

The Impacts of Head Loss on the Bulb Turbine's Hydropower Utilization and Running Performance

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Abstract

Because of the truth that the earth resources become increasingly tense, Low-head bulb turbine group was relatively fast developed and constructed in a time. The number of its running on the various types of rivers has reached a certain degree. However, its main problems are water utilization and running performance are not optimal. Its stand-alone capacity is small, therefore the problem has not attracted attention in the academia. In this paper, we based on the typical bulb turbine as the research object, using UG to the whole flow passage of mathematical modeling, based on the model of the operating characteristic curve, through Ansys software analyzes unit internal flow field calculation, and found that in a combination of guide vane and the blade opening, the head loss is the major cause of water can not efficient conversion. When increase the effective water head, can improve the output and efficiency of unit. Further analysis of the whole flow passag, the runner outlet flow patterns and the runner blade pressure, finding that the conditions can improve the turbines running performance at the same time. In the real machine test and long running practice, the above calculation results were verified.

Keywords: the bulb tubular turbine, head loss, water utilization, running performance

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1. Introduction

In order to obtain clean energy, the countries all over the world was once developed hydropower priority, to increase the utilization of water resource. In view of ecological protection, on the Danube river in Austria and Rhone river in France, the Rhine in Germany, Yellow river in China and other river, the bulb tubular turbine hydroelectric station of no capacity, low head and large flow has been constructed and operated in a certain degree already [1]. Bulb tubular turbine unit was designed for the development of low head of water resource, the low head hydraulic unit has an inevitable problem: the factors of head change sensitive, water utilization is not optimal [1]. In the academic, mere study about the bulb tubular turbine was included. Only Yang Minlin analyzed in the tubular turbine flow field measurement in energy experiment platform; Song Wenwu and other people Using UG and Fluent software to make 3-D model design and the analysis of flow field for conical tubular turbine water guide. Tubular turbine research is currently still in the stage of exploration and development. There still have some gaps between theoretical analysis and actual operations. When it running under the design water head, efficiency and the operation condition is not stable especially for the analysis about the water utilization and running performance of the of bulb tubular unit.

In this paper, aiming at the existing problems in the operation of the bulb tubular turbine, exploring the influence on the efficiency of hydro-generator units and running performance when increasing effective water heads appropriately. In order to provide a solution to letting low head unit run efficiently, and improve the utilization of the water resources.

2. Bulb Unit's Water Utilization and Running Performance Problems

The turbine of Chai ji Xia hydropower station is a typical bulb tubular unit which running on the mainstream of the Yellow river. It has a 6.8m water head, single capacity is 24MW. At the

beginning of the operation period, due to accumulated debris from the inlet trash rack of the unit and the downstream river bed is not unobstructed, the head loss is more seriously, the unit output and efficiency of measurement under the rated conditions can not meet expectations, under some conditions, the generator running performance is bad, which caused some damage to the equipment. As shown in Figure 1 for the rotor of the generator and runner chamber cracks in the run, affect the efficient operation of the generator set, this kind of phenomenon is widespread in the similar unit.



Figure 1. Generator Rotor Stand and Runner Chamber Cracks

3. Bulb Turbine'S Internal Flow Field Calculation after Increasing Effective Heads.

3.1. Three-Dimensional Turbulent Flow Field Mathematical Equations

Bulb turbine is a horizontal structure, the internal flow is a complex three-dimensional viscous incompressible turbulence, its variation can be described by Navier-Stokes equations [3, 4].

$$\begin{cases} \nabla \cdot \mathbf{u} = 0 \\ \rho \frac{d\mathbf{u}}{dt} = \rho \mathbf{F} - \nabla p + \mu \nabla^2 \mathbf{u} \end{cases} \quad (1)$$

