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THE STANDARD SERIES OF S - TYPE TUBULAR TURBINE IN CHINA*

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ABSTRACT:
S-type tubular turbine has the advantages of compact construction, convenience in maintenance, low investment costs and high efficiency. Furthemore, the diffculties to accommodate a generator in the small bulb of the runner diameter less than 3 m for the design, installation and maintenance can be solved. Therefore, for medium and small output, S-type tubular turbines are suitable for the developing low head hydropower energy. A lot of hydraulic research, testing work and standard series designs of prototype units have been carried out by Tianjin Design and Research Institute of Electric Drive.
Following materials will be discussed in the paper:
1. Hydraulic performances for S-type tubular turbine;
2. Constructional features;
3. Standard series of products;
4. The application of S-type tubular turbine in China.

INTRODUCTION:

During the recent ten years, a lot of low head turbine-generator sets have been designed and manufactured for developing low head hydropower resources which are abundant in China.

In the same period, some bulb and open-pit turbine-generator sets were successfully commissioned. For example, GD004-WS-300 an open-pit turbine — generator set with a runner diameter of 3 m and capacity of 250 KW under 1.2 m rated head had been commissioned in May 1974; GZ003-WP-550 a bulb turbine-generator set of large size with a runner diameter of 5.5 m and capacity of 10 MW was successfully commissioned in July 1984. However, in case of medium and small horizontal bulb turbine with runner diameter less than 3 m, the turbine has a too small diameter of bulb, so that it is difficult to accommodate a generator in it from the design and maintenance viewpoint. The tubular turbine has the draft tube in S-shape, therefore, the generator can be installed outside of waterpassage on the downstream side of the turbine. The problem occurred to bulb turbine with small runner diameter would be solved. Furthermore, S-type tubular turbine has the advantages of compact construction, convenience in maintenance, minimum civil work, reliable in operation and high efficiency, therefore S-type unit used for exploiting low head hydro-power resources and rebuilding the old hydro-power stations is economically and characteristically better than vertical Kaplan turbine.

1. Hydraulic performances for S-type tubular turbine:

S-type tubular turbine is ideal for low head and large discharge. The characteristic of runner as well as the dimensions and configuration of the waterpassage will determine the hydraulic performances of S-type tubular turbine. A lot of research and testing work on the draft tube with different shapes and parameters, wicket gates with different numbers and several model runners have been carried out by our institute. The model runner GZ006 is possessed of good characteristic and suitable configuration of the waterpassage for S-type tubular turbine, it ensures a good operating performance of prototype unit.

1.1. The influcence of the draft tube on hydraulic characteristic:

Because the generator is installed outside of waterpassage for S-type tubular turbine, therefore the draft tube is bent in S-shape and the turbine shaft passes through it. In this case, the hydraulic loss in the large discharge region is increased due to the bending of draft tube in S-shape. The kinetic energy at runner exit is very large for the runner with high specific speed for low head, so that efficiency. recovering in draft tube is very important.

S-shaped draft tube consists of three parts: inlet conical tube, bending part and outlet diffuser. The flow in the draft tube is complex. Major hydraulic loss consists of diffusion, kinetic energy loss at outlet as well as the head loss caused by rotating shaft.

To make the axial length of the unit as short as possible and to have a good recoverable efficiency of draft tube, inlet conical tube with relative length $L/D_1 = 1$ and conical angle 16.5° are selected.

The bending part is an important piece constituting the draft tube in S-shape. To find out a suitable bending tube, two projects A and B were designed. Bending tubes are specified by cross sectional shapes at various locations. They have the same round cross section at inlet and rectangular cross section at outlet but different shape of cross sections between inlet and outlet. The change law of cross sections F_i along the geometrical centerline in bending tube for projects A and B are shown in Fig1.

The outlet diffuser is a horizontal one with rectangular cross section. The bottom of the diffuser has an inclination of 16.5°, what the diffusion effect is caused. The top of the tube is horizontal and the two side walls are parallel to each other.

