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Experimental Study on Jet Leakage Stopping Technology for Hydroelectric Gate

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Abstract: *In order to solve the problem that the leakage stoppage control of hydropower station gates cannot effectively meet the needs of water supply and flood discharge, and timely control the operation status of the gates, a jet type leakage stoppage technology and experimental research for hydropower station gates were proposed. The gate leaf, support hinge, support arm, top section gate and other components shall be hoisted by hoisting method; Based on the actual operation and characteristics of the hydropower station, it determines the influencing parameters of the hydropower station gate; Using displacement sensors and control boxes, real-time control of hydropower station gates is completed. Based on the obtained layout scale of the hydropower station, the flow distribution points of the hydropower station are determined. Based on this, the closure planning scheme for hydropower stations is determined based on the flow coverage of each hydropower station, and a gate jet closure planning model for hydropower stations is constructed. By using the combination set of closed planning paths for hydropower stations, a weight set for closed planning of hydropower stations is constructed. The comprehensive weight value of closed planning is represented by the feature correlation matrix, and the design of gate jet sealing technology for hydropower stations is achieved. The experimental study shows that the proposed technology has a low water leakage rate for plugging; The plugging effect is good, and the amount of leakage after the application of this technology is lower than before.*

Keywords: *Hydropower station gate; Jet type; Plugging technology; Displacement sensor*

1. Introduction

Hydropower stations are relatively common infrastructure and have a wide range of applications. It can simultaneously meet the requirements of production and domestic water use, flood control and disaster reduction, farmland irrigation, etc., and has practical application value [1-2]. The gate of hydropower station is an important component in hydraulic engineering, which plays an important role in the production and operation of hydropower stations and in flood control and flood discharge. The jet sealing technology for hydropower station gates is an important problem in water conservancy engineering [3-4]. Due to the large number of working gates, their volume and weight, and their high installation and control difficulties, it is necessary to ensure both installation quality and construction safety during the installation process. If there are significant installation quality issues, they will affect the normal production and operation of hydropower stations, and are not conducive to centralized control. Therefore, the leakage blocking technology for hydropower station gates has become an important challenge that needs to be faced in the construction of water conservancy projects.

Reference [5] proposes testing and evaluating the vibration response of hydropower station gates. This article uses standard vibration sources to verify the method of obtaining vibration displacement through frequency domain filtering and integration. The vibration responses of the gate, such as acceleration, dynamic stress, and displacement, were tested. The vibration acceleration is less than 3 m/s, the vibration displacement is less than 0.25 mm, and the dynamic stress is less than 153.2 MPa. During the initial stage of gate lifting, the maximum vibration displacement exceeded the standard requirements. The vibration of the gate was evaluated through acceleration, displacement, and dynamic stress. Reference [6] proposes to automate and simplify the maintenance of stoplogs. There are numerous stoplog structures used worldwide for the storage and flow control of small and medium-sized dams. In many cases, stoplogs must be operated to achieve the required hydropower station water level control, sometimes weekly or more frequently, depending on on-site hydrological

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management requirements. Dams require frequent access by operators, and electric gates can be installed under adverse conditions; However, for small dams, the cost is difficult to justify, especially if the dam does not yet have electricity to supply. Reference [7] proposes a new water intake gate for the expansion project of the Chiver Plant in Colombia. The power plant has a power generation capacity of 1000 MW, and was built to develop the potential of the Bata River. The average flow rate is 60 m~3/s, the minimum historical flow rate is 2.8 m~3/s, and the maximum flow rate is 1500 m~3/s. The first phase of the factory began commercial operation in 1978, and the second phase began in 1982. The initial life expectancy of the project is 50 years. In 2012, owners began implementing a plan to measure sediment characteristics and remaining life expectancy. Considering the accelerated deposition rate, a strategy has been developed to mitigate the potential impact of sediment, which will reach the current water intake baseline level within 10 years. On the basis of the above research, the article proposes a hydraulic power station gate jet plugging technology and experimental research, which proves the feasibility of the technology through experiments.

