Nghiên cứu thiết kế hệ thống thuỷ lực nâng hạ cửa đập ngăn mặn tại tỉnh Bình Định

TÓM TẮT

Hiện nay, các đập ngăn mặn chủ yếu sử dụng cơ cấu quay tay trục vít me bằng tay hoặc sử dụng động cơ điện để vận hành nâng hạ, ở các phương pháp này có nhiều hạn chế như phụ thuộc tính chủ quan con người, quá trình đóng mở không phù hợp, dễ gây biến dạng trục chính dẫn đến hỏng các cơ cấu hộp số vít me. Để khắc phục vấn đề trên, giải pháp sử dụng xi lanh thủy lực đã được tác giả đề xuất trong bài báo này. Dựa trên các số liệu thực tế, tác giả đã thiết kế hệ thống vận hành đóng mở các đập ngăn mặn tại tỉnh Bình Định bằng hệ thống thuỷ lực. Kết quả mô phỏng cho thấy hệ thống vừa bảo đảm về mặt kỹ thuật vừa hiệu quả tính kinh tế, khắc phục các hạn chế vận hành trước đây. Giải pháp này không chỉ cải thiện chất lượng vận hành mà còn mở ra khả năng ứng dụng công nghệ mới để tự động hoá và giám sát từ xa trong quá trình vận hành cho các đập thủy lợi tương tự.

Từ khóa: *Đập ngăn mặn, thuỷ lực, vít me, đập thuỷ lợi, Bình Định.*

Research and design of the hydraulic system for raising and lowering the saltwater barrier gates in Bình Định province

ABSTRACT

Currently, the majority of saltwater barrier dams use manual ball screw mechanisms or electric motors for dam gate raising and lowering operations. These methods have several limitations, such as dependence on human subjectivity, improper dam gate raising and lowering processes, and the risk of main shaft deformation, leading to damage to the ball screw gearbox mechanisms. To address these issues, the use of hydraulic cylinders has been proposed by the author in this paper. Based on actual data, the author has designed a hydraulic system for operating the dam gate raising and lowering of saltwater barrier dams in Binh Dinh province. Simulation results demonstrate that the system not only meets technical requirements but is also economically efficient, overcoming previous operational limitations. This solution not only improves operational quality but also paves the way for adopting new technologies to automate and enable remote monitoring during the operation of similar irrigation dams.

Keywords: *Saltwater barrier dams, hydraulic, ball screw, irrigation dams, Binh Dinh.*

1. INTRODUCTION

The coastal area of Binh Dinh frequently faces challenges such as flooding and saltwater intrusion, which have a severe impact on freshwater resources, agricultural production, and the livelihoods of local residents. To address saltwater intrusion, saltwater barrier dams have been constructed. However, water regulation still largely depends on human control and tidal fluctuations along the coast, leading to difficulties in efficient management and operation. This results in frequent flooding and saltwater contamination in the inland areas of Binh Dinh's coastal region. The saltwater barrier gates typically have the following characteristics: they are not large in size, the lifting load is moderate, and they are not subjected to the high pressures found in hydropower dams. The water level difference between the inside and outside of the gates usually fluctuates by a few meters, they handle large flow rates, and the flow currents are slow. These gates require high water-tightness, timely operation to prevent flooding and saltwater intrusion into the inland areas, and are exposed to harsh weather conditions. They are located far from residential areas, and the dam gate raising and lowering times vary according to tides and seasonal needs.

Binh Dinh province currently manages 39 gates on embankments, 11 dams on embankments, 17 spillways on embankments, and 12 saltwater barrier dams. [1]

Currently, the most common method for opening and closing dam gates is manual operation due to the lack of electricity at the 17 spillways on the East Embankment (**Figure 1a**); the use of manual ball screw mechanisms at saltwater barrier gates (**Figure 1b**); or motorized control for opening and closing at saltwater barrier dams (**Figure 1c**, Lai Giang dam); and the use of winches, pulleys, and hoists (**Figure 1d**, Ha Gach dam). According to the report from the Institute of Irrigation Management and Economics, most saltwater barrier dams in Binh Dinh province use two lifting solutions: hoists and pulleys, and ball screw mechanisms. With pulleys, there are difficulties in pressure difference when lowering the dam. The ball screw mechanism allows for manual or motorized operation to raise or lower the dam gates. This is a simple and cost-effective drive mechanism. The ball screw mechanism is easy to integrate into gate operation systems, with a compact design and minimal installation space requirements.

