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AXIAL - FLOW TURBINE SERIES ZD760 FOR LOW HEAD*

Prepared by

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ABSTRACT

The Axial-flow turbine ZD760 with fixed-blades and vertical shaft is the most simple and cheapest of all types of turbines. This paper aims to introduce the whole set of standard turbine including the runner, which has been researched, designed and manufactured by a factory.

The following will be described in the paper:

1. The test research results obtained in the test of the turbine with fixed-blades and adjustable guide vanes;
2. The construction features covering open flume, draft tube and coupling methods;
3. The standard series of this type of the turbine;
4. The typical application examples installed in the existing power stations.

China is rich in hydropower resources. Since the founding of the People's Republic, the hydroelectric utility has developed very quickly and the manufacture of hydraulic turbine has boomed accordingly.

Because turbines are being made by individual manufacturers the turbine products are of wide varieties and their application ranges overlapped, some are even out of date in construction. As a preliminary rectification, the first standard series of hydraulic turbines turned out in 1965.

After more than 10 years of experiments in manufacture, installation and operation, the unified design of turbine series with unit capacity of less than 500 kW was carried out. It includes 4 types of turbines, 8 types of runners and 32 products suitable for water heads of 2-270m and discharges of 0.07-8.6 m^3/s. (Fig. 1)

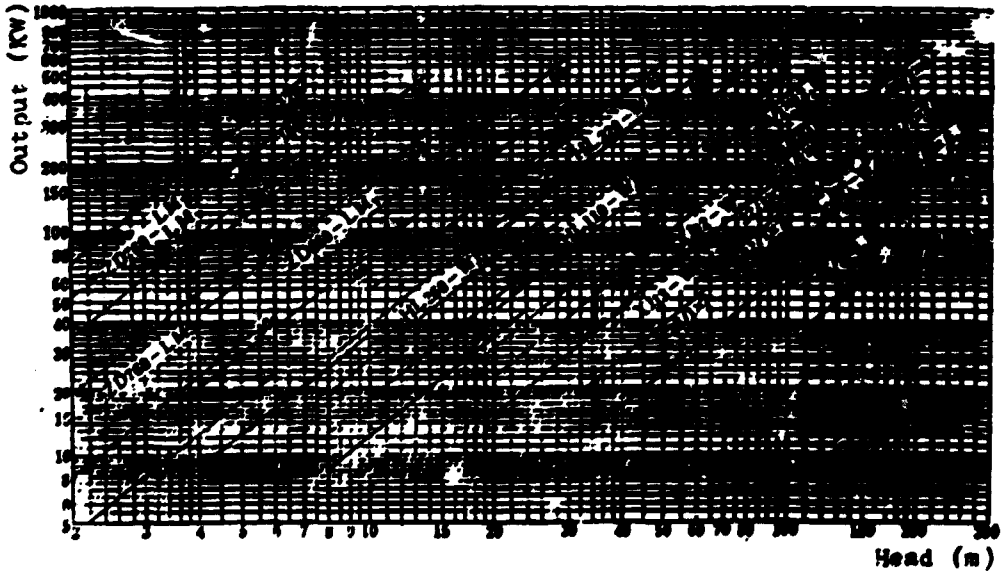

Fig.1 Range of application for turbine series below 500KW

Several years later, according to the requirement of standardization an overall planning of the turbine series within 500-10000 kW capacity was completed. In the application range, 4 types of turbines, 19 types of runners were selected and 53 turbine products were listed up, of which 38 were old ready-made types. (Fig.2)

