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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machines

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poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

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☎ (0-58) 341-12-71 wew. 141, fax: (0-58) 341-61-44,
e-mail: esli@imppan.imp.pg.gda.pl

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ADAM ADAMKOWSKI[1], JANUSZ STELLER[1]

Performance and diagnostic tests on hydraulic gensets in Polish Hydro Power Plants

The paper summarises experience accumulated within the last decade resulting from an intense collaboration of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences with the Polish hydro power industry. The scope and aims of this activity are characterised on the background of extremely low percentage of utilised hydroelectric potential of Poland and a lack of significant investments in this field. Qualitative changes in the measurement and diagnostic techniques having taken place with the advent of digital data acquisition and processing systems are stressed. Experience referring to the discharge measurement, by means of various kinds of current-meter, pressure-time and Winter-Kennedy methods are discussed. Possibility to correct roughly the cam dependence of double-regulated machines based on the measurement of pressure fluctuations in the draft tube is confirmed. Examples of utilising diagnostics signals for identification of the sources and assessment of the level of excessive loading to the guide bearing of a hydraulic turbine are discussed. Recent work on cavitation diagnostics is illustrated by histograms of cavitation pulses taken from the draft tubes of several Kaplan turbines. Finally, case studies concerning some specific performance and dynamic features of Kaplan turbines and Francis-type pump turbines are discussed.

1. Introduction

Poland is a country of poor hydrological resources. Even so, its total harnessable hydro power potential, estimated at the level of 13 700 GWh/annum, is used only in some 14 %, bringing a contribution slightly exceeding 1.2 % to the total balance of electrical energy. In fact, the significance of hydro power plants in the power supply system of Poland results mainly from the easily accessible peak power capacity of over 1600 MW delivered by few pumped storage power plants. After abandoning ambitious plans to increase this capacity by some

[1]Institute of Fluid-Flow Machinery, Polish Academy of Sciences, ul. Fiszera 14, 80-952 Gdańsk

4500 MW within the next two decades [8] and stopping the Lower Vistula Cascade project, the effort of investors is focused today on development of small and medium size plants (up to 5 MW power capacity) and rehabilitation of the already existing ones. The trend is easily discernible also in the policy of the Elektrownie Szczytowo-Pompowe S.A. (Pumped Storage Power Plants Inc.), owner of the main pumped storage power plants, and the largest hydro power investor in this country. The investment decisions are usually preceded by a thorough study of the technical state of existing hydraulic equipment which includes quite often extensive performance and diagnostic tests of the gensets. The other purpose of conducted tests is to detect the source of specific operating problems (e.g. low efficiency, increased vibrations, failure of bearings) or to optimize performance parameters and operating conditions of the machine. During the last 5 years the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN) has made a major effort to develop its measurement and diagnostic techniques and to accumulate further experience needed to respond to the current needs of the Polish hydro power industry. The data acquisition and general digital processing is performed now using the DIATEST software [14] while WATEST and GIBSON codes [29, 1] are used to calculate discharge and other performance parameters. Codes processing cavitation signals (including those of acoustic emission) are currently under development. In the subsequent sections an outline of the measurement and data processing techniques applied will be followed by several results of general significance.

2. Measurement and data processing techniques

2.1. Discharge

General remarks

Reliable measurements of discharge are usually considered the most responsible and difficult part of a hydraulic machine performance test. Fortunately, a lot of experience has been accumulated throughout the past years and valuable recommendations can be found both in international and national standards [15, 17, 18, 19] and in numerous papers and textbooks [9, 25, 26, 28, 32, 33, 35]. In European practice the current-meter method is generally applied for the purposes of field acceptance tests and measurement of genset efficiency while the Winter-Kennedy index method is often used to determine the optimum cam curve of a double-regulated turbine. In this subsection it is shown that with the advent of digital recording and processing techniques, the much cheaper pressure-time method can be preferred in some cases. Practical hints and conclusions resulting from application of the current-meter and Winter-Kennedy methods are also included.

Current-meter method

The method is widely used to measure discharge in penstocks and intake structures of hydroelectric power plants. Difficulties may arise when measuring in a short converging conduit with uneven and/or unstable velocity distribution as well as oblique flow to the current-meters. Measures applied to remedy these difficulties either by a straightening device or by special measuring techniques are described in the IEC 41 standard. Practical assessment of the systematic error introduced by unfavourable measurement conditions can be conducted using a simplified 2D analysis of the velocity field. The same approach can be successfully applied when designing structures supporting current-meters so as to avoid their effect on the measured velocity. Results obtained recently [27] confirm that the deviation resulting from close distance between the current-meter and the supporting cylindrical rod may be calculated using the formula

$$\frac{\Delta v_x}{v_x} = \frac{r^2\left(a^2 - z^2\right)}{\left(a^2 + z^2\right)^2} \tag{1}$$

where r is the rod radius while a and z denote the propeller trailing edge distance from the rod axis as measured in directions parallel and perpendicular to the main flow vector (Fig. 1). Alike procedure is applied to check for the excessive obliqueness of the flow in respect to the current-meter axis. The authors of this paper use the Arkansas V current-meters of the Ott Messtechnik GmbH&KG manufacture in which case the obliqueness exceeding 5° should be avoided.