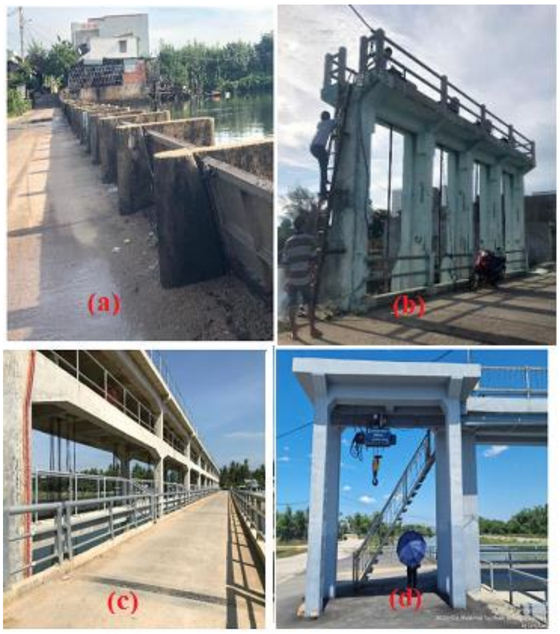

Figure 1. The manual lifting and lowering operating mechanism is through a Vitme.

Although ball screws have many advantages, they also have certain limitations, such as being prone to wear, requiring frequent lubrication, operating slowly, and being difficult to apply for dams with significant water level differences or requiring rapid raising and lowering. They are also susceptible to overloading during improper operation, often resulting in shaft bending and joint damage. Therefore, ball screws are typically used for smaller structures, such as field sluice gates, and they are expected to be replaced by more modern systems in the future.

In the document automatic flap gates operate based on the principle of changes in upstream water pressure and the equivalent stiffness of the spring system F=f(Kx). When the moment generated by hydrodynamic pressure, combined with the gate's own weight and the friction at the pivot, exceeds the stiffness of the spring system, the gate will open to a state of equilibrium with the compressive (or tensile) force of the spring system. [2]

If the pressure remains unchanged and the compressive (or tensile) force of the spring system remains constant, the gate's opening angle will also remain unchanged. When the moment caused by hydrodynamic pressure continues to exceed the compressive (or tensile) force of the spring system, the gate will fully open (reaching a horizontal position). Conversely, when the compressive (or tensile) force of the spring system surpasses the moment generated by hydrodynamic pressure, the gate's weight, and frictional force, the gate will automatically close (returning to a vertical position).

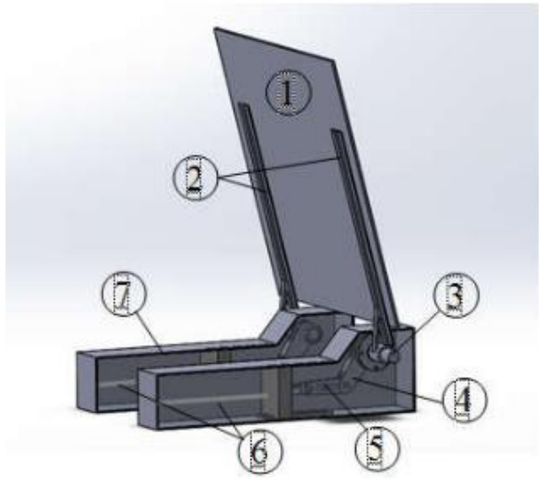

Figure 2. Structure of automatic flap valve. [2]

This system is only suitable for dams designed for automatic flood discharge, it is not suitable for saltwater barrier dams. The hydraulic solution is also proposed in the article, featuring a system of cylinders arranged in a rather complex manner, which reduces the reliability of the operation process. [3] The curved gate principle used in this system is suitable for hydropower dams that require very high lifting forces.

Smart dam gate raising and lowering control monitoring solution is included in the application. [4] This dam system helps increase the accuracy of the dam gates opening and closing system which in turn helps the economy and saves lives. It also reduces the chances of human error.

The operation of opening and closing dam gates using pulleys is commonly applied to gates with significant weight, slow flow rates, and low water level differences, making them easy to operate. [5] However, this method is unsuitable when dealing with strong water currents, as gravity alone is insufficient to overcome the resistance pressure of the water to achieve full closure.