When calculating the internal flow field in turbine, using the reference coordinate system with the impeller to rotate Goes around the Z axis at a fixed angular velocity ω relative rectangular coordinate system (x, y, Z) , N - S equation of the form to:

$$\begin{cases} \frac{\partial u_j}{\partial x_j} = 0 \\ \rho \frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = F_i - \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \frac{\partial^2 u_i}{\partial x_j^2} \end{cases} \quad (2)$$

In the equation, ρ is fluid density, μ for hydrodynamic viscous coefficient, u_i, u_j ($i = 1, 2, 3; j = 1, 2, 3$) for the velocity components, p is pressure, for the angular velocity ω , g is acceleration of gravity, F, F_i is unit mass force for the relative coordinate system: $F_1 = \omega^2 x + 2\omega v, F_2 = \omega^2 y - 2\omega u, F_3 = g$

In this paper, using Realizable K-E model to calculate the internal turbulence, the thoughts proposed by Shin, T-H [5, 6].

3.2. Ansys Numerical Calculation

Bulb tubular turbine is mainly composed of the inlet passage, the guide mechanism, the runner chamber, draft tube. Guide vane and the blade is complex space distorted shape, the modelling method is basically the same, which according to the block diagram, calculate the blade coordinates of points on the section line, to creat one by one. Then use non-uniform b-

spline curve fitting, get the cross section model, create the blade surface, closing a adult, so through the modeling idea of point - line - plane - body, to complete the modeling [7].

The guide vane and the blade in this paper using unstructured tetrahedral element mesh, the inlet passage, draft tube using a structured mesh, and the whole flow passage calculation domain formed the 2573345 grid nodes, 11208813 grid cell.

In this calculation, the turbine inlet boundary of inlet for the rule-shaped tube, the flow direction is perpendicular to the inlet, export turbulent kinetic energy and turbulent dissipation rate can be obtained by calculation. Outlet boundary is the export of the draft tube, the outflow directly into the downstream, calculations using the free outflow [9, 10].

To Select the turbine guide vane opening 51.5 °, blade opening is 19 °, calculate the penetration of water bulb turbine combined characteristic curve of the finest unit speed line (n₁₁ = 192 r/min, Q₁₁ = 157500 kg/s), the corresponding flow, the water head, according to the bulb turbine combined characteristic curve, shown in Figure 2, according to (1), (2) the type of inlet flow and head were calculated, respectively, in 180754 kg/s, 180754 kg/s, 192754 kg/s, 192754 kg/s, respectively, to 5.49 m, 6.49 m, 7.07 m, 7.57 m flow field is calculated.

$$H = \left(\frac{n \times D}{n_{11}} \right)^2 \tag{3}$$

$$Q = Q_{11} \times D^2 \times \sqrt{H} \tag{4}$$

Type of H is the head, m; N is the rated speed, r/min; D is the wheel diameter, m; N₁₁ is the unit speed, r/min; Q is the actual flow, kg/s; Q₁₁ is the unit flow, kg/s.

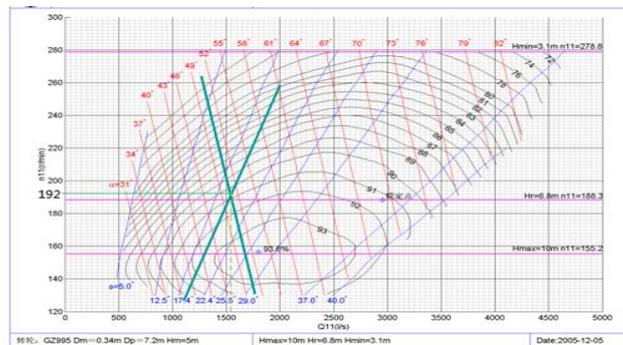


Figure 2. The Combined Characteristic Curve of the Bulb Turbine

4. The Analysis and Study of Bulb Turbine Group’s Calculation Results

4.1. The Analysis of Power and Efficiency

Table 1. The Unit's Flow, Efficiency and Output Under Different Water Head

Water head(m)	Flow rate(kg/s)	output(MW)	efficiency(%)
5.49	180754	8.73268	89.6955
6.49	188754	11.3264	94.2107
7.07	192754	12.6926	94.9732
7.57	208754	18.5823	94.9837