WATEST code integrates the velocity field over a rectangular or trapezoidal measurement section using the formula

$$Q = \int_0^h dy \int_{x_0(y)}^{x_{n+1}(y)} v(x,y)dx \tag{2}$$

where $x_0(y)$ and $x_{n+1}(y)$ denote x – co-ordinates of the left and right section edge measured at height y above the bottom edge, n is the number of current-meters at each measurement level and h is water depth in the section. Integration in circular sections is conducted using the formula

$$Q = \int_0^{2\pi} d\theta \int_0^R v(r,\theta)rdr \tag{3}$$

where (r,θ) denote polar co-ordinates of the current point and R is the section radius. In both cases cubic splines are applied to interpolate between the current-meter positions.

In the gap between the wall section and the current-meter no.1 the velocity distribution is assumed to be described by the formula

$$v(x) = mAx^{\frac{1}{m}} + Bx + \frac{1}{2}Cx^2 \tag{4}$$

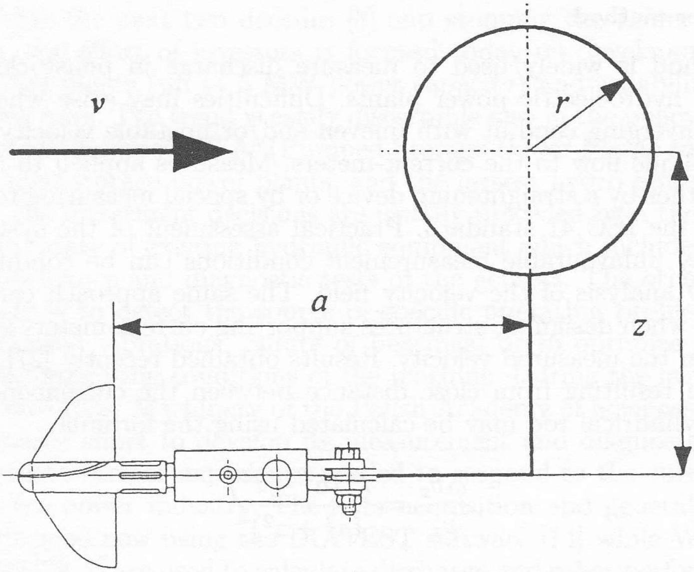


Fig. 1. Schematic of the current-meter situation respective to a cylindrical supporting rod.

with x – distance from the wall, m – empirical exponent (usually close to 7), and A, B, C – coefficients to be determined from the smoothness conditions

$$\begin{cases} mA\Delta x_1^{\frac{1}{m}} + B\Delta x_1 + \frac{1}{2}C\Delta x_1^2 = v_1, \\ A\Delta x_1^{\frac{1}{m}-1} + B + C\Delta x_1 = -\frac{\Delta x_2}{3}M_1 - \frac{\Delta x_2}{6}M_2 + \frac{\Delta v_2}{\Delta x_2}, \\ \frac{1-m}{m}A\Delta x_1^{\frac{1}{m}-2} + C = M_1, \\ \frac{(1-m)(1-2m)}{m^2}A\Delta x_1^{\frac{1}{m}-3} = \frac{M_2-M_1}{\Delta x_2} \end{cases} \tag{5}$$

where subscripts denote current-meter numbers, (Δx_i and Δv_i stand for the x – co-ordinate and velocity increments between current-meters no. $i-1$ and i (with points no. 0 and $n+1$ situated at the section edges), and M_i are second derivatives of the interpolating function corresponding to the current-meter no. i. As it can be easily shown, the above set of equations results in the following relationship between M_1 and M_2

$$M_1\left(3\Delta x_1\Delta x_2 + 2\Delta x_2^2 + 3m\Delta x_1^2\right) - M_2\left(3m\Delta x_1^2 - \Delta x_2^2\right) \\ = 6\left[v_2 - v_1\left(1 + \frac{\Delta x_2}{\Delta x_1}\right)\right]. \tag{6}$$

Applying the same procedure at the opposite edge of the section and using standard smoothness conditions in nodes $2,\ldots,n-1$ [22]) yields complete set of linear equations to be solved in order to determine all the spline coefficients. In case of a current-meter situated directly beneath the free surface the smoothness conditions in the node n are substituted by the requirement of continuous third derivative in the node $n-1$. WATEST code plots resulting velocity distributions on the computer screen which allows to detect easily spurious errors due to malfunction of individual current-meters or incorrect reading of the number of pulses.

