

USING PIV ON THE SPLASH WATER IN A PELTON TURBINE

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Abstract: At the Institute for Waterpower and Pumps, Vienna University of Technology, we have done several scientific projects in the field of flow observation in the casing of Pelton turbines. An important step in the direction of a fundamental analysis will be the measurement of the velocities of the droplets traveling in the casing and on the wall of the casing. The Austrian science fund kindly has provided a PIV-system for these investigations. The first measurements have been done on the jet at the outlet of the nozzle of the turbine. Oncoming research work will include the exact documentation of the flow through the bucket and inside of the turbine - casing.

Keywords: PIV – Measurement, Pelton – Turbines, flow analysis in the turbine casing

1 Introduction

High head turbines are mostly of the Pelton type, in which a Pelton wheel, comprised of buckets, is driven by a cylindrical water jet. The discharge and diameter of this jet are regulated by a nozzle-needle system, which is fed by a distributing manifold.

In spite of the fact, that the Pelton turbine has met a significant improvement according to efficiency and reliability during the last century, the analysis of the flow through injectors and runner buckets is still on a research level and the physical phenomena involved are far from being fully understood and described. Even though today's Pelton turbines are highly developed, considerable experimental data of the velocity field in the bucket and inside of the casing is needed before further theoretical calculations (e.g. Computed Fluid Dynamics) can be applied to the turbine in order to maximize the efficiency of this type of rotating machinery.

There is even less knowledge concerning the casing and the interaction between casing and runner. The casing however is an essential part of the turbine. It has to drain off the water coming out of the buckets without hindering the runner. Up to now the investigations of the flow in the casing of Pelton turbines are limited to visual documentation of the splash water distribution. On the basis of this visual documentation a casing is qualified to be good or not. Efficiency measurements assist these findings.

To acquire more accurate data we applied a Particle Image Velocimetry (PIV) – System, which was provided by the Austrian science fund, to our Pelton turbine testing stand.

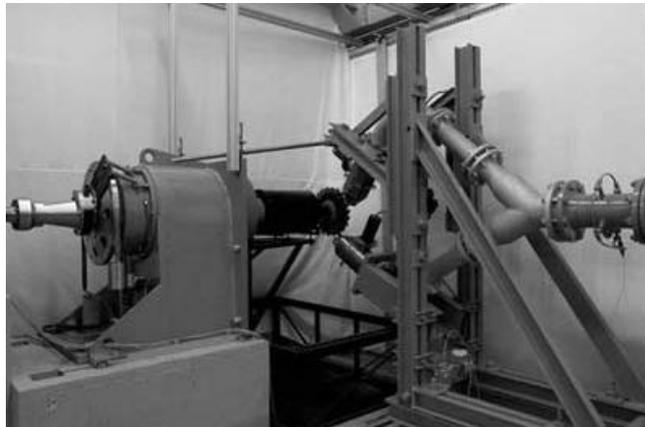


Figure 1. Testing Stand at the Laboratory

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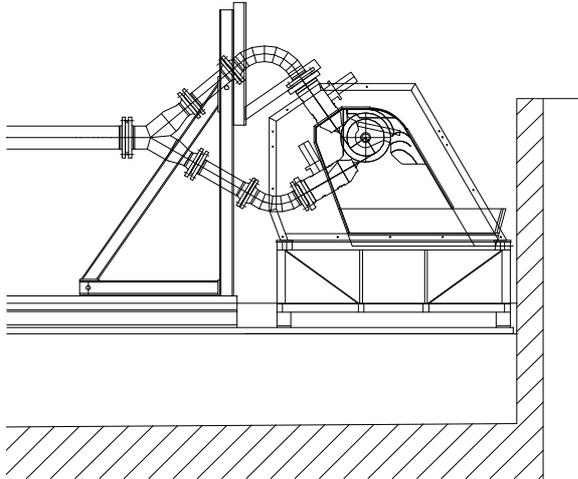


Figure 2. Two jet Pelton turbine

The priority of the project was the analysis of the influence of different guiding plates on the efficiency of the turbine. The visual observation of the splash water however was an important resource for the interpretation of the test results. The photos supplied information on the flow direction of the water along the wall of the casing. Figure 3 for example shows the splash water distribution near the best efficiency point of the turbine. We can see the influence of the parts built in on the reflection of the flow and the effect to the system jet-runner. This however may be a subjective assessment that is less helpful for a fundamental analysis of the casing. The knowledge of the real velocities and the overall flow field would deliver more general statements. This fact and the know-how gained from former investigations has matured the idea to make a step in the direction of a more fundamental analysis of the flow in the casing by means of measurements of the velocities of the droplet leaving the buckets and traveling in the casing. Comparing and analyzing the available measurement techniques the PIV was chosen as the most promising one to meet our requirements.