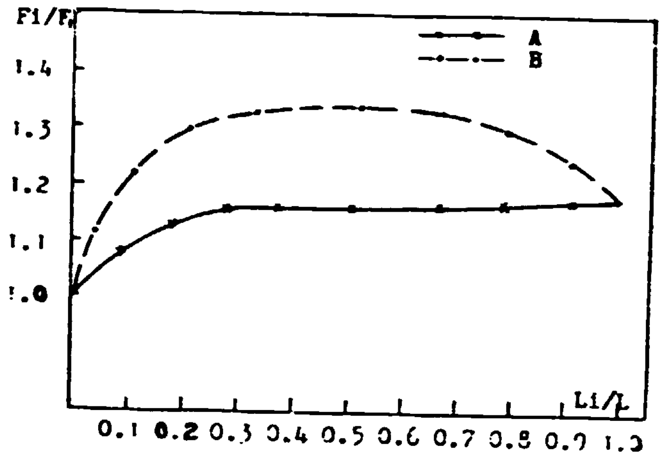


Fig1. The change low of cross sections F_i for projects A and B.

Both draft tubes in S-shape for projects A and B having the same inlet conical and outlet diffuser, but different shapes of bending tubes have been tested. The test results are shown in Fig2. The test results show that the efficiency of project A is better than that of project B by different values unit speed n_1'.

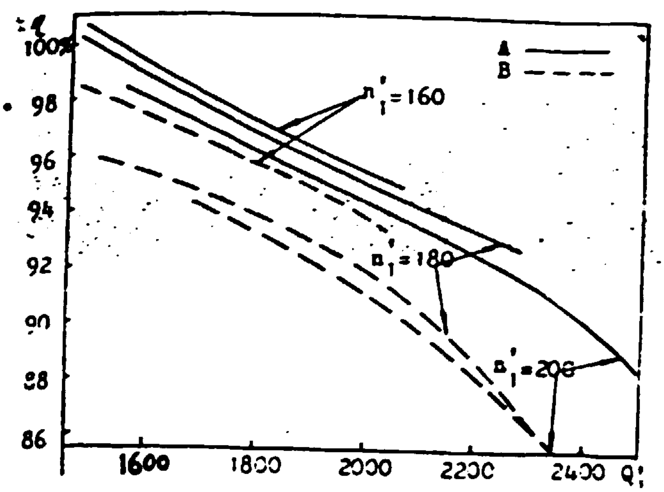


Fig2. The relation between relative efficiency and unit discharde Q_1' for projects A and B of draft tube.

1.2. The influence of the wicket gates with different numbers on hydaulic characteristic:

To meet the needs of S-type tubular turbine with different control systems and to simplify the construction of small output unit as well as to reduce the costs of production, two projects A and B with different numbers have been designed and tested. A and B projects have same outlet angles φ at each cross section. Project A is adjustable, l/t values at each cross section of the wicket gate are constant and the number of wicket gates is 12; project B has fixed gate, l/t=0.8 at outer section and l/t=1.2 at inner section and the number of wicket gates is only 7.

Projects A and B of the wicket gates with coordinative opening $a_0 = 50°$ have been tested in S - type tubular waterpassage. The test results are shown in Fig3. As can be seen in Fig3, the efficiency of project A is better than that of project B, in different values of n_1', $\Delta\eta = 1 \sim 3\%$. The efficiency of project B drops sharply, because of the too small numbers of wicket gates which may cause unsettled flow between the neighbouring wicket gates, so that hydraulic losses at runner blade inlet edge are increased. Therefore, the project with small numbers of wicket gate is suitable only for micro or small turbines, and project with bigger numbers of wicket gates is suitable for S-type tubular turbine with larger runner diameters and larger capacities.

