ABSOLUTE FLOW MEASUREMENT ON HPP OZBALT USING 320 CURRENT-METERS SIMULTANEOUSLY

Tomaz Rus, M. Sc., Turbine R & D, Turboinstitut
Rovsnikova 7, SI-1210 Ljubljana, Slovenia, E-mail: tomaz.rus@turboinstitut.si
Vesko Djelic, M. Sc., Manager of Turbine R & D, Turboinstitut

Abstract

This paper describes low head Kaplan turbine flow measurement at HPP Ozbalt using the current-meter method. Measurements with 320 current-meters were performed on each of three units HPP Ozbalt. These tests were undertaken in order to optimise operation link (on-cam) between guide vanes and runner blade angle. Description of very reliable measuring system, which gives results with acceptable total error of measurements and excellent repeatability, is given.

1. Introduction

Turboinstitut has experience in current-meter flow measurement about 30 years. First use of a computer controlled current-meter measurements started from the year 1987 [1,2]. This paper discusses Turboinstitute's most comprehensive current-meter measurements, which were held on HPP Ozbalt in years 1997 and 1998.

The Ozbalt power plant (owned by Dravske elektrarne Maribor, Slovenia) is the fourth power plant in the Slovene section of the Drava river downstream of the Austrian border and exploits the energy potential of the river section from the Vuhred power plant to the beginning of the Fala power plant reservoir (Fig. 1). It has 3 Kaplan turbines with rated power 20,4 MW each, maximum head 17,3 m and maximum nominal discharge 3 x 137 m^3/s. The average annual production reaches 314 million kWh. The dam structure consists of three turbine piers between four spillways, and an additional building at both the left and right side river bank. The turbine piers accommodate vertical Kaplan turbines with generators above them.

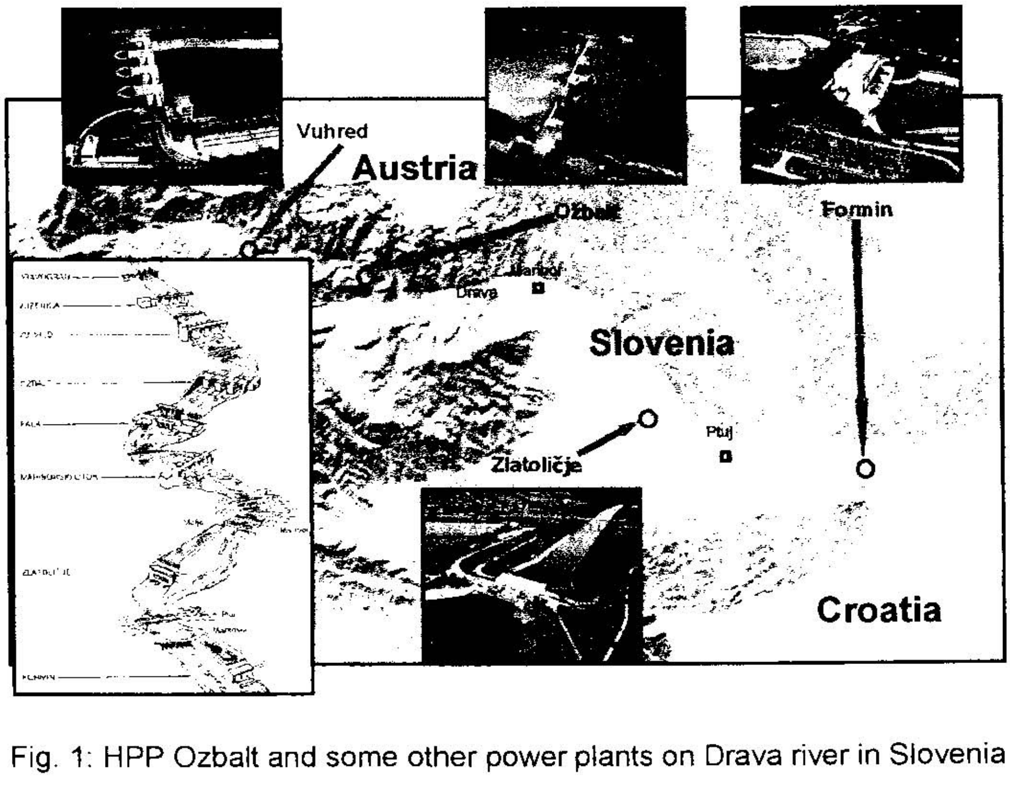

Fig. 1: HPP Ozbalt and some other power plants on Drava river in Slovenia

Measurements of the HPP Ozbalt were part of a project on Drava river where four HPP (Vuhred – 3 units, Ozbalt – 3 units, Zlatolicje – 2 units and Formin – 2 units) were measured with current-meter flow measurement for the following reasons:

- efficiency measurements,
- Winter-Kennedy flow meter calibration,
- on cam calibration (optimal relationship between guide vanes and runner blades angle),
- dynamical diagnostic (bearings vibration and turbine's shaft displacement in dependence of flow and head),
- flow calculation in dependence of generator output power and gross head for remote control and water management purposes on Drava river HPP chain.

Measurements with 320 current-meters were performed on each of three units HPP Ozbalt (unit 1 in March 1997, unit 2 in November 1997 and unit 3 in February 1998).

2. Current-meter support in flow measuring cross-section

Measuring cross-section, where the current-meter support is mounted, is located at the inlet part of spiral case (Fig.2). There are horizontal and vertical piers (Fig.3). They divide measurement plane in four sections (upper part dimension: 2 x 6,3 m x 4,7 m, lower part 2 x 6,3 m x 5,0 m). In accordance to the IEC 41 recommendations [3] and ISO 3354 [4] standard the number of current-meters must increase in the vicinity of each wall, total number of used current-meters is large: 4 x 80 = 320. In comparison with HPP Vuherd, where exists only vertical pier in inlet cross section (dimension 2 x 6,0 m x 11,5 m), only 2 x 112 = 224 current-meters are sufficient.

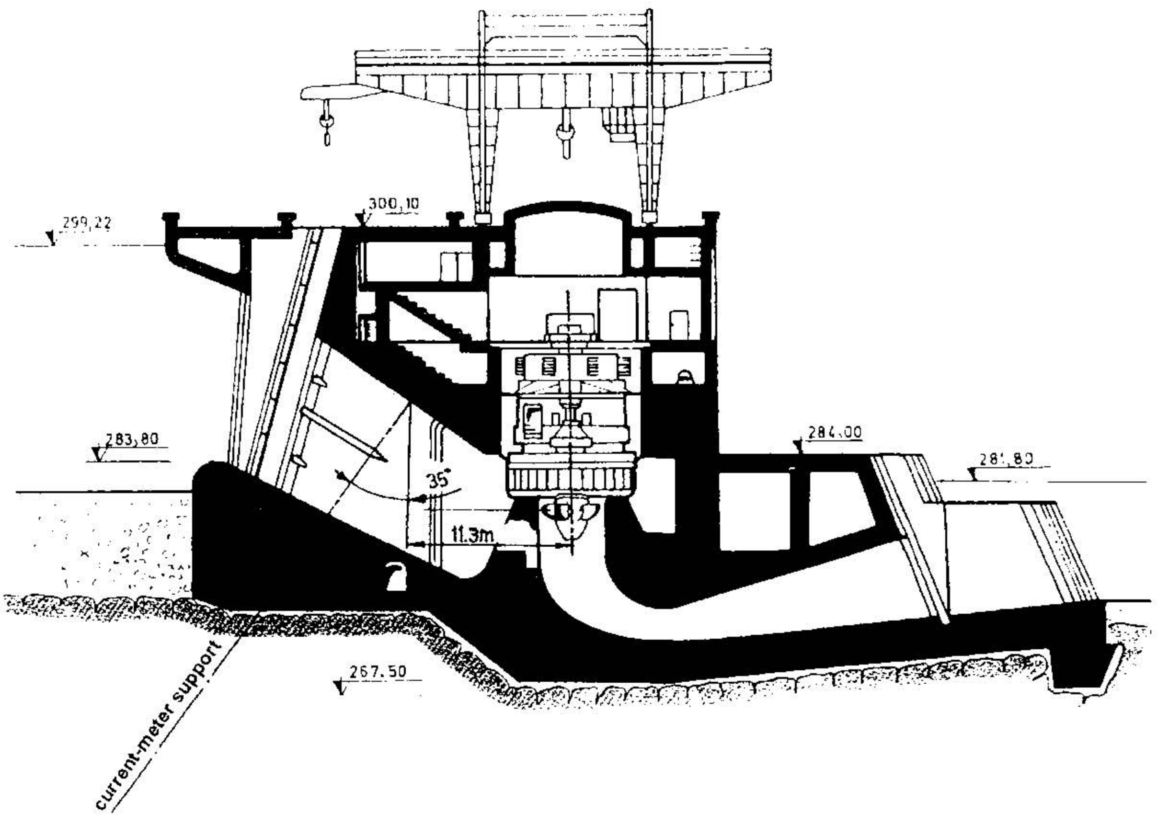

Fig. 2: Position of current-meters support in cross section of HPP Ozbalt

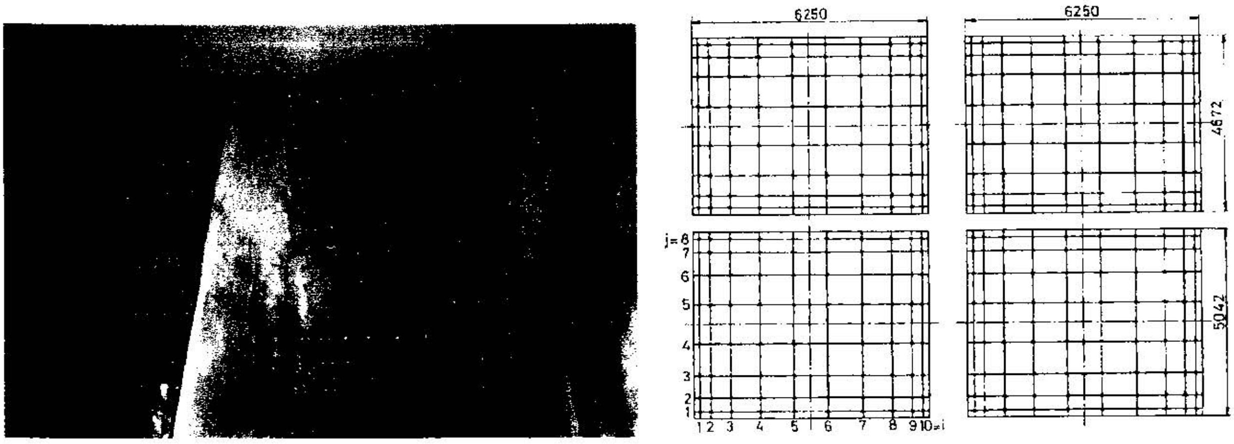

Fig. 3: Current-meter support on HPP Ozbalt

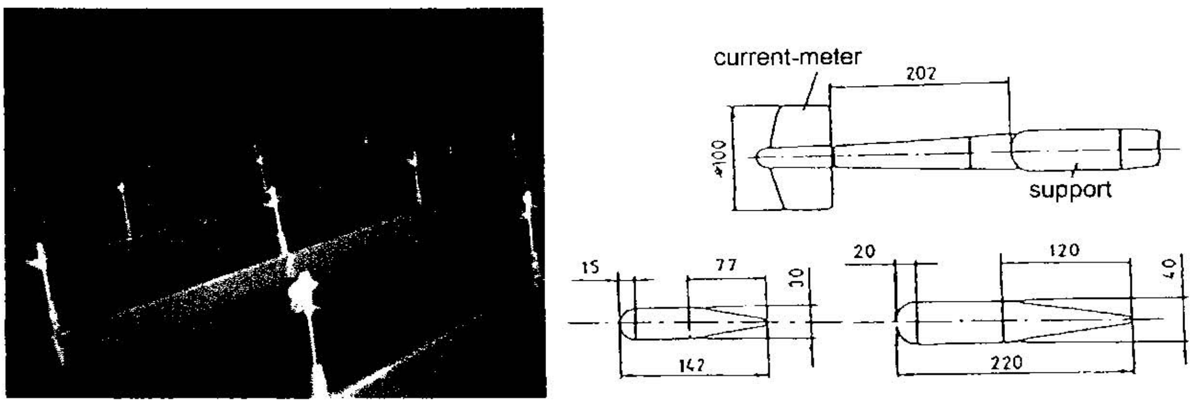

Fig. 4: Support profiles for current-meters

The assembly of large current-meter support is executed under required safety conditions. The time needed to prepare flow measurement on site (assembly of current-meter support, cabling and installation of the current-meters) took with skilled team 9 days.

