Assessment Performance of Pumps as Hydro-Turbines

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Abstract

The basic principle work of hydro-turbines are reversal of pumps, therefore, an alternative solution that can be developed in overcoming problem to get hydro turbines are by using pumps, by flowing water in the reverse direction through in the pumps, as hydro turbines. Those are supported by availability of pumps widely in the market and have been mass-produced hence they were relatively cheap. The aims of this research are to determine performances of pumps as turbines - reverse pumps. This experiment assesses performance of two small pumps that are centrifugal 'diffuser-pump' and 'volute-pump' as hydro turbines with various debit and head of water flow resource, such as output-powers and their efficiencies. The results show that the centrifugal diffuser-pump as hydro turbine performs maximum efficiency about 20,6%, where is as pump from its brochure suppose 47%. In the other hand, the centrifugal volute-pump as turbine achieves maximum efficiency about 32%, where is expected 26% as pump from its brochure. Both type of the pumps present that the maximum efficiency as turbines performed at head of water flow resource through the pumps as high as their maximum characteristic head of the pumps. Furthermore, both pumps as turbines generate high shaft revolution that was about 1.500 rpm at their maximum efficiency. Although those efficiencies are considerably low to an ideal efficiency 100%, however, the volute-pump as turbine performs a reasonably efficiency (32%) that higher than (at least is same as) the efficiency of its pump characteristic (26%), and this pump available very widely in the market. Should be pointed out that bigger dimension pumps propose higher efficiency up to about 86%, therefore they are expected to give higher efficiency as well. So, centrifugal volute-pumps are potential alternative solution to be used as hydro turbines.

Key words: Pump, Hydro turbins, Reverse pump, Pump as turbine

Abstrak

Pengujian Performa Pompa sebagai Turbin Air

Prinsip kerja dasar dari turbin air adalah kebalikan dari kerja pompa, yang selanjutnya dapat dijadikan suatu alternative yang dapat dikembangkan dalam memecahkan masalah untuk mendapatkan turbin air dengan menggunaan pompa yaitu dengan mengalirkan air denga arah berlawanan ke dalam pompa sebagai turbin air. Hal ini didukung dengan tersedianya pompa secara luas di pasaran dan telah diproduksi dalam skala besar. Penelitian ini menguji unjuk kerja dua pompa kecil yaitu diffuser-pump dan volute-pump sebagai turbin air dengan variasi debit dan head dari sumber air, seperti daya output dan efisiensinya. Penelitian menunjukkan bahwa centrifugal diffuser-pump sebagai turbin air menghasilkan efisiensi maksimum 20,6%, dimana sebagai pompa berdasarkan brosur sekitar 47%. Sedangkan centrifugal volute-pump sebagi turbin air memberikan efisiensi maksimum sekitar 32%, dimana sebagai pompa di brosur dicantumkan sekitar 26%. Kedua jenis pompa menunjukkan bahwa efisiensi maksimum dicapai pada head aliran air yang melalui pompa setinggi karakteristik maksimum dari head pompa. Selanjutnya, kedua pompa sebagi turmin menghasilkan putaran turbin yang tinggi yaitu sekitar 1.500 rpm pada efisiensi maksimumnya.Walaupun efisiennya rendah untuk suatu efisiensi ideal 100%, namum, volute-pump sebagai turbin menghasilkan suatu efisiensi yang layak (32%) yang lebih tinggi (minimal sama) dengan efisiensi karakteristik pompanya (26%), dan pompa jenis ini tgersedia cukup luas di pasaran. Harus dicatat bahwa semakin besar dimensi pompa menawarkan efisiensi semakin tinggi (di atas 86%), selanjutnya diharapkan memberikan efisiensi yang lebih tinggi juga. Jadi, centrifugal volute-pump merupakan solusi alternative yang potensial digunakan sebagai turbin air.

Kata kunci: Pompa, Turbin air, Pompa balik, Pompa sebagai turbin

1. Introduction

Now days, the world has been paced seriously energy crisis and environment impact. In Indonesia, energy demand growths about 15.4 percent per year. Therefore, the government has taken policy on diversification and conservation energy. Renewable energy technologies produce profitable energy by converting natural phenomenon into useful energy forms. One of renewable energy technology is hydropower. Hydropower systems convert hydraulic energy of water, potential and kinetic energy of water into mechanical or electrical work, and then the water can be used for other purposes such as irrigation.

