The above studies are all from the perspective of hydraulic characteristics to seek a better shape of the inlet / outlet, that is, to study the hydraulic characteristics of the set shape through physical model test or numerical simulation, and to adjust the shape for unfavorable hydraulic indexes and then to study until a satisfactory shape is obtained.

This type of body shape optimization method belongs to the traditional research method. Its disadvantages are strong dependence on the experience of researchers and many repetitive operations. For the numerical simulation method, the modeling efficiency is low and the CFD calculation takes a long time. For the model test method, the test cycle is long and the test cost is high.

In fact, most body shape optimization problems can be regarded as multi-objective optimization problems, while multi-objective optimization problems have multiple optimal solutions [11]

Therefore, it is often converted into the weighted sum of all targets in engineering, and then analyzed and solved by single-objective optimization technology.

Island genetic algorithm (multi-island genetic algorithm, MIGA) is a typical single-objective optimization algorithm

Wait for a variety of studies to be right.

Elephants are widely used. The above-mentioned body shape optimization studies are all carried out under the condition of one-way flow, while the lateral inlet / outlet of pumped storage power station is a two-way flow. It is necessary to comprehensively consider the hydraulic problems such as too large head loss coefficient, too large cross-section velocity non-uniform coefficient and non-uniform flow distribution between orifices under two-way flow conditions. Therefore, the body shape optimization problem under the condition of two-way flow is more complicated.

Focusing on the multi-objective optimization problem of the shape optimization of the lateral inlet / outlet under the condition of two-way flow, this paper uses the weighted method to transform it into a single-objective optimization problem, and uses the multi-island genetic algorithm to optimize the shape. In the optimization, the weighted head loss coefficient under both inflow and outflow conditions is taken as the objective function, and the non-uniform coefficient of flow velocity in the orifice section and the non-uniform coefficient of flow between orifices are taken as the constraint conditions. In view of the great influence of the shape of the diffusion section on the hydraulic characteristics of the outlet of the inlet /, this paper takes the diffusion section as the focus of optimization, selects the length of the diffusion section, the height of the orifice and the width of the orifice in the tail pier of the diversion pier as optimization variables, and conducts hydraulic optimization research on the shape of the outlet of the inlet /. In order to improve the modeling speed and optimization efficiency, parametric modeling method and response surface model based on CFD are used for optimization calculation.

Establishment and verification

Parametric Modeling For the side inlet / outlet, the anti-vortex beam section, adjustment section, diffusion section and gradual change section are sequentially arranged along the inlet direction. Since the shape of the diffusion section has a decisive influence on its hydraulic characteristics, the shape of this section is mainly optimized. The shape parameters of the side inlet/outlet and diffusion section are sH_{O}wn in fig. 1. the main shape parameters are: orifice height ho, orifice width W_{O}, diffusion section length L_{DS}, and diffusion section end height

In, the geometric relation satisfied by each body type parameter is as follows:

(1) The outlet of the inlet / is symmetrical, and the sizes of all orifices are the same:

(2) In order to ensure that the cross-sectional flow velocity of the trash rack is equivalent, the single-hole flow area remains unchanged:

(3) The section size at the tail pier of the diversion pier will not change:

This paper takes the lateral inlet / outlet of the lower reservoir of a pumped storage power station as an example. Previous studies on numerical simulation and shape optimization of the / outlet mostly adjusted the shape of the diffusion section based on engineering experience, and any geometric size adjustment needs to re-establish the model. To achieve automation has a great influence on the hydraulic characteristics of the outlet of / "

Therefore, this paper selects this 3 individual parameter as the optimization variable.

Quantity, given its value range; Other parts of the water outlet of the / are adjusted according to the change of the diffusion section. Values of various body shape parameters in diffusion section

The range is listed in table 1.

The calculation area is shown in Figure 2 , including part of the lower reservoir, tailrace open channel, outlet of inlet / and part of tailrace tunnel. During inflow, the water body flows from the reservoir area to the tunnel; During outflow, the water body flows from the tunnel section to the reservoir area. The boundary of the reservoir area, the section of the reservoir area 140 m from the outlet of /, gives the reservoir water level; The boundary of the tunnel, the cross section of the tunnel, which is 20 times the tunnel diameter (20 *d*) from the end of the gradual change section of the emergency gate well, shall be given the flow rate according to the flow rate; No slip condition is adopted for the solid wall boundary. The shape of the outlet of the inlet / adopts hexahedral grid, the grid size near the orifice is 0.3 m, and the rest is 0.3 ~ 1.0 m. The total grid number of the inlet / outlet under different shape parameters varies from 110 million to 1.3 million.