In order to verify the flow angle at the plane, where current-meters were installed, the semi-spiral casing was analysed numerically. Numerical analysis was done by finite volume method. It was performed by CFX-TASCflow computer code. Standard k-ε turbulent model was used. Inclination angle between current-meter shaft, which is perpendicular on measuring plane and flow streamlines on HPP Ozbalt, did not exceed 5°. This inclination gains additional error to velocity measurement if current-meter does not measure velocity component perpendicular to measuring plane accurately. The used current-meters measure the perpendicular velocity component with systematic error +0,3 % (current-meter rotates 0,3 % faster as it should) at inclination angle 10°. This was determined during current-meter calibration.

3. Current-meter calibration

Current-meter calibrations are performed in the large towing tank of Ship building institute (length 276,3 m, width 12,5 m, depth 6,0 m, speed range 0,014 to 14 m/s, maximum acceleration 1 m/s^2), Zagreb, Croatia in accordance with ISO 3455 standard [5]. The calibrations are performed with the same hardware and software as on power plant measurements. Our experience shows that 32 current-meters on four vertical supports horizontally spaced approx. 0,8 m can be successfully calibrated simultaneously (Fig. 5). This support has the same profiles as those used for site measurements (the top and bottom row of current-meters on site is mounted on similar, but smaller profiles Fig. 4). This way of calibrations is shorter and cheaper. Four current-meters were calibrated for comparison also in the Calibration Laboratory of the Swiss National Hydrological and Geological Survey, Bern, Switzerland in March 1995.

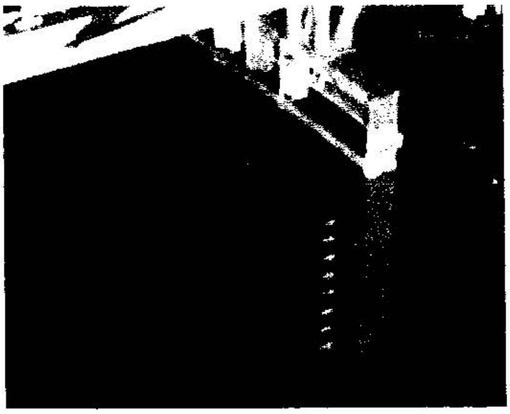

Fig. 5: Simultaneously calibration of 32 current-meters

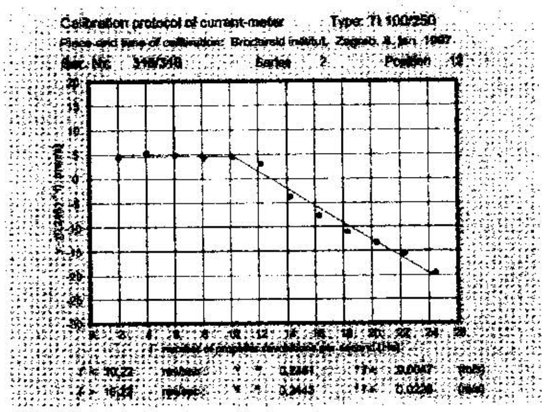

Fig. 6: Current-meter calibration diagram

After each calibration run, the carriage is driven back to its initial position with velocity 0,1 m/s to minimise additional disturbance of water. Time between calibration runs is 35 to 50 min (including carriage return) for velocities up to 2 m/s. For these conditions most of the measured calibration points are within the band ±0,2% around the calibration lines computed with linear regression (Fig. 6). Instability of carriage's velocity has maximum standard deviation 0,002 m/s and typical 0,001 m/s, what has negligible effect on the quality of current-meter calibration. The most critical parameter in these calibrations is settling time of tank's water.

4. Current-meters measuring system

Turboinstitut owns altogether 330 current-meters with diameter 100 mm of which have 250 spiral pitch 125 mm (for velocities up to 4 m/s) and 80 spiral pitch 250 mm (for velocities up to 8 m/s). All of them are designed and manufactured in Turboinstitut.

