With the development and application of advanced design and manufacturing techniques in China, it has made a great progress of techniques in the industry of hydro turbine in the past 10 years. A brief introduction of the latest progress of the R&D and manufacturing is presented in this paper.

Keywords: Water Turbine; Design; Manufacturing; Hydroelectric Machinery

1. Introduction

Over the past 10 years, with computer aided techniques (CAD / CFD / CAE / CAM / MPS / CNC) and some advanced manufacturing technology (AMT), being developed and gradually used in hydro turbine industry, a great progress of techniques in the R&D and manufacturing has been made in China. Because China has abundant hydraulic power resources and huge market in hydroelectric equipment, a lot of the foreign power-generating equipment manufacturers have been trying to intensify the cooperation with the major Chinese power-generating equipment manufacturers in design and manufacturing of hydro turbines, which accelerates the progress of hydro turbine industry. Dongfang Electrical Machinery Co., Ltd. (DFEM, hereinafter) and Harbin Electrical Machinery Works (HEM, hereinafter) are two major Chinese hydroelectric equipment manufacturers. They have reached the international advanced level in both the R&D and manufacturing.

2. General development of hydroelectric units in China

There are $3.78 \times 10^8 \text{ kW}$ hydroelectric power resources that can be exploited in China, but it has been developed only 16% of the total so far and the capacity of hydroelectric units will have been installed is $1.25 \times 10^9 \text{ kW}$ (about 33%) till the year of 2010\(^1\). According to the national planning, the R&D will be placed emphasis on the hydroelectric units with unit capacity of 500-700MW in the future 10 years. Apart from Sanxia Hydro Power Station that is in constructing, a series of huge Hydro Power Stations (such as Qiluodu, Shuibuya, Xiaowan, Longtan, Laxiwa and Pubugou) with unit capacity of 500-700MW and turbine runner’s diameters of 6-9m will have been built before 2010. Chinese hydro turbine industry was started in 1927.
and there are more than 20 manufacturers up to now in China, two biggest of them are DFEM and HEM. According to statistics, the output and marketing shares of DFEM and HEM is each 1/3 in China, and the total of other manufacturers is about 1/3. China had successfully developed and made the unit capacity of 200MW hydroelectric units in 1970s, 300MW in 1980s, and 550MW in 1990s. The major manufacturers and researchers also devoted to develop the unit capacity of 700MW hydroelectric units in 1990s. In the beginning of 1980s, DFEM had successfully developed and made the Kaplan turbine with runner diameter of 11.3m that is the largest in the world so far. In 1987, DFEM successfully developed and made 320MW Francis turbine with runner diameter of 6m, and HEM made Francis turbine with runner diameter of 8m in 1992. It should be mentioned that some of Chinese hydro turbine manufacturers co-manufactured turbines for power stations in China with GE Hydro, Voith Hydro Inc., Kvarner, Neyerpic, Toshiba, Fuji Voith Hydro, Hitachi etc. in the past 10 years. DFEM and HEM are manufacturing Sanxia hydroelectric unit that is the largest Francis turbine with unit capacity of 710MW and runner diameter of 10m[2] in cooperation with GE Hydro, Voith Hydro Inc., Kvarner, Alsthom. It is shown in Table 1 that the scope of hydro turbines has been made by the major Chinese manufacturers.

After the reconstruction and reorganization in the recent years, DFEM and HEM have enhanced their manufacturing ability to produce Sanxia hydro turbines. They have reached the international advanced level in manufacturing ability and techniques in a majority of types in hydro turbine, but they are still weak in the types of pump/turbine and tubular turbines.

### 3. Hydraulic R&D for hydro turbines

The major hydro turbine researchers and manufacturers began to develop the special CAD software in hydraulic design of turbine in 1980s[3]. During the ending of 1980s and the beginning of 1990s, more than four universal and high accuracy hydraulic test stands with maximum testing head of 100m were set up in China. The test stand met the requirements for the international commercial test in accuracy and automation. In the ending of 1990s, several of the large discharge and high accuracy hydraulic test stands with testing head between 10-25m were established for Kaplan and Tubular turbines. All the test stands found good conditions for the developing of high performance turbines. The major hydro turbine researchers and manufacturers had also done a lot of works in the methods of quasi-3D flow computing and analysis, cavitations and wear in hydro turbines during the same period, which are applied in practical engineering and get the satisfied solutions. In the recent years, CFD has been gradually used in the R&D of hydro turbines, the commercial software such as Fluent® and TascFlow®