Bulb tubular turbine belongs to the Kaplan turbine, we can get the turbine running external characteristic after calculating in the selection condition, the specific data as shown in Table 1 can be seen, as the head increase, machine flow also does, and calculate the turbine output increase gradually, growth of 9.8455 MW, it accords with the theory. Efficiency is an

important indicator for the evaluation of the turbine's operating characteristic, checking from the design of the integrated characteristic curve, the point efficiency between 90% and 91%, the efficiency of numerical calculation can be seen from Table 1, as the change of water head from 5.49m to 7.57m, the efficiency increased by 5.2882%.

4.2. The Whole Flow Passage Flow Patterns Analysis

The turbine guide in the combination of the opening of the vane in 51.5° and the blade in 19° , the water head gradually changes from 5.5m to 5.5m, the whole flow passage was calculated in four kinds of working conditions, calculation results as shown in Figure 3, 4, it can be seen that flow in front of the unit, also is the inlet part, maximum velocity of increase is about 0.331 m/s, which matches the increasing of the unit power. draft tube partial flow field and flow patterns stable is directly related to the unit's efficiency and the whole shafting stability. Draft tube vortex rope is the main hydraulic factors of the bulb unit's unstable flowing. See from the calculation results in four kinds of working condition, while with the increase of water head, draft tube positive circulation has increased significantly, but did not form a part of the Draft tube vortex rope obviously, flow increase after there is no the eccentric vortex, uniform velocity distribution base, has a certain symmetry, no secondary flow, local flow and reflow phenomenon, tail water partial pressure pulsation can be expected to compare stability [12]. Bulb turbine has a low head, the flow is relatively large, a large proportion of total energy outlet kinetic energy [13], the amount of change from the analysis of the entire ring, whole flow passage of the kinetic energy difference increases with the head, this kinetic energy difference form, for water use, electricity is particularly important.

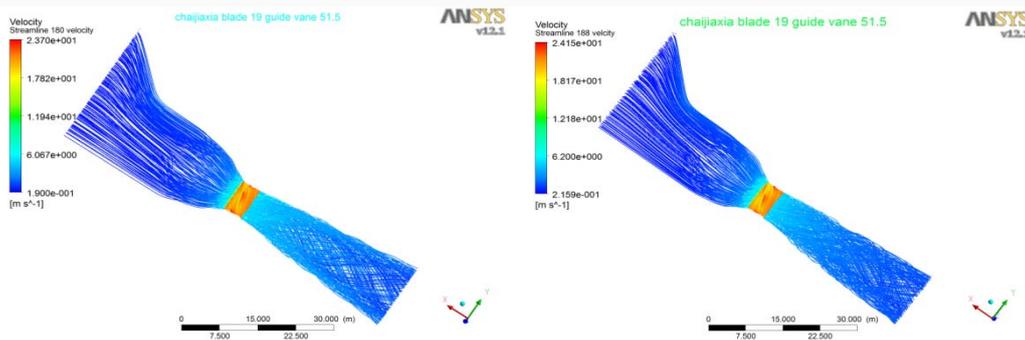


Figure 3. The Flow Pattern in the Full Hydraulic Duct of the Unit When Head of 5.5m And 6.5m

