Application of thermodynamic efficiency measurement with turbine cover drainage led into the draft tube cone

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Abstract

This paper is an upgrade of the measuring method presented at IGHEM 2016, "Application of thermodynamic efficiency measurement using temperature sensors installed into the water passage system".

Francis units typically have a turbine cover drainage system installed to decrease the water pressure acting on the runner crown and thus to decrease axial loading of the thrust bearing.

This paper presents the successfully applied measurement setup where the turbine cover drainage system was in place and the drainage flow was led into the draft tube cone, downstream of the runner while the downstream temperature and pressure measurements were conducted with the probes installed within the water passage system.

1. Introduction

Litostroj Power conducted a refurbishment and upgrading of a 113 MW vertical Francis unit with nominal net head 269.6 m and nominal discharge 45.0 m^3/s. A new runner and wicket gates were designed, manufactured and installed into an existing flow passage system. For official site efficiency test the thermodynamic method in accordance to IEC 60041 code [1] was mutually agreed.

According to the code, drawing of a part of the water on the turbine upstream side (location "11") and downstream side (location "21") is proposed, see Figure 1. Water energy on both locations is then measured, using temperature and pressure probes.

On the tested unit, a design of the draft tube elbow did not allow drawing part of water outside of the flow passage system for the purpose of the measurements. It was shown on previous measurements [5] that the measuring arrangement with temperature and pressure probes installed directly into the downstream flow passage system (location "20") can be successfully applied.

General measurement setup as used on site is presented in Figure **1**.

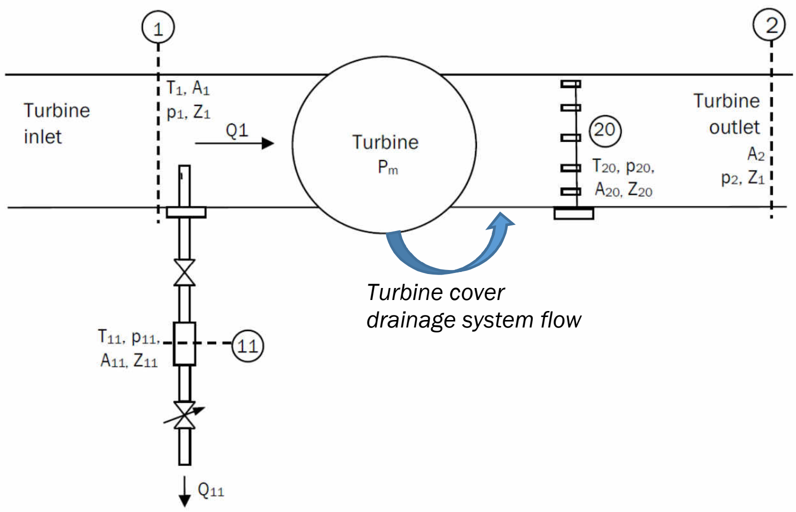

Figure 1: General measuring setup

2. Measurement setup

2.1. Cross-section "11" upstream of the turbine

Upstream of the turbine, the measuring cross-section was defined according to IEC 60041 recommendation. A portion of water was drawn out of the flow passage system immediately after the turbine inlet valve and approximately one inlet pipe diameter upstream of the entrance to the spiral case. Figure 2 presents the gauging used at upstream measuring location "11".