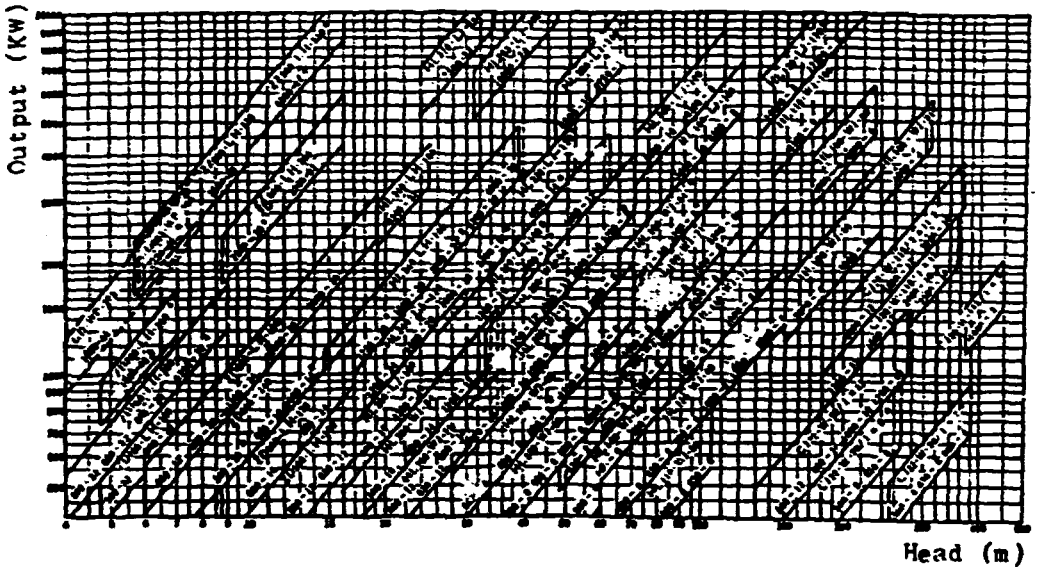

Fig.2 Range of application for turbine products within 500-10000KW

The advantages of the turbine series are:

1. The turbine sizes in the application range are arranged reasonably without overlaps.
2. Unified construction is adopted and a large quantity of standard components are selected, therefore, it is possible to organize production and to install on site with a result of raising the economic benefit of operation.
3. A formal technical standard has been set up, for example, common technical requirements of water turbine and technical requirements of passage for the water turbine. Therefore, the quality of turbine products can meet the stipulations for the Quality Grades of Water Turbines, the accuracy and surface finish of water passage are all similar to those standard of International Electrical Commintee. The above mentioned measures greatly accelerate the development of turbine manufacture.

1. HYDRAULIC DEVELOPMENT

Because of high investment, it is impossible to test more model runners for small turbines similar to those of large ones, the water passages are always adopted similar to those of large turbines but in reduced-scale. Take Axial-flow turbine as example, the movable axes of blades for large Axial-flow turbines are placed in the middle of blade profiles, it will minimize the hydraulic moment of blades, available for regulation of load during operation. But the runner ZD760 was investigated in a different way. In 1960's there were many Propeller turbines in operation in rural power stations. Some troubles often occured in operation, such as insufficient output or low efficiency. Technicians from manufacturers were called

to the sites for the repair. After being dismantled, sometimes defects in the water passage could be found. After it had been repaired by welding, cutting or grinding, it was reassembled and put into operation again. Through hundreds of actual practices on site in this way the technicians have accumulated a wealth of experience on how to improve the runner performances etc.

In the middle of 1960's a new runner scheme was designed, it is characterized by the blade profiles and the blade position of the movable axes, they are especially suitable for use in small-size propeller turbines. In site tests proved that the runner was full of promise, after that, a former model turbine with the type runner was manufactured and tested at the test stands in hydraulic laboratories. Test results also showed that it was good possessing high efficiency, large unit discharge and high unit speed.

Later, this runner type was coded as ZD760. At the efficiency stand the parameters of its water passage are shown in Fig.3 and the following table.

Relative height of guide vanes $\frac{B}{D_1}=0.45$

" hub " runner $\frac{d}{D_1}=0.35$

" height " draft tube $\frac{h}{D_1}=4$

Nominal diameter of runner 400 mm
The number of guide vanes Z = 12

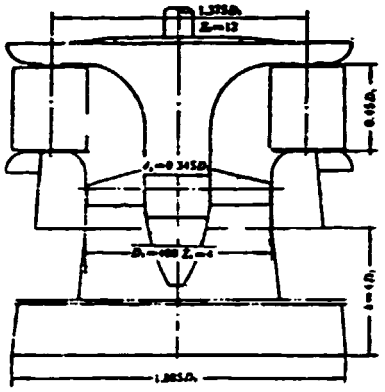

Fig.3 Water passage of ZD760 at efficiency stand

The test results obtained are shown in Fig.4, and the main performance is as follows:

φ	Q'_{ont}	n'_{ont}	η
0°	1670	181	87.6%
5	1920	170	87.3%
10°	2200	164	85.3%
15°	2340	145	82.8%

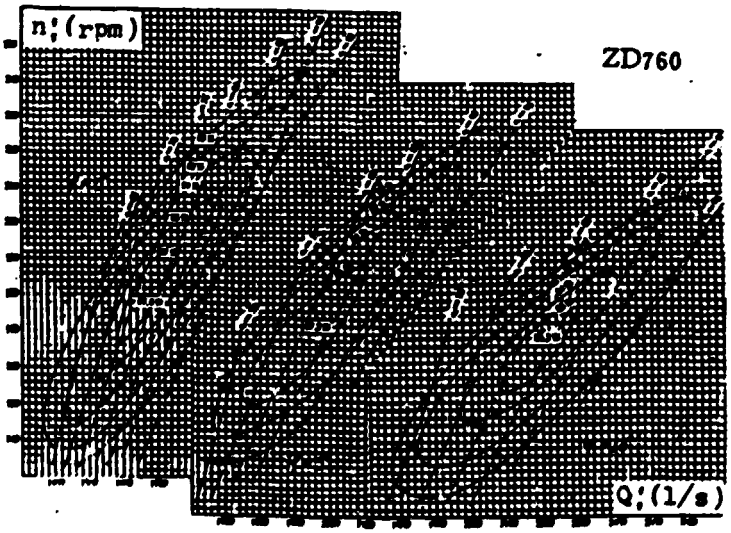

Fig.4 Chill curve of ZD760 at efficiency stand

At cavitation stand, the water passage and geometric parameters of ZD760 turbine are slightly different from those at the efficiency stand, as shown in Fig.5 and following table:

the model turbine with square spiral case

low relative height of guide vanes $\frac{B}{D_1} = 0.4$

low relative height of draft tube $\frac{b}{D_1} = 3$

relative length of draft tuve $\frac{l}{D_1} = 4.5$

the number of guide vanes $Z = 16$

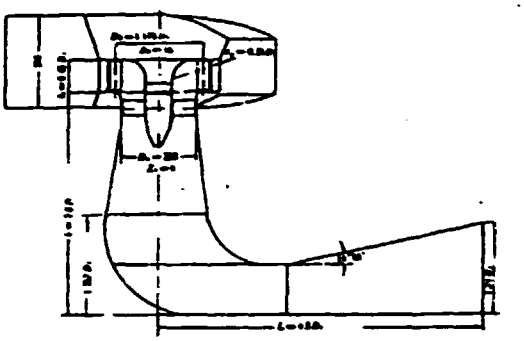

Fig.5 Water passage of ZD760 at cavitation stand

The optimum parameters, such as unit speed, unit discharge and maximum efficiency obtained at the cavitation stand were a little less than those at the efficiency stand.

In comparison with the old runner, the efficiency in the hill curve at $n_1' < 220$ is 1% higher and that at $Q_1' > 1800$ about 0.5 - 1% higher. The cavitation coefficient at $\varphi = +15°$ lies between 1.1 - 1.42 about 0.2 smaller than that of the old runner.

Then a batch of ZD760 runners were manufactured and sent to various sites for trial run.

Having been operated in many small hydro power stations for several years, the ZD760 type turbine has been proved to posses an excellent performance both in efficiency and cavitation. In 1978, it was recommended as standardized turbine and was listed in small turbine series below 500kW.

2. APPLICATION RANGE

Axial-flow turbine can exploit hydro-energy of low head and large discharge. The change of the discharge and the optimum hydraulic performance may be achieved by regulating runner blades or guide vanes.