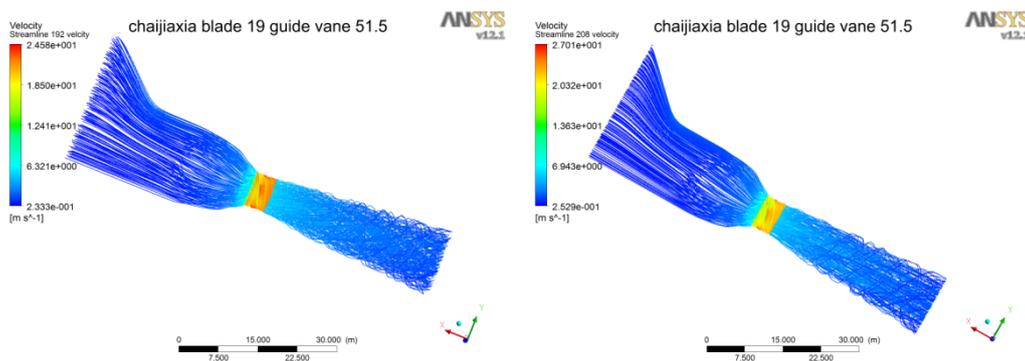


Figure 4. The Flow Pattern in the Full Hydraulic Duct of the Unit When Head of 7.0m And 7.5

4.3. The Analysis of Turbine Runner Outlet Flow Patterns

Runner is the most core flow components in turbine, and Water flow through the runner to complete energy conversion. The quality of the fluid flow pattern in the runner play a decisive

role in the efficiency of the energy conversion. Figures 5, 6 for four calculation under the condition of runner outlet flow, usually analysis runner outlet speed factor and circulation factor change [14] velocity circulation factor, It can be seen that with increasing available head, runner circumferential velocity increases too, Maximum velocity of increase about 0.418m/s, the kinetic energy of the water becomes big, and that is the basic mechanism of water power utilization rate increase. Turbine running performance has a great relation to the runner, Cavity vortex rope is the main causes of runner chamber vibration different sound. Theoretically, cavity vortex rope and runner outlet vortex flow pattern is closely related [15], see from turn state changes in turn, low water head, small flow positive circulation is not obvious, recirculation zone is large, the velocity distribution is unevenly, there is an eccentric vortex, with the increase of water head and flow, the positive circulation is more and more obvious, Velocity distribution is symmetric, local recirculation zone decreases.

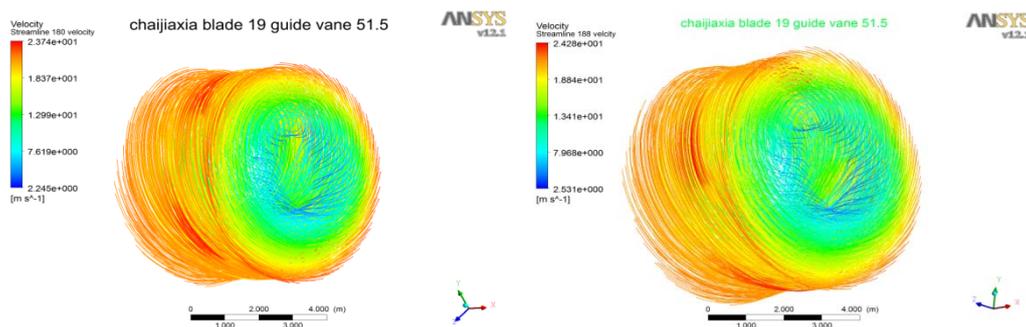


Figure 5. The Flow Patternn in the Outlet of the Runner When Head of 5.5m And 6.5m