In case of discharge measurement in the intake structures the so called direct integration method is often applied. The frame supporting current-meters is moved slowly upward across the measuring section so that the mean flow velocity between extreme positions of each current-meter is directly determined by the number of pulses. Equations solved in order to determine the velocity distribution in the area between the bottom edge of the section and the lowest position of the current-meters get greatly simplified as all the M_i parameters vanish.

The method is usually at least as accurate as stationary one [33] provided no backflow phenomena take place, and the transversal velocity is low enough to avoid oblique flow to the current-meter and to allow counting sufficient number of pulses.

Pressure-time method

The method is used to determine the discharge in closed conduits following the procedure shown schematically in Fig. 2. Theoretical basis of the method result from the second principle of dynamics applied to the bulk of water decelerated (or accelerated) in a closed conduit [12, 15]. The discharge under initial flow conditions and its subsequent change are determined from the time course of the pressure difference between two transversal conduit sections when cut the flow is off. The main advantages of the pressure-time method include:

- low cost and easy installation of the measuring system,
- accuracy close to that of classical methods,
- capability to determine the time-discharge curve (most other methods lack this valuable feature).

The disadvantages of the method include:

- requirements concerning the measurement segment which result in reduction of the applicability of the method to the penstocks of sufficient length,
- the necessity to evaluate the leakage discharge in cut-off devices (gates),
- the necessity of rapid closing the cut-off device during each measurement run.

The authors of this paper are unaware of any industrial application of this method in Poland up to mid nineties. The increased accuracy of pressure gauging

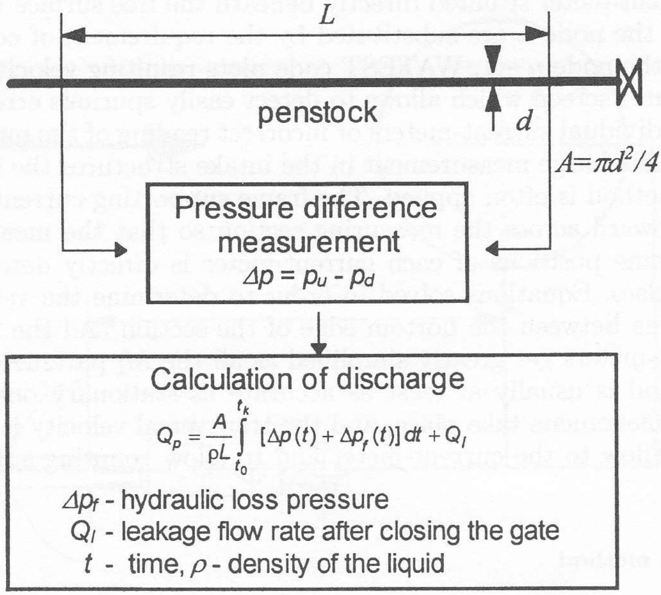


Fig. 2. The principle of the pressure-time method.

instrumentation and common access to the digital data acquisition and processing techniques can contribute substantially to the rise of its attractivity. Several Polish hydroelectric power plants provide measurement conditions suitable for application of the method during water turbine performance tests.

Experimentally validated tools, allowing to apply the pressure-time method in practice, have been recently developed at the IMP PAN. The tools mentioned include the DIATEST data acquisition system [14] and the GIBSON computer code [1] used to calculate the discharge from the recorded time-pressure curves.

Performance of developed tools has been recently validated experimentally during tests conducted in Bielkowo Hydro Power Plant [2, 4]. The schematic of the water delivery system to the turbines is shown in Fig. 3. The pressure difference was measured using two pressure transducers installed at a straight penstock segment, in measuring sections situated at a distance $L = 60$ m from each other. The mean internal diameter ($D = 3$ m) of the penstock segment was determined basing on repeated measurements in several cross-sections.

The tests consisted in rapid cutting off the flow by means of the wicket gate in one of the Francis turbines. The generator remained switched to the grid. Gates in the other turbines (spherical valves and wicket gates) were closed. Each run was preceded by careful setting of the steady-state operating conditions. An example of pressure variation curves (recorded by means of the DIATEST system) as well as the discharge variation curves (calculated by means of the GIBSON code) is shown in Fig. 4.