Almost a decade ago the first research project on the splash water distribution in the casing of Pelton turbines has been realized at the Institute for Waterpower and Pumps. We started with fundamental investigations on a rectangular casing and continued with measurements on a double-jet turbine (Fig. 2.), analyzing the influence of the casing on the performance of the turbine [1]. In order to get visual access to the flow we used transparent walls, to be able to photograph and film the flow in and around the buckets of the runner, (Fig. 4., [2]).

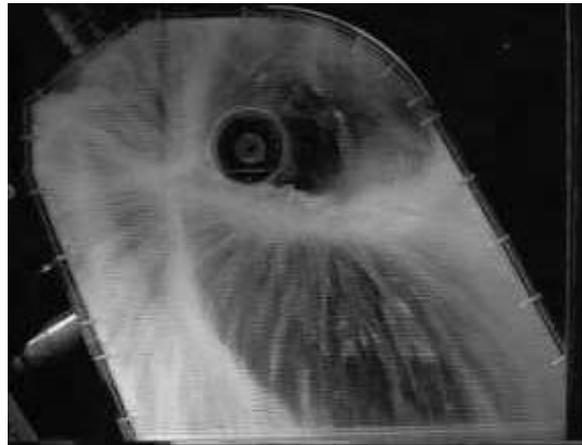


Figure 3. Splash water on the wall of the casing

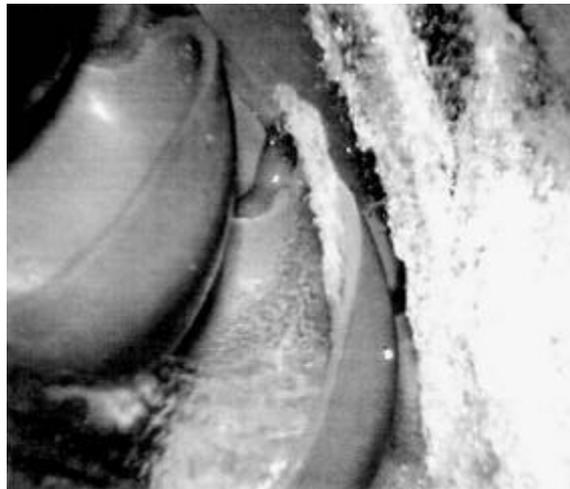


Figure 4. Flow in the bucket

3 THE PIV-SYSTEM

The Dantec Flow Map PIV 2100 we use is a real time correlating system with various possibilities of data analysis and presentation features.

The system itself consists of the following components:

- PIV 2100 processor
- Twin-chamber 50 mJ 15 Hz Nd:YAG laser
- Kodak Megaplug ES-1.0 camera with 1k x 1k CCD chip and a double frame rate up to 15 Hz

3.1 The PIV measurement process

3.1.1 Seeding the flow

Usually polyamide particles are suspended in the fluid to trace the motion of the fluid and achieve a proper signal. In our case no such seeding particles were added because the highly inconstant, rough surface of the jet coming out of the nozzle offers enough contrast for the correlation process.

3.1.2 Flow field illumination

When a thin slice of the flow field is illuminated by a light-sheet (Nd:YAG laser), the illuminated particles scatter the light. This is detected by a digital camera (Kodak Megaplug ES-1.0) placed at right angles to the light-sheet. The light-sheet is pulsed twice at a known time interval, synchronized to the shutter of the camera. We use two different setups of our measuring instruments as shown in Fig. 5a. and Fig. 5b. where we interchange the position of laser and camera, in order to get the best position for any kind of flow observation inside the casing.