<table>
<thead>
<tr>
<th>Parm.</th>
<th>Francis</th>
<th>Pump/Turbine</th>
<th>Deriaz</th>
<th>Kaplan</th>
<th>Fixed blade propeller</th>
<th>Bulb Tubular</th>
<th>Pelton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head (m)</td>
<td>10 ~ 400</td>
<td>60 ~ 550</td>
<td>30 ~ 77</td>
<td>4 ~ 80</td>
<td>2.8 ~ 25.6</td>
<td>2 ~ 20</td>
<td>188 ~ 830</td>
</tr>
<tr>
<td>Runner Dia. (m)</td>
<td>0.5 ~ 10</td>
<td>&lt;5</td>
<td>1.6 ~ 1.9</td>
<td>1.4 ~ 11.3</td>
<td>0.46 ~ 6</td>
<td>2 ~ 8</td>
<td>0.8 ~ 1.7</td>
</tr>
<tr>
<td>Capacity (MW)</td>
<td>0.18 ~ 710</td>
<td>40 ~ 300</td>
<td>8 ~ 20</td>
<td>2.4 ~ 200</td>
<td>0.008 ~ 5</td>
<td>10 ~ 33</td>
<td>0.84 ~ 13</td>
</tr>
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</table>
is applied in 3D viscous flow analysis and performance estimation in hydraulic R&D, so it decreases model testing dramatically. For optimization hydraulic design, the whole flow passage that includes the spiral case, stay vanes, wicket gates, runner and draft tube is numerically simulated and carefully designed with CFD and CAD. After hydraulic design, the commercial software such as UG®, I-Deas®, ANSYS®, NASTRAN®, Adams® is widely used in the 3D geometric design, mechanical design, mechanism and dynamics analysis. CIMS and virtual manufacturing are gradually applied in the major manufacturers, so it has been speeding up the R&D and manufacturing of hydro turbines. In order to investigate the internal flow of hydro turbines, some universities and institutes introduce the advanced instruments such as PIV and PDA/LDA, which can be used to verify the numerical simulation and improve the hydraulic design. Fig. 1 shows a runner that it was primarily designed with special developed CAD software (on left) and further optimized with CFD analysis (on right). Fig. 2 shows an efficiency hill diagram that is estimated with developed software and CFD for the turbine with the optimized runner shown in Fig. 1.

As to the manufacturing techniques of testing model, the most of parts are machined on CNC machines with the self-developed CAM techniques. The series of the excellent hydraulic models of turbine, head of that is in range from 2 to 400m, have been developed in past 10 years. The maximum efficiency of model turbines is up to 94.8% for Francis and 92.5% for Kaplan. A kind of new Francis blade called “X shape” was developed in 4 years ago after GE Hydro and KE.

4. Manufacturing techniques for the large hydro turbines
4-1 Machining capabilities and main equipments of the major manufacturers

The CNC controlled equipment is more than 20% of their total amounts in the major manufacturers. The main equipments in the major manufacturers include: 5-axis simultaneous CNC controlled large size gantry machine (4 sets, made in Germany), 5-axis and 3-axis simultaneous CNC controlled heavy duty Horizontal Milling & Boring Machine with spindle diameter of 250 and 260mm (5 sets, made in Germany and Italy), the CNC controlled Vertical Lathe with maximum machining diameter of 12.5m,
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Fig. 3 Typical blade manufacturing flow chart for large size hydro turbines

15m, 16m, 18m and 22m (7 sets, made in Germany and China), the CNC controlled Horizontal Lathe with maximum machining length of 16m and maximum machining diameter of 2.5m (4 sets), and the CNC controlled large size Gas cutting machine (4 sets, made in Germany, Japan and China). The Machining capabilities can meet the requirements for hydroelectric unit with unit capacity of 850MW.

4 - 2 Manufacturing techniques for the large size runners

The manufacturing techniques of the runners are most important in manufacturing of hydro turbine. The progress of manufacturing techniques is synchronization for the major manufacturers. They have the similar techniques and experience of different type of runners. For the large size Francis runner, the manufacturers mainly apply a kind of fabricated technique called combination welding, because they have very strong ability at welding. The band, crown and blade can be in the same kind or different kind of steel by welding. They have the design and manufacturing experience of Kaplan runner with Di =11.3m and Francis runner with Di =10m.

It was 10 years before that all the blades were manually grinded in China. In the recent 10 years, 5-axis simultaneous CNC machine is widely used in the major manufacturers. For the high head Francis blade, a kind of technology called heat press forming with moulds is also gradually used. The typical blade manufacturing flow chart is shown in Fig. 3.