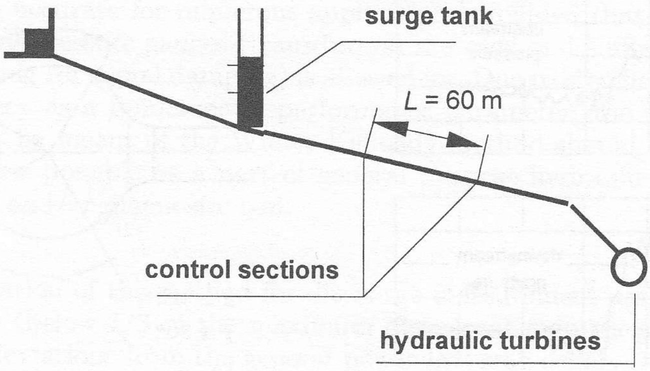


Fig. 3. Schematic of the water delivery system in Bielkowo Hydro Power Plant.

In order to validate the results of the pressure-time measurement, each run was preceded by a current-meter measurement. The accuracy of the current-meter method was estimated at the 2% level.

Discharge in the case of completely closed turbines was evaluated from the width of gaps in the wicket gate system of the turbine tested. Two other turbines were assumed to be tightly closed by means of the spherical valves. The leakage discharge, evaluated by such a procedure, did not exceed the value of $Q_1 = 0.1\ m^3/s$.

The initial discharge values determined by means of the methods applied and their relative differences are put together in Table 1. Differences below 2 % keep within typical uncertainty bands of the methods compared. The results confirm the validity of the measurement system and the code developed as tools to be applied when determining the discharge by means of the pressure-time method.

Table 1. Comparison between results of discharge measurement using the current-meter and pressure-time method

test no.	current-meter method $Q_h [m^3/s]$	pressure-time method $Q_p [m^3/s]$	relative deviation %
1	8.20	8.06	1.7
2	7.40	7.26	1.9
3	6.54	6.45	1.4
4	5.71	5.63	1.4
5	8.17	8.09	0.98

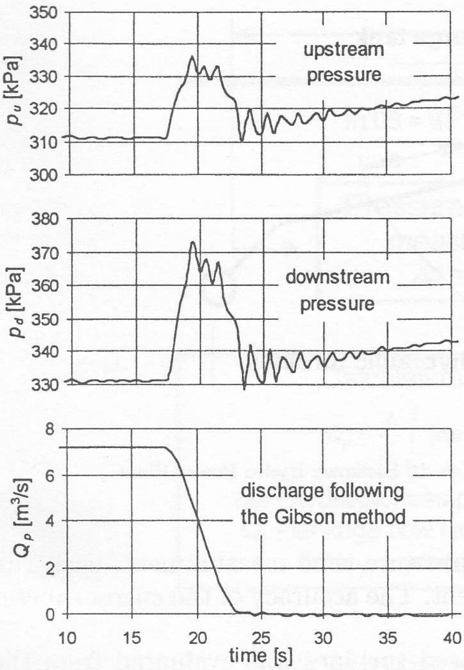


Fig. 4. Pressure variations at 2 measuring sections and the discharge calculated by means of the GIBSON code (Bielkowo Hydro Power Plant, 1996).

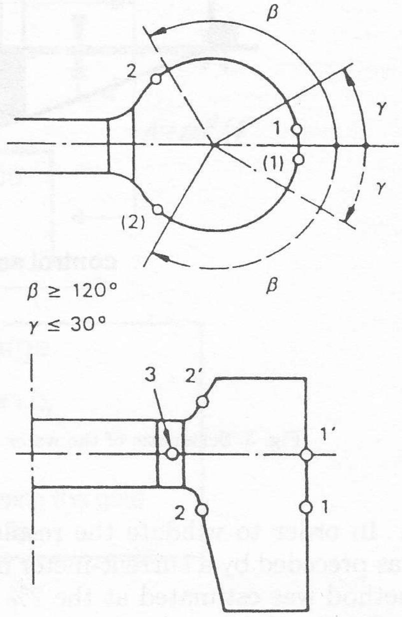


Fig. 5. Location of taps for Winter-Kennedy method of discharge measurement through a turbine equipped with a steel spiral case (a) and a concrete semi-spiral case (b). 1 – inner taps; 2,3 – outer taps. [15].