The shaft of a current-meter rotates on two small ball bearings submerged in petroleum. On the current-meter shaft there is permanent magnet of cylindrical shape. North and south pole of the magnet are perpendicular on current-meter axe. Each pole of the magnet switches on reed relay mounted in current-meter casing when it is close to it. For each propeller revolution occurs four changes of reed relay position (from 0 to 1 or vice versa), what is detected with measuring system. Average frequency of a current-meter is calculated with expression:

$$f = \frac{n_{tot}}{4 \cdot t_n} \ \text{(Hz)} \qquad (1)$$

where is n_{tot} total number of reed relay position change in time t_n.

Signals from current-meters are wired to an optical isolating device (Fig. 7). Current-meters are connected to optical isolating device via 20 wires shielded cables. On each cable is connected up to 16 current-meters. Each current-meter has one signal wire. The second junction is current-meter metal casing, so all current-meters on the support in measuring plain have common ground (single ended connection).

From the optical isolating device the signal is fed into a 240 TTL channel digital I/O interface board (Intelligent Instrumentation PCI-20378W-1, ISA slot) installed in PC computer with Pentium 133 MHz processor (Fig. 7). Software is written in Turboinstitut in Borland Turbo Pascal for MS DOS operating system. HPP Ozbalt was the only power plant where two computer systems were needed: first for upper two measuring planes and second for lower two measuring planes. Each system processed in this case 160 current-meters simultaneously.

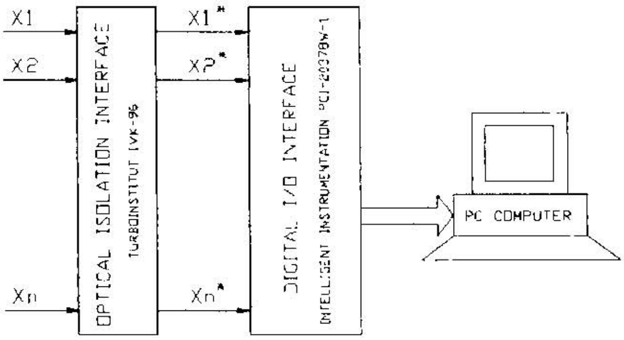

Fig. 7: Current-meters measuring system

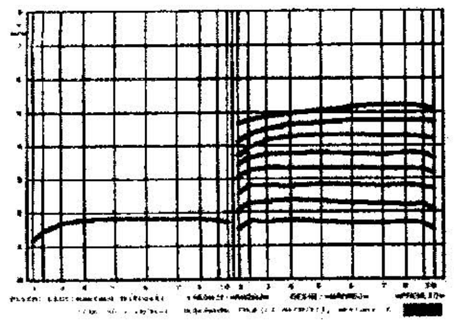

Fig. 8: Velocity profile checking and correction

Velocity profiles are after measurement immediately visually checked and corrected if particular current-meter fails before integration of the flow. Graphic display for velocity profile checking and correction is divided in two parts (Fig. 8). On the left part is shown velocity profile (measured with 10 current-meters) along selected horizontal support profile. On the right part shape of velocity profiles (not absolute values) of all 8 rows in one sector are shown simultaneously. Highlighted profile is shown in left part of the display and can be corrected with the mouse if some current-meter fails to operate. Correction of failed current-meter is taken with regard to the shape of the neighbour velocity profiles. This process takes about one minute of operator work. Together with power and head measuring results efficiency is immediately calculated and displayed in spreadsheet diagram on another computer before measurement of the next point starts. Such on line approach is necessary for fast and reliable measurements.

Flow integration and determination of boundary layer coefficient *m* is programmed exactly as stated in the ISO 3354 [4]. Boundary layer coefficient is limited $7 < m < 11$.

Table 1: Repeatability of flow and efficiency measurement

No.	Q	$(Q-Q_{avg})/Q_{avg}$	η_{tur}	$(\eta-\eta_{avg})/\eta_{avg}$
(/)	(m^3s^{-1})	(%)	(%)	(%)
80	91,63	0,07	92,71	-0,06
81	91,54	-0,03	92,75	-0,02
82	91,53	-0,04	92,85	0,09

Repeatability of flow measurement and turbine efficiency under stable operating conditions was better than ±0,1 %. In Table 1 are as example shown three points measured successive at constant head and same guide vane and runner blade opening.