There are a lot of key techniques in CNC machining of large blades. One example is that how to set up correctly for each blade casting on machine in a very short time, an efficient method for computing the right spatial setup position is applied with measuring each blade casting by theodolites. Fig. 4 shows that a blade casting is being measured with the high accuracy theodolites (Made by Leica) (536). Another example is that how to correctly compute the tool path for 5-axis machining of the large blade’s sculptured surfaces with large size face milling cutters, the tool path simulation and machine simulation techniques have been developed to verify
and modify the tool path. Fig. 5 shows the simulation for machining of a Francis blade and Fig. 6 shows that this blade is machining on the large size 5-axis CNC controlled gantry machine. Fig. 7 shows the simulation for machining of a Kaplan blade.

In consideration of the transportation from the manufacturers, the large Francis runner is often split into 2 or 4 pieces. The crown and band are machined on the NC controlled vertical lathe and their split face machined on NC controlled boring machine, and the weld preparation of blade milled on the 5-axis simultaneous CNC controlled machine. When fabricated and weld them into a runner, a series of the combined templates is used to control and ensure the inlet and outlet angles of blades and the openings of runner. After finished welding, 100% of UT and MT are carried out for checking welding seams. Then, the runner is machined on the large size NC controlled vertical lathe with boring functions for all operations at one set-up, and a method called stress bar is used to balance the runner. Generally speaking, the major manufacturers have kept in step with the international advanced level in manufacturing technology of the runners.

5. Typical hydro turbines recently manufactured in China

During the past 3 years, the annual output of DFEM and HEM is over 24000MW in each year. With the progress of the turbine manufacturing technology, the capabilities of manufacturing are greatly improved and the quality of products is also up to the international advanced standards. The whole process from the R&D of products, purchasing of raw materials, manufacturing of products, inspection of the finished products to after-sale services, has also reached the international
### Table 2 Typical hydro turbines manufactured by the major manufacturers in China

<table>
<thead>
<tr>
<th>Parm</th>
<th>Gezhouba</th>
<th>Longyangxia</th>
<th>Manwan</th>
<th>Lijiaxia</th>
<th>Yantan</th>
<th>Tianshengjiao</th>
<th>Ertan</th>
<th>Sanxia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Head (m)</td>
<td>18.6</td>
<td>122</td>
<td>89</td>
<td>122</td>
<td>59.4</td>
<td>176</td>
<td>165</td>
<td>80.6</td>
</tr>
<tr>
<td>Rated power (MW)</td>
<td>175.3 / 129</td>
<td>326.5</td>
<td>255.1</td>
<td>408</td>
<td>307.1</td>
<td>225</td>
<td>582</td>
<td>710</td>
</tr>
<tr>
<td>Runner Diam. (m)</td>
<td>11.3 / 10.2</td>
<td>6</td>
<td>5.5</td>
<td>6.03</td>
<td>8</td>
<td>4.5</td>
<td>6.5</td>
<td>10 (VGS)</td>
</tr>
<tr>
<td>No. of Machines</td>
<td>2 / 5</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>Type of Hydro</td>
<td>Kaplan</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
<td>Francis</td>
</tr>
<tr>
<td>Turbine</td>
<td>DFEM/HEM</td>
<td>DFEM</td>
<td>DFEM</td>
<td>DFEM</td>
<td>HEM</td>
<td>HEM</td>
<td>HEM</td>
<td>DEEM, HEM, VGS, KE</td>
</tr>
<tr>
<td>Remarks</td>
<td>Maximum Kaplan in size so for in the world</td>
<td>With heat press forming technology for blades</td>
<td>The 1st of 14 sets comanufacturing, the 2nd of 12 sets will be made independently by Chinese manufacturers</td>
<td></td>
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</table>

 standards. Their hydro turbines not only install in the domestic, but also export to the abroad. The typical hydro turbines manufactured in China over the past 15 years is shown in Table 2.

### 6. Conclusions

During the past 10 years, Chinese hydro turbines industry had made a gigantic development in both the R&D and manufacturing technology. They not only pay more attention to research and develop by themselves, but also import the advanced foreign technology and enhance to make cooperation with well-known foreign companies. The manufacturing technology of the major manufacturers has reached the international advanced level in most types of hydro turbines, and their products not only service in China, but also export to foreign countries. They are trying every effort to keep in step with the international advanced technology in the whole hydro turbines industry.

### References