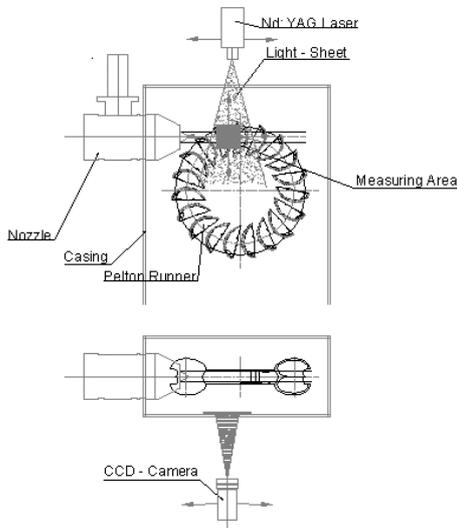


Figure 5a. measuring setup A

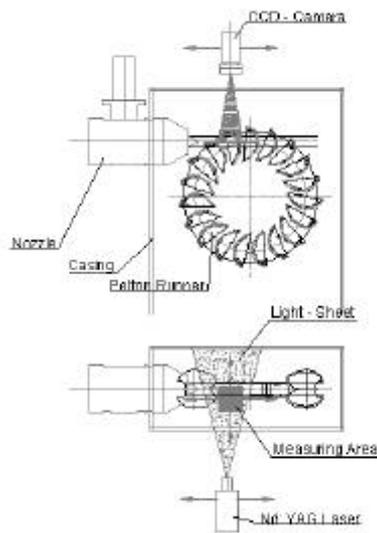


Figure 5b. measuring setup B

3.1.3 Image acquisition and processing

The first pulse of the laser freezes images of the initial positions of the particles onto the first frame of the camera. First frame data remains in memory, while the second frame of the camera is exposed to the light scattered by the particles from the second pulse of laser light. There are thus two camera images, the first showing the initial positions of the seeding particles and the second their final

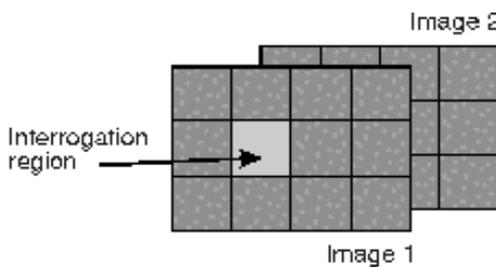
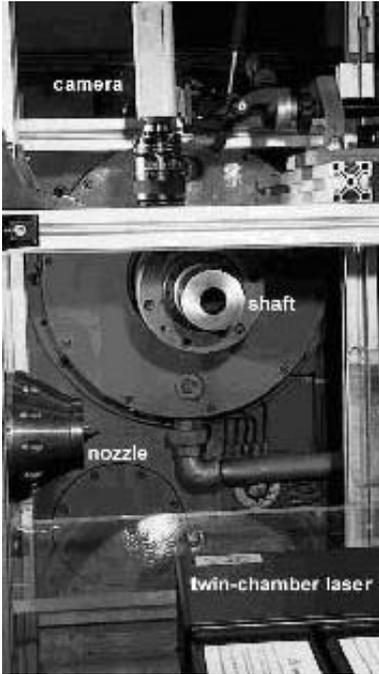


Figure 6. image processing scheme

positions due to the movement of the flow field. The two camera frames are then processed to find the velocity vector map of the flow field. This involves dividing the camera frames into small areas called interrogation areas (Fig 6.). In the actual measuring an interrogation area size of 64x64 pixel was used. The time between two laser pulses varied between 8 and 20 ms. In each interrogation area, the displacement of groups of particles between frame 1 and frame 2 is measured using correlations (which are implemented using FFT algorithms).

4 Using the PIV-system on the jet



At the test rig for Pelton turbines the single jet configuration was installed. The runner was dismantled from the bearing shaft. At the rear end of the casing a pipe with a knee was fixed in order to divert the jet to the tailwater. The camera equipped with a 60 mm lens was mounted on the upper side of the casing. The twin-chamber laser was fixed on a tripod at the side of the casing with the light sheet adjusted horizontal. Figure 7 shows the experimental arrangement. Figure 8 shows the use of the PIV-system on the jet. The vertical position of the light sheet is adjusted to meet the axis of the jet. One image obtained that way is shown in figure 9. It is the first image of a double-frame taken by the system. The size of the image is 1008x1018 pixel, the diameter of the jet is approximately 30 mm. The aperture is set to 5.6.

Clearly visible is the highly rough surface of the jet surface., The velocities obtained thus are the velocities on the surface of the jet and not those of the cross section of the jet where the light sheet is positioned.

The surface structure has the advantage to get a vector field of the flow without the use of seedings. But on the other hand the visual pattern of the jet surface is very dominant, which makes it hardly possible to watch the inside of the jet.

A multitude of tests have been made varying the aperture of the camera and the position of the light sheet.