Potential hydropower in around Indonesia is predicted about 75.624 MW, which spread on 1.315 locations. These are in Irian Jaya about 22.371 MW, in Kalimantan about 21.611 MW, in Sumatera about 15.804 MW, in Sulawesi about 10.203 MW, in Java about 4.531 MW, in Bali + NTB + NTT about 674 MW, and in Maluku about 430 MW.

Especially on Bali, there is not a big hydropower resource, but there are a lot of small hydropower resources that can be developed as micro hydro. By now, Electrical power in Bali has been mainly supplied from java using under seawater cables. Therefore, micro hydropowers are potential and attractive solution.

The basic principle of hydropower is if the water can be piped from a certain level to a lower level, then the resulting water head can be used to do work. If the water head is allowed to move a mechanical component then that movement involves the conversion of the potential energy of the water into mechanical energy. Hydro turbines convert water head into mechanical shaft power, which can be used to drive an electricity generator and other useful device.

The selection of the best turbine for any particular hydro site depends on the site characteristics, dominant one being head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have power speed characteristics. They will tend to run most efficiently at a particular speed, head and flow combination.

However, main problem is getting a turbine for a micro hydro. Its design and fabrication are complicated, and a turbine is not available widely in the market especially in Indonesia. In addition, reaction turbines are not available in small size. There are many potential sites with 2 to 10 meters of head and low flow that not served by the market. So, it makes happen why micro hydropower development is not attractive.

Because of the basic principle work of hydro-turbines are reversal of pumps, therefore, an alternative solution that can be developed in overcoming problem to get hydro turbines are by using centrifugal pumps, by flowing water in the reverse direction through in the pumps, as hydro turbines.

Those are supported by availability of pumps widely in the market and have been mass-produced hence they were relatively cheap. Cunningham and Atkinson [1998] stated that centrifugal pumps could be used as practical substitutes for reaction turbines with good results.

They can have high efficiency and are readily available (both new and used) at price much lower than actual reaction turbines. Furthermore, Klunne [2000] noted that centrifugal pumps can be used as turbines by passing water them in reverse. However, their performance characteristics are not available and poorly understood. Therefore, Klunne notify that further researches are required to enable the performance of pumps as turbines to be predicted more accurately.

2. Methodology

Method of solving problem defined in problem formulation is by experiment. The first step of this experiment is to set all devices used as in Figure 1 and Figure 2. The next step is to vary capacity and head of water resource, and set for varying turbine load. Pumps that are used in this experiment are:

1) A centrifugal turbine-type pump which have 0,22 m3/menit maximum capacity, 46 m maximum head, and 1.5 kW power of motor.
2) A centrifugal volute-type pump which have 0,13 m3/menit maximum capacity, 13 m maximum head, and 0.4 kW power of motor.

2.1. Schematic of the experiment

2.1.1. The centrifugal turbine-type pump as turbine

The wire of motor of the pump is removed then connected to torsi-meter and other equipments. Its arrangement is as in Figure 1. This experiment was running on reservoir of Denpasar Water Supply to get enough water supplies to drive the pump as turbine. In order to varying capacity and head of supplies setting the degree opens water of valve.

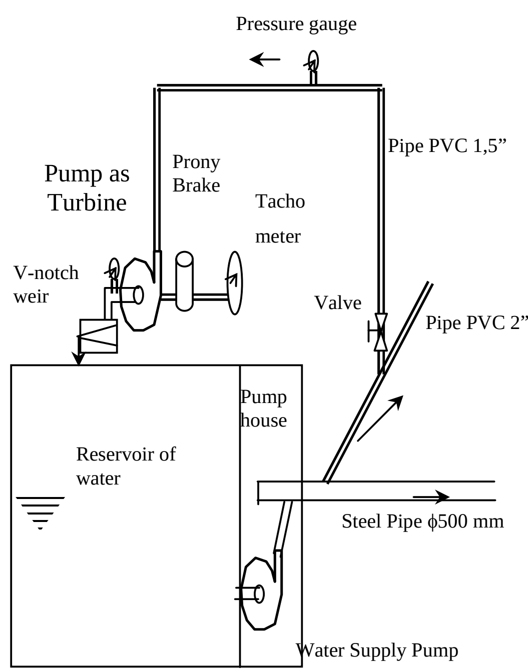

Figure 1: Schematic of experiment of turbine-type pump as turbine

2.1.2. The centrifugal volute-type pump as turbine

As previously, the wire of motor of the pump is removed as well, then connected to torsi-meter and other devices. Its arrangement is as in Figure 2. In order to varying capacity and head of supplies setting the degree opens water of valve.

