PTV-Measurements of Flow in a Low Specific Speed Pump

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Abstract

In order to measure the flow in a centrifugal pump for low specific speed, a new system of PTV method is developed. This system uses the mass-produced and cheap digital camera and LED(Light Emitting Diode) lamps. The tracer particles, which are lighted by red and green LED flash, are exposed into one picture image, and divided in the post process. There is no inner-clock, so this system can synchronize the rotation of impeller with good accuracy. Also the interval time between red and green flash can be changed freely. Using the blue markings for calibration in the flow area, we can distinguish these markings from particles during the measurement. Though the intensity of light must be improved a little more, the array of high-brighted LED can generate enough light to trace the moving particle.

1 Introduction

The flow characteristics in a low specific speed range is not known well yet. The authors have revealed that the performance characteristics of a centrifugal pump of an extremely low specific speed is much different from those of an ordinal specific speed pump, but much detailed information is needed to improve the low efficiency of the pump. In this type of pumps,the flow is unsteady and not symmetric. Also it goes through the very narrow channel, so we cannot use pitot tube to measure the velocity in it.

Here, the flow measurements are performed by use of PTV method with the test pump apparatus made of acrylic resin. To apply the PTV method to this flow, several problems arise as shown below:

1) Pictures must be taken at the absolutely same position of an impeller vane in order to know the interference between the impeller vane and spiral casing.

When the normal CCD video camera is used, or even when a very high speed video camera is used, there exists some inner clock of the video camera system. Therefore there is small fluctuation of the position of vane in the taken image. Though the fluctuation is under 3 [degree] in the case of our high speed camera system, the error may become larger with the increase of rotating speed. To synchronize inner clock on the interval of trigger from impeller, it needs some complicated electrical circuit.

2) The impeller rotates so fast that the interval time of taking continuous images must be very short. If the camera is rotated with the axis, the relative velocity can be taken much easier. But the camera must be small and light to be rotated. Or, we must use high speed camera, which is very expensive.

3) In order to calibrate the taken picture, we must put some markings in the flow area. From the accurate position of these markings and taken picture of them, we can change the unit of vector from pixel per second to meter per second. If these markings are left while measuring, some particles may be hidden by markings. So we must remove markings or plate on which markings are written, before starting the measurement.

To solve these problems, we developed an new lighting method with red and green LED(Light Emitting Diode) to get much higher accuracy, easiness, and efficiency of measuring. Comparing the results from this new system and the ordinary PTV system that uses the high-speed digital video camera, the accuracy of new system is verified.

2 Experimental Methods

2.1 Pump System

The test impeller is a semi-open type with two-dimensional vane. Its outer radius is 120[mm], and the designed specific speed is 100[rpm,m^3/min,m].

The vane angle is 90[deg.], that shows a good performance in the low specific speed area in our experiments. Number of vane is 6, and its thickness is 4[mm], which is made by transparent acrylic resin. The rotating speed of impeller is 700[rpm], and the designed flow rate is 2.25[m^3/s]. The width of volute is 9[mm],.

The front cover of casing is made by transparent acrylic resin, so that the flow in the impeller and in the volute can be seen at the same time, except for the very near area of suction pipe.

2.2 Measurement System

Figure 1(a) shows our measurement system, and Figure 1(b) shows the schematic chart of our PTV system. In this system, the light has two colors (red and green) generated by LED array. The optical sensor picks up the rotating position of impeller and causes trigger signal. According to this signal, the red LED twinkled for a flashing time.After some interval time, the green LED gives green light for the flashing time. During this period, the camera keeps opening its shutter, so two different images are put into the one colored image data. This system has no its own clock, so it can synchronize with very good accuracy. Also, the interval time can be changed widely.

The camera (FUJIFILM DS-330) is not special one but popular one, whose interval of twice taking picture is more than 1 second. Its resolution is 1280 x 1000, and it can save the TIFF image without any data compression. This resolution is much larger than that of the TV video camera.

Furthermore, using the blue markings in the flow area, we do not have to remove the markings after calibration. That means we do not have to disassemble the pump after the calibration.

The major problem in this system is the intensity of the LED lamp. Table 1 shows the characteristics of LEDs in this system. These LED of high-brightness type are arrayed to two rows that are connected in parallel. Twenty red LEDs and 20 green LED consist these rows and they make a sheet of light.We use two set of such LED array. The response of LED to the short pulse is confirmed until under 0.1[ms], which is enough for our purpose.

The captured image data was processed by five steps.