2. Jet sealing technology for gate of hydropower station

2.1 Determine the layout scale of hydropower stations

Before determining the layout scale of hydropower stations, first establish a hydropower station layout scale index, including the total length of water conservancy and hydropower projects, construction equipment density index, and transportation capacity index [8]. The total length of a water conservancy and hydropower project can be calculated by formula (1), namely:

$$L=\sum_{i=1}^{n} L_i \quad i=1,2,3,\cdots,n \tag{1}$$

In formula (1), L_i represents the length of the i construction line for water conservancy and hydropower projects, and L can indirectly describe the scale of the hydraulic power station gate jet plugging plan. Assuming that the construction equipment density index is described by G_{HJ}, it can be calculated by formula (2), namely:

$$G_{HJ}=\frac{S_h S_K}{W_E}\times L \tag{2}$$

In formula (2), S_K represents the local area of the hydropower station, and W_E represents the population within the layout area of the hydropower station. The effect of the data category of leakage plugging points for hydropower stations is calculated by formula (3), namely:

$$\lambda=\sum_{i=1}^{n} P_i \times G_{HJ} \tag{3}$$

In formula (3), P_i represents the hydropower transmission capacity of the i water conservancy and hydropower project construction line, and λ can reflect the impact of hydropower stations in water conservancy and hydropower projects.

According to the national land resources, when determining the total construction length of water conservancy and hydropower projects, taking into account the close relationship between the national land area and hydropower flow, a mathematical model can be established as shown in Formula (4), namely:

$$\theta=Q^{\alpha}\times S^{\beta}\times\lambda \tag{4}$$

In formula (4), α represents the undetermined coefficient of hydropower flow, β represents the undetermined coefficient of national land area, Q represents the expected value of hydropower station flow, and S represents the floor area of the hydropower station. The total flow of the hydropower station can be calculated using the regression results of formula (5), which is:

$$Z_{LL} = A_a \times Q_k \times \theta \tag{5}$$

In formula (5), Z_{LL} represents the total flow of the hydropower station, A_a represents the delivery rate of the hydropower station flow, and Q_k represents the expected flow value of the hydropower station. Based on formula (5), the layout scale of the hydropower station can be calculated, namely:

$$G_M = B_I \times Z_{LL} \tag{6}$$

In formula (6), G_M represents the total flow of the hydropower station, and B_I represents the proportion of the hydropower station flow to the total flow of all hydropower stations.

By determining the total length of water conservancy and hydropower projects, construction equipment density indicators, and transportation capacity indicators, the layout and scale of the hydropower station are obtained, eliminating the impact of construction equipment on the planning of jetting leakage stoppage for hydropower gates.

2.2 Construction of a planning model for hydraulic gate jet plugging

Mark the flow distribution points on the construction route of water conservancy and hydropower projects, and mark the alternative stations along the flow distribution points one by one at the hydropower stations. According to the flow coverage of each station, determine the planning scheme for hydraulic power station gate jet plugging [9], effectively preventing hydraulic power station gate jet plugging water seepage.

If there are a total of W alternative hydropower stations in the hydropower station collection, selecting O hydropower stations can be expressed as follows:

$$O = \frac{G_M}{\left| sign\left(\frac{o/W}{\overline{a}} \times D_F \times R_H \right) \right|} \tag{7}$$

In formula (7), o represents the total number of hydropower stations on the construction line of water conservancy and hydropower projects, $sign(\cdot)$ represents a rounding function, $\overline{a}$ represents the average distance between the gates of the hydropower station, taking a value between $a_{\min}$ and $a_{\max}$, D_F represents the regulated storage capacity of the hydropower station gates, and R_H represents the normal water level.

The starting point of the hydraulic power station gate jet plugging plan is taken as the center of the circle [10], and the radius of $a_{\min}$ and $a_{\max}$ is taken as the radius to intersect with the construction line of the hydraulic and hydropower project at two points, respectively. All hydraulic power stations between the two intersections are considered as alternative stations. If there is only one alternative site, then this hydropower station is the only closure planning scheme. If there are multiple alternative hydropower stations, then there are multiple planning schemes for gate jet plugging in hydropower stations. Once again, round each alternative site until the next hydropower station is left, and use it as an alternative site to obtain multiple closure planning schemes [11].