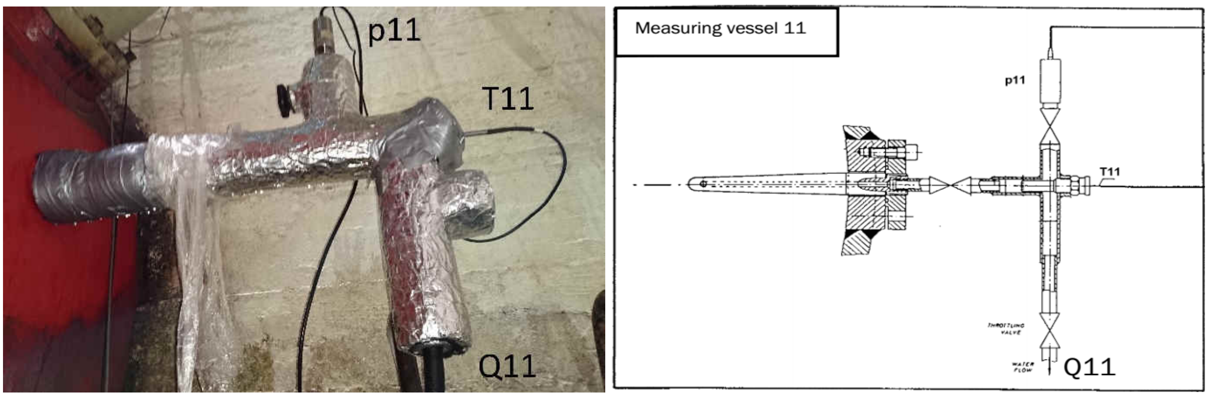

Figure 2: Inlet water temperature measurement and meassuring vessel with sensors

At the same cross section, specific hydraulic energy was measured via manifold pressure taps as shown in Figure **3**.

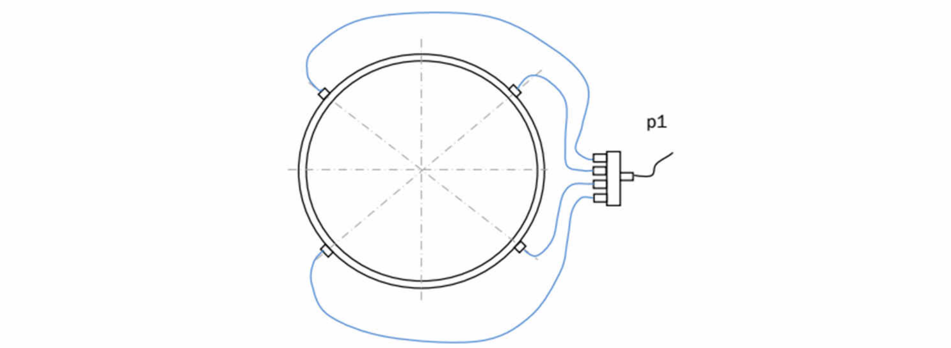

Figure 3: Inlet pressure measurement

2.2. Turbine cover draining flow

Francis units have turbine cover drainage system to decrease axial load of hydraulic force to the thrust bearing. According to the turbine design, turbine cover drainage flow is led into the draft tube cone, downstream of the runner, see Figure 4.

For the purpose of measurements this system was left in place so higher temperature measurement deviations and pulsations were to be expected during the measurement. Namely, the turbine cover drainage flow is a heated stream of water that enters the water passage in the area of the draft tube. Depending of the draft tube flow conditions, mixing of heated water with the main flow is expected, however perfect heat distribution can never be achieved.

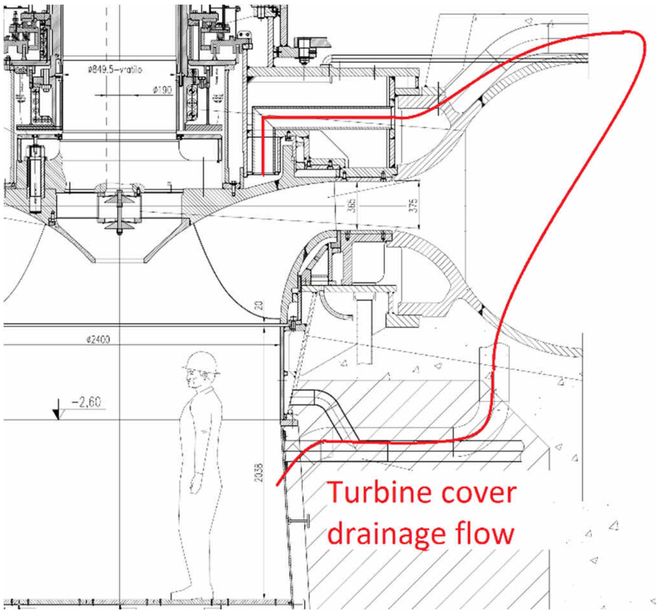

Figure 4: Turbine cover drainage flow to draft tube cone.