1) Subtract the background image from the flow image to remove the stationary objects and

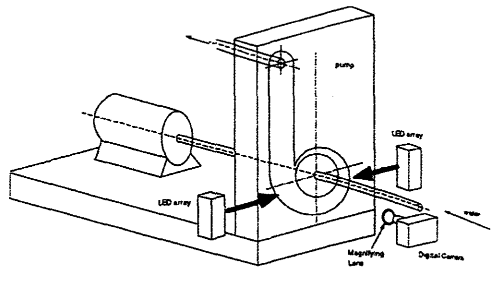

Figure 1(a) Pump and measurement system

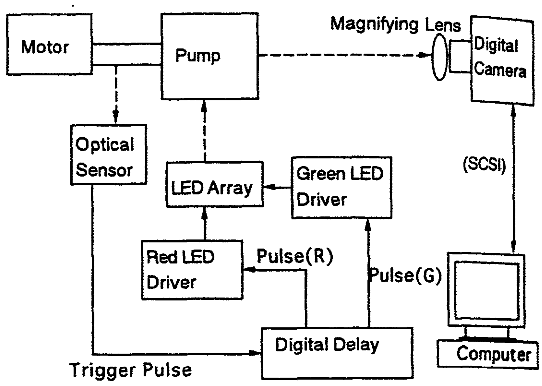

Figure 1(b) PTV system

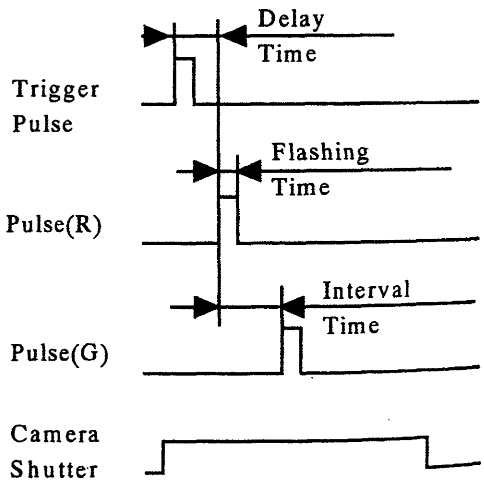

Figure 1(c) Timing chart of lighting

Figure 1: Experimental System

Table 1 LED Characteristics

Type	Color	Luminous Intensity
TLRH180P	Red	6000 [mcd]
E1L51-3G	Green	5600 [mcd]

reflection of lamp.

2) From the color image, first (red) image and second(green) image are divided. The cross talk between red and green component is very small.

3) Calculate the center of mass of particles by the algorithm for particle recognition developed by Kato [1].

4) Trace these recognized particles within continuous two images of red and green in order to get the velocity vector. The pattern matching algorithm proposed by Adachi [2] is used.

5) Change the coordinate from that in the image to real one. To do this mapping process, we used the calibrating data, that is calculated from the picture taken with some special plates in the pump. Comparing these measured position and position that is detected from the image data of this plate, the relation between the position in the image data and real position is estimated. This method is developed by Kato[1], also.

The tracer particle is made by nylon-12, whose specific gravity is 1.02. The diameter is selected from 0.5 [mm] to 1.0 [mm]. These particles can go through the relatively wide gap between impeller blade and front casing wall.

3 Results

3.1 Measurement of Channel Flow

To check the accuracy of our PTV system, we measure the velocity distribution at the discharge channel, whose width is 69[mm] x 9 [mm]. Figure 2 shows the measured velocity distribution. Velocity component v is the velocity of main stream (y direction), and u is that in span direction(x direction). The velocity profile is almost same as other reports for the discharge channel of centrifugal pump. Also the quantity of flow integrated from this distribution is 2.39 [m³/h], thinking the thickness of boundary layer. This value agrees with 2.41 [m³/h] which was measured by electromagnetic flowmeter at the same time. Our system shows good performance in the flow field of such slow velocity.

3.2 Check of Fast Rotating Particles

To check the ability of our new system for the fast flow such as flow in the impeller, we fixed 14 tracer particles on the impeller plate with glue, and measure the rotation of such particles while the impeller rotates with 700 [rpm].

Figure 3 shows the results. The abscissa is the radial position in the impeller, and solid line means the solid rotation (r ω), that is the correct rotating velocity.

The solid circle shows the average of measured velocity of 14 glued particles for 100 samples. Its standard deviation is shown also as an error bar.