The radial gate mechanism controlled by a hydraulic system is typically used in hydropower dams with steep water gradients, high water pressure, and complex control systems. These mechanisms are commonly employed in dams with significant water level differences but are not suitable for saltwater barrier dams. [6,7].

Hydraulic cylinders can generate very high thrust with stable pressure, making them suitable for applications that require large forces, such as opening and closing dam gate valves. The hydraulic system can adjust the oil flow to control the opening and closing speed flexibly. It is less affected by friction compared to the screw-nut system, helping to extend operational lifespan. Hydraulic cylinders can operate stably in wet conditions and are more resistant to corrosion. While hydraulic cylinders have a high initial investment cost, their low operating costs are beneficial for long-term operations, such as dam operations. Due to their low friction coefficient, high efficiency, and lower energy consumption compared to the screw-nut system, hydraulic cylinders experience less wear and tear, offering higher durability and reducing component replacement costs.

2. IMPLEMENTATION CONTENT

2.1. Structural design criteria

All the saltwater barrier dams currently in use in Binh Dinh province are of the vertical panel type; therefore, the calculation of the force distribution on the gates is based on this design. The load case considered when structurally analyzing the dam gate is that of the hydrostatic pressure, with two edges simply supported. In particular the case when the gate is fully closed and there is no flow. [1]

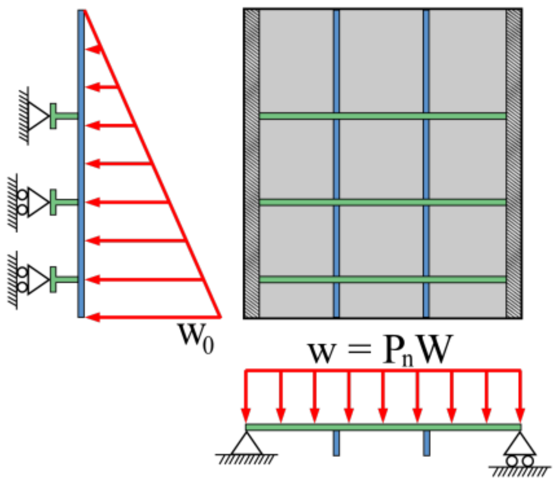

Figure 3. The structurally idealized gate; W is uniform distributed load [N/m]; W_0 linearly varying load [N/m]; Girder reaction force [N].

There are many methods of defining the deflection of a beam due to bending. However, the method chosen for calculating deflection is Castaglianos theorem which is a relatively simple way of determining beam deflection. Castigliano's theorem is defined in equation (1).

$$\delta_i = \frac{\partial U}{\partial F_i} \tag{1}$$

Where U is the strain energy, and F_i is the force in the direction of the displacement. Strain energy due to bending can be defined in equation (2)

$$U = \int_0^L \frac{M^2}{2EI} \tag{2}$$

Where M is the equation of bending moment along the beam, E is the elastic modulus, I is the second moment of area and L is the length of the beam. Equation (2) can be combined with equation (1) to form an equation for Castagliano's theorem for bending, as seen in equation (3)

$$\delta_i = \int_0^L \frac{1}{EI}\left(M \frac{\partial M}{\partial F_i} \right) \tag{3}$$

A method used to determine the deflection at a point where a force F_i is not present is to introduce a fictitious force F_* at i. This force can be set to zero after calculating the partial derivative $\frac{\partial M}{\partial F_i}$

The vertical stiffeners will be analyzed first. They are idealized as beams supported at the positions of the main girders. Since the number of main girders often exceeds two, the vertical stiffeners will in those cases be statically indeterminate. The superposition method can be utilized to simplify the indeterminate system into a determinate one. To achieve this the vertical stiffener can be idealized as a beam with two supports and point loads equal to the support reactions in the redundant supports (n>2). The deflection of the main girders is simpler to find, since it is idealized as a simply supported beam under uniformly distributed load, see **Figure 3**. This is a common standard load/support case where the deflection at point x along the beam can be defined in equation

$$\delta(y) = \frac{w_n y\left(W^3 - 2Wy^2 + y^3\right)}{24EI} \quad (4)$$

Thus, the option of selecting vertical steel gates with reinforced frames is suitable for installation in saltwater barrier dams.