Control Equation includes continuity equation and momentum equation, and is closed by Realizable and K-ε models.

(1) continuity equation

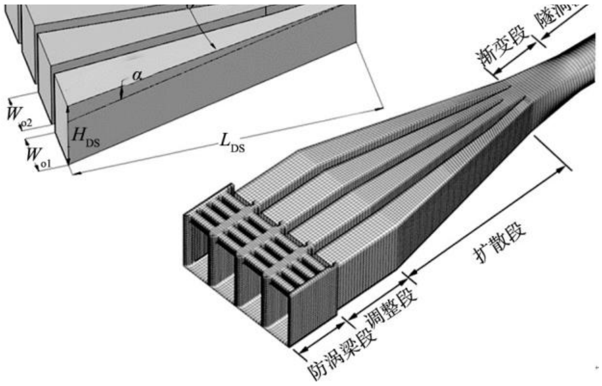
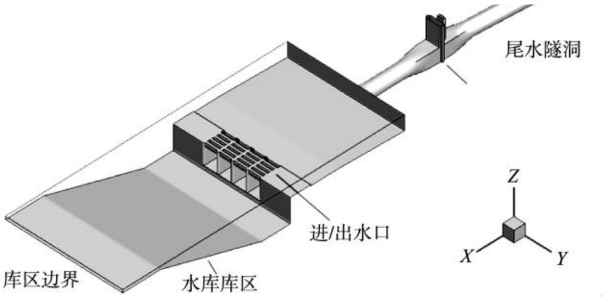


Figure 1 Side Entry / Shape Parameters of Outlet and Diffuser

Table 1 Range of Body Shape Parameters in Diffusion Section

Body type parameter	Minimu	Maximum	Optimization
diffusion length l_{ds}	36	46	0.001
HDS/m *orifice height*	8	10.9	0.001
WDSM/*m* middle hole of	1.5	1.7	0.001
horizontal diffusion	25	45	
Vertical Diffusion	3	5	



(2) momentum equation

Figure 2 Calculation Area

Volume Force of Mass Water Body; $K = U'_I$ and $U'_I 2$ "are turbulent kinetic energy per unit mass. ε is turbulent kinetic energy dissipation rate; ν is the kinematic viscosity coefficient; ☆T and Wei

2

The viscosity coefficient of turbulent motion is determined by turbulent $\frac{k}{}$ kinetic energy K and turbulent kinetic energy dissipation rate ε, $\nu_T = C_\mu$ ε; C, $_\mu$ 、 $C_{1\varepsilon}$ 、 $C_{2\varepsilon}$, σ, $_K$ and σ ε are models " Universal constants, taking 0.09, 1.44, 1.92, 1.0 and 1.3 respectively.

In this paper, commercial software Fluent® is used for calculation. The finite volume method is used for solving the equation, the second-order upwind scheme is used for spatial dispersion, and the SIMPLE algorithm is used for pressure-velocity coupling.

Model Verification of 2.3 uses the established mathematical model to numerically simulate the shape of the lateral inlet / outlet, to study the velocity distribution and flow distribution of the cross section of the trash rack at the outlet /, and to compare with the model test results of the lateral inlet / outlet. The velocity distribution of the side holes in the trash rack section under the inflow and outflow conditions is shown in Figure 3, and the flow distribution between the holes is shown in Table 2. The numerical simulation of the velocity distribution in Figure 3 is basically consistent with the experiment, but the numerical simulation value of the velocity in the middle section is slightly larger, which may be caused by the size of the numerical simulation grid and the measurement accuracy of the experiment. Table 2 flow distribution numerical simulation is basically consistent with the test. In general, the numerical simulation results are in good agreement with the experimental values, and the mathematical model can be applied to body shape optimization research.