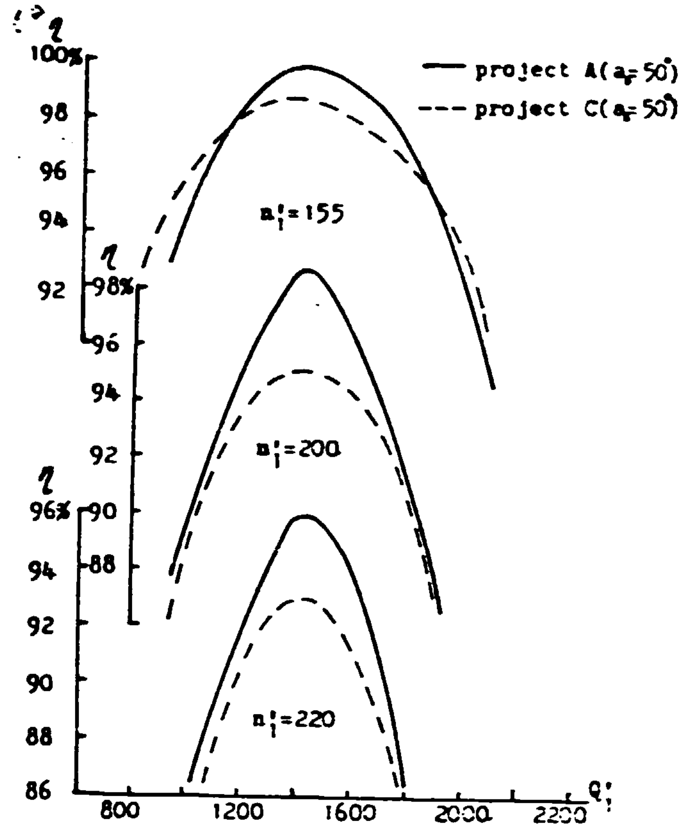


Fig3. The relation between relative efficiency and unit discharge Q_1' for projects A and B.

1.3. Comparison of four kinds of turbine performances with different combinations of runner blades and wicket gates:

There are four of S-type tubular turbine according to the different combinations of the wicket gates and runner blades:

Double regulated tubular turbine with adjustable runner blades and wicket gates ; Single regulated tubular turbine with adjustable runner blades and fixed wicket gates; Single regulated tubular turbine with adjustable wicket gates and fixed runner blades; Tubular turbine with fixed runner blades and wicket gates.

There are significant differences in hydraulic perfomance for the four kinds of S-type tubular turbine. They are proved by characteristic test of GZ006 model runner.

In Fig4, the solid line shows the double regulated unit, The broken shows the single runner blades regulated unit; The long and short

dash line shows the single wicket gates regulated unit;Small circle shows turbine with both runner blades and wicket gates are fixed.
It is worth noting that the runner hub of GZ006 is spherical and the throat ring is semi-spherical,under those conditions, all tests including the fixed blade propeller were carried out.

As can be seen in Fig4, there are differences in the efficiency of these turbines except at one point. Usually this point is close to the turbine rated flow. Except for this point,the difference in performance is significant. For double regulated type, excellent discharge variation and head variation performances are obtained, especially by discharge changes, the efficiency is apparently higher than the single regulated types. However, among them, the efficiency drop for single wicket gates regulated type is heavier in comparison with the single runner regulated type, and the discharge variation performance is extremely deteriorated.

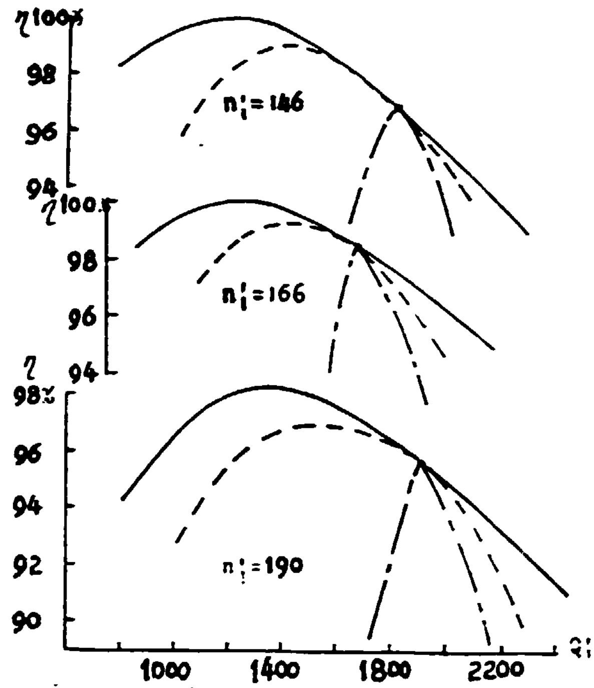


Fig4.A comparison of relative efficiency with discharge variations of the four kinds of S-type tubular turbine.