2.2. Calculation of forces acting on the dam gate

The forces acting on the dam gate include weight F_m, hydrodynamic force F_{hd}, sediment force F_s, wave force F_w, friction force F_{ms}, and reaction force F_n... These forces are categorized into two directions: vertical and horizontal. [8]

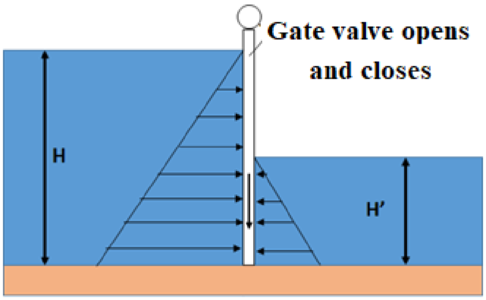

Figure 4. Door system to prevent salinity.

$$\begin{aligned} \sum F_x &= F_{hd} + F_w + F_s + F_{ms} - x \\ \sum F_y &= F_m - F_n - F_{ms} - y \end{aligned} \quad (5)$$

Neglecting minor impacts on the dam gate, equation (5) is rewritten as:

$$\begin{aligned} \sum F_x &= F_{hd} - x \\ \sum F_y &= F_m - F_n - y \end{aligned} \quad (6)$$

In a static state, gravity and the reaction force are balanced, with only water pressure acting on the dam gate. This value depends on the pressure difference between the water levels inside and outside the gate. Thus, to calculate the lifting force required for the hydraulic dam gate, two main forces must be overcome:

- The weight of the dam gate is G(kg), which is converted to gravitational force in the vertical direction as:

$$F_m = G.g \quad (7)$$

Where:

F_m: Gravitational force (N)

G: Weight of the dam gate (kg)

g: Acceleration due to gravity (≈9.81 m/s^2)

- The frictional force between the gate and the dam wall depends on the normal (contact) force between the gate and the wall, as well as the coefficient of friction f, which is determined by the materials used for the gate and the dam wall. The frictional force can be calculated as:

$$F_{ms} = f.N \quad (8)$$

Where:

F_{ms}: Frictional force (N)

f: Coefficient of friction (depends on the materials)

N: Normal force (N), which is the contact force between the gate and the dam wall.

$$N = \rho.g.H.A \quad (9)$$

ρ: Density of water (typically around $1000\ kg/m^3$

H: Water level difference

A: Area of the gate surface in contact with the water.

Thus, the total lifting force acting on the dam gate is:

$$\sum F = F_m + F_{ms} \quad (10)$$

2.3. Propose a solution using hydraulic cylinders

There are several solutions when implementing the lifting and lowering of the dam gate using hydraulics: Hydraulic Cylinder System, Cable-Operated Hydraulic System, Hydraulic Screw System… For saltwater barrier dams, which typically have low water levels and require frequent operation of opening and closing, the solution of choosing a Hydraulic Cylinder System is suitable. [9]

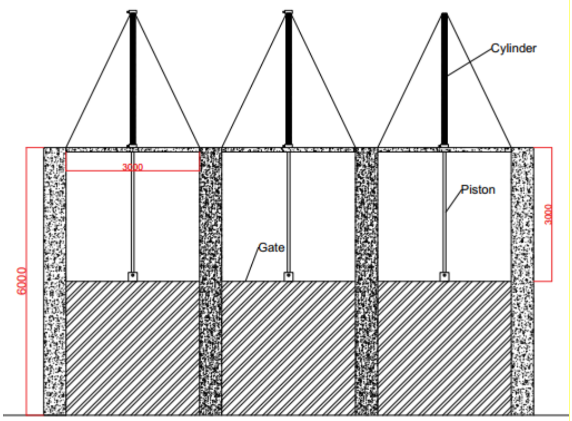

Figure 5. The opening and closing system of the salinity prevention dam is hydraulic.

The relevant quantities include weight F_m (N), water pressure F_n (N), frictional force F_{ms} (N), operating speed v (m/s), lifting stroke L (m), hydraulic pressure P (bar), piston diameter D (m), and cross-sectional area of the piston s (m²). The lifting force of the cylinder is determined by the formula.

$$F = P.s = P.\frac{\pi D^2}{4} \text{ (N)} \tag{11}$$

The L/D ratio should not exceed 20 to avoid the phenomenon of bending or deflection of the piston. The required hydraulic oil flow rate Q (m^3/s) to operate the cylinder.

$$Q = v.s \tag{12}$$

Where:

s : Piston cross-sectional area (m^2)

The power of the pump P_b (W) can be determined using the following formula

$$P_b = \frac{Q.P}{\eta} \tag{13}$$

Where:

η: System efficiency (typically ranging from 0.8 to 0.9).