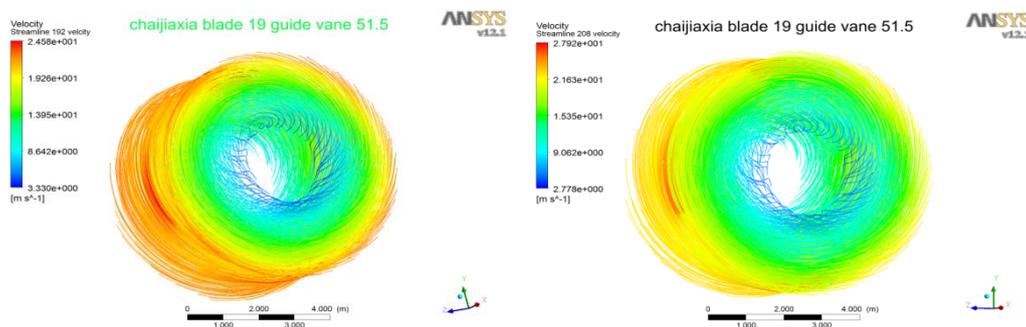


Figure 5. The Flow Patternn in the Outlet of the Runner When Head of 7m And 7.5m

Theoretically, a small flow rate zone pressure pulsation is caused by eccentric vortex, which is often accompanied with the appearance of recirculation area. in the recirculation zone axial velocity gradient is large, easy to form a vortex [16], coupled with positive circulation, the eccentric vortex circumferentially running strengthened, extending to the downstream, and formed eccentric vortex at the same time. And it is also one of the reasons for the deterioration of running conditions. The calculation results show that the small flow runner chamber is the leading causes of cracks.

4.4. Pressure Analysis of Turbine Runner

Figure 7-10 is the pressure distribution on the front and back of the runner, when the head is 5.5m-7.5m. To analysis the calculation results, with the increase of efficient water head, flow, pressure distribution of blade gradually increases, front and rear differential increases too, the kinetic energy has widened, while pressures are gradually become smaller from inlet to outlet, this accords with the improved water utilization. From the cloud maps of pressure

distribution, when the flow rate of 180754kg/s, the whole front of the blade is relatively small. On the back of blade inlet side there is a small amount of low pressure area, when flow rate increases to 208754kg/s, the pressure on the front and back of the blade increased, the low pressure area on the back become more and more unobviously. It can be predicted that the performance can be improved. According to Bernouli's equation, in the condition of the pressure from the water flow increased, thus the pressure on the blade increased correspondly, while, when the flow is small, the pressure at the outlet of the front and inlet of the back is relatively low, as well as the back edge of the blade also has low-pressure area, the flow is unstable and easily subject to cavitation damages [17-19].

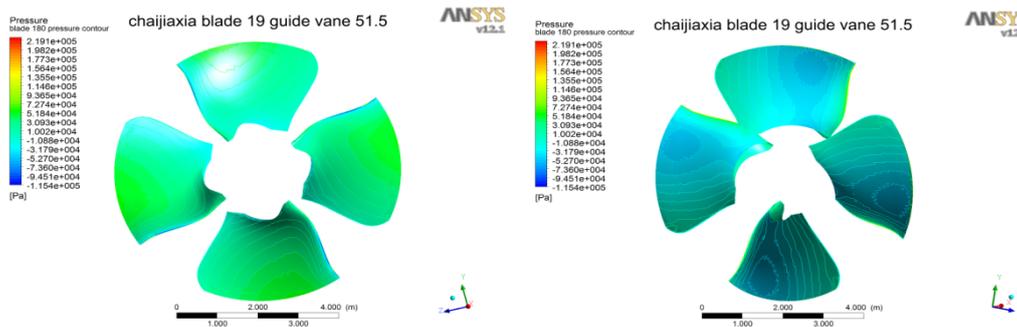


Figure 7. The Pressure Distribution on the Front and Back of the Runner Blade When Head of 5.5m

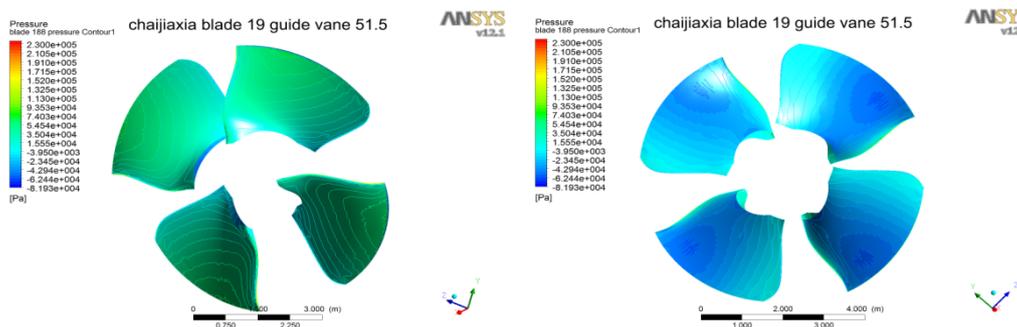


Figure 8. The Pressure Distribution on the Front and Back of the Runner Blade When Head of 6.0m