Measurement error analysis in case of HPP Ozbalt gave the next values:

- systematic uncertainty of efficiency measurement (head or specific energy ±0,1 %, energy counter ±0,2 %, voltage transformer ±0,5 %, current transformer ±0,5 %, flow ±1,0 %)

$$f_{\eta s} = \frac{e_{\eta s}}{\eta} = \sqrt{f_{Es}^2 + f_{Pecs}^2 + f_{Pvts}^2 + f_{Pcts}^2 + f_{Qs}^2} = \sqrt{0{,}1^2 + 0{,}2^2 + 0{,}5^2 + 0{,}5^2 + 1{,}0^2} = \pm 1{,}24\ \%$$

- random uncertainty of efficiency measurement

$$f_{\eta r} = \frac{e_{\eta r}}{\eta} = \sqrt{f_{Er}^2 + f_{Pr}^2 + f_{Qr}^2} = \sqrt{0{,}05^2 + 0{,}15^2 + 0{,}1^2} = \pm 0{,}19\ \%$$

  where f_{Er}, f_{Pr}, f_{Qr} are random uncertainties for head (or specific energy), turbine power and flow,

- total uncertainty of efficiency measurement

$$f_{\eta t} = \sqrt{f_{\eta s}^2 + f_{\eta r}^2} = \sqrt{1{,}24^2 + 0{,}19^2} = \pm 1{,}25\ \%.$$

5. Measuring results

Typical velocity profile in measuring cross-section is shown in Fig. 9 for turbine's full load operating point. At higher flowrates are velocities significantly smaller in the left and right corners at the bottom of the measuring plane. Fig. 10 shows the ratio between flow through left two parts (upper and lower) and right two parts of measuring plane for all three units of HPP Ozbalt in dependence of total flow through turbine. Diagrams are similar, but they show that units have slightly different inlet flow conditions.

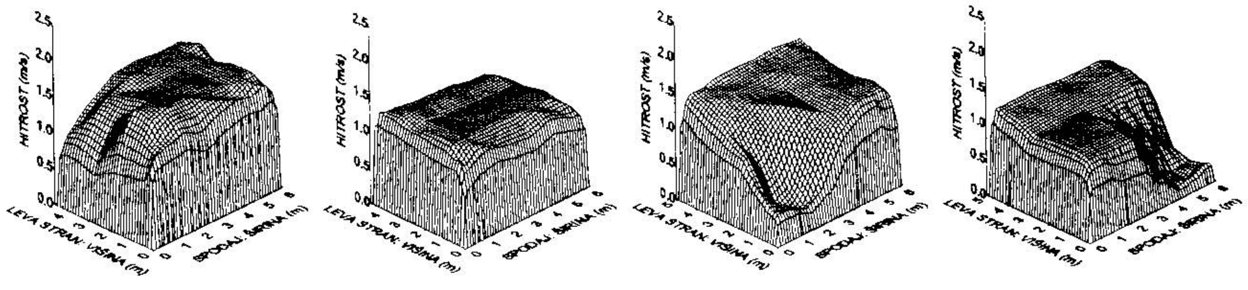

Fig. 9: Velocity profiles in measuring cross-section: upper left, upper right, lower left, lower right – as observed upstream

Each of three units of HPP Ozbalt has two pairs of Winter-Kennedy taps for relative flow measurement. All of them were calibrated with absolute flow measuring method. One of Winter-Kennedy taps calibration diagrams is shown in Fig. 11. In this case it can be seen that exponent is slightly different from 0,5 which is valid for regular inlet conditions (Fig. 9). Due to our experience exponent of the Winter-Kennedy taps is in range from 0,475 to 0,524 [2].

