Energy Loss and Efficiency of Baoying Pumping Station System

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Abstract. In order to decrease energy loss and improve efficiency for Baoying pumping station system, under different operating conditions, energy loss of each part was calculated, and the influences of the number of running pumps and the pump assembly head on the energy consumption and efficiency were analyzed. The results show that under design condition, with the increment of the number of running pumps, the energy loss rate of main pump units is increased first and then decreased, and that of the auxiliary equipment, power transmission and transformation is gradually decreased and increased respectively. Under the same head, the system efficiency is the highest when two pump units are running. As the pump assembly head increasing, the system efficiency is increased gradually, and it is decreased when the head reaches 8 m. The results are of great significance for the optimal design and optimization operation of similar pumping station systems.

Introduction

In order of energy transportation and conversion, the energy loss of large pumping station system includes energy loss of power transmission and transformation, main pump units and auxiliary equipment. At present, the pump efficiency of large pumping stations has reached more than 90%, and the motor efficiency has reached more than 95%. There have been many in-depth studies on the energy performance of main units (including flow passages) in pumping stations, and it is difficult to greatly improve the unit efficiency from design perspective.


In the optimization operation of pumping station, Pawel Olszewski [8] studied genetic optimization and experimental verification of complex parallel pumping station with centrifugal pumps. Zhang Haoran et al. [9] put forward a hybrid computational approach for detailed scheduling of products in a pipeline with multiple pump stations. If the pumping station takes full account of the energy consumption of each part in the optimization operation calculation, the result will be further optimized.

Therefore, it is necessary to comprehensively analyze the performance and energy consumption of all energy-consuming equipment in the pumping station system, and the results will provide a basis for mining energy-saving potential of the system and improving system efficiency.
Engineering Situation of Baoying Pumping Station

The Baoying pumping station is a part of the source pumping station of Eastern Route of the South-to-North Water Transfer. The engineering is located in Baoying County, Jiangsu Province, China. In the pumping station, four vertical mixed-flow pumps with the regulation mode of adjustable blades are installed, where one is standby. The total design flow rate is 100 m$^3$/s, and which is 33.4 m$^3$/s of single machine. The design head is 7.6 m, the rated power is 3400 kW, and the impeller diameter of the pump is 2 950 mm. Elbow type inlet passage and siphon outlet passage are used. The mainly function is to transfer water to the north, and the secondary is drainage.

In the pumping station, auxiliary equipment continuously operating includes four excitation transformers, two water supply pumps (where one is spare), ten ventilators (where two for each main pump and two for the main transformer), four cleaning machines, one belt conveyor, and lighting equipment, etc. Their unit capacity is 100, 22, 0.25, 10, 22.5 and 10 kW respectively.

In the pumping station, one main transformer of SFZ10-20000/110/10.5 type is installed, and its no-load loss is 16 kW, load loss is 88 kW, no-load current is 0.5%, and impedance voltage is 10.5%. One station transformer of SCB10-500/10 type is installed, and its no-load loss is 1.16 kW, load loss is 4.88 kW, no-load current is 0.6%, and impedance voltage is 4%. From the substation to the main transformer, the overhead line is 25.1 km long and the cable is 1.895 km long, and their resistance is 0.1542, 0.0972 R/(Ω·km) respectively. From the main transformer to the main motor bus, the cable is 0.02 km long, and its resistance is 0.727 R/(Ω·km).

Calculation Method

The effective power $P_{\text{eff}}$ (unit: kW) of pumping station system is

$$P_{\text{eff}} = \sum_{i=1}^{n} \frac{\rho g Q_i H_z}{1000} \tag{1}$$

where $\rho$ is the water density, kg/m$^3$; $g$ is the acceleration of gravity, m/s$^2$; $Q_i$ is flow rate of the $i$th pump, m$^3$/s; $H_z$ is pump assembly head, m; $n$ is the number of running pump units.

The system energy loss $\Delta P_{\text{loss}}$ is the sum of the energy consumption of the main units, auxiliary equipment and power transmission and transformation, that is

$$\Delta P_{\text{loss}} = \Delta P_{\text{main}} + \Delta P_{\text{aux}} + \Delta P_{\text{power}} \tag{2}$$

where $\Delta P_{\text{main}}$ is the energy loss of main units, kW; $\Delta P_{\text{aux}}$ is the energy consumption of auxiliary equipment, kW; $\Delta P_{\text{power}}$ is the energy loss of power transmission and transformation, kW.