Winter-Kennedy method

The method consists in determining the discharge basing on the pressure difference Δp_{12} between pressure taps located in the outer and inner side of the spiral case (Fig. 5). Following the theoretical considerations, the discharge is proportional to the square root of Δp_{12} and the proportionality coefficient can be derived from the spiral case geometry and pressure taps location [32]. The main advantage of the method is its simplicity. The IEC 41 standard recommends its use for the purpose of so called index tests conducted in order to determine the optimum relationship between the runner blade angle and the guide vane opening in double-regulated machines. In such a case, the absolute discharge value is of minor significance and the general power law $Q \sim \Delta p_{12}^n$ is often used. After suitable calibration by means of one of the so called fundamental methods, the Winter-Kennedy method may be also applied in order to determine the absolute value of discharge. The experience with Winter-Kennedy installations, accumulated by the authors in Polish hydro power plants can be summarised as follows:

- The Winter-Kennedy method is a low cost and reliable technique, sufficiently accurate for numerous applications provided that high quality differential pressure gauges (transducers) are used and sufficient time of data averaging (or signal damping) is allowed for. Due to significance of hydraulic efficiency as a fundamental performance parameter, the discharge measurement by means of the Winter-Kennedy method should be recommended wherever possible as a part of general purpose hydraulic machine performance and/or diagnostic test.

- Application of the method for discharge measurement under low load conditions (below 1/3 of the maximum discharge) requires particular care as some deviations from the general power law may occur.

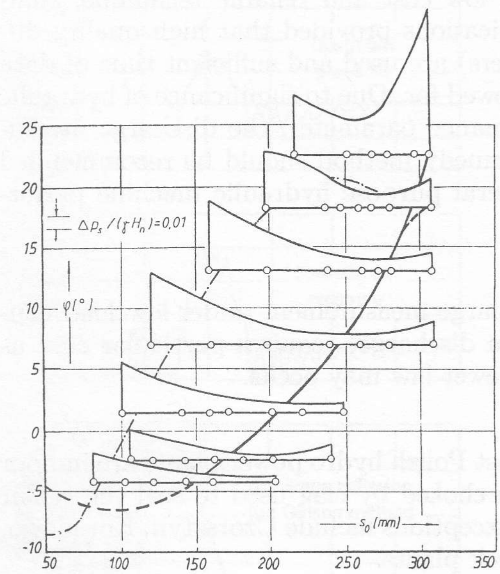
- Winter-Kennedy installations in most Polish hydro power plants are in poor condition – impulse pipes are often choked by clag used to seal the repair gates in the intake structures. Few exceptions include Czorsztyn, Koronowo, Myczkowce and, partially, Włocławek plants.

2.2. Pressure fluctuations

Pressure fluctuations measured at various sites of the flow system [16] give insight into flow dynamics and the quality of energy conversion in a hydraulic machine. In particular, incomplete energy conversion in the runner is known to give rise to intense pressure fluctuations in the draft tube. In the case of double-regulated turbines, variation of the r.m.s. fluctuations vs. wicket gate opening a_0 (or servomotor piston rod position s_0) and runner blade angle ϕ allows often to draw conclusions on the need to optimise the so called cam dependence $\phi = \phi(a_0)$ (Fig. 6)

Detailed interpretation of phenomena taking place in the flow system requires spectral analysis, usually performed by means of the FFT technique. In particular, too low wicket gate opening under partial load conditions results, as a rule, in powerful subharmonics of the rotation frequency (Fig. 7), which can be attributed to the vortex ropes flowing down from the hub and massive flow separation starting beneath the turbine cover [11]. In the case of turbine overload the situation gets more complicated due to a significant contribution of the wakes coming down from the runner blades trailing edges.

The optimum cam curve under overload conditions is usually shifted in respect to the minimum r.m.s. pressure fluctuations towards higher wicket gate openings (Fig. 6). The rise of pressure fluctuations may be also used as a general guideline in determining the load limits of a genset. Typical values allowed for by the authors in case of medium head ($H = 20 \div 30$ m) Kaplan turbines do not exceed the level of $6 \div 8$ kPa.



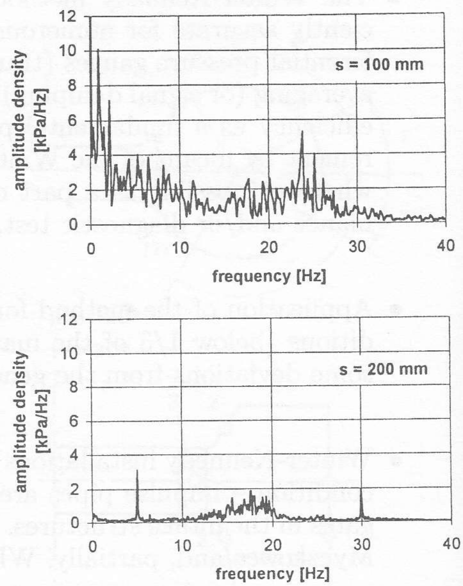


Fig. 6. Cam curves and r.m.s. pressure fluctuations in the draft tube of Kaplan turbine no.1 in Myczkowce Hydro Power Plant vs. piston rod position of the wicket gate servomotor and the runner blade angle [20]. Original cam curve is shown by means of the dot-and-dash line. The solid bold line shows the cam curve optimised using the maximum efficiency criterion (cf. Fig. 10). Corrections introduced in order to allow for proper start-up procedure and to avoid excessive fluctuations at overload are shown with dashed bold line. Pressure fluctuations are related to the turbine net specific energy.