2.Constructional features:

There are four kinds of constructional type as mentioned above for S-type tubular turbine.The construction of unit with double regulated type is more complex than those of single regulated types, therefore suitable type of unit should be selected according to particular conditions on the site.

The principal components of S-type tubular turbine generator set are as follows:

Intake closure device.

Inlet section with guide vanes and guide bearing.

Distributor.(if unit is a double regulated type)

Turbine shaft with runner.

control unit.

Speed increaser and generator.
Major features of S-type tubular turbine with adjustable runner blades and fixed wicket gates, designed by our institute will be discussed in this chapter:

Intake closure device:

The intake closure divice provides tight shut-off of the waterpassage, while the unit is shutdown. In addition, it must be able to provide for emergency shutdown in event of loss of load or any other malfunction. The intake closure device and its operating mechanism must therefore be carefully selected and designed to meet the necessary operating conditions. According to the runner diameters and output, butterfly valve or high-speed gate may be chosen.

There are two types of construction for adjustable runner blades:

2.1. The inlet section including guide vanes is a welded construction of steel. The vanes which are welded in position, also support the upstream bearing located within a water-tight housing. The bearing is oil-lubricated, and a device of waterproof seal is located at downstream side of the guide bearing in the bulb. Lubricating oil supply and drain pipes for the guide bearing pass through inside cavity of the vanes which are shaped for optimum hydraulic performance.

The turbine throat ring is a fabricated steel extension of the vaned intake, it is connected to inlet section by a flange joint. The draft tube having a hydraulically favourable configuration with smooth bends is of high energy recovery. Stiffening ribs are provided to minimize distortion and vibration. The top portions of both draft tube and throat ring are removable for access and removal of the runner and shaft. The lower portion of draft tube is concreted into the bedding. The shaft packing box with an adjustable gland is mounted on the draft tube elbow and conventional woven square packing is used.

The adjustable blade operating mechanism consists of steel levers attacked to the blade trunnions. The levers are connected by links to the crosshead which interlocks all blades at same angle. It is positioned by the blade operating rod which extends through the turbine shaft to a hydraulic blade positioner located on the outboard side of the speed increaser. The runner hub linkage and blade trunnions are supported on bronze bushing which are lubricated by oil

from within the hub.
A shaft extension is provided from the runner hub into the upstream bearing in the bulb and another extension is used in conjunction with the outboard combination guide and thrust bearing. These bearings carry all mechanical and hydraulic loads imposed by the turbine.
The hydraulic blade positioner consists of a pivot mounted hydraulic cylinder and some levers. The cylinder is controlled by either a speed frequency governor, load controller, or a head water level sensing control.
For hydraulic power stations with low head, to reduce costs a standard type high-speed generator is employed. A speed increaser is located between the turbine shaft and generator to provide a suitable step-up ratio from the rated turbine speed to the generator speed. The speed increaser will contain the turbine downstream guide and thrust bearing.
The generator may be either of the synchronous or induction type depending upon relative economics and system limitations.

2.2. Main features of another construction with adjustable runner blades are as follows:
The runner blade servomotor, oil supply head and the upstream guide bearing are located in the bulb. Lubricating oil supply and drain pipes for the oil supply head and guide bearing pass through the inside cavity of the vanes. The hydraulic blade positioner is replaced by the runner blade servomotor located in the bulb.
A shaft extension is provided in the upstream bearing, one end of