With the above characteristics, the proposed system for lifting and lowering the saltwater barrier gate is shown in **Figure 6**. The system includes: a oil supply source, an electric control mechanism, a hydraulic drive mechanism, and other measuring devices.

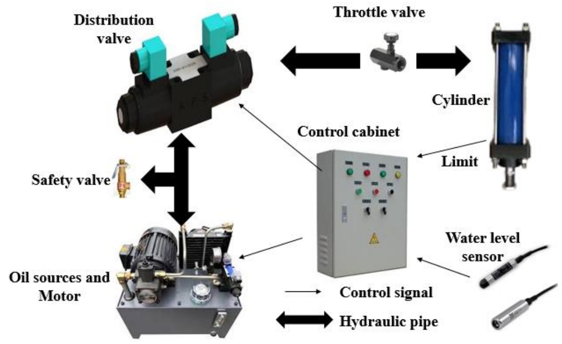

Figure 6. Hydraulic Cylinder System control diagram.

2.4. The problem of practical verification

Considering the data of Ha Gach Dam in Phuoc Thang Commune, Tuy Phuoc District, and given the diagram shown in **Figure 5**, the dam gate is made of sheet steel, with dimensions: 3x3x0.1m³, density $\gamma = 7850$ kg/m^3, lifting speed v = 0.05 m/s, friction coefficient f=0.3, and efficiency η=0.9.

The weight of the dam gate is calculated as:

$$F_m = V \times \gamma \times g = 0.9 \times 7850 \times 9.81 = 69307 \text{ N} \tag{14}$$

Assuming the maximum water level difference H is 3 meters:

$$N = \rho \times g \times H \times A = 264870 \text{ N} \tag{15}$$

$$F_{ms} = f \times N = 0.3 \times 264870 = 79461 \text{ N} \tag{16}$$

The force required to lift the dam gate is:

$$F = F_m + F_{ms} = 148768\text{N} \approx 14{,}9 \text{ kN} \tag{17}$$

Thus, a hydraulic cylinder with a capacity of 15 tons should be selected in order to lift the dam gate under maximum load conditions. Choose a cylinder with a stroke length L=3 m, and piston diameter D/d=150/250 mm.

The cross-sectional area is:

$$s = \pi \times 0.25^2 / 4 = 0.049 \text{ m}^2.$$

The hydraulic pressure on the piston surface is:

$$P = \frac{F}{s} = \frac{14{,}9}{0.049} = 304 \text{ kbar} \tag{18}$$

The required hydraulic oil flow rate to operate the cylinder is:

$$Q = v \times s = 0.00245 \text{ m}^3\text{/s} = 2450 \text{ cm}^3\text{/s} \tag{19}$$

The power of the pump is:

$$P_b = \frac{Q.P}{\eta} = \frac{0.00245x.3036082}{0.9} = 8265 \text{ w} \quad (20)$$

Choose a motor with a maximum operating power of 11 kW. If the opening and closing occur when the water levels on both sides are balanced, the system load will only be the weight, neglecting the water pressure. The system has 3 gates operating non-synchronously, and the operating time for the entire system is:

$$t_{\Sigma} = 3.t_i = 3.\frac{L}{v} = 180 \text{ s} \quad (21)$$

With the calculated parameters, the hydraulic equipment available on the market fully meets the requirements of the problem. The calculated power supply for the system is not too large, so for some saltwater barrier dams without access to the electrical grid, the solar energy power system is a suitable solution for operating the lifting and lowering of the saltwater barriers.

2.5. Simulation results and discussion

The author uses Automation Studio software to simulate the operation process of the gate-lifting system using a hydraulic cylinder based on the parameters provided in the problem above. The hydraulic system model (**Figure 7**) includes a double-acting cylinder with a 3-meter stroke arranged vertically to lift and lower the gate, a ¾ directional control valve, a 300kbar hydraulic pump, an oil tank, a throttle valve, and a piping system.

