

Hydraulic Performance Comparison for Axial Flow Impeller and Mixed Flow Impeller with Same Specific Speed

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Abstract. An axial flow impeller and a mixed flow impeller with same specific speed were experimentally investigated, and the suction performance was studied with the help of CFD simulations. The results show that the axial impeller is roughly better than the mixed flow one. Especially under the design condition and a low flow rate condition range near the designed one, the axial flow impeller is more stable and therefore more suitable to be used in a water jet propulsion, while under these conditions the mixed flow impeller displays significant discrepancies. On the other hand, though its efficiency at the best efficiency point is lower than that of the axial flow one, the mixed flow impeller has a larger range of high efficiency conditions and is more convenient to be controlled to satisfy the irrigation and drainage systems that ought to be adjusted to varied flow rate conditions under a fixed head. In addition, the numerical investigation at the rated point shows that the axial impeller has a much better suction performance than the mixed flow impeller, which contradicts with the experience knowledge and therefore details need to be further studied.

1. Introduction

Heuristic materials show that an axial flow impeller is adopted when the specific speed n_s of the pump is larger than 500, while a mixed flow one is more reasonable if the specific speed n_s is lower than 500 but greater than 300. However, recently more and more mixed flow impellers with vane diffusers are used in the electric power plants, condensation systems and so on, which shows aggressive applications at even higher specific speed that axial flow impeller are conventionally selected [1]. As both mixed flow pumps and axial flow pumps with vane diffusers have too much long length in the axial directions and their guide bearings are submerge in the liquid medium, more recently mixed flow impellers with volute casings are also under consideration as alternative configurations. In addition, in the field of water jet propulsion, whether axial flow impellers or mixed flow ones are more convenient is always of discussion due to the limitation of the vessel hull [2]. Subsequently, more and more efforts are performed to investigate the details of the pumps, especially the flow structures such as tip leakage vortex, wake characteristics and so on. However, rarely comparative study has yet been carried out to examine their difference on overall performance. In this paper, both an axial flow impeller and a mixed flow impeller, which have the same specific speed n_s of 576, are experimentally investigated to examine their inherence difference.

Individuals argued that commercial CFD code, though it is used to tackle many engineering problems, is so time consuming and leads to complex consequences, and is not possible, as yet, to



draw general conclusions over a wide parameter range [3]. In addition, Ni insisted that the CFD code plays a certain negative role on the development of hydraulic machinery as the design process for them receives less and less attention it deserves [4]. Nevertheless, a CFD technology was performed to evaluate the suction performance of the impellers as the gauges of the test rig in this research were not accurate enough to measure the cavitation phenomenon.

2. Design parameters and test apparatus

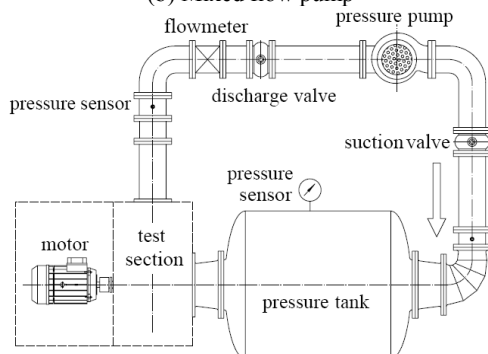
The axial flow impeller with vane diffuser and the mixed flow one with volute are shown in Fig. 1(a) and Fig. 1(b). According to the model test requirements, the normal diameters of the impellers are 300mm. The rotation speed is $n=1450\text{r/min}$, the designed flow rate is $Q=0.347\text{m}^3/\text{s}$, the designed head is $H=9.5\text{m}$, and therefore the specific speed is $n_s=3.65nQ^{0.5}/H^{0.75}=576$. The obvious features of the two structures are that the axial flow pump has a larger axial length and a compact radial size, while that of the mixed flow one has a pancake type and therefore a robust configuration.