Fig.6 shows a comparative efficiency curve depending on the discharge of their various combination. The turbine with adjustable blades and adjustable guide vanes, having better efficiency and higher output over a wide range of operation, is very expensive and is complicated in construction. But the turbine with fixed blades and adjusted guide vanes, on the other hand, is characterized by very simple construction and easy manufacture. If such units are applied to multiple unit sites, where output can be adjusted to varying load conditions by controlling

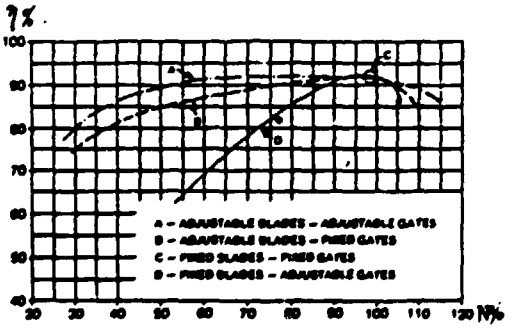

Fig.6 Comparison of Axial-flow turbine performance

the number of units on the line, the shortage of large efficiency drop at part load range may be compensated. This is why, according to the statistical data, you will find, there are always 3 - 4 units of Propeller turbines installed in a single hydro power station in China.

The following table shows the standard turbine ZD760. There are 5 runner sizes (40, 60, 80, 100 and 120 cm) for turbine series below 500 kW (see Fig.1). All of them are equipped with straight draft tube, and besides, with open flume intake for heads of 2 - 6 m and with pressure flume intake for heeds of 2 - 7 m. There are 3 runner sizes (180, 200, 250 cm) with elbow draft tube and concrete spiral case for turbine products within 500 - 10000 kW (see Fig.2) regulating a range of discharge of Q between 14 - 28 m^3/s, heads between 2 - 7 m and output more than 10000 kW. All of them are of Propeller type and vertical shaft.

Fig.7 shows one characteristic curve of operation for ZD760. The generator is of synchronous type with vertical arrangement, the rated voltage is 400 V matching turbines of less than 500 kW and 6300 V for turbine products with 500 - 10000kW capacity.

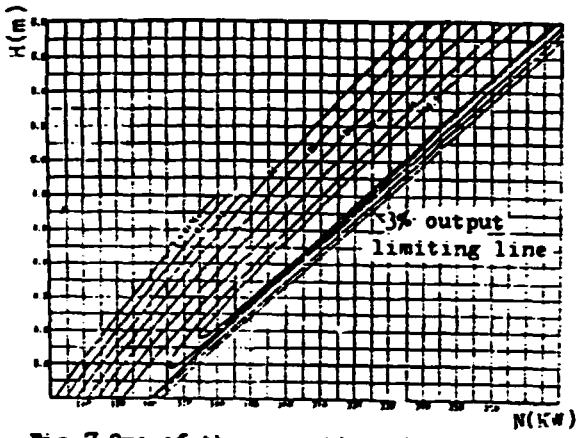

Fig.7 One of the operation characteristic for ZD760

Intake Form	Runner diameter(cm)	blade angle	design head (m)	Generator capacity (kW)	Governor type	Transmition method
Open flume	40	5	3.5-5.5	12-26	TT-75	"V", "D"
		10	3.4-5.0	12-26	TT-75	"V", "D"
		15	3.2-4.9	12-26	TT-75	"V", "D"
	60	5	2.6-6	18-75	TT-75, TT-150	"V", "D"
		10	2.5-6	18-75	TT-75, TT-150	"V", "D"
		15	2.4-5.8	18-75	TT-75, TT-150	"V", "D"
	80	5	2.9-6.0	40-125	TT-150 TT-300	"V" "G"
		10	2.7-5.5	40-125	TT-150 TT-300	"V" "G"
		15	2.6-6.0	40-160	TT-150 TT-300	"V""G""D"
Open flume or pressure flume	100	5	2.7-7	55-250	TT-150 TT-300	"V""G""D"
		10	2.5-6.5	55-250	TT-150 TT-300	"V""G""D"
		15	2.4-7.0	55-320	TT-150 TT-300 TT-600	"V""G""D"
	120	5	2.6-6.6	55-320	TT-300 TT-600	"V""G""D"
		10	2.4-7	75-400	TT-300 TT-600	"V""G""D"
		15	2.3-7	75-400	TT-300 TT-600	"V""G""D"
Concrete spiral case	180	5°	5-6.7	500, 800	YT-1000 YDT-1800	"D"
	200	5°	4.2-8	500, 630, 800, 1250	YDT-1800 YT-3000	"D"
	250	+5°	5.2	1000	YT-3000	"D"

Note: "V" belt transmition; "D" direct coupling; "G" gear transmition.