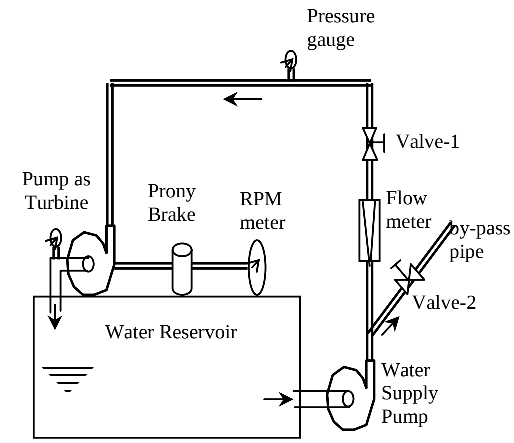

Figure 2: Schematic of experiment of volute-type pump as turbine

2.2. Procedure of the experiment

2.2.1. Assessment of the centrifugal turbine-type pump as turbine

1. Prepare the device as in Figure 1.
2. Rotate hand-wheel of the valve to one revolution from close position to supply water to drive the pump as turbine.
3. Record and tabulated the data such as pressure *p1*, *p2*; mass of torque-meter *m1*, *m2*; height of water throughout V-notch weir *h*; and revolution of turbine shaft *n*.
4. Repeat step 2 up to 3 by adding valve opened until the valve full opened.

2.2.2. Assessment of the centrifugal volute-type pump as turbine

1. Prepare the device as in Figure 2.
2. Set the valve-1 on full opened position.
3. Start the water supply pump for supplying water to drive the pump as turbine.
4. Rotate hand-wheel of valve-2 to full opened position.
5. Record and tabulated the data such as flow Q; pressure *p1*, *p2*; mass of torque-meter *m1*, *m2*; and revolution of turbine shaft *n*.
6. Repeat step 4 up to 5 by adding valve closed until the valve-2 full closed.
7. Stop the water supply pump.

2.3. Theoretical water power

Theoretical water power that is used to drive the turbine is

$$P_W = \gamma . Q . H \qquad (1)$$

Where:

P_w = Theoretical water power (Watt)
Q = Water flow capacity (m3/det)
H = Head (m)
γ = Specific weight of water (N/m3)

The head of water can be calculated by formula:

$$H = (z_2 - z_1) + \frac{(p2 - p1)}{\gamma} + \frac{(v_2^2 - v_1^2)}{2g} \qquad (2)$$

Where:

z_1, z_2 = lower and upper elevation to turbine axis (m)
p_1, p_2 = input and output water static pressure (N/m^2)
v_1, v_2 = input and output water velocity (m/s)

Velocity of water flow though in the turbine can be determined from flow capacity, which is measured using 90º v-notch weir [Streeter, 1975, p. 477]:

$$Q = 1{,}38.h^{2{,}50} \qquad (3)$$

Where:

Q = water flow capacity (m3/det)
h = water level at v-notch weir (m)

2.3. Turbine performance

The torque at shaft of pump as turbine is measured by using a manual prony-brake then can be calculated as follows [Keane & Phillips, 2003]:

$$T = (F_1 - F_2).R_p = (m_1 - m_2).g.R_p \qquad (4)$$

where:

F_1, F_2 = the force on the belt of the prony brake (N)
m_1, m_2 = the scale reading on the prony brake (kg)
g = acceleration of the gravity (m/det2)

R_p = the drum radius of the prony brake (m)

Then, the power extracted from the pump as turbine is

$$P_t = T.\omega \qquad (5)$$

in which $\omega = 2\pi n/60$ is the angular speed in rad/sec.

Turbine efficiency is simply defined as

$$\eta_t = \frac{P_t}{P_w} \qquad (6)$$

3. The results and discussion

3.1. Diffuser-pump as turbine

From the measurements that have made, then they are plotted in the graphs.