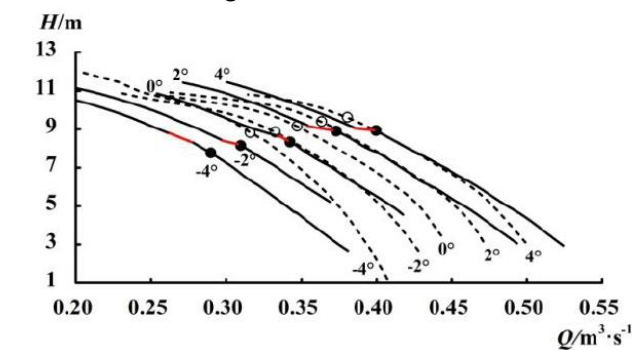
(a) Axial flow pump



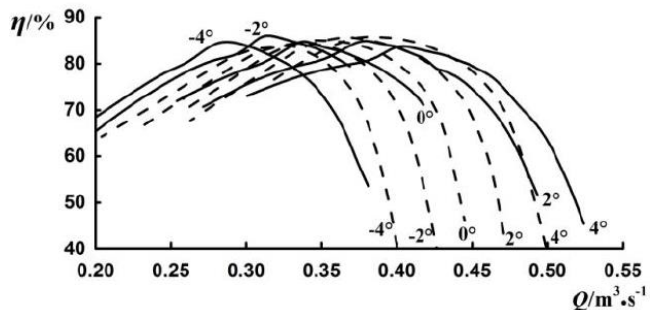
(b) Mixed flow pump



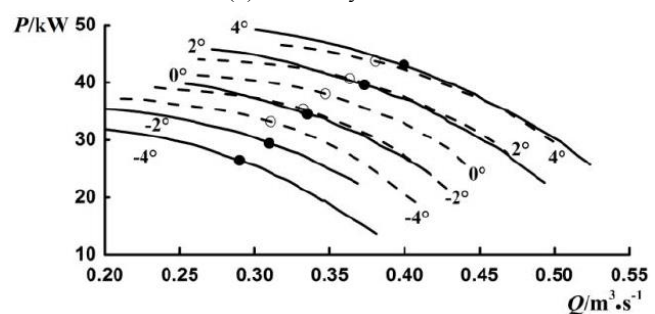
(c) Schematic of closed test rig



(a) Head curves



(b) Efficiency curves



(c) Power curves

Figure 1. Pumps and test rig.

Figure 2. Tested performance of pumps.

The experimental investigation was conducted at the closed loop rigs of the National Research Center of Pumps, Jiangsu University. As the configurations of the two pumps are of significant difference, the measurements of the two pumps were performed on two different test beds that of the

same experimental methods as schematically shown in Fig. 1(c). The connection parts aft and prior the pump section should be replaced according to the pump flanges or other junctions.

3. Analysis on tested data

Figure 2 shows the tested performance curves in which the dashed lines indicate the data for the axial flow pump and the solid lines for the mixed flow one. Some open and closed circles shown in both Fig. 2(a) and Fig. 2(c) are the best efficiency points. The head-capacity curves of $+4^\circ$ and $+2^\circ$ show good coincidence with each other in a certain large flow rate range from the best efficiency point, while the curves of 0° , -2° and -4° for the mixed flow pump significantly drift to the left. Consequently, the adjustable range for flow rate of the mixed flow impeller is rather larger than that of the axial flow one, therefore the mixed flow impeller is more suitable for applications of flow rate large change with head nearly fixed. Nevertheless, insignificant discrepancies were found at the region that lower and near the best efficiency points on every head-capacity curves of the mixed flow pump, and with the blade angle increases, the discrepancies are more and more easily recognized.

For a mixed flow pump, a kind of discrepancy may appear on the head-capacity curves, which occurs under the conditions of about 0.5-0.7 times of the design flow rate and is related with an instability so-called rotating stall. In this case as shown in Fig. 2(a), the left limit flow rates of the discrepancy regions are roughly 0.904, 0.958, 0.938, 0.949 and 0.964 times of the flow rate under best efficiency points for the blade angles -4° , -2° , 0° , $+2^\circ$ and $+4^\circ$, respectively. More recently, Liu displayed similar discrepancies near the design points on a pump-turbine under pumping mode, who insisted that the phenomenon was contributed by low cavitation number and showed some variation of the event with the cavitation number changing [5]. Obviously, the discrepancies displayed here are not the same as that of the rotating stall related, which is somewhat similar with the rotating choke. Further investigations in detail will be conducted in the future.

Returning now to the comparison of the axial flow impeller and the mixed flow impeller, the mixed flow one studied here is not capable of being used to a water jet propulsion as the latter is usually working under the condition that appreciably lower than the design point to achieve the largest thrust. In general, the axial flow impeller has higher efficiency under a narrow range of flow rates near the best efficiency point, while the mixed flow impeller has higher efficiency under conditions that higher than the best efficiency point and has a wider high efficiency zone. Moreover, according to the power curves of $+4^\circ$ and $+2^\circ$, the start-up power of the axial flow impeller is smaller.