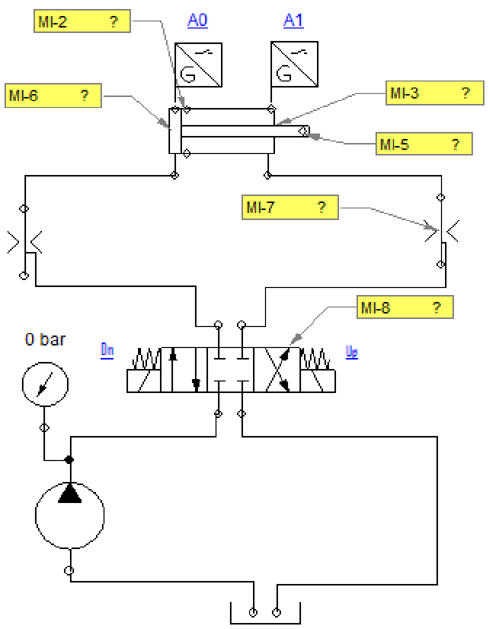

Figure 7. Hydraulic circuit model.

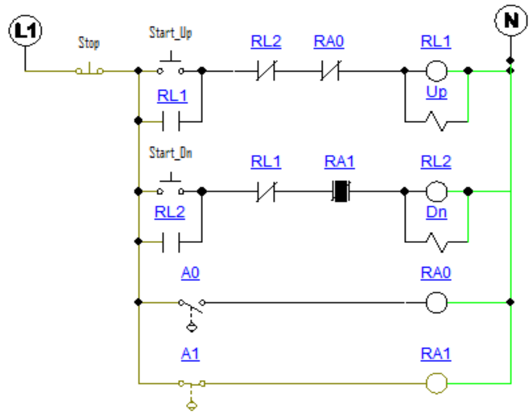

Figure 8. Logic control electrical diagram for the lifting and lowering of the saltwater barriers.

The electrical control system (**Figure 8**) comprises a solenoid coil for lifting (Up) and lowering (Dn), lift limit A0, lower limit A1, lift-lower-stop push buttons, and a control circuit power supply with a voltage of 220 V.

The process of hydraulic flow during the gate-lowering operation (**Figure 9**) shows that at a stroke of L = 2613 mm, the measured pressure in the pipeline is 2.54 kbar. The directional control valve is fully open in the lowering position, and the parameters during the gate-lowering process fully comply with the design specifications.

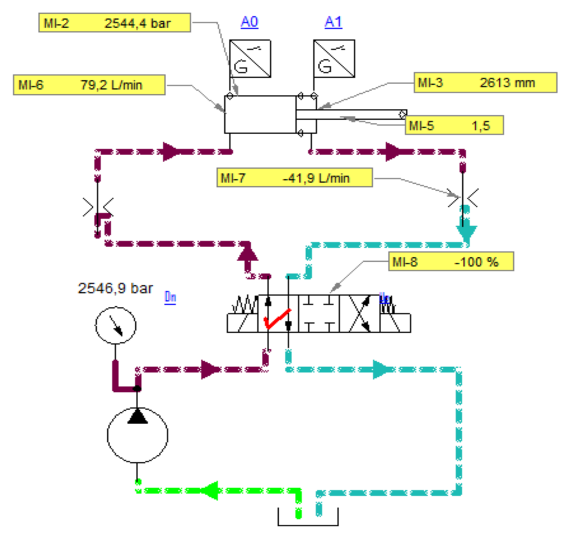

Figure 9. Hydraulic diagram for the gate lowering process.

The time for the piston to lower from 0 to 3000 mm within 2 minutes (**Figure 10**) shows that during the startup phase from 0 to 4 seconds, the piston hardly moves. Starting from the 6th second, the piston must overcome two factors:

inertia, friction, and the accumulation of hydraulic pressure.

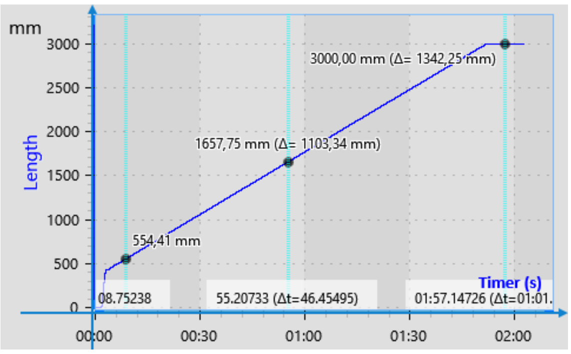

Figure 10. Position diagram for gate lowering.