3. CONSTRUCTION FEATURE

Coming from the inlet gate, water enters the intake and guide vanes. After imparting its energy to the runner, it goes through the draft tube and finally to the tailrace.

The major components of the turbine include runner, main shaft, guide vanes and their mechanism, guide and thrust bearing, intake part and draft tube.

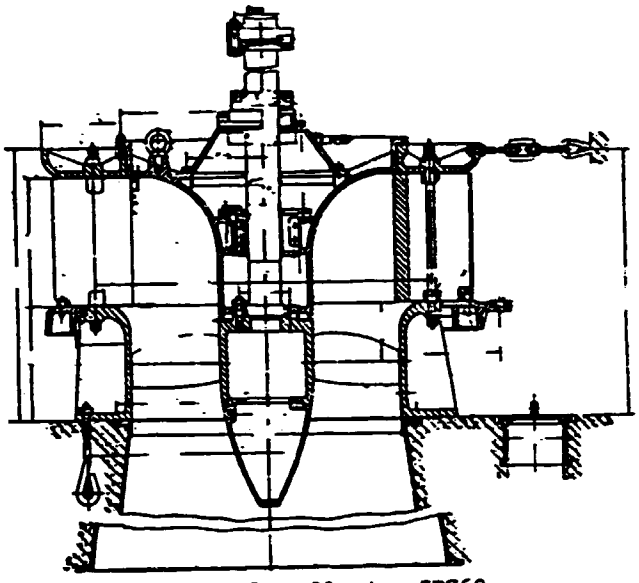

Fig.8 Section of small size ZD760

The intake arrangements can mainly be classified into open flume (Fig. 8) and concrete spiral case (Fig.9). The former is economical for head up to 6m, otherwise the length of the main shaft may become excessive. The latter with the nose angle of 225° can be adopted for high head.

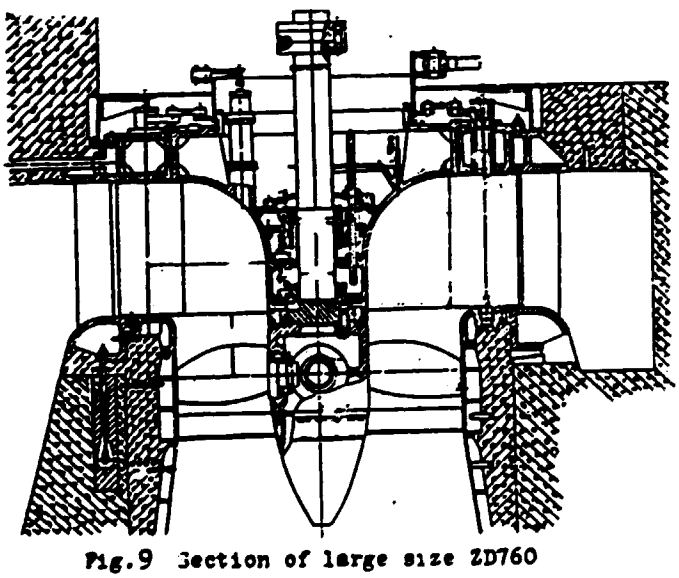

Fig.9 Section of large size ZD760

The runner is the heart of the turbine, three propeller runner angles: +5°, +10° +15° are used for normal diameter each to meet the needs of different discharges. The intergral castiron runner is suitable for diameter of less than 0.6m while the cast steel one is for high head. Recently, the cast-weld construction is widely made use of and greatly simplifies the manufacturing techniques.

There are two types of draft tubes lined in the small turbine series. the straight draft tube, very simple in construction and easy to manufacture, is suitable for mini-size units, but the elbow draft tube is for large units.