Although hydropower stations can be selected according to the above steps, it is difficult to determine $a_{\min}$ and $a_{\max}$, and there is no fixed value between $a_{\min}$ and $a_{\max}$. When selecting a hydropower station, the distance difference between $a_{\min}$ and $a_{\max}$ will be large, resulting in an increase in the number of options for the final gate jet plugging planning for hydropower stations. It is assumed that a total of X alternative river closure planning options have been generated in the gate jet plugging planning for hydropower stations, with each planning option having Y hydropower stations. According to the application of the flow distribution range in hydropower stations, as shown in Figure 1.

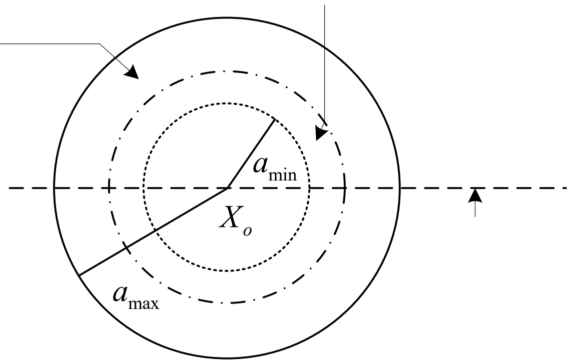

Figure 1: Flow Distribution Range of Hydropower Station

According to Figure 1, within the flow distribution range, the distance between all hydropower stations and X_o is $[a_{\min}, a_{\max}]$. Based on the flow distribution range of the hydropower station, a flow model is constructed to effectively calculate the leakage prevention and leakage amount. The flow model of the hydropower station point X_o in the gate jetting leakage prevention planning scheme of the m hydropower station is:

$$X_o = \frac{\rho_j O}{\left(\frac{a_{\max} + a_{\min}}{2}\right)^2} \times S_{Bk} \times B_i \tag{8}$$

In formula (8), ρ_j represents the weighted sum between the hydropower flow and the distribution density of the hydropower station, S_{Bk} represents the intersection area of the hydropower station area and the drainage ring, and B_i represents a constant.

According to the flow model of a hydropower station, the flow rate of the hydropower station in the gate jet plugging planning of the hydropower station is obtained, the flow rate of the hydropower station is analyzed, and the hydropower station gate jet plugging planning scheme with the largest flow rate is selected to obtain the flow rate of the hydropower station in the optimal planning scheme, namely:

$$\zeta = \max\left\{X_o\right\} \times \rho_j \tag{9}$$

By marking the flow collection and distribution points of the hydropower station, and according to the flow coverage of each station, the planning scheme for hydraulic gate jet plugging is determined. According to the flow collection and distribution range of the hydropower station, the flow model of the hydropower station is constructed.

2.3 Design of Jet Sealing Technology for Hydropower Station Gate

In the planning process of hydraulic power station gate jet plugging technology, the correlation between hydraulic power station gate jet plugging paths is comprehensively considered, and the final technical planning result is obtained by obtaining the weight between hydraulic power station gate jet plugging paths. The steps of river closure planning for hydropower stations are as follows: establish a

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set of jetting leakage stoppage paths for hydropower stations' gates, analyze the set, and achieve technical planning for jetting leakage stoppage for hydropower stations' gates by establishing a weight set.

Assume that e represents the jet plugging path for hydropower station gates, and the composition set of planned jet plugging paths for hydropower station gates is expressed as E, namely:

$$E = \{e_1, e_2, \ldots, e_m\} \tag{10}$$

In formula (10), m represents the number of planned paths for river closure.

By analyzing the composition set E of the river closure planning path, the characteristic parameter v of the river closure planning path is extracted, and a river closure path analysis set is constructed, expressed as:

$$V = \{v_1, v_2, \ldots, v_z\} \tag{11}$$

In formula (11), z represents the number of characteristic parameters for the planned path of river closure.