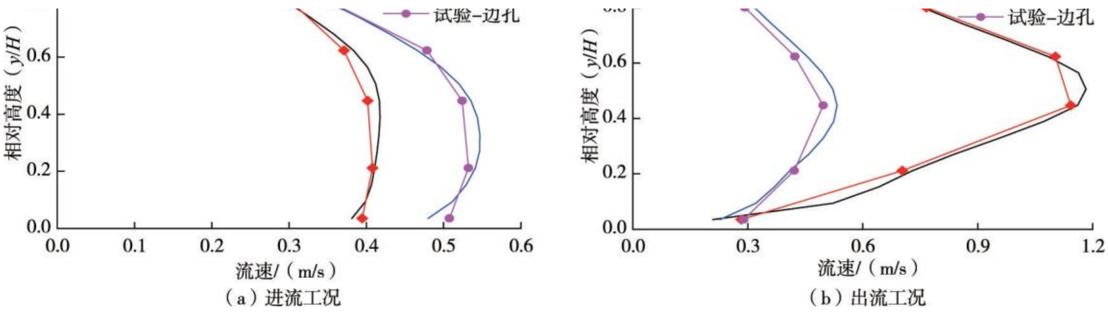


Figure 3 Velocity Distribution of Vertical Line in Side Hole in Trash Trash Bar Section

Table 2 Flow Distribution between Orifice

Orifice label	T e	i n	d i	T e	O u	d i
1-1	2 7		2 7	2 3		2 3
1-2	2 2		2 2	2 6		2 6
1-3	2 2		2 2	2 6		2 6
1-4	2 7		2 7	2 3		2 3

Optimization Design Method

First of all, on the basis of the original shape, the optimization variables such as the orifice height, the length of the diffusion section and the width of the middle hole at the tail pier of the diversion pier are adjusted to obtain a series of different types of inlet / outlet shape and form a sample space of side inlet / outlet shape. Then, the sample points of the lateral inlet / outlet shape are selected from the sample space, and the flow field is calculated by using Fluent software to obtain hydraulic indexes such as head loss coefficient, flow velocity nonuniformity coefficient and flow nonuniformity coefficient under the condition of inlet / and outlet. In order to reduce the call of CFD calculation program in subsequent optimization calculation and improve the effectiveness of optimization calculation, this paper uses response surface model to describe the relationship between hydraulic index value and optimization variables through functional relationship. Aiming at the multi-objective optimization problem of the shape optimization of the outlet of the contralateral inlet /, the shape optimization is carried out through hydraulic indexes, and the weighted head loss coefficient is taken as the objective function of the optimization. At the same time, the non-uniformity coefficient of orifice velocity and the non-uniformity coefficient of flow between orifices will be used as constraint bars. Multi-island genetic algorithm is a global optimization algorithm with high optimization efficiency. This paper uses this optimization algorithm to optimize body shape.

Any combination of optimization variables of response surface model can ensure the best shape of the lateral inlet / outlet, i.e. the optimization process needs to cover the best

The whole sample space formed by adjusting variables. In order to achieve this goal, the response surface model is adopted in this paper

The whole response surface is simulated and the relationship between hydraulic characteristic indexes and optimization variables is described by functional relation. Improved Latin Superelevation

The square experiment design method is a multi-dimensional stratified sampling method with the characteristics of fast speed and uniform sample space coverage, so it is used for

This paper presents the spatial sampling of the side inlet / outlet. The application of response surface model can reduce the call of CFD calculation program in subsequent optimization

The calculation time is greatly saved and the optimization efficiency is improved. The accuracy of response surface model is evaluated by correlation coefficient r^2

The response surface model $r^2 = 0.97 > 0.9$ can meet the accuracy requirement.

After calculation, this article adopted

Multi-Island Genetic Algorithm Genetic Algorithm is a global optimization developed by learning from the genetic and evolutionary process of organisms in natural state

[20]

The transformation algorithm. Multi-island genetic algorithm is a parallel genetic algorithm based on group grouping, which is formed on the basis of traditional genetic algorithm.

Different from the traditional genetic algorithm, the multi-island genetic algorithm divides the initial population into a plurality of subgroups, and isolates each subgroup from each other on different "islands", so that each subgroup can evolve independently, not the whole population adopts the same evolutionary method, and at the same time, each "island" carries out information exchange through a "migration" operation within a certain period of time. Multi-island genetic algorithm can significantly improve the operation speed, while independent evolution of several subgroups can improve the genetic diversity of the whole population, so it can also avoid the premature phenomenon of traditional genetic algorithm, and then find the whole population.

[21]

Local optimal solution

。 Table 3 shows the parameter settings of the multi-island genetic algorithm used in this paper.