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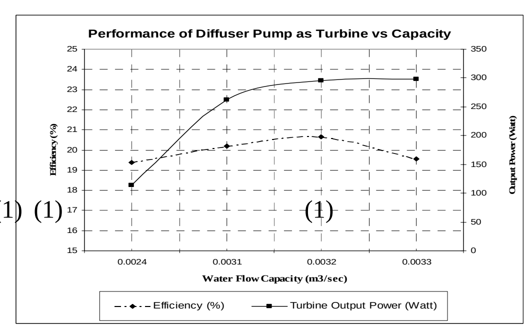

Figure 3: Performance diffuser pump as turbine at variation of capacity

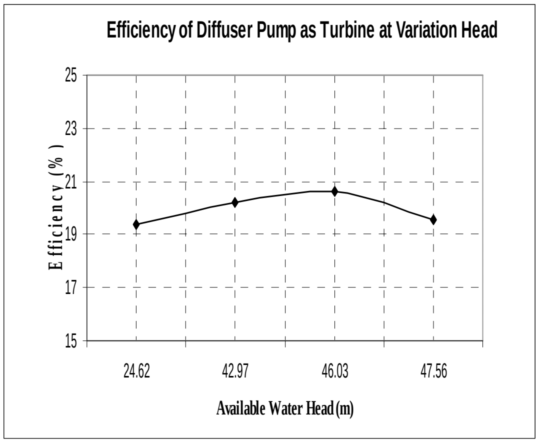

Figure 4: Efficiency of diffuser pump as turbine at variation of the available head

Figure 3 shows that the power extracted from the turbine is increasing if the flow of water capacity increasing as well. This is accordance with moment of momentum concept that turbine power proportional to mass flow rate. However, the maximum efficiency (20.64%) is reached at water flow rate about 0.0032 m^3/sec, where the maximum pump capacity is about 0.0037 m^3/sec at head 46 meter. The maximum efficiency of the pump as turbine takes place at the same as the maximum head of the pump characteristic in brochure (46 m) as is shown in Figure 4.

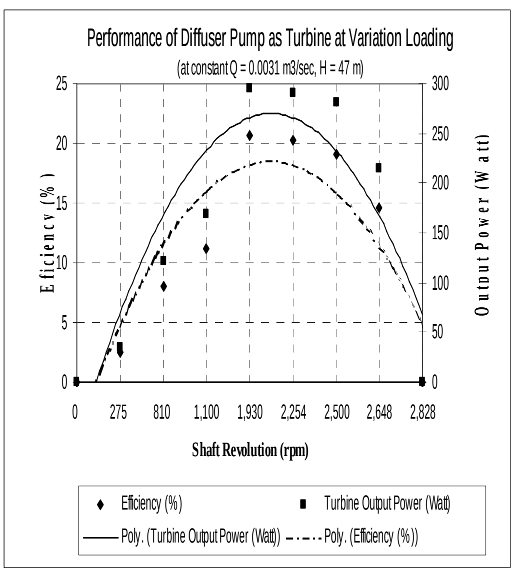

Figure 5: Performance of the diffuser pump as turbine at various shaft revolutions

Figure 5 presents Performance of the diffuser pump as turbine at various loading. The revolution of the turbine high enough to drive a generator, for example, that is about 1500 rpm. The maximum revolution is about 2928 rpm at runaway speed, and is about 1930 rpm at maximum efficiency.