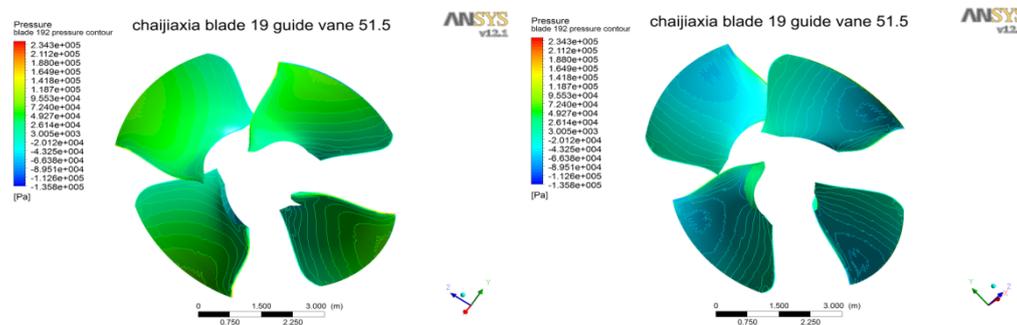


Figure 9. The Pressure Distribution on the Front and Back of the Runner Blade When Head of 7.0m

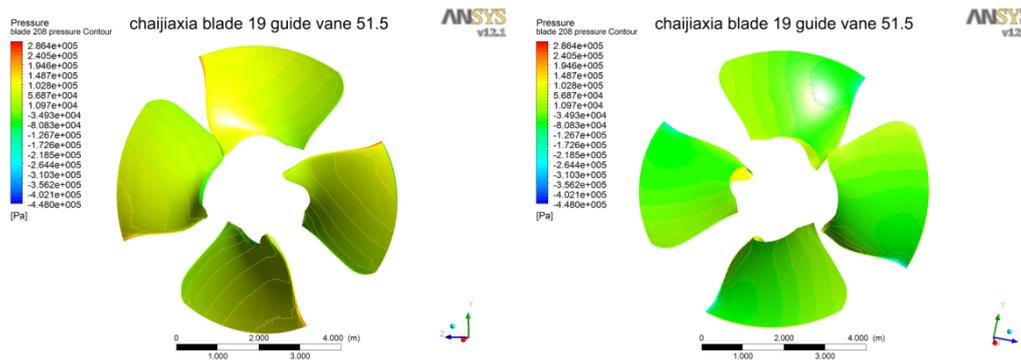


Figure 10. The Pressure Distribution the Runner Blade When Head of 7.5m

It can be inferred that, runner chamber and generator rotor crack related to the unit run for a long time in small load area. The existence of a small flow of low pressure area, the resistance of the blade become greater, leading the difference of pressure on the partial pressure surface and suction pressure surface greater too [20]. When the water flow into the blade cascade in relative velocity, portion of the velocity head at the inlet edge of the blade all become into pressure head, then along the inlet edge of the blade flowing around. The centrifugal force generated by bending often off the flow of the water from the blade, which can easily lead to water loss and flow instability [21]. Thereby forming a hydraulic vibration, causing the turbine and shaft vibration.