There are some particles with larger errors than other's. The brightness of each particle images have large correlation with these errors. Some error are caused by the shadow from the bolt on the impeller. Other error comes from the distortion of lens, especially near the vane area. In this area, the trace algorithm may make wrong trace.

3.3 Measurement at Shut off Point

We already measure the velocity distribution at shut off point, with ordinary PTV system that uses the high speed digital video camera. Here we compare it with present distribution.

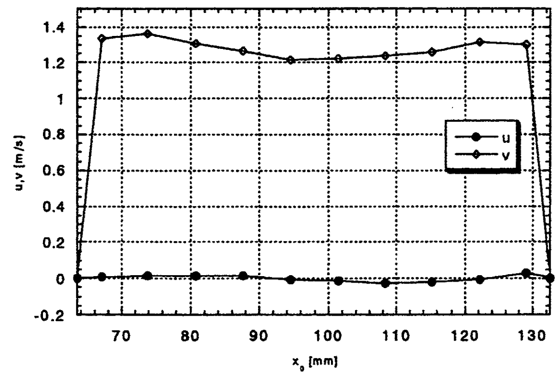

Figure 2 :Velocity distribution at the discharge channel

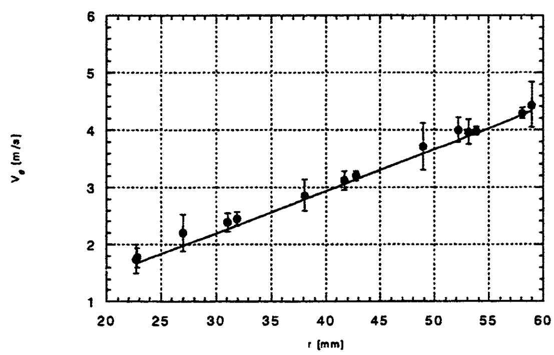

Figure 3 : Accuracy check on the rotating particles

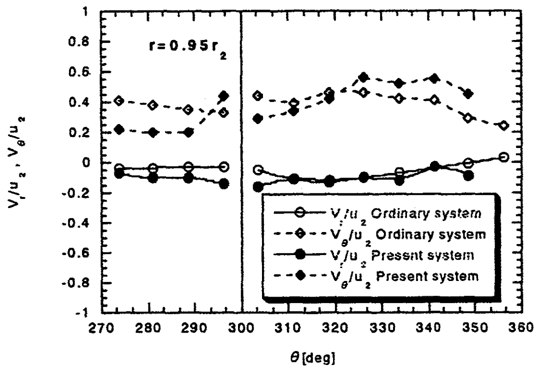

Fig. 4(a) Comparison of velocity distribution in the impeller area (r= 0.95 r_2)

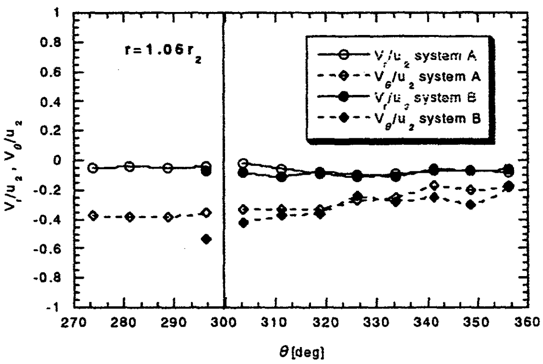

Fig. 4(b) Comparison of velocity distribution in the spiral casing area (r= 1.05 r_2)

Figure 4 : Comparison of Two PTV System

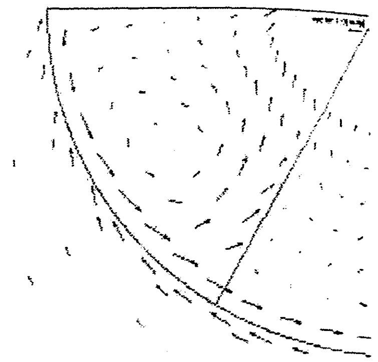

Fig.5(a) data from ordinary PTV system

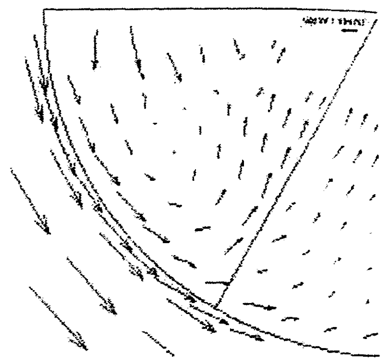

Fig. 5(b) data from new system

Figure 5 : Velocity field at Shut Off Point

Figure 4 shows the comparison between two PTV systems. As we see in the previous section, our new system causes some errors near the vane and some special area in the impeller. In Figure 4(a), we can see the same tendency of error. But in Figure 4(b), at the spiral casing, both tangential and radial velocity distribution agrees well with the result of ordinary system. So our system can use for the fast flow, but in the impeller flow we need some improvements.