Table 3 Multi-Island Genetic Algorithm Parameter Setting

E	N	Numbe	M	C	P	M
1	1	10	2	1	0	0

3.3 Objective Function and Constraints Lateral Head Loss at the Outlet of / Directly Affects the Operation Efficiency of Pumped Storage Power Station. In order to obtain the maximum economic benefits, this paper takes the head loss coefficient under the inflow and outflow conditions as the objective function to carry out optimization calculation in order to obtain the design shape of the outlet of the inlet / with the smallest head loss coefficient. At the same time, the non-uniform coefficient of orifice velocity and the non-uniform coefficient of flow between orifices are selected as constraints to meet the design requirements for hydraulic characteristics.

The objective function of 3.3.1 is the coefficient of head loss under the two working conditions of comprehensively considering the inflow and outflow of the lateral inlet / outlet, in order to coordinate the acquisition of various objectives

[22]

In this paper, the linear weighting method is used to deal with the multi-objective function

[23]

Multi-objective optimization by specifying weight coefficients

The problem is transformed into a single objective optimization problem, which is then solved by multi-island genetic algorithm.

The advantage of the linear weighting method is that the importance of inflow or outflow can be reflected by adjusting the values of the weight coefficients ω_1 and ω_2 in the objective function.

[24]

Sex. After calculation, it is found that when the weight coefficients of inflow and outflow are 0.33 and 0.67 respectively, i.e. the ratio is 1：2 , the comprehensive head loss coefficient is

(The sum of the head loss coefficients under inflow and outflow conditions) has a minimum value, and the body shape obtained at this time can be used as the recommended body shape. Using the weight coefficient to construct the objective function f of head loss under the condition of bidirectional flow is as follows:

calculation, where h_f
For head loss

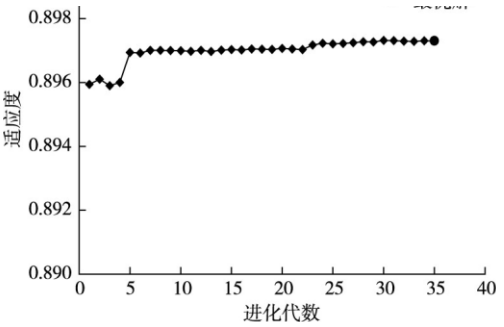
Loss, V is the average velocity of the tunnel section; Ω and Ω are the weight coefficients of the objective function under inflow and outflow conditions, and Ω + Ω = 1; α is kinetic energy
In genetic algorithm, the objective function is often transformed to obtain the fitness function. When constructing fitness function, the meter should be reduced as much as possible.
The fitness function of each point is inversely proportional to the quality of the solution.
Constraint Conditions The non-uniformity coefficient of flow velocity at the trash rack at the side inlet / outlet refers to the ratio of the maximum flow velocity of the trash rack to the average flow velocity of the trash rack.
Guidelines for Design of Pumped Storage Power Stations
There is no clear requirement for the non-uniformity coefficient of flow velocity, combining with engineering experience
,generally requires the flow.
Full, but less than 20% is more in line with the actual conditions of the project.
20 %。For this reason, this paper sets the upper bound of the value of the number of flow nonuniformity under the condition of / outflow as

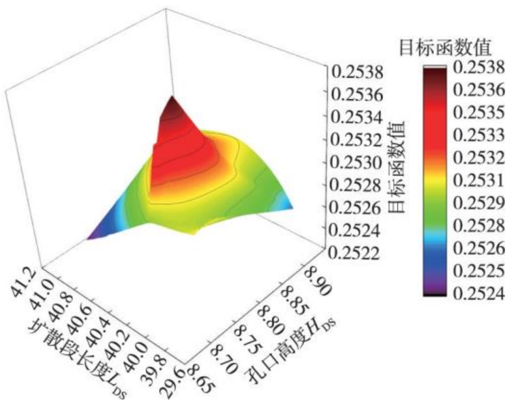
To sum up, the nonuniform coefficient of flow velocity at each orifice is based on C *and* v''=
v
$_{Max}$ Calculation, V 、 $\bar{V}$ are the maximum flow rate and average flow rate of each orifice through the grid. Adjacent