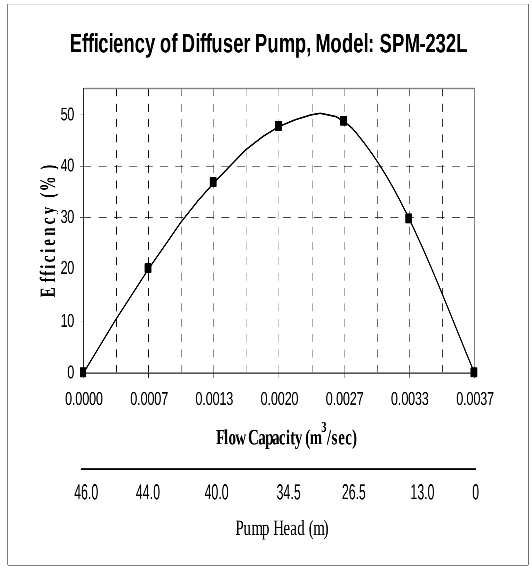

Figure 6: Efficiency of the diffuser pump model SPM-232L

The maximum efficiency of the diffuser pump as turbine (20.64%) is significantly lower than the maximum efficiency the pump itself, about 48.65%, as shown in Figure 6. This is due to imperfectness on the water flow passage and its tips of the guide vane of the pump as depicted on Figure 7. Beside of that, the weakness of this pump as turbine is not wide availability in the market, so it is difficult enough to get this type of the pump.

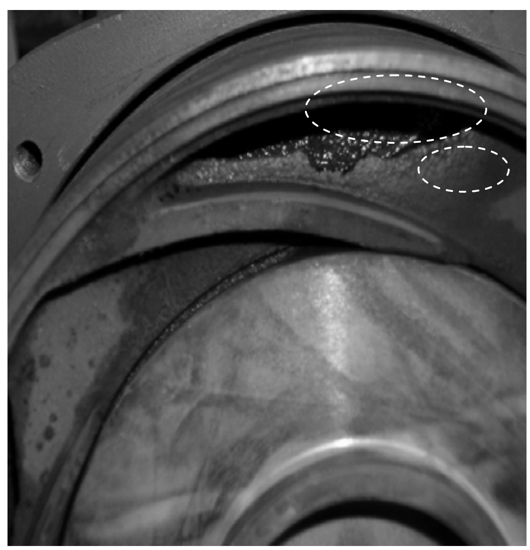

Figure 7: Imperfectness on the flow passage of guide vane

3.2. Volute-pump as turbine

Figure 8 shows that the power extracted from the turbine is increasing if the flow of water capacity increasing as on diffuser pump as turbine. However, the maximum efficiency (32.63%) is reached at water flow rate about 0.067 m^3/min, where the maximum pump capacity is about 0.13 m^3/min at head 13 meters. The interesting results show the same phenomenon as in diffuser pump that the maximum efficiency of the pump as turbine (32.63%) takes place at the same as the maximum head of the pump characteristic in brochure (13 m) as is shown in Figure 9. This maximum efficiency is slightly better than its pump characteristic efficiency (27.54%) as depicted on Figure 11. If the flow capacity can be raised up to the maximum capacity of the pump (0.13 m^3/min) so its output power will be predicting to increase too from 44.66 Watt to 86,65 Watt.

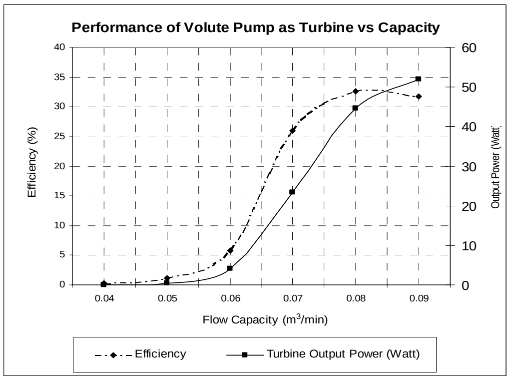

Figure 8: Performance volute pump as turbine at variation of capacity

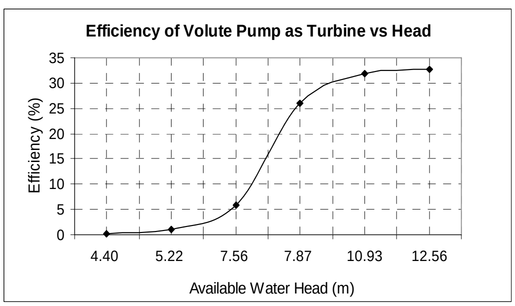

Figure 9: Efficiency of volute pump as turbine at variation of the available head