4. Suction Characteristics

Figure 3 shows the curves of $NPSHR$ vs. flow rate at the blade angle of 0° , in which the critical value of $NPSHR$ was evaluated at the point that the efficiency decreased 1 per cent. The axial flow impeller has a better suction performance than the mixed flow one under a flow rate range near the design point. The test instruments shown in Fig. 1(c) and the results in Fig. 3 cannot depict the suction performance in detail. Therefore the numerical simulated data were displayed to discuss some of the difference. The best efficiency points at blade angle of 0° were taken into consideration, and the calculated critical points were that the efficiency decreased 1 per cent as the tested ones.

Commercial CFD code Fluent was performed to calculate the flow field in the impellers, in which the cavitating turbulent flow was simulated using the Partially-Averaged Navier-Stokes (PANS) method and a mass transfer cavitation model with the maximum density ratio effect between the liquid and the vapor, and Fig. 4 shows their suction performance under the best efficiency points. The best efficiency for the axial flow pump and the mixed flow pump are 85.19% and 85.27%, respectively. As shown in Fig. 4, the cavitation number under which the performance degradation occurs due to cavitation for the axial flow pump ($\sigma=0.22$) is much lower than that for the mixed flow pump ($\sigma=0.41$). Meanwhile, the critical cavitation number for the axial flow pump ($\sigma=0.16$) is also lower than that of the mixed flow one ($\sigma=0.26$). The results partly demonstrated the conclusion that leading edge cavitation for Kaplan turbines is less likely to occur than that for Francis turbines. While the

conventional belief is that a mixed flow hydraulic machine has better suction performance than an axial flow one. Cavitation volume fraction profiles for six conditions marked by open or solid circles in Fig. 4 were also attached, the cavitation fraction is depend upon not only the cavitation number but also the geometry of the blade, details need more investigations.

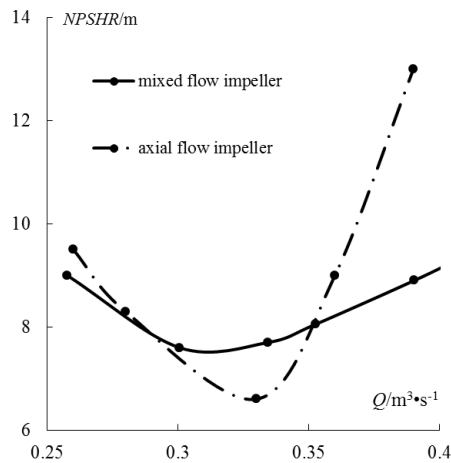


Figure 3. NPSHR curves tested.

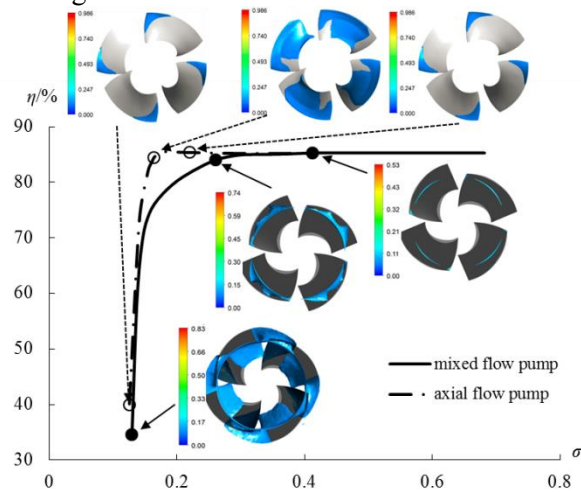


Figure 4. Suction performance calculated.

5. Conclusions

The axial flow impeller with a vane diffuser has a long axial length and compact radial configuration. Therefore it is more conveniently horizontal installed in a thin hull of high performance vessel to be a water jet propulsion. The mixed flow impeller with a volute collector has a robust pancake profile and is of vertical reliability.

Discrepancies near the design points were found on the performance curves of the mixed flow pump. Further study need to be done to investigate the detail as there have rarely materials concerning this phenomenon. The axial flow impeller has a good performance under the design condition while the mixed flow one has a larger region of high efficiency. In addition, the axial flow impeller also has a better suction performance under the design point, which contradicts with the experience knowledge and therefore details need to be further studied.

6. Acknowledgements

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