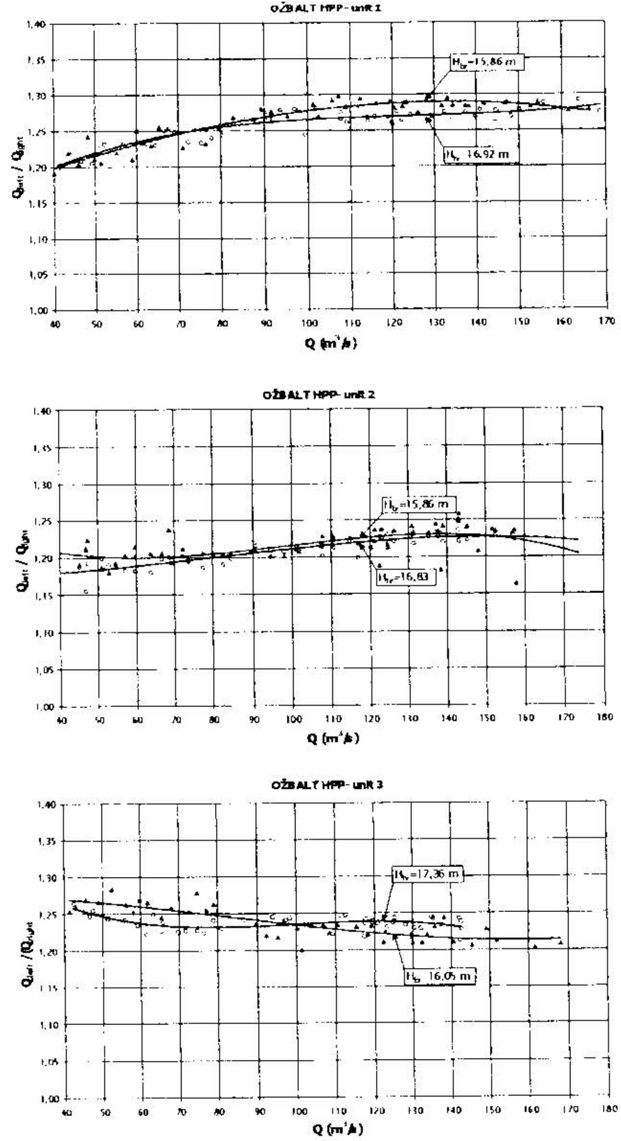

Fig. 10: Ratio between flow through left two parts and right two parts of measuring plane for all three units of HPP Ozbalt (top unit 1, bottom unit 3)

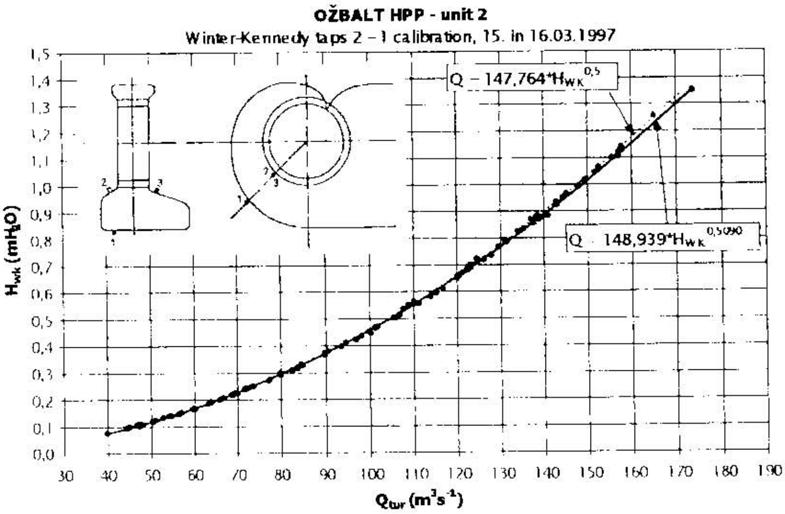

Fig. 11: Winter-Kennedy taps calibration (HPP Ozbalt, unit 2)

One part of optimisation results of operation link (on-cam) is shown in Fig. 12. This diagram consists of efficiency, power and guide vanes opening curves for a measured unit at one constant operating head. Dash-dotted line shows old efficiency and operation link curve, solid lines show optimised values. Achieved increase of weighted efficiency for HPP Ozbalt's units is up to 0,83 %.