2.3. Cross-section "20" downstream of the turbine

As heated water from the turbine cover draining system is entering the draft tube, it influences the water temperature distribution and consequently the measurement downstream of the runner. Higher number of temperature probes are to be installed directly into the water passage. Furthermore, the higher number of temperature measuring probes are to enable the analysis of the draft tube water temperature distribution over the measuring cross-section and its pulsations during constant unit operational conditions.

Position of the downstream measurement cross-section was selected about 1.5 m upstream of the outlet [2], [3], see Figure 5. At this position, we expected that:

- main turbine and turbine cover drainage flow are well mixed
- minor or no backflow will be present

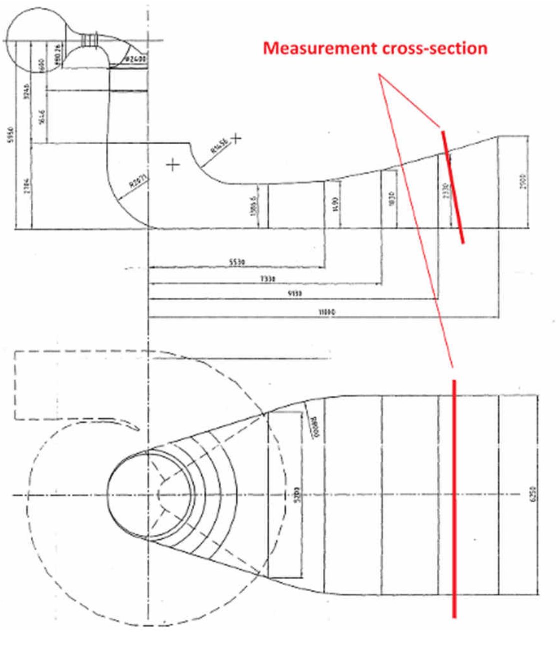

Figure 5: Measurement cross-section downstream of the turbine.

Within the draft tube a considerable pulsation of the velocity profile is expected, even at the unit constant output. The only point with a consistent flow velocity is supposed to be at the centre of the cross-section [3].

For measurement of the average water temperature, various probe arrangements were considered. Due to the presence of turbine cover drainage water in the draft tube, high temperature difference between neighbouring temperatures probes were expected. Finally, it was decided to use fifteen temperature probes. One probe was installed into the centre of the cross-section, while 14 of them were arranged as shown in Figure 6.

Temperature probes were not placed centrically over the measured cross-section. The probes were placed towards the centre of the cross-section, where less influence from the wall heating was expected. Moreover, placing of the temperature probes around the centre decreased a possibility of a draft-tube back-flow and corner vortices influences on the average temperature measurement.

We placed the temperature probes into the flow passage in line with the main flow direction. In such a manner, friction and stagnation heating of the temperature probes were minimized, allowing slightly higher flow velocities at the measuring section. Maximal flow velocity at full discharge trough the cross-section "20" was 3.8 m/s.

Pressure was measured with two submersible pressure probes. They were mounted to the frame as presented in Figure 6.