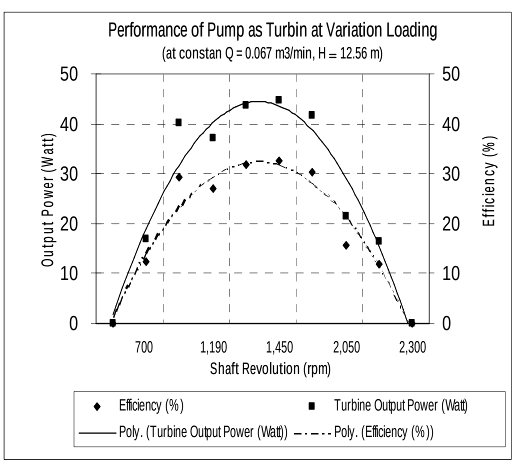

Figure 10. Performance of the diffuser pump as turbine at various shaft revolutions

Figure 10 presents performance of the volute pump as turbine at various loading. The revolution of the turbine high enough, that is about 1450 rpm at maximum efficiency, therefore, it can be direct coupled to a load such as a generator.

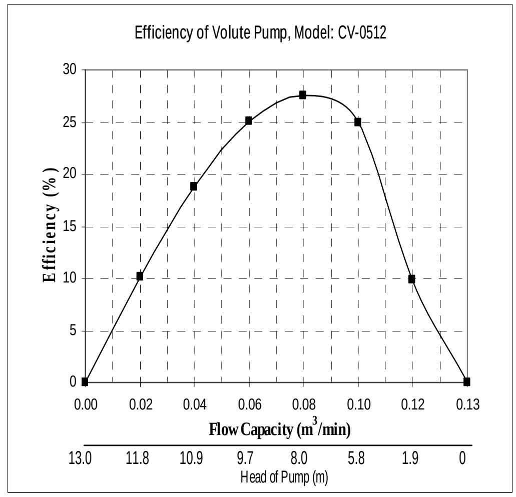

Figure 11: Efficiency of the volute pump model CV-0512

Performance of the volute pump as turbine offers better efficiency than the diffuser pump. Moreover, this type of pump is widely available in the market from small to big size.

Although this efficiency of pump as turbine is still low enough, it is caused by its pump efficiency is lower. From pump brochures can be see that for the bigger pump it will offer higher efficiency as well up to about 86%, therefore as turbine is expected to present higher efficiency too.

Furthermore, the optimum efficiency will generally be achieved when the shock losses at the inlet runner (impeller tips of the pump) is near zero. Therefore, modification must be made to the impeller tips of the pump, by grinding the inlet ends of the impeller tips of the pump to a bullet-nose shape to preclude excessive turbulence for efficiency consideration as presented on Figure 12.

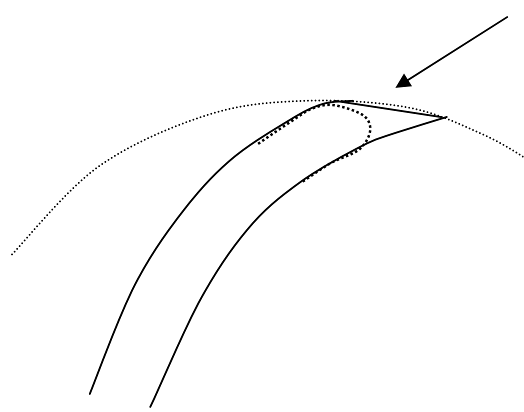

Figure 12: A pump impeller tip shape

4. Conclusions

From the experiments and discussion, the following conclusions are obtained:

1. Performance of a diffuser-pump and a volute-pump as turbines showed that both type of the pumps present that the maximum efficiency as turbines performed at head of water flow resource through the pumps as high as their maximum characteristic head of the pumps.
2. The efficiency of the volute-pump operating as turbine is slightly better than or at least equal to the pump efficiency.
3. The efficiency of the volute-pump operating as turbine is slightly better than diffuser pump; therefore, centrifugal volute-pumps as turbines become very attractive.
4. Furthermore, both pumps as turbines generate high shaft-revolution that is about 1.500 rpm at their maximum efficiency; therefore it can be coupled directly to the load, a generator for example, without reduction gear.

5. Recommendations for further work

1. It is important to further work on experiment for assessing this volute pump as turbine at constant head that is at maximum head of the pump with various flow capacities.
2. The optimum efficiency will generally be achieved when the shock losses at the inlet runner (impeller tips of the pump) is near zero. Therefore, modification must be made to the impeller tips of the pump, plus a testing that is required to verify the performance of the finished the pump as turbine.

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