Fig. 7. Spectra of pressure fluctuations in the draft tube of a Kaplan turbine in Myczkowce Hydro Power Plant at the runner blade angle $\phi = 1.6°$ and the piston rod of the wicket gate servomotor in $s_0 = 100$ and 200 mm positions [5].

2.3. Shaft displacements and vibrations

Vibroacoustic measurements are the main source of information on the mechanical effort taken over by the critical structural points of a turbomachine. In case of hydraulic gensets, relative lateral shaft displacements close to the guide bearings (especially those of the turbine runner or pump impeller) are of particular interest. Absolute displacements in the longitudinal (axial) direction can be a significant source of information on the thrust bearing loading.

Under steady-state conditions the p-p longitudinal displacements are closely correlated with dynamic phenomena taking place in the draft tube and can be used in some cases to indicate the need of cam curve optimisation [31]. Under transient conditions pressure difference between the space upstream and downstream the runner cascade is of primary significance. Tests conducted in Dychów Hydro Power Plant [23] prove that rotating set displacements as high as 4 mm are of no danger to the thrust bearing so far as the displacement velocity does not exceed the threshold resulting out of the elasticity constant of the supporting structure.

Experience on lateral shaft displacements shows that displacement amplitude brings scarce data on the dynamic state of a hydraulic machine and the recommendations in this respect [36] should be considered a very rough criterion. In fact, a lot of information can be derived from the shaft axis trajectory. In particular, irregular, random displacements within the whole range of bearing clearance are usually due to partial load operation and can be avoided by increasing the wicket gate opening. On the other hand side, regular circular trajectories result as a rule from misalignment of the turbine and generator shafts, shaft bending as well as mechanical or hydraulic unbalance. In the last case the trajectory is expected to depend on the point of operation. A reliable test allowing to distinguish between the hydraulic and mechanical origin of displacements consists in permitting the turbine runner to rotate in air. The displacement vs. speed curves in Fig. 8 show clearly that both shaft bending (and/or misalignment) and mechanical imbalance are responsible for excessive displacements in the case of a Kaplan turbine in Włocławek Hydro Power Plant [3].

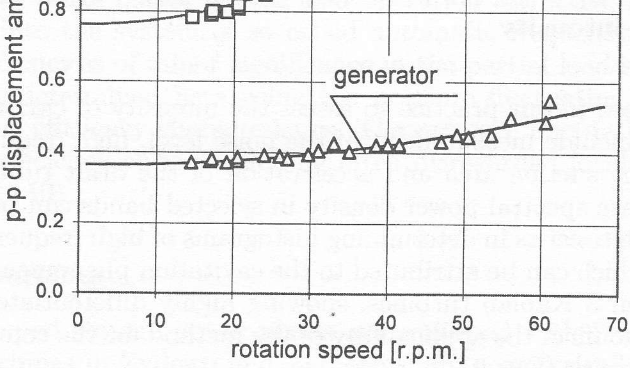


Fig. 8. P-P shaft displacement vs. rotation speed at a Kaplan turbine and generator guide bearings in Włocławek Hydro Power Plant. Runner chamber filled with air.

Lateral displacements of the shaft neck provide qualitative information on the dynamic loading of the guide bearing. Reliable quantitative evaluation is possible in the case of:

- flexible (rubber) bush of known elasticity modulus,
- special provisions for radial force measurements introduced in the design

Rough assessment can be attempted using two approaches:

- 3D finite difference model of the rotating set is assumed and stimulating forces are introduced so as to achieve the shaft axis trajectory close to that resulting from the measurements [37]
- 1D model of shaft dynamics is assumed and hydraulic forces acting on the runner are determined based on recorded shaft axis acceleration course in cases the shaft neck loses its contact with the liquid film [7].

In most practical cases assessment of dynamic loading of a guide bearing is made by measuring the r.m.s. vibration velocity or absolute displacement of the housing. Due to low rotation frequency (usually well below 10 Hz), seismic transducers of special design or high quality accelerometers with time integration system can be applied. The advantage of the last method is its low cost and easy attachment of the transducer to the bearing housing. Following our laboratory tests and field experience [13] Brüel & Kjaer accelerometers 4371 with 2635 preamplifier are excellently suited for the purposes of hydraulic genset tests down to at least 2 Hz frequency.