Figure 7: PIV set-up for measurements on the jet

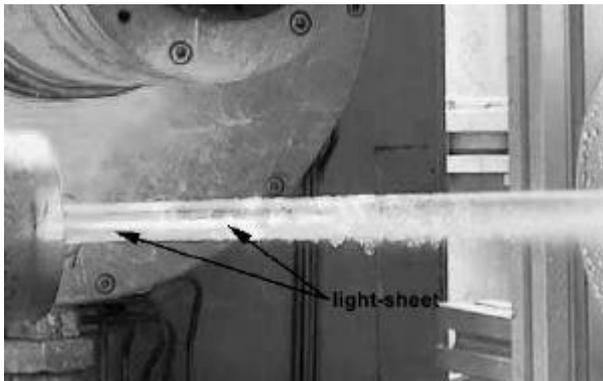


Figure 8. PIV measurement on the jet

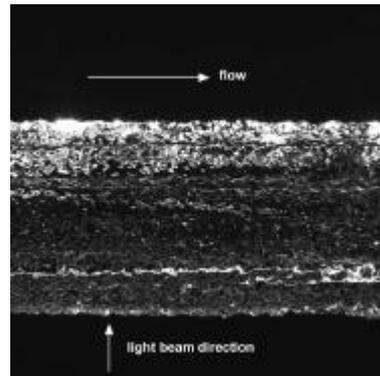


Figure 9. image of the jet

Figure 10 shows one image (1008x1018 pixel) of a double-frame shot with an aperture of 8. The camera position is chosen to capture an image of the jet at the nozzle end. The needle of the nozzle can be recognized in the left area of the photo where the light sheet is reflected by the conical form of the needle.

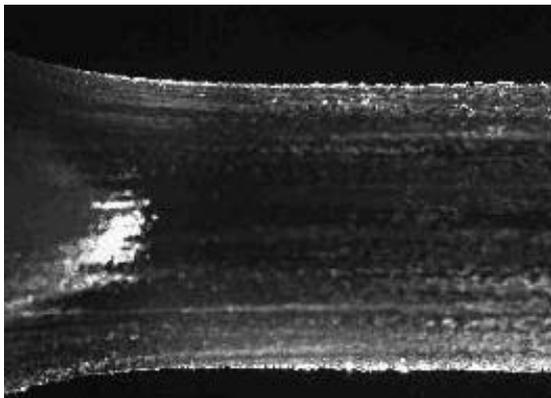


Figure 10a. Image of the jet at nozzle end

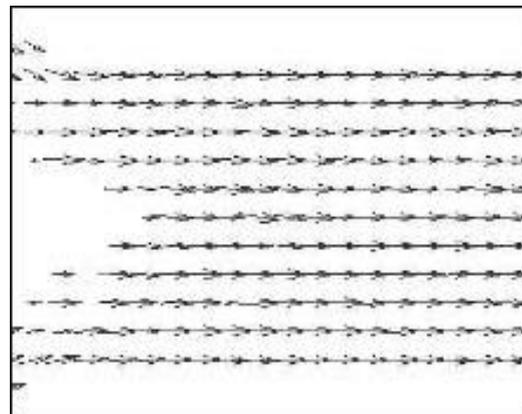


Figure 10b. Vector field at the nozzle end

The general data for this test are:

- flow out of the nozzle: 0.0107 m³/s
- head at the nozzle: 50 m

The diameter of the jet can be estimated to be approximately 25 mm. Thus the mean velocity of the jet results in 21.8 m/s. Converting this velocity with the resolution of the chip and the image size we get a value of about 0.6 pixel/ms. The set-up for the PIV-system thus is selected to:

- duration of one pulse: 0.01 ms
- time between pulses: 10 ms

Using cross-correlation with an interrogation window of 64x64 pixel and an overlap of 25 % the velocities are calculated. The vector field received this way is presented in figure 10b. The size of the vectors is almost identical and amounts to 22 m/s.

The vector field clearly maps the convergent periphery of jet coming out from the nozzle. The contour of the needle is visible too, the velocities at the boundary line however are not tangential. As soon as the light sheet lightens an area of the jet the surface pattern is responsible for the velocities calculated.

5 INVESTIGATIONS INTENDED

The objective of the project is the investigation of the flow coming out of the runner. The experience so far indicates two areas suitable for PIV-measurements:

5.1 Determination of the velocities at the outlet edge of the bucket

At the outlet edge of the bucket we can see a screen of water (Fig. 4.). A light sheet horizontally positioned will be used to determine the velocities at the outlet edge of the bucket.

5.2 Determination of the velocities at the side wall of the casing

The flow of the splash water along the side wall of the casing (Fig 3.) is extremely significant for the assessment of the operation of the turbine. Moreover the observation of the flow along this flat wall is without difficulties. As the size of the measuring area is limited due to the CCD-chip of the camera and the resolution required it is not possible to view the entire side wall with one camera position. A positioning device will enable a scan of the wall at a constant operating condition of the turbine.

6 SUMMARY

At the Institute for Waterpower and Pumps a PIV system will be used to investigate the flow in the casing of a Pelton turbine. The first investigations are performed on the jet coming out from the nozzle. Due to the highly rough surface of the jet it is possible to get a vector field of the flow without the use of seedings. On the other hand the visual pattern of the jet surface is very dominant. It is hardly possible to watch the inside of the jet.

7 REFERENCES

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