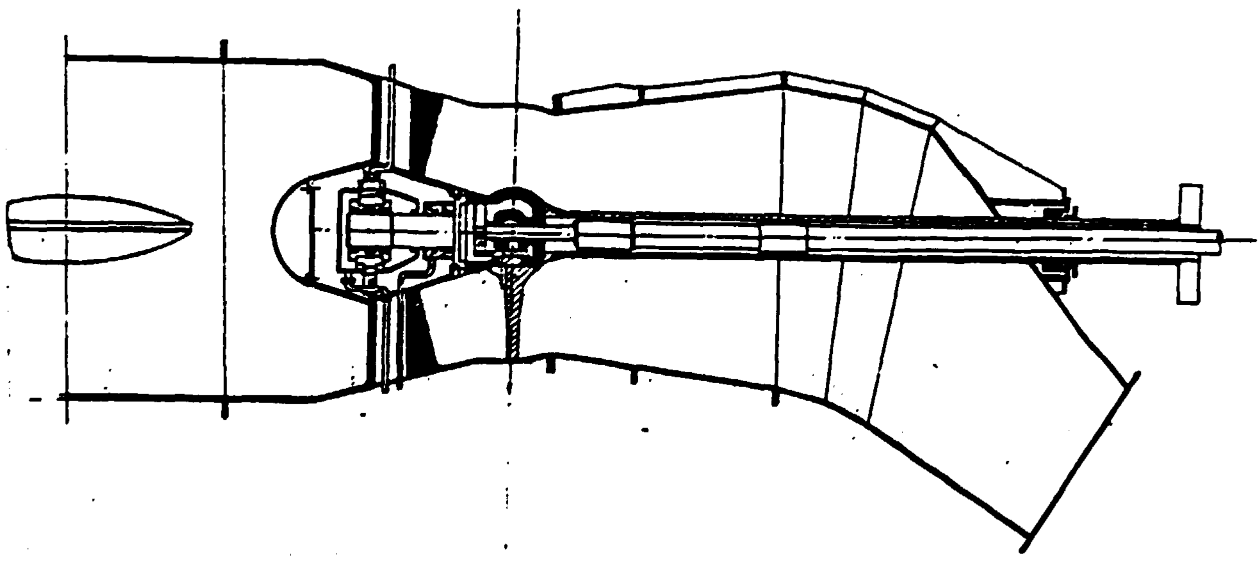


Fig5. Cross section of S-type tubular turbine.

shaft is connected with oil supply head and another end is connected with servomotor cylinder cap. The oil supply and drain pipes for the runner blade servomotor pass through the shaft hole. The lever of servomotor piston is connected to the crosshead which interlocks all blades at the same angle via steel links. Another shaft is a seamless tubing which extends through the draft tube and is used in conjunction with the outboard combination guide and thrust bearing. Other constructions are as mentioned above.
Cross section of S-type tubular turbine is shown in Fig5.

3. Standard series of products:
Standardized hydroelectric units of S-type tubular turbine can reduce the power plant and equipment costs. Standard series of products are adoptable for upgrading the old existing low head plants, for making previously uneconomic sites attractive and also for new power installations. Bulb turbines have good efficiency and large discharge. For bulb turbine-generator sets with large capacity, there isn't any difficult to acommodate a generator in the bulb, therefore better economic benefit could be obtained if bulb units were adopted.
We consider that it is available to adopt bulb unit when runner diameter is greater than 3 m; However, when runner diameter is less than 3m, for medium and small output, S-type tubular turbines with the generator installed outside of waterpassage are the ideal type.
S-type tubular turbine are suitable for:
Head: H=2~15m, Flow: Q= 0.5~60 m^3/sec, Output: N =55~5000 kw.
Eleven standard turbine sizes with runner diameter ranging from 800 mm to 3000 mm, provide generator outputs from 55 kw to 5000 kw under 2~15 m head.
The standard sizes in diameter are as follows:

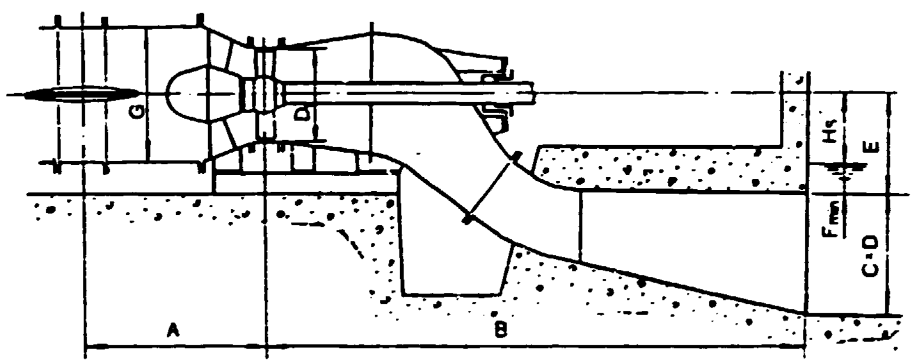
800, 1000, 1200, 1400, 1600, 1800, 2000 mm (ascending in 200 mm stages)

2250, 2500, 2750, 3000 mm.(ascending in 250 mm stages)

According to conditions on the site, one of them can be selected.
If the turbine discharge is mainly constant, the turbine can be very simplified and costs be reduced by using fixed position runner blades.
Where flow control is necessary such as at run-of-the river installations or where it is economically justified by added kilowatt hour output, adjustable runner blades provide a wide range of good efficiency.

When $n \geq 600$ rpm, (n: Speed of turbine) the turbine is direct connected with the generator;
When $n < 600$ rpm, a speed increaser is used.
When $H \geq 11$ m, runner with 5 blades;
When $H < 11$ m, runner with 4 blades.
To simplify the maintenance, the elevation of erection of the turbine should have positive values . When head $H < 10$ m, model cavitation coefficient of runner should be to ensure H_s a positive value; When head $H > 10$ m, H_s may have a negative value, but at best not lower than – 2 m. In this case, the draft tube gate is provided at outlet of the draft tube .
Main dimensions of standard tubular turbine are shown in Fig6.

Main dimensions of Tubular turbine



D_1	A	B	C	D	E	G
1000	1800	5900	1520	2110	1060	1400

Note F min ≥ 300 mm

Fig6. Main dimensions of standard tubular turbine.

Application diagram for standard tubular turbine is shown in Fig7. Example shows how application diagram can be utilized. According to conditions on the site, determine the net head and unit flow: For example: H= 8 m, Q =20 m^3/sec, according to application diagram, for a head of 8 m and unit flow of 20 m^3/sec, the turbine runner diameter will be D_1 = 1800 mm. Also from application diagram, we find the power developed at turbine shaft by linear interpolation between the power curves; We thus obtain a rating of 1200 kw for the turbine having the selected 1800 mm runner diameter.

4. The application of S-type tubular turbine in China:

In recent years, research work of S-type tubular turbine, in scope of medium and small capacities, is crowned with success, and some S-type turbines with small capacities have been designed and manufactured. S-type tubular turbines have been gradually replacing the traditional vertical shaft axial turbines for small capacities.

For example:

GD560-WZ-60 and GD003-WZ-80 had already been commissioned.

GD560-WZ-60 with a runner diameter of 0.6 m and capacity N =55~220 kw under H =8~14 m is a S-type tubular turbine-generator set with single wicket gates regulation.

GZ003-WZ-80 with a runner diameter of 0.8 m and capacity N =128 kw under H= 6 m is a S-type tubular turbine-generator set with single runner regulation.