The main function of the guide bearing is for positioning the main shaft as well as taking up the radial load, and the water-lubricated guide bearing, very simple in construction, may be located as near to the runner as possible in order to absorb the viberation of the unit. Therefore, it is widely adopted in the open flume type turbines.

Impurity in water is filtered by the double skin filtering network installed above it, hence the erosion inside the bearing can be prevented.

When the head is higher, an intermediate guide bearing is added on top of the flume in order to increase stability in operation, on the other hand a replacable anti-wear sleeve is fixed or stainless steel is overlapped on the cylindrical surface of the main shaft where the intermediate guide bearing is placed.

Radial thrust bearing is located on the generator floor and supports radial load, hydraulic thrust load and the weight of rotating parts. All of them are of plain bearings, lubricated by oil and cooled by water through a pipeline.

There are two types of guide vane mechanism. The simple one is of inside regulation for runner diameter less than 120 cm (see Fig.8) and the outside one is for large size (See Fig.9). If water in the river is sandy, an auti-wearing ring is equipped on the water passage of the bottom ring and the hand cover.

Brake devices are needed for turbines equipped with plain bearings. As the unit begins to shut down the speed of the main shaft becomes lower and lower. When its speed reduces to about 30% of the rated value, the device will be actuated to stop the movement of the shaft immediately, otherwise the bearing may be burnt out at such low speed. Besides a temperature-measuring device is always fitted inside the bearing body to protect it by sending temperature signal.

The turbine of this type, possessing position suction head, is always located at positive setting (see Fig.10) and a vacuum break valve ought to be mounted on the upper portion of the head cover near the main shaft to guard against the possible lifting of the unit, due to an upward thrust of the runner when the guide vanes are suddenly closed.

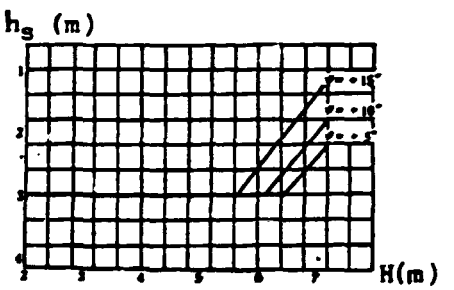

Fig.10 Range of application for ZD760

A comb shape labyrinth sealing structure is placed on the head cover to reduce the leakage of water.

There are two methods of connecting the turbine to the generator in this series, i.e. by direct coupling or by transmission through "V" belt or gears, the belt-type coupling is used for the unit with capacity less than 75kW and the latter for the unit with capacity within 100-160kW.

The electrically-controlled and manually-operated speed regulating devices or automatic governors of types YT, TT are installed for small-type turbines as customers prefer.

On the whole, components of unified construction, standardization and universalization are widely applied in this standard turbines. For

example, bearing, flywheel and guide vanes etc., which make it more reasonable and up to date.

4. TYPICAL ARRANGEMENT

The six largest units (see Fig.11) with runner diameter of 2.5m and capacity of 500 kW each are installed at Bengbuzha hydropower station, Anhui Province. The design head is 4.1m, the maximum head is 6m and the minimum head is 2.5m.

The types of the turbine-generator set selected are as follows:

Turbine ZD760-LM-250
Generator SF 1000-48/3250
Governor YDT-3000

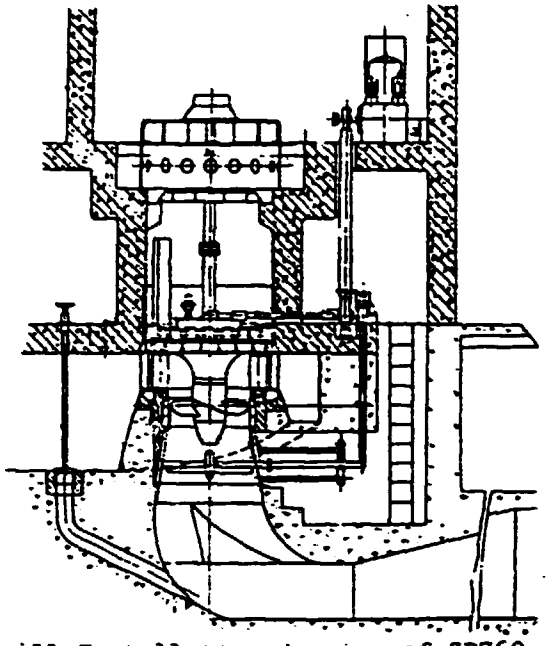

Fig.11 Installation drawing of ZD760 with concrete spiral case

As the hydraulic structure of the site has already been completed before hand, the dimension of the elbow draft tube and the concrete spiral case are determined, with minor changes. The relative height of the draft tube is only 2.24; some new techniques have been adopted at the site, for example, guide vane sleeves are made of hylon and electroplating method is applied in manufacturing the guide vane journals instead of using sleeve-inlaid or overlapping stainless steel.

This hydro power station was commissioned last March and has been operating normally up to now.

There are altogether five units with capacity of 250kW each at Rengonghu hydropower station, Guangdong province. The vertical Propeller open-flume type turbine (ZD760-LM-180)is equipped with head cover and guide vanes made of steel mesh reinforced concrete. This hydropower station is of low head run-of-river type, completed in 1983 with a design head of 3.6m and unit discharge of $8m^3/s$, and is connected to the national grid.

The ZD760-LM-120 type turbine with direct coupling and pressure flume has been operating at Xiangtu hydropower station, Sichuan province. Since Nov.1981, the application range is as follows (see Fig.12)

$H = 2.6 - 8.4$ m
$N = 94 - 454$ kW
$n = 215 - 375$ rpm

Three turbine-generator sets each with capacity of 150kW and water heads of 3 - 4m have been installed at Yi Cun hydropower station, Zhejiang province. (see Fig.13).

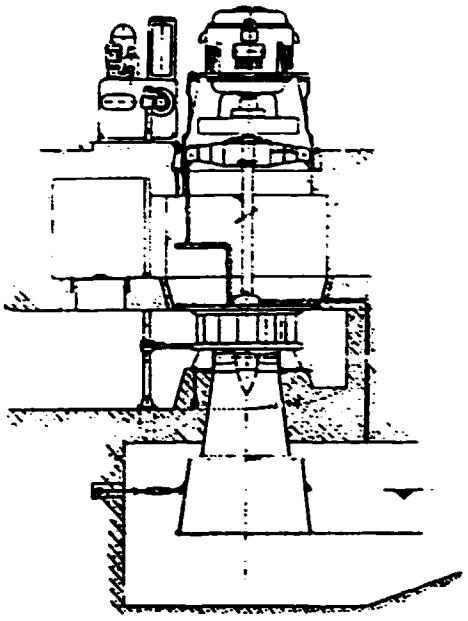

Fig.12 Arrangement drawing of ZD760 with pressure flume

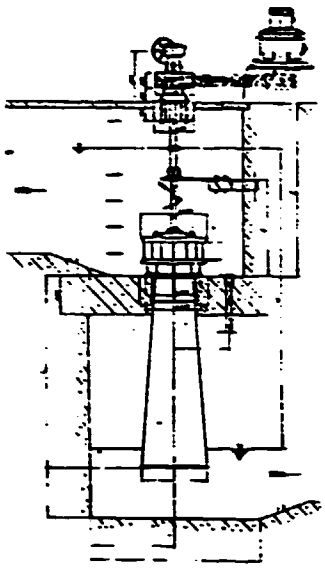

Fig.13 Installation drawing of ZD760 with open flume

The Beijing-Miyun diversion canal is another example to use this type turbine . Located 90kM away from the centre of the city, Beijing, it is the main system for conveying water to the city.

The total head of 35m is exploited for five hydro power stations with a total installed capacity of 11400 kW and the total discharge of 60-70m^3/s.

With a view to decreasing the different types and numbers of machines, the same type ZD760-LM-200 of 15 turbines is supplied for all the cascade, coupled with 15 generators of two different types.

All the five stations were commissioned in 1978-1979 and were connected into the state grid. The annual generation hour reaches 3840 - 4730 hours and the cost per kW is 1332 yuan (RMB) for the 3rd station and 2000 yuan for the 2nd.