Optimization Results

In this paper, CFD is used to carry out hydraulic calculation on the lateral inlet / outlet, and hydraulic indexes such as head loss coefficient, flow velocity non-uniform coefficient and flow non-uniform coefficient are obtained under the condition of inlet / outlet. The response surface model is used to obtain the functional relationship between hydraulic indexes and optimization variables. Aiming at the multi-objective problem of the shape optimization of the lateral inlet / outlet under the condition of two-way flow, the shape optimization is carried out through hydraulic indexes, and the weighted head loss coefficient is taken as the optimization objective function. At the same time, the non-uniformity coefficient of orifice velocity and the non-uniformity coefficient of flow between orifices will be used as constraint bars. In order to obtain the optimal body shape with hydraulic index, multi-island genetic algorithm is used as the optimization algorithm for global optimization.
Analysis of Optimization Results Figure 4 is the change process of fitness with evolution algebra. From figure 4 , it can be seen that the population fitness increased rapidly in the 5 generation, and then maintained a steady growth, and the system's excellence has been improving. In the 35 generation, the fitness value 0.8973 is close to 1. It is considered that at this time
The fitness function has an optimal solution
shows the relationship between the objective function value and the shape parameters of the diffusion section, and the three-dimensional curved surface in the figure represents the objective function value.
According to the distribution of, it can be seen from the graph 5 that there are many local optimal solutions to the objective function value, while the multi-island genetic algorithm can avoid the premature phenomenon, thus being conducive to obtaining the global optimal solution.
In terms of calculation efficiency, the optimization of the side-type inlet / outlet configuration has

carried out a total of 10,000 iterations of 100 generation, and the same amount of CFD calculation is difficult to realize under the conventional computer configuration. The parametric modeling method and the response surface model based on CFD adopted in this paper speed up the modeling and numerical simulation speed of the scheme, improve the design accuracy and reduce the dependence of researchers' experience, thus improving the global optimization efficiency.





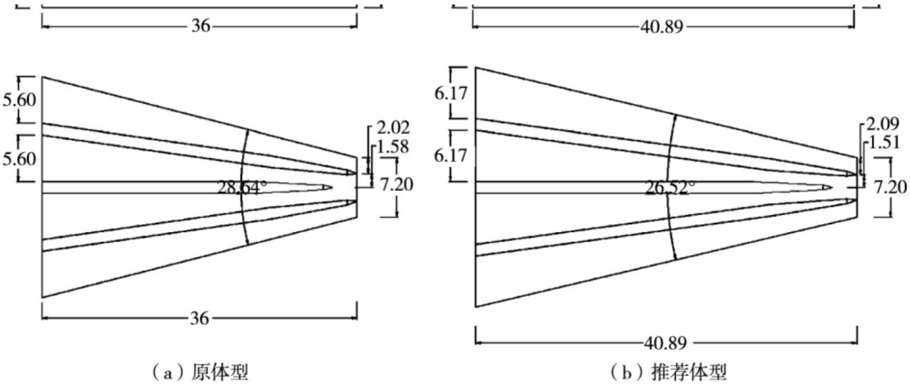
Graph 4 Curve Diagram of Relationship between Fitness and Evolution Algebra 5 Relationship between Objective Function Value and Shape Parameters of Diffusion Segment

Figure Hydraulic Characteristics of Recommended Body Type 6 is the size of the diffusion section of the original body type and the recommended body type. Compared with the original body type, the recommended body type orifice

The height is reduced from 9.80 m to 8.91 m. In order to ensure the constant flow area, the corresponding orifice width is increased from 5.60 m to 6.17 m; Diffusion section

The length was extended from 36.00 m to 40.89 m; The width of the middle hole at the tail pier of the diversion pier is reduced from 1.58 m to 1.51 m and the width of the side hole is increased from 2.02 m To 2.09 m.

Table 4 shows the comparison of hydraulic indexes between the recommended body type and the original body type. The hydraulic indexes of the recommended body type are obviously improved compared with the original body type, the head loss coefficient ζ and the outflow condition ζ are reduced by 7.51% ；； The total head loss coefficient of the inflow / outflow (the sum of the inflow and outflow head loss coefficients) is reduced by 3.35%. The velocity nonuniformity coefficient C $_V$ is not much different *and is better for the two types of C* $_V$ in inflow condition, but the C $_V$ in outflow condition is obviously improved and reduced by 14.50% (recommended type 1.799, original type 2.104). Non-uniformity coefficient c $_q$ between orifices, original shape



The flow rate in the outflow condition is relatively balanced, but the flow rate distribution between orifices in the inflow condition is extremely uneven (greater than "20%); Recommended body discharge conditions

It is getting worse, but the flow distribution between ports tends to be uniform under the inlet flow condition, and the difference between the inlet and outlet flows of / is small (1%), the overall optimization is achieved under the two-way flow condition, and C $_Q$ is less than 20%.