The path analysis set for hydraulic power station gate jet plugging planning can provide planning reference for river closure planning and construct a weight set. The purpose of building a weight set is to measure the importance a of each river closure planning path. UAV remote sensing technology considers the more important river closure planning paths. The weight set of hydraulic power station gate jet plugging planning is obtained, expressed as:

$$A = E \times V \tag{12}$$

In the planning process of hydraulic power station gate jet plugging, the characteristic correlation matrix can be used to represent the comprehensive weight value of the closure planning, namely:

$$H = \xi \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1m} \\ h_{21} & h_{22} & \cdots & h_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n1} & h_{n2} & \cdots & h_{nm} \end{bmatrix} \tag{13}$$

In formula (13), r represents the correlation degree between the planned paths for jet plugging of hydropower station gates. As there is a corresponding relationship between the planning solution of the hydraulic power station gate jet plugging path and the characteristic parameters, the evaluation set D of the hydraulic power station gate jet plugging planning can be obtained, which is expressed as:

$$D = A \times H \tag{14}$$

The maximum value, minimum value, and estimated value appearing in the evaluation set D of hydraulic power station gate jet plugging planning can be averaged to obtain the hydraulic power station gate jet plugging planning value.

To sum up, using the composition set of planning paths for hydraulic power station gate jet plugging, a set of analysis of closure paths is constructed, and the weight set of hydraulic power station gate jet plugging planning is constructed. The comprehensive weight value of closure planning is expressed using a characteristic correlation matrix, realizing the research on hydraulic power station gate jet plugging technology.

3. Experimental study

In this experiment, a hydropower station A in a certain area was selected as the research object. The hydropower station controls a runoff area of approximately 62700 km2, and is mainly responsible for agricultural irrigation and water supply. The hydropower station gate is arranged on the bank of the spillway, which is an exposed radial gate with an orifice size of 7.5m * 3.5m. The overall gate structure

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is an I-beam structure, controlled and operated by a lower hanging hydraulic hoist. The gate of Hydropower Station A is mainly responsible for the flood discharge of the hydropower station, and is remotely controlled by a hydraulic hoist. Firstly, install a gate control cabinet in the gate control center of the hydropower station, connect to the monitoring center of the gate management room through EtherNet, and remotely monitor the operation status of the hydraulic hoist and the gate. Through the collection function of on-site sensors, real-time collection of hydropower station gate operating conditions data is conducted, and the collected hydropower station gate operating conditions data is used as an input layer to input into the model. The functional functions of each layer of structure are different, and the collected working condition data are converted and processed. According to the converted working condition data, the operation status of the hydropower station gate is controlled in real time.

Under the above circumstances, the disadvantages of flat head joints that are prone to cracking and leakage are minimized, further ensuring the stability of the gate jet type leakage blocking structure. In addition, the installation of the jetting culvert pipe and base must be kept horizontal with the mortar blocks near the gate. The specific experimental parameters are shown in Table 1.

Table 1: Main Parameter Settings of Hydropower Station

Order number	Feature Name	Parameter details
1	Length of culvert body	10.35
2	Adjusting performance	Incomplete
3	Dead water level/m	731.00
4	Normal high water level/m	780.00
5	Regulating storage capacity/106m^3	5796.20
6	Midpoint target water level	The average value of the highest and lowest water levels in a hydropower station per unit time measured using a floating ball sensor
7	Gate opening	Directly reflect the magnitude of gate opening and closing
8	Midpoint weighted water level	Weighted average value of feedback after gate water level calculation

Table 1 shows the control parameters that affect the hydropower station gates analyzed in this article, and completes the preset of the directional parameters for the technical indicators of gate jet plugging. The proposed technology is set as an experimental group, while the reference [5] hydropower station gate vibration response testing and evaluation technology and the reference [6] automated simplified stoplog gate maintenance technology are set as a control group.