The energy loss of the main units can be calculated according to known parameters such as pump assembly efficiency, motor efficiency and transmission efficiency, that is

$$\Delta P_{\text{main}} = \frac{P_{\text{eff}}}{\eta_z \cdot \eta_{\text{mot}} \cdot \eta_{\text{int}}} - P_{\text{eff}} \tag{3}$$

The auxiliary equipment includes water supply system, ventilation system, cleaning system, lighting system and station transformers, etc. Its energy consumption is the sum of the energy loss of electrical equipment in the pumping station participating in the operation, and the specific calculation method can be found in the literature [10]. The energy loss of the power transmission and transformation system is related to the power supply load, rated parameters of the transformer and the cable.

Thus, the input power $P_{\text{sys}}$ and the system efficiency $\eta_{\text{sys}}$ of pumping station system can be expressed as

$$P_{\text{sys}} = P_{\text{eff}} + \Delta P_{\text{loss}} \tag{4}$$
\[ \eta_{sys} = \frac{P_{eff}}{P_{sys}} \]  

**Results and Analysis**

For Baoying pumping station, under the design conditions, the pump assembly head is 7.6 m, and the pump blade angle is -2°. According to Eqs. (1)–(5), for different number of running pumps, the energy consumption of auxiliary equipment and the energy loss of power transmission and transformation are shown in Table 1 and Table 2, respectively. It can be seen that as the number of running pumps increases, the energy loss of each part increases, and the increase rate is not proportional to the number of running pumps.

Table 1. Power of auxiliary equipment in pumping station under design conditions.

<table>
<thead>
<tr>
<th>No. of Running Pumps n [set]</th>
<th>Water Supply System ΔP_{sys}[kW]</th>
<th>Trash Rake ΔP_{t}[kW]</th>
<th>Ventilation ΔP_{vent}[kW]</th>
<th>Lighting ΔP_{lig}[kW]</th>
<th>Station Transformer ΔP_{itr}[kW]</th>
<th>Auxiliary Equipment ΔP_{aux}[kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.90</td>
<td>11.41</td>
<td>1.00</td>
<td>10</td>
<td>2.01</td>
<td>38.32</td>
</tr>
<tr>
<td>2</td>
<td>14.82</td>
<td>22.82</td>
<td>1.25</td>
<td>10</td>
<td>3.26</td>
<td>52.15</td>
</tr>
<tr>
<td>3</td>
<td>16.00</td>
<td>34.24</td>
<td>1.50</td>
<td>10</td>
<td>5.23</td>
<td>66.97</td>
</tr>
<tr>
<td>4</td>
<td>16.86</td>
<td>45.65</td>
<td>1.75</td>
<td>10</td>
<td>7.92</td>
<td>82.18</td>
</tr>
</tbody>
</table>

Table 2. Energy loss of power transmission and transformation under design conditions.

<table>
<thead>
<tr>
<th>No. of Running Pumps n [set]</th>
<th>Line from Bus to Main Motor ΔP_{lin}[kW]</th>
<th>Line from Main Transformer to Bus P_{in2}[kW]</th>
<th>Overhead Line ΔP_{lin2}[kW]</th>
<th>Main Transformer ΔP_{itr}[kW]</th>
<th>Power Transmission and Transformation ΔP_{power}[kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.011</td>
<td>1.71</td>
<td>4.02</td>
<td>34.74</td>
<td>40.48</td>
</tr>
<tr>
<td>2</td>
<td>0.022</td>
<td>6.76</td>
<td>15.93</td>
<td>60.73</td>
<td>83.44</td>
</tr>
<tr>
<td>3</td>
<td>0.033</td>
<td>16.08</td>
<td>38.05</td>
<td>108.68</td>
<td>162.84</td>
</tr>
<tr>
<td>4</td>
<td>0.044</td>
<td>28.56</td>
<td>67.93</td>
<td>172.99</td>
<td>269.52</td>
</tr>
</tbody>
</table>

Table 3 shows the calculation results of the effective power, total energy loss and system efficiency of the pumping station system. It can be seen that as the number of running pumps increases, the effective power and total energy loss are increased. When two pumps are running, the system efficiency reaches the maximum, which is 78.4%. And when four pumps are running, the system efficiency reaches the minimum, which is 77.9%.