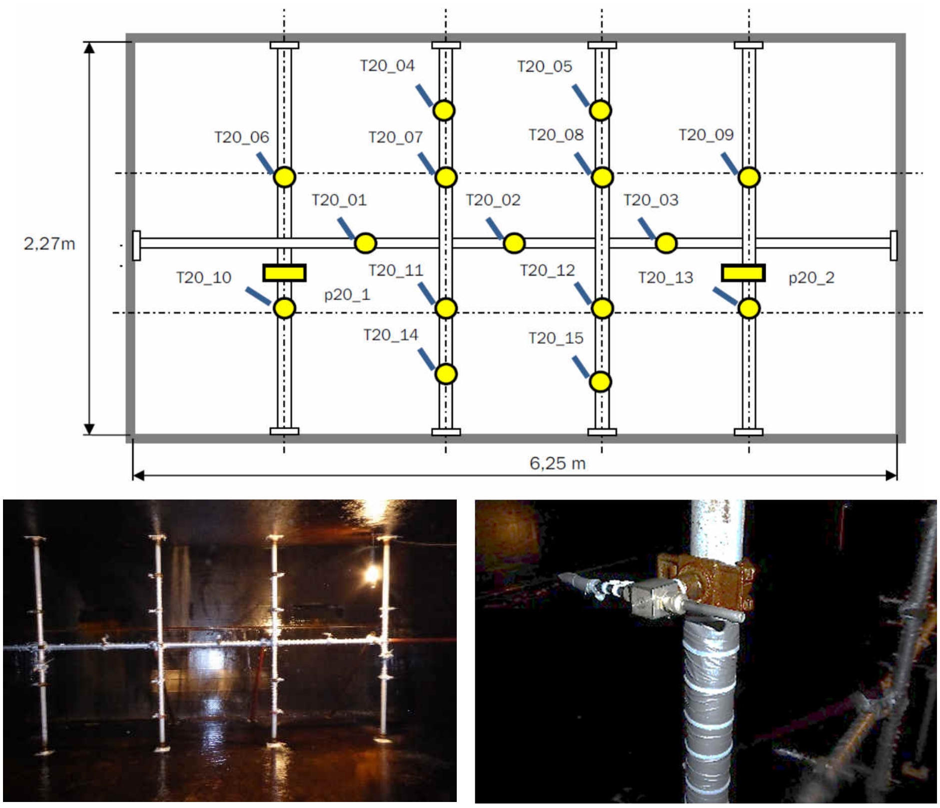

Figure 6: Sensor layout at cross-section ''20'' downstream of the turbine.

2.4. Air admission during efficiency measurement

Air admission trough the main shaft was fully closed during efficiency measurement.

2.5. Temperature measurement equipment

For the tested turbine we calculated, that each percent of hydraulic losses heats up the water for 6.3 mK. The aim was to measure temperature with measurement uncertainty of 1 mK or less.

Pt1000 probes with a 24 bit data acquisition system were used. Expected temperature measurement resolution was 0.08 mK.

Detailed measuring equipment selection and its calibration procedure was presented at IGHEM 2016 [5].

3. Measured water temperature distribution at downstream measuring section

Water temperature distribution at cross-section "20" was analysed as a deviation between the individual measured temperatures comparing to the temperature measurement by the centrally positioned probe. Figure 7 presents measured temperature deviations for unit rated output and 65 % of the rated output.

Measured temperature profile indicates, that drained water from turbine cover is mixed with the main flow better, when unit operates out of the rated output. Central part of measured cross-section is cooler compared to outer part for:

- approximately 7 mK at unit rated output
- approximately 3 mK, when unit operates out of the rated output.

Maximal temperature differences between any of the measured positions are up to 31 mK at the unit rated output and 15 mK at 65 % of the unit rated output. Temperature difference between two measured neighbouring positions were up to 21 mK at the unit rated output.

At all other unit operating outputs, differences between two neighbouring positions were up to 9 mK. High temperature difference between two neighbouring positions at the unit rated output is attributed to stable and almost linear main flow over the draft tube exit and consequently lower extent of mixing of the main and the heated turbine cover drainage flow.

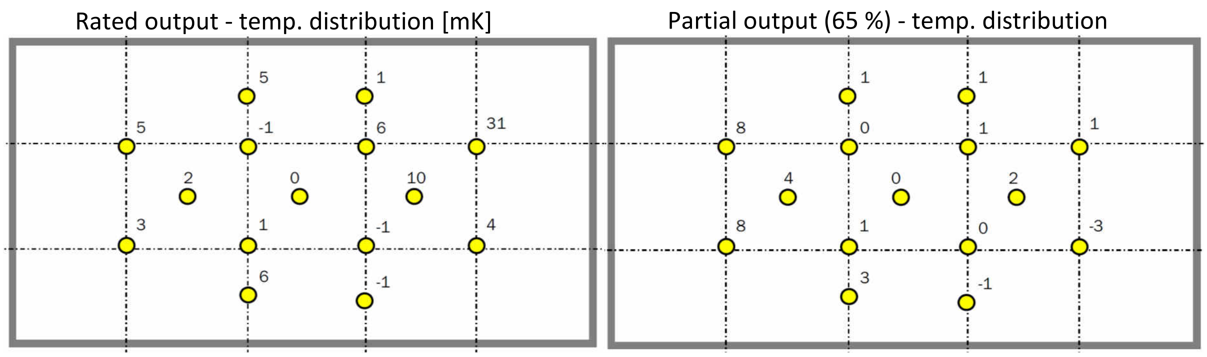

Figure 7: Draft tube water temperature distribution at location "20"