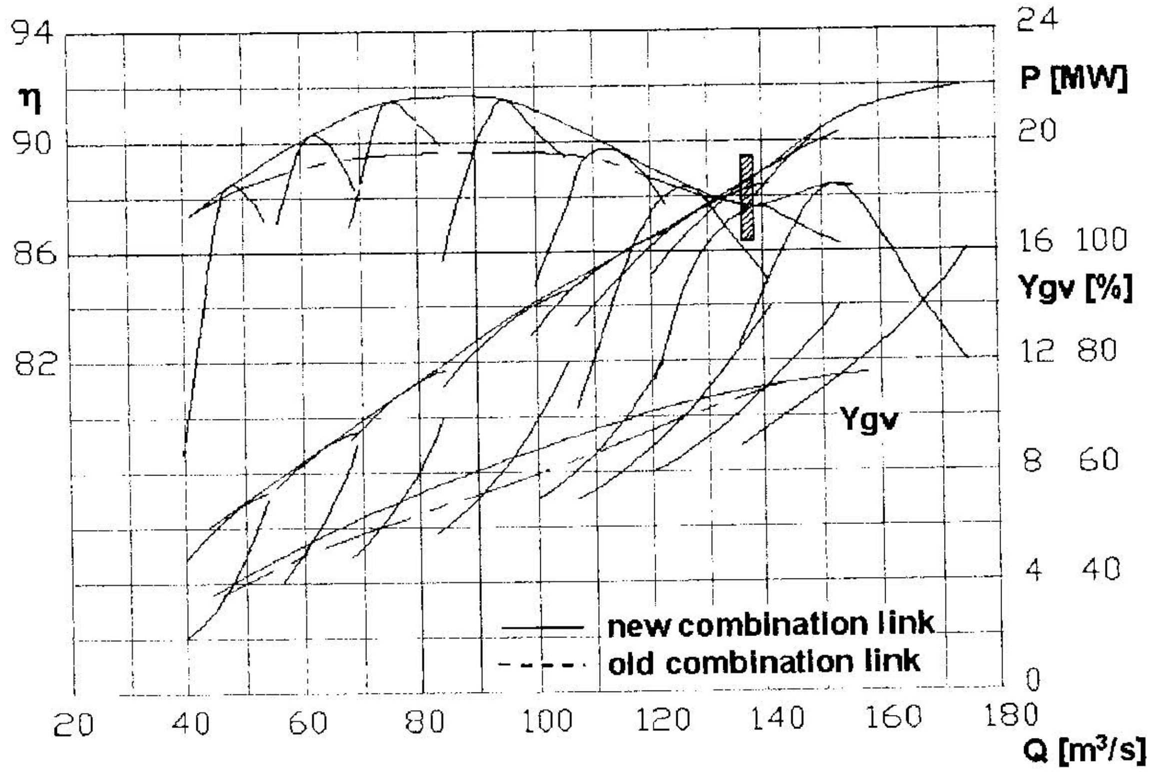

Fig. 12: Comparison of old and new operation link curves (HPP Ozbalt, unit 2)

6. Conclusion

Flow measurement with large number of current-meters (320) are possible, if all necessary activities are done on a high skilled level. Especially are important:

- current-meters calibration,
- installation of current-meters in measuring plane,
- data acquisition system with on line velocity profile checking and flow calculation.

So built measuring system is very reliable and enables acceptable total error of measurements with excellent repeatability.

At low head Kaplan turbine one of the best methods for absolute flow measurement is current-meter method with large number of fixed installed current-meters.

7. References

[1] Kercan V. and Rihtarsic B., *Some Experiences with the Current-Meters Discharge Measurements on Hydro Power Plants.* The 20th Meeting of International Current-Meter Group, St. Malo, 1991.

[2] Kercan V., Djelic V., Rus T. and Vujanic V., *Experience with Kaplan Turbine Efficiency Measurements – Current-meters and/or Index Test Flow Measurement.* IGHEM Seminar, Montreal, 1996.

[3] International Standard ISO 3354 *Measurement of clean water flow in closed conduits – Velocity-area method using current-meters in full conduits and under regular flow conditions.* International organization for standardization, Second edition, 1988.

[4] International Code IEC 41 *Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.* International electrotechnical commission, Third edition, Geneva, 1991.

[5] International Standard ISO 3455 *Liquid flow measurement in open channels – Calibration of rotating-element current-meters in straight open tanks.* International organization for standardization, First edition, 1976.