Fig. 7 is the velocity distribution of the mid-vertical line of the cross section of the mid-hole trash rack of the original type and the recommended type under the outflow condition. Fig. 8 is a nephogram of the sectional velocity of the trash rack at the entrance / and exit 4 . It can be seen from the figure that there is an obvious reverse velocity zone at the top of the mesopore in the original shape, and the velocity nonuniformity coefficient is relatively large. The recommended shape has no reverse flow velocity at the trash rack and the flow pattern is improved.

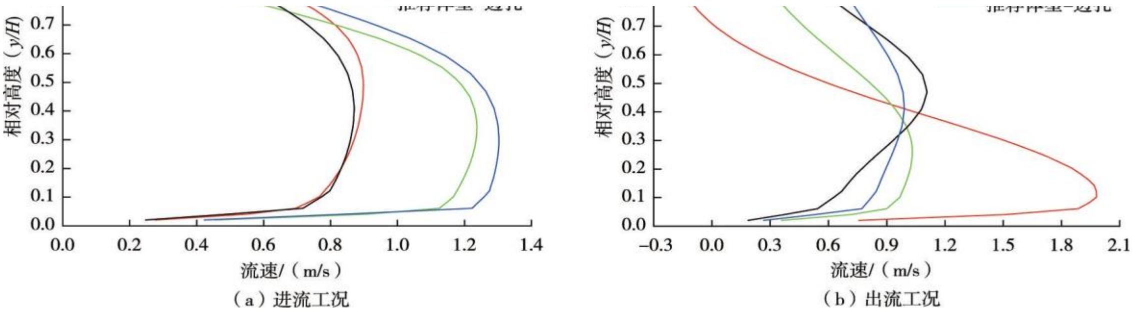


Figure 7 Comparison of Velocity Distribution of Vertical Line in Cross Section of Trash Bar of Original and Recommended Shape

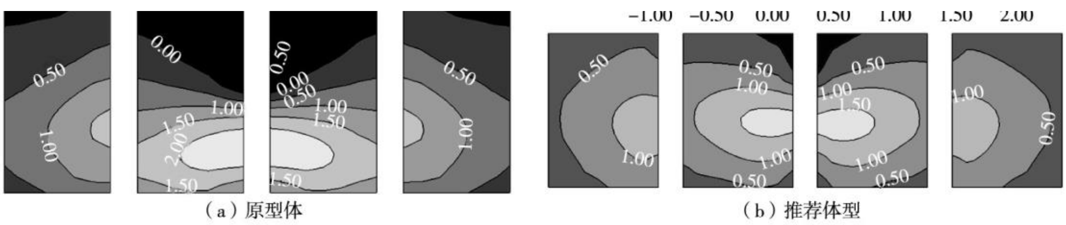


Figure 8 Original Type and Recommended Type of Outflow Condition 4 Flow Velocity Cloud Map of Trash Gate Section at Orifice

Conclusion

Hydraulic structure shape optimization generally studies the hydraulic characteristics of the set shape through physical model test or numerical simulation, and then studies the shape adjustment for unfavorable hydraulic indexes until a satisfactory better shape is obtained. This is the traditional method. The shape optimization of the lateral inlet / outlet under the condition of two-way flow is a multi-objective optimization problem. In this paper, the hydraulic index is taken as the objective function to obtain the optimal shape.

(1) In this paper, a linear weighted method is used to synthesize the head loss coefficient under inflow and outflow conditions into a single objective function, which is transformed into a single objective optimization problem. At the same time, the non-uniformity coefficient of flow velocity and the non-uniformity coefficient of flow between orifices are selected as constraints. The multi-island genetic algorithm has high optimization efficiency, and the optimal body shape can be obtained when the body shape of the lateral inlet / outlet is optimized. In addition, the application of parametric modeling method and response surface model based on CFD flow field calculation speeds up the modeling and numerical simulation of scheme selection.

(2) the hydraulic indexes of the recommended body type obtained by the optimization method in this paper are obviously improved compared with the original body type, the total head loss coefficient under the condition of two-way flow is reduced by 3.35%, the non-uniform coefficient of flow velocity at the orifice section under the condition of outflow is reduced by 14.50%, and under the condition of two-way flow

The flow distribution between orifices is basically uniform, and the coefficient of flow non-uniformity is less than 20%.

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