Throughout the motion, the velocity of the piston is nearly linear, which is consistent with a first-degree equation in the motion where only the piston component is involved. If the velocity varies over time, the piston movement can be described by a derivative equation:

$$v_{piston} = \frac{dx}{dt} \tag{22}$$

Where:

v_{piston}: Piston velocity over time (m/s)

x: Position of the piston (m)

t: Time (s)

Throughout the gate-lowering process, the velocity remains almost constant at 2.41 cm/s², corresponding to a load force of 1.52 tons (**Figure 11**), which aligns with the calculated results.

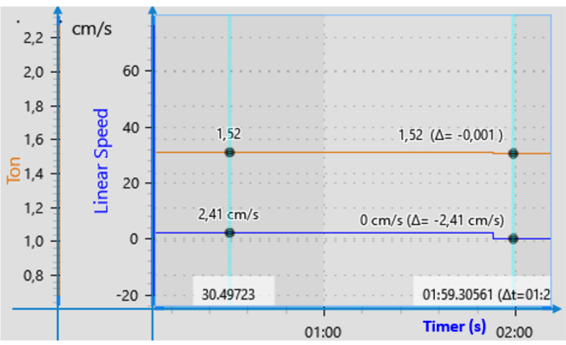

Figure 11. Velocity/force diagram for gate lowering.

In contrast to the gate-lowering process is the gate-lifting process (**Figure 12**). It is assumed that the maximum load and the lifting pressure are higher than during the lowering process due to the opposing gravitational force of the gate. The remaining values are equivalent.

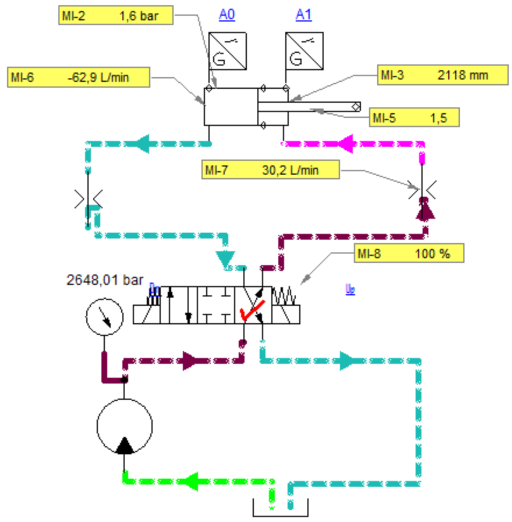

Figure 12. Hydraulic diagram for the gate lifting process.

The gate-lifting time is 2.5 seconds (**Figure 10**), compared to the gate-lowering time of 2.0 seconds (**Figure 13**). With this result, the simulation time is longer than the ideal theoretical calculation, as it takes into account the gravitational force during lifting and the startup time of the piston. During the gate-lifting process, the piston also moves linearly for most of the stroke.

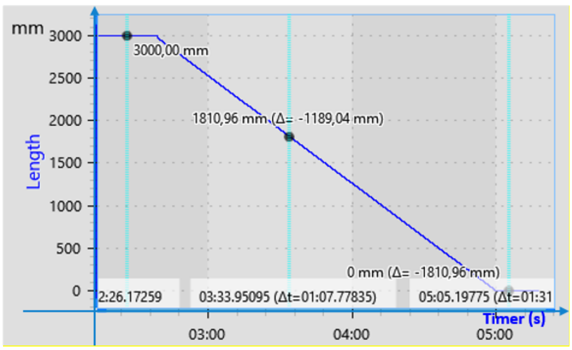

Figure 13. Position diagram for gate lifting.

In the simulation diagram of velocity and force during the gate-lifting process (**Figure 14**), similar to the gate-lowering process (**Figure 11**), the velocity remains constant at 2.14 cm/s throughout the stroke, corresponding to a load force of 1.52 tons. The simulation results are consistent with the experimental problem above.