5. Operational Measures

Based on the above calculation and analysis, in the combination of a guide vane and the opening of the turbine blade, to increase the effective head appropriately has a certain role in improving the utilization of the water and the stabilization of the unit. Generally, the unit has a small reservoir inundation region, low water head, and constructed close to the residential area, easily lead to the dam of garbage clogging, especially in the flood season, the bags, straw, foam and other suspended matter in the water close to the trash rack, Severely narrowed the water flow area. The loss of trash rack between about 1-2m, Therefore, changing the decontamination method is an effective measure to reduce head loss. After the implementation, get of 0.5-1.4m head increases, the draft tube must has a certain length and diffusivity to complete the recycling water. However, many stations builded in an economic perspective, increase the length of the draft tube, excavation will greatly increased, and the cost be increased too. For small stations, they often can not constructed it in accordance with the design philosophy, led tail water level is too high. Additional, when removing the cofferdam after completing the construction, impacted by the working environment and schedule, they often can not excavate completely, which always affected the tail water. In addition, after a long term operation, riverbed gravel accumulated in downstream lead part of the bed increased gradually, so that a decline in net head [23]. So, clean the tail water riverbed, reducing its level is also an important measure to increase the effective head. After the implementation, we can get 0.5-0.8m head increases. The bulb turbine unit has a very low water head, Changes in water level upstream runoff could easily lead to instability, often resulted in the instantaneous loss of head. So, to take the ground preservation, adjustment operation mode another effective measure to increase the effective head, after the implementation we can get 0.2-0.5m head increases.

6. Real Test and Operating Results

In taking measures to increase the effective head, Effective field measurement head weights increased by approximately 0.78-1.02m. Real testing in the long-running practice, conclusions on the numerical calculation and analysis were verified on-site analysis of test results and calculation results are basically consistent.

6.1. Increase the Effective Output Before and After the Test Head

In the real machine test, in order to obtain accurate data and ensure measurement accuracy of the head, downstream water level sensors used in Germany GPH500 code disk. According to the site license conditions, adjust the turbine guide vane (51.5°) and the blade opening (19°), head in the 5.342~7.500m during the long-running. Operating data are shown in Table 2, with the increasing of head unit, the output is increasing, changes and calculation results are basically consistent.

Table 2. The Power before and after Increasing Effective Water Head

Water head (m)	output (MW)						
5.342	8.395	6.603	11.991	6.990	12.122	7.611	19.989
5.301	8.100	6.599	11.956	7.115	12.707	7.500	19.400
5.421	8.587	6.311	11.223	7.200	13.102	7.321	18.391
5.403	8.459	6.515	11.402	7.002	12.433	7.400	18.427
5.339	8.382	6.498	11.294	6.998	12.004	7.500	19.400

6.2. Draft Tube Pressure Pulsation Test

Real Test in tail water partially installed in the unit dedicated pipelines, leads to tail pipe ministries pressure, the pressure sensor with Swiss KELLER, accuracy of $\pm 0.2\%$, by measuring, can be collected into the tail pipe pressure fluctuation. Figure 11 is to increase the effective head around the draft tube pressure pulsation increases with head, tail pipe pressure pulsation changes basically stable, but declined slightly, which basically consistent with the conclusions of numerical calculations.

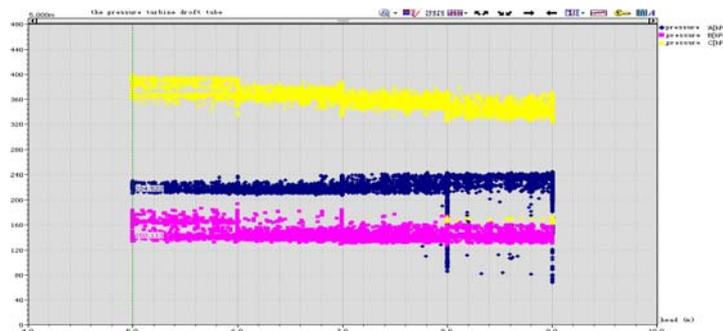


Figure 11. The Pressure Pulsation of the Turbine Draft Tube after Increasing Effective Water Head