Similar as the absolute temperature distribution over the cross-section, the peak-to-peak temperature pulsations of individual temperature probe was observed – see Figure 8.

Individual probe temperature pulsations during the measurements for any turbine operational point are from 3 to 10 mK. Interestingly, at best efficiency point, the temperature pulsations shows to be equal as at unit partial load. Temperature pulsations at unit rated output are up to 9 mK and up to 10 mK out of the unit rated output.

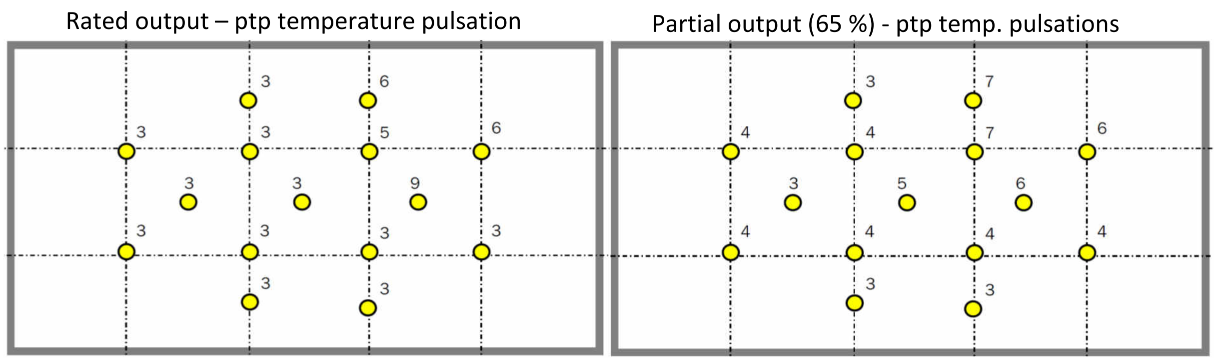

Figure 8: – Drat tube measured water temperature pulsations at location "20"

Finally, at the unit operation at part load, we did not observe any higher temperature pulsations caused by vortex developed bellow the runner.

Although temperature measurement value pulsations and deviations between the measuring points seems to be high, by sampling the measurements for the time exceeding 2 minutes we received stable as well as repeatable efficiency results.

4. Conclusions

Litostroj Power successfully conducted absolute efficiency measurement by the thermodynamic method on the refurbished Francis unit, where turbine cover drainage was led directly to the draft tube cone while the downstream water temperatures were measured within the draft tube main flow.

Turbine cover drainage flow led to the main flow, contributed to higher temperatures closer to the cross-section boundaries and lower temperatures in the centre of the selected cross-section. For presented type of measurement, it is showed that temperature measurement position arrangement should be such to enable sampling of heated water closer to the outer parts of selected cross-section, but also that higher number of sampling probes are to be installed over the downstream measuring cross-section to receive the good representation of the average flow temperature.

5. References

[1] IEC 60041: Field Acceptance Tests on Hydraulic Machines, 1991.

[2] H. Mesplou, “Applied thermodynamic method without drawing off fluid”, E.D.F.

[3] Robert F. Karlicek, “Test equipment and results from 25 hydraulic turbine tests using the thermodynamic method”, IGHEM 1996.

[4] G. Alič, “HPP Dubrovnik efficiency measurement report”, Litostroj Power, 2017.

[5] G. Alič & D. Dolenc, “Application of thermodynamic efficiency measurement using temperature sensors installed into the water passage system”, IGHEM 2016.