The relative velocity field to the impeller is compared in Figure 5. We can see a very large eddy structure in the impeller vane area. But the vectors in upper area of figures, that is, near the vane area, have large differences. It is the error in our previous system. (In Figure 5(a), the velocity vector in the casing area is absolute one.)

3.3 Measurement at Maximum Efficiency Point

Figure 6(a) and 6(b) show the velocity distribution of our pump at the maximum efficiency point (ϕ = 0.051). In Fig. 6(a) , vectors are the absolute velocity, and in fig. 6(b), all vectors are relative vector to the impeller. Each vector is the ensemble average of 100 independent measured vectors. We can see very unstable flow field in the impeller, that is almost same as the result by ordinary PTV system.

There is some flow that goes over the impeller vane. This flow becomes very clear in our pump, because the gap between the vane and casing cover is very wide. In each area between vanes, the velocity field is different. Therefore when the position of vane and tongue is changed a little, the flow changes very much.

Figure 7 shows the effect of number of samples. In each measuring cells, we get 100 or 300 sample vectors and get an ensemble average of these vectors. As shown in Figure 7, the 100 sample may be enough in almost all area, but near 30 degree that is the position of impeller vane, the tangential velocity is changed by the number of sample. In this area, the uncertainty of PTV measurement becomes large.

The accuracy of measurement is almost enough in the casing area by our new PTV system, but we cannot get good accuracy in the impeller area. The main reason of the error is weakness of light and low ratio of signal to noise.

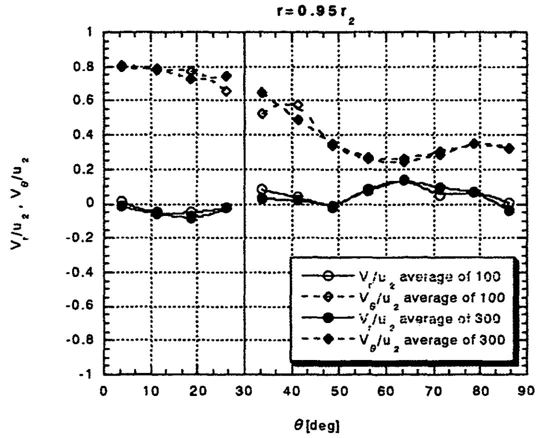

Figure 7 :Effect of Sample Number of Vector

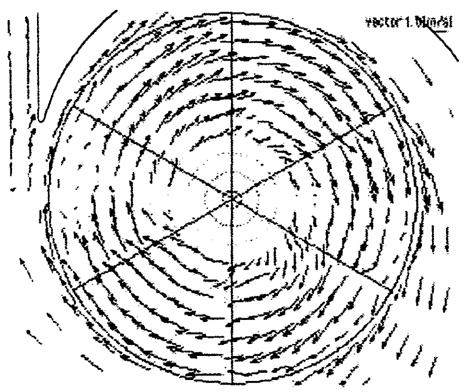

Fig. 6(a) Absolute velocity

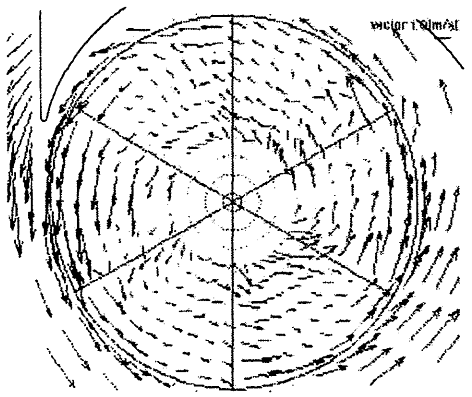

Fig. 6(b) Relative velocity

Figure 6: Velocity field at Maximum Efficiency Point

4 Concluding Remarks

PTV measurement system is developed for the flow in the centrifugal pump with low specific speed.

With digital camera and LED array lamp, we success to measure the flow with some accuracy.

By additional software techniques, we can improve the number of detected valid velocity vectors.

Some improvement of lighting system and of image-processing algorithms is necessary for measuring in the impeller flow.

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