Table 3. Energy loss and efficiency of pumping station system under design conditions.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2438.14</td>
<td>604.12</td>
<td>38.32</td>
<td>40.48</td>
<td>682.92</td>
<td>3121.1</td>
<td>78.12</td>
</tr>
<tr>
<td>2</td>
<td>4876.27</td>
<td>1208.25</td>
<td>52.15</td>
<td>83.44</td>
<td>1343.84</td>
<td>6220.1</td>
<td>78.40</td>
</tr>
<tr>
<td>3</td>
<td>7314.41</td>
<td>1812.36</td>
<td>66.97</td>
<td>162.84</td>
<td>2042.17</td>
<td>9356.6</td>
<td>78.17</td>
</tr>
<tr>
<td>4</td>
<td>9753.54</td>
<td>2415.49</td>
<td>82.18</td>
<td>269.52</td>
<td>2767.19</td>
<td>12520.7</td>
<td>77.9</td>
</tr>
</tbody>
</table>

The energy loss rate is defined as the percentage of this energy loss and total energy loss of the system. The energy loss rate of main units is the maximum, which is 87.3%~89.9%. Also, the energy loss rate of power transmission and transformation is 5.9%~9.7%, and that of auxiliary equipment is 3.0%~5.6%. Fig.1 shows the change law of the energy loss rate of auxiliary equipment, power transmission and transformation and main units of the pumping station with the number of running pumps. It can be seen that as the number of running pumps increases, the energy loss rate of main units increases to the highest value first, and then gradually decreases, but the varying rate
is not large. When two pumps are running, the energy loss rate of main units is the largest; and when four pumps are running, the energy loss rate of main units is the least.

As the number of running pumps increases, the energy loss rate of auxiliary equipment gradually decreases, and that of power transmission and transformation gradually increases. There are two main reasons: (a) The power of single pump unit is large, so is the current through the transmission line, and the energy loss of transmission increases exponentially with the increase of the number of the running units. (b) The rated capacity of the main transformer is large (20000kVA), and its rated no-load loss and rated load loss are also large. When all pump units in the pumping station are operating, the load rate of main transformer reaches 0.58. Therefore, the loss of main transformer is large in actual operation.

![Figure 1. Relation between rate of energy loss and No. of running pumps under design operation conditions.](image)

![Figure 2. Relation among system efficiency, pump assembly head and No. of running pumps.](image)

As shown in Fig. 2, in the actual operation of pumping station, the efficiency of pumping station system varies with the number of running pumps and the pump assembly head. It can be seen that under the same head, the system efficiency is the highest when two pumps are running. Therefore, if the user only needs to meet the pumping volume within a certain period of time, and does not limit the operating flowrate of pumping station, two pump units could be operated to achieve the purpose of improving system efficiency and saving energy.

With the increment of the pump assembly head, the system efficiency is increased gradually first, then the system efficiency is decreased. When the pump assembly head is 8 m, the system efficiency is the highest. At the design head 7.6 m, the system efficiency is slightly lower than the maximum value and is located in the high efficiency area. When the pump assembly head is less than 5 m, the system efficiency is decreased rapidly and is far from the high efficiency area.

According to the former calculation and analysis, the energy loss rate of auxiliary equipment and power transmission and transformation equipment is about 10%, and there is certain energy saving
potential. Therefore, we can further study the countermeasures to reduce the energy consumption of the pumping station system from the two aspects.

Conclusions
Through the calculation and analysis of Baoying pumping station system, the following conclusions are obtained.
(1) The energy loss rate of main units, power transmission and power transformation and auxiliary equipment under design conditions are 87.3%~89.9%, 5.9%~9.7% and 3.0%~5.6%, respectively.
(2) With the increment of pump assembly head, the system efficiency of pumping station accords with the law of first increasing and then decreasing. In the case of certain pump assembly head, as the number of running pumps increases, the system efficiency is increased first and then decreased. The design head of pumping station is located near the highest point of system efficiency.

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References