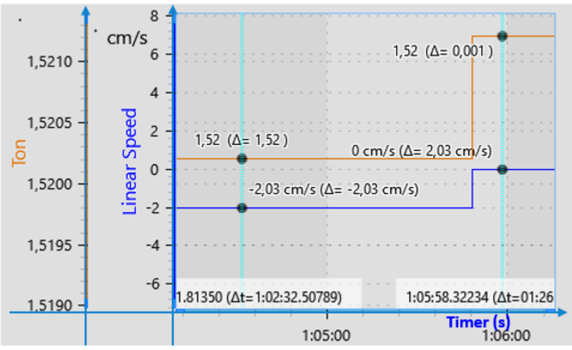

Figure 14. Velocity/force diagram for gate lifting.

Thus, during the gate-lifting and gate-lowering processes, the system parameters remain nearly unchanged. The only differences are the time and force, with the lifting force being greater than the lowering force.

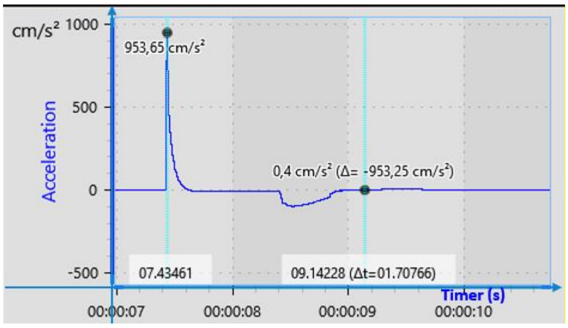

Figure 15. Piston acceleration process.

Although most of the piston's stroke involves linear motion, at certain moments, the piston's motion undergoes nonlinear acceleration (**Figure 15**). At the beginning of the gate-lowering process, the acceleration is higher compared to the gate-lifting process, which depends on the state of the piston, whether in the pushing or retracting mode. Based on these results, to increase the lifespan and reduce damage to the hydraulic systems, it is necessary to reduce the values associated with the acceleration process or the piston startup process.

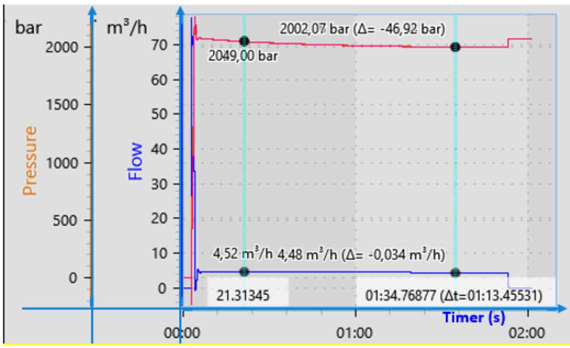

Figure 16. Flow rate and pressure in/out of the throttle valve during the gate lowering process.

For the throttle valve and hydraulic piping, the simulation results show that the pressure remains relatively stable throughout both the lifting and lowering processes, indicating that the system operates stably, ensuring the flow rate and pressure stay within the allowable range. Similarly, for the pump, the acceleration process at the beginning occurs, with the transient period lasting for 2 seconds. To minimize the transient process, the author will propose a solution in another article.

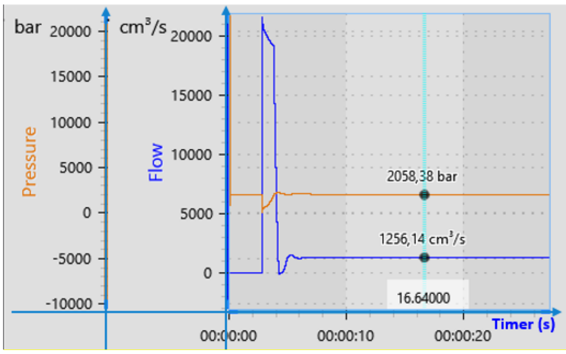

Figure 17. Flow rate and Pressure of the pump.

3. CONCLUSION

The paper has achieved the following results:

The hydraulic system for lifting and lowering sluice gates in saltwater barriers in Binh Dinh province has been studied and designed.

Designing a system based on the actual data from the Ha Gach Dam demonstrates the feasibility of implementing the proposed hydraulic drive system, which is entirely compatible with the economic criteria and ensures technical reliability.

The simulation results using Automation Studio, based on actual data, are consistent with the theory and align with the calculated data presented above.

In addition to the results of the paper proposing the use of a hydraulic system for operating the gate lifting and lowering, the content also opens up the possibility of using solar energy to power saltwater barriers that currently do not have access to the electrical grid.

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