Different techniques are used to test whether the gate of the A hydropower station in a certain area has leakage stoppage. The detection time is 36h, and every 6h, the hydropower station is checked for water leakage stoppage, and the amount of leakage stoppage is recorded. The recorded data are shown in Table 2.

Table 2: Comparison Results of Leakage and Permeability of Different Technologies/L

Different technologies	6h	12h	18h	24h	30	36
Proposed technology	0.16	0.26	0.34	0.46	0.53	0.58
Reference [5] Technology	1.12	1.25	1.31	2.41	2.54	2.64
Reference [6] Technology	1.14	1.36	1.69	1.56	1.90	2.05

Among them, the amount of leakage from reference [5] and reference [6] technologies is higher, and the amount of leakage from the proposed technology is lower than that of the control group. The reason is that the proposed technology sets the flow distribution range of the hydropower station. Within the flow distribution range, the distance between all hydropower stations and X_o is within [$a_{\min}$, $a_{\max}$]. Based on the scope of flow collection and distribution of hydropower stations, a flow model is constructed to effectively calculate the amount of leakage prevention and control, so the

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leakage prevention and control amount of the proposed technology is relatively low.

Set three types of leakage point data, represented by A leakage point, B leakage point, and C leakage point. Obtain the effect of the proposed technology on different leak plugging point data categories according to formula (3), and the results are shown in Figure 2.

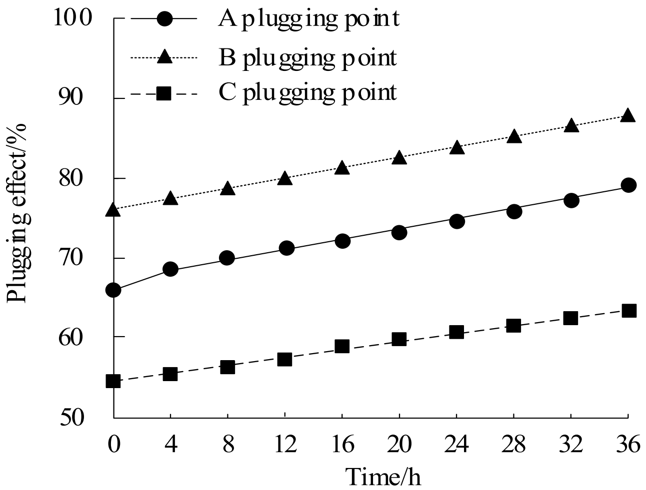

Figure 2: Effect of Jet Sealing for Hydropower Station Gate

As can be seen from Figure 2, using the proposed technology to detect the data of the three leak plugging points, the leak plugging effect is lower than 100%, and all show an upward trend, with the value of the B leak plugging point being the highest. The research shows that the proposed technology has good plugging effect, can complete the effect detection of different plugging points, and provide reliable results for jet plugging of hydropower station gates.

4. Conclusion and prospects

The article proposes the technology and experimental research of hydraulic power station gate jet plugging, and obtains the following conclusions through verification:

(1) With the increase of time, the amount of leakage through plugging increased with different technologies, and the leakage through plugging of the proposed technology was lower than that of the control group;

(2) Using the proposed technology to detect the data of the three leak plugging points, the leak plugging effect is lower than 100%, and all show an upward trend, with the highest value of the B leak plugging point.

(3) After completion of plugging through the proposed technology, the amount of leakage through plugging is reduced compared to before the application of the technology.

Due to various debris flows blocking the gates of hydropower stations, there are certain limitations, and specific applications need to be further modified to more accurately predict the situation of jet plugging of hydropower station gates. Due to the significant constraints on the stress and settlement conditions of the gate during dynamic water closing, it is difficult to directly measure and regulate it. Therefore, research on the regulation of this factor can be carried out in the next step; In the open flow state behind the gate, as the water level rises, the situation of vertical oscillation when the gate of a hydropower station is closed will become more significant. However, due to the many reasons for this oscillation, it is difficult to explore its generation mechanism. Therefore, future work can conduct in-depth research on this, more in-depth exploration of the hydraulic power station gate jet plugging technology, and more experimental verification.

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