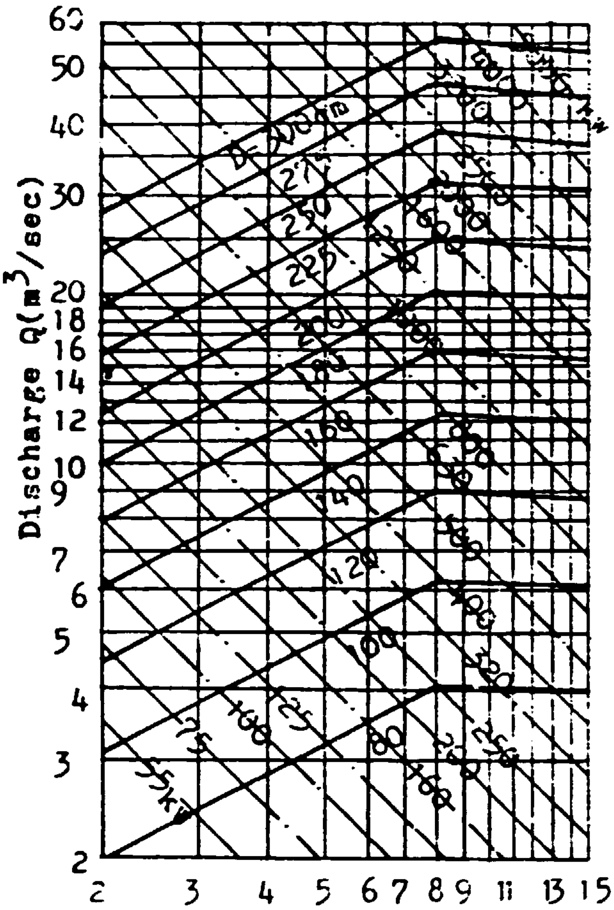


Fig7. GZ-WZ series tubular turbine application diagram.

GD003-WZ-200 of S-type tubular turbine with a runner diameter of 2 m and capacity N =1250 kw under H =7 m installed in the AI BA power station had been put into commission in 1986. Prototype GD003-WZ-200 is shown in Fig8.

Through adopting S-type tubular turbine, obvious economical benefits have been obtained in the AI BA power station.

Main data in the AI BA power station:

Rated head: H = 7.16 m.

Rated flow: Q = 52 m^3/sec.

Installed capacity: N = 4 X1250 kw

Runner diameter: D_1 = 2 m.
Speed of turbine: n =187.5 rpm.
Speed increaser: speed ratio i=1/4
Comparisons between GD-WZ-200 and vertical shaft Kaplan turbine ZD760-LH-200 were made for AI BA power station.
S-type tubular turbine has a higher efficiency and larger discharge than that of vertical shaft Kaplan. When S-type tubular turbine is installed the annual energy production will increase by 2.35 MKWH; Cost saving of main equipments will be approximately 660,000 YUAN(RMP); The total investment costs of the civil work and power house have a saving by 20%.

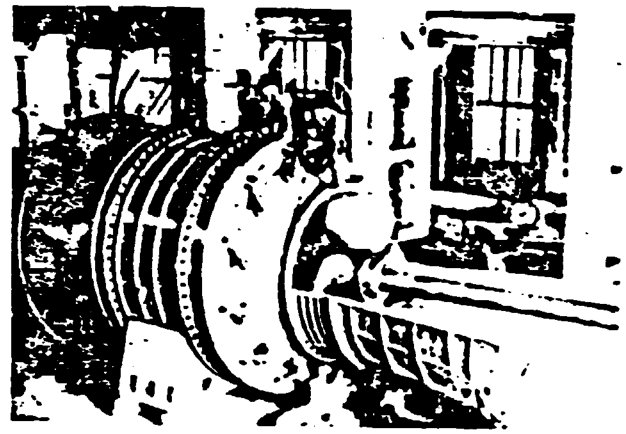


Fig8. Prototype GD003-WZ-200 unit

The model runner GZ006 of S-type tubular turbine is a new outcome obtained by our institute recently. GZ006 has a good efficiency and cavitation performance. It has been applied to the standard series of products of S-type tubular turbine. For example: S-type standard turbine generator units of GZ006-WZ-180, GZ006-WZ-160 and GZ006-WZ-140 are being manufactured. Units of GZ006-WZ-180 for YU QIAO power station will be commissioned at the end of 1987.
Comparisons between GZ006-WZ-180 and vertical shaft Kaplan ZD560-LH-180 were made for YU QIAO power station.
When GZ006-WZ-180 is selected ,the annual energy production will increase by 14.7%; Saving of concrete estimated by 24%.
Series of S-type tubular turbine containing 11 standard turbine designs with runner diameter ranging from 800 mm to 3000 mm can be delivered to customens at home and abroad.

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Allis-Chalmens Fluid Products Company,
Stsndardized hydroelectric generating units;
Tianjin Design And Research Institute Of Electric Drive, China.
Standard series design of products for S-type tubular turbine;
Carroway Enterprises Limited,
Hydro generating units;