6.3. Vibration Test

Runner chamber and generator For bulb turbine group is concerned, the generator rotor chamber and the turbine runner problems are more prone to crack [24]. After increasing the effective head of the operating characteristics of the unit test, you must examine the runner chamber and generator vibration [25]. In real machine test, with on-site installation of PSTA2003 system, vibration sensor of MLJ-9-type, swing sensor of Canadian PCS-3.2 type, etc. the system can complete the data monitoring, processing and analysis. Changes in the head range 0.78-1.02m, Figure 12 can be noticed. In the low-head section runner chamber, vibration is relatively large. With an effective head increases, vibration are decreasing and gradually stabilized which is consistent with the conclusions of the flow field analysis. After long-running runner chamber cracks can not be found. Hydraulic affected by the vibration generator, the stator of the generator can be one of the bulb head representative[26]. It can be seen from the figure, the bulb head vibration increases as the effective head, gradually reduced, the rotor crack can be effectively controlled.

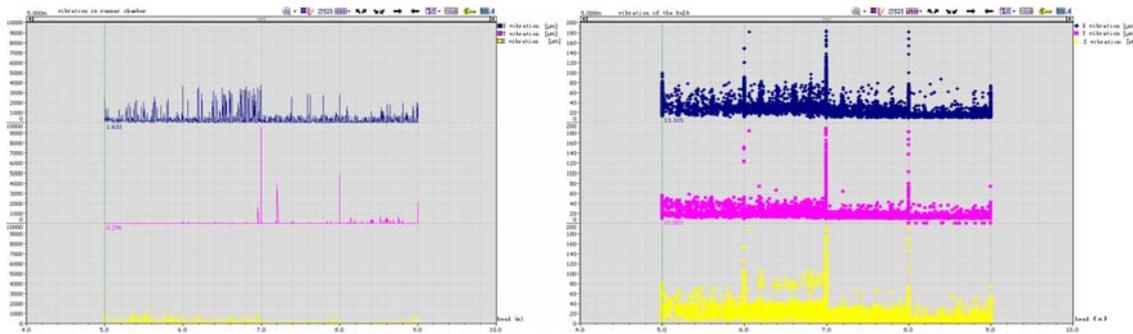


Figure 12. The Vibration of the Runner Chamber and Bulb after Increasing Effective Water Head

7. Conclusion

In this paper, ubiquitous Bulb turbine efficiency up to expectations, the problem of poor running performance. Research in bulb turbine guide vane (51.5°) and the blade opening (19°) working conditions combinations. Four head whole flow passage, blade runner and flow field, the calculated whole flow passage and the runner flow pattern, the blade pressure distribution, through the analysis found that with increasing head, draft is a significant increase in positive circulation, a substantially uniform velocity distribution, the whole flow kinetic energy difference increases. Overall circumferential wheel speed increases, the increase of the kinetic energy of water; blade increases and uniform pressure distribution, the front and back difference increases, the kinetic energy differential increase. These phenomena are the very underlying causes of increased water use efficiency. Calculating the maximum efficiency can be improved 5.2882%, and get experimental verification. Meanwhile more and more obvious with the nest cavity, partial chest disappeared, reducing the recirculation zone, high and low pressure zone is gradually leaves uniform, which is the turbine operating performance quality improvement mechanism. On this basis the conclusion decontamination methods used to change the scene to clean up the tail water riverbed way to keep the water level stable, increasing the effective head of about 0.78-1.02m. In the same conditions after real test with long-running, the above calculation conclusion consistent with the test results, to some extent, improve water utilization, unit operating performance improved runner chamber and generator rotor cracks not been seen again. This research will be applied to group bulb turbine vanes and blades in any combination and can be applied to both types of rivers currently running on low-head similar units. This study provides a similar way which is starting from the actual situation, through theoretical calculations and verified in practice to solve the problem. For the current trend of ecological protection of clean water bulb turbine water use will have a huge significance

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