3. Cavitation intensity

Techniques used in our practice to assess the intensity of cavitation in a hydraulic machine include measurement of the noise level, high frequency pressure fluctuations in the suction area and acceleration of the draft tube manhole cover. In the last case spectral power density in selected bands can be determined. Another approach consists in determining histograms of high frequency (> 2 kHz) pressure pulses which can be attributed to the cavitation phenomenon. Tests conducted in 1987 on 3 Kaplan turbines, showing highly differentiated runner rim erosion severity, confirm the applicability of the method for the comparative tests of cavitation intensity (Fig. 9).

The time consuming analog signal processing procedure of 1987 has been recently replaced by a highly efficient data acquisition and processing technique. Validation tests of 1995 [31] have confirmed full applicability of the DIATEST system for the aforementioned purposes.

Following the encouraging results of Voith Hydro [21], efforts are being made to develop the acoustic emission signal based technique of assessing intensity of cavitation interaction with flow confining walls.

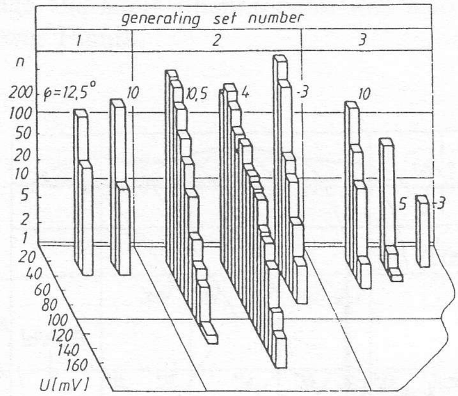


Fig. 9. Pressure pulses histograms taken in the suction area of Kaplan turbines in Dychów Hydro Power Plant at various runner blade angles [34].

4. Case studies

4.1. Kaplan turbines

Experience accumulated in numerous low- and medium head hydro power plants indicates that the existing cam curves often deviate from the optimum ones. This is especially the case in the partial load operating range, often disregarded during previous performance tests. Current method of payment for available power range makes partial load operation attractive for all the plants incorporated into the system of so called automatic frequency and power control. High efficiency is of minor significance in the partial load area and the cam curves can be determined here using the pressure fluctuation propeller curves rather than the efficiency characteristics. The pressure fluctuation curves reflect the shape of efficiency curves including often disregarded local minima in their envelopes (Fig. 10)

4.2. Pump-turbines

Polish pumped storage power plants are equipped with Francis-type pump-turbines. Machines in Żydowo and Żarnowiec are geometrically similar. An interesting feature is their different response to the change of head under pumping and turbining regimes (Fig. 11) which can be attributed to different operation ranges at the universal hill diagram as discussed in detail in [24] and [30].

A weak hydraulic resonance was revealed in the wicket gate/runner gap of Żydowo pump-turbines [10]. The phenomenon increases the third harmonic of the runner vane passage frequency in the wicket gate ring and guide bearing vibration signal (Fig. 12). No threat to the machines was stated. According to

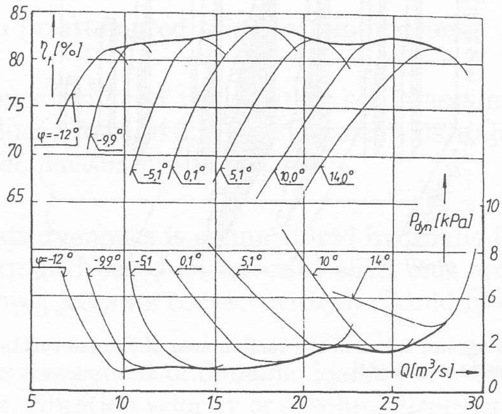


Fig. 10. Net hydraulic efficiency and r.m.s. pressure fluctuations in the draft tube of Kaplan turbine no.2 in Myczkowce Hydro Power Plant [6].

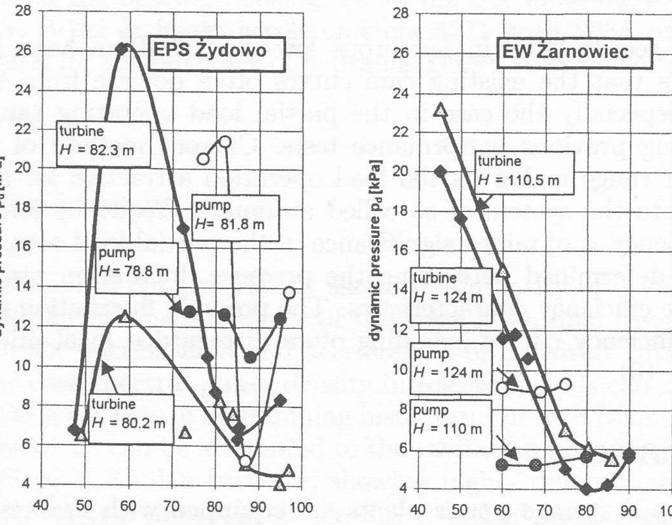


Fig. 11. Pressure fluctuations in the draft tubes of FR-25 pump-turbines in Żarnowiec (a) and Żydowo (b) pumped storage power plants.

the authors knowledge the same phenomenon was also reported in Solina and Żarnowiec Hydro Power Plants.

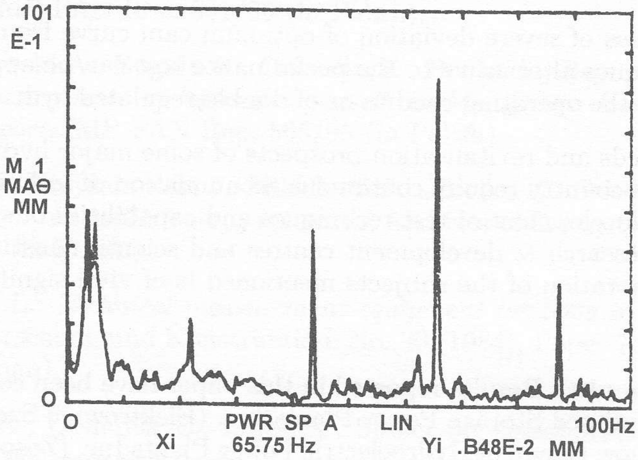


Fig. 12. Spectrum of a guide vane lever displacement in the pump-turbine no.1 of Żydowo Pumped Storage Power Plant. Rotation frequency and subsequent harmonics of the runner vane passage frequency are clearly discernible. Wicket gate opening: $a_0 = 95$ % ; electrical power: $P = 54.5$ MW; turbining regime.

5. Conclusion

1. Hydraulic gensets operated in Polish hydro power plants show differentiated technical state. In some cases of low output turbines, scarce data on their performance and dynamic properties exist.

2. Existing cam curves of numerous double-regulated (Kaplan) turbines do not always coincide with the optimum ones. This state of the art results usually in lowered efficiency, limited allowable operating range and increased dynamic loading of critical structural points.

3. Advanced techniques of discharge measurement and evaluation of dynamic state parameters, described in this paper, allow to undertake the following tasks of vital significance to the users of gensets installed in hydroelectric power plants:

    - performance tests aimed to assess the performance parameters or to optimise the cam curve of a hydraulic machine,

- diagnostic tests aimed to assess the dynamic state of a genset or to reveal the sources of specified operational problems.

4. In hydro power plants with long penstocks and single-regulated hydraulic turbines the pressure-time discharge measurement method can be used effectively instead of the classic current-meter technique.
5. In some cases of severe deviation of optimum cam curve from the existing one, techniques alternative to the performance test can be applied in order to optimise the operating conditions of double-regulated hydraulic turbines.
6. Current needs and revitalisation prospects of some major hydro power projects in this country require continuous accumulation of technical expertise, as well as development of test techniques and capabilities of specialised enterprises, research & development centres and scientific institutions. Long term collaboration of the subjects mentioned is of vital significance in this respect.

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Doświadczenia eksploatacyjne i diagnostyczne z badań urządzeń hydraulicznych w polskich elektrowniach wodnych

Streszczenie

Artykuł stanowi podsumowanie doświadczeń wynikających z prac prowadzonych w ostatnim dziesięcioleciu przez Instytut Maszyn Przepływowych PAN na rzecz polskiej energetyki wodnej. Na wstępie scharakteryzowano cele tych prac w kontekście nadzwyczaj niskiego wykorzystania dostępnych zasobów hydroenergetycznych kraju oraz braku znaczących inwestycji w tej dziedzinie. Następnie wskazano na jakościowe zmiany w technice pomiarowej i diagnostycznej związane z wprowadzeniem cyfrowej akwizycji i obróbki danych. Omówiono doświadczenia własne związane z pomiarem natężenia przepływu za pomocą różnych odmian metody młynkowej, metody Gibsona oraz metody Winter-Kennedy'ego. Potwierdzono możliwość zgrubnej korekty zależności kombinatorowej maszyn o podwójnej regulacji w oparciu o pomiar pulsacji ciśnienia w rurze ssącej. Wskazano przykłady wykorzystania sygnałów diagnostycznych do identyfikacji przyczyn i oceny poziomu nadmiernych obciążeń łożyska prowadzącego turbiny. Poinformowano o pracach nad diagnostyką zjawiska kawitacji. Na zakończeniu podano przykłady zastosowania wybranych technik pomiarowych do identyfikacji szczególnych własności eksploatacyjnych turbin Kaplana i maszyn odwracalnych typu Francisa.