Application of Pressure – Time method in pump mode

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Abstract

The present standard IEC EN 60041 as well as the updating proposal of this standard which is prepared by the IEC WG 28 recommend using of Pressure - Time method only for turbine mode despite it works also for the pumps.
OSC has a lot of experience with pressure time method applied on reversible turbines in the both modes as well as on pumps in pumping stations. Especially the reversible units provide easy detection of potential systematic errors in flow rate determination on the same penstock. E.g. increase of flow rate caused by some phenomenon brings in turbine mode lower efficiency and in pump mode the higher one than expected.
The paper brings some examples of flow rate evaluation in both modes including relative efficiency of the tested units and recommendation for flow rate evaluation in pump mode.

1 Introduction

The OSC Hydro Power Group is an independent team performing hydro power tests and operating worldwide. The most commonly used method for measuring water efficiency is Pressure - Time due to its advantages, such as low cost and minimal limitation of unit operation. This method has been used since 1990 and its algorithm is continuously improved using experience obtained by large number of performed tests (so far more than 150 units). Principles and procedures for flow rate evaluation are in detail described in [2] ÷ [4].
Approximately 10% of tests was performed on reversible units and pumps – see Table 1. Detailed description of these tests and results comparison in turbine and pump mode is presented below.

Year	Activity	Country	Contractor
1999	PSHP Dalešice - pump turbine TG3 - performance test before refurbishment	CZ	ČKD Blansko
1999	PSHP Dalešice - pump turbine TG3 - GM after refurbishment	CZ	ČKD Blansko
2000	PSHP Dalešice - pump turbine TG1 - performance test TG1 before upgrade	CZ	ČKD Blansko
2001	PSHP Dalešice - pump turbine TG1 - GM	CZ	VA TECH E-W
2003	PSHP Dalešice - pump turbine TG4 - performance test before upgrade	CZ	ČKD Blansko Eng.
2004	PSHP Dalešice - pump turbine TG4 - GM	CZ	ČKD Blansko Eng.
2007	PSHP Dalešice - pump turbine TG2 - GM - low head	CZ	ČKD Blansko
2008	PSHP Dalešice - pump turbine TG2 - GM - high head	CZ	ČKD Blansko
2009	PSHP Ziarnowiec - pump turbine after upgrade - GM (IMP) – supervision *)	PL	ČKD Blansko
2011	Pumping station Trei Ape - 2 pumps - performance tests	RO	KSB
2011	PSHP Dlouhé Stráně - pump turbine TG1 - performance test before upgrade	CZ	Litostroj ČBE
2012	PSHP Dlouhé Stráně - TG1 pump turbine - GM	CZ	Litostroj ČBE
2014	Pumping station Trei Ape - 2 new pumps - GM	RO	Sulzer
2018	PSHP Dlouhé Stráně – TG2 pump turbine before upgrade	CZ	Litostroj ČBE

*) Guarantee measurement performed by IMP Gdansk, Poland. Author checked flow rate calculation of some points.

Table 1: Pressure – time measurement on pumps performed by OSC

2 PSHP Dalešice

2.1 Plant description

Pumping storage plant Dalešice is equipped by 4 reversible Francis turbines with nominal output 120 MW working with the head approx. 70 ÷ 90 m. Each unit has own penstock with long straight part which is accessible from outside in the whole length. The measuring section of length more than 160 m was established on each penstock – see Figure 1. Almost laboratory conditions for Pressure – Time method can be considered here.

PSHP Dalešise has been put into operation in 1978 and unit's refurbishment / upgrade was initiated after 20 years of very successful operation. Ground of this decision wasn't unit's amortization but better parameters of runners with new design. Comparison of guarantee measurement in turbine mode from year 1978 performed using current meters and measurement carried out in 1998 using pressure – time is presented in Figure 2. Good correlation of both methods is evident; current meters measurement shows bigger points dispersion.

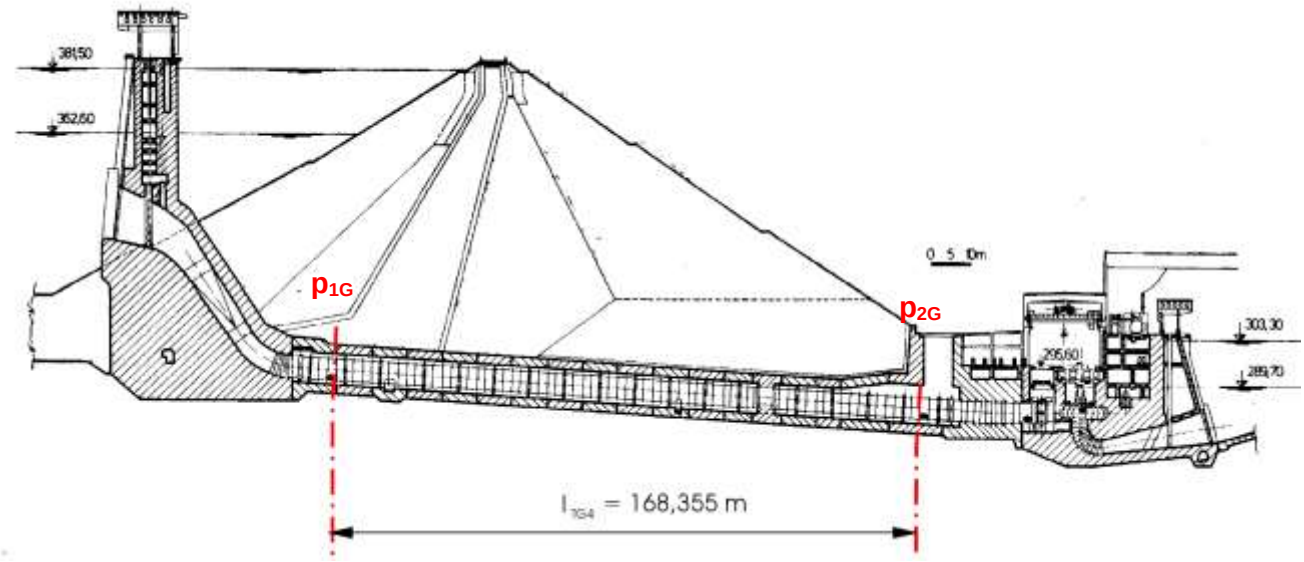


Figure 1: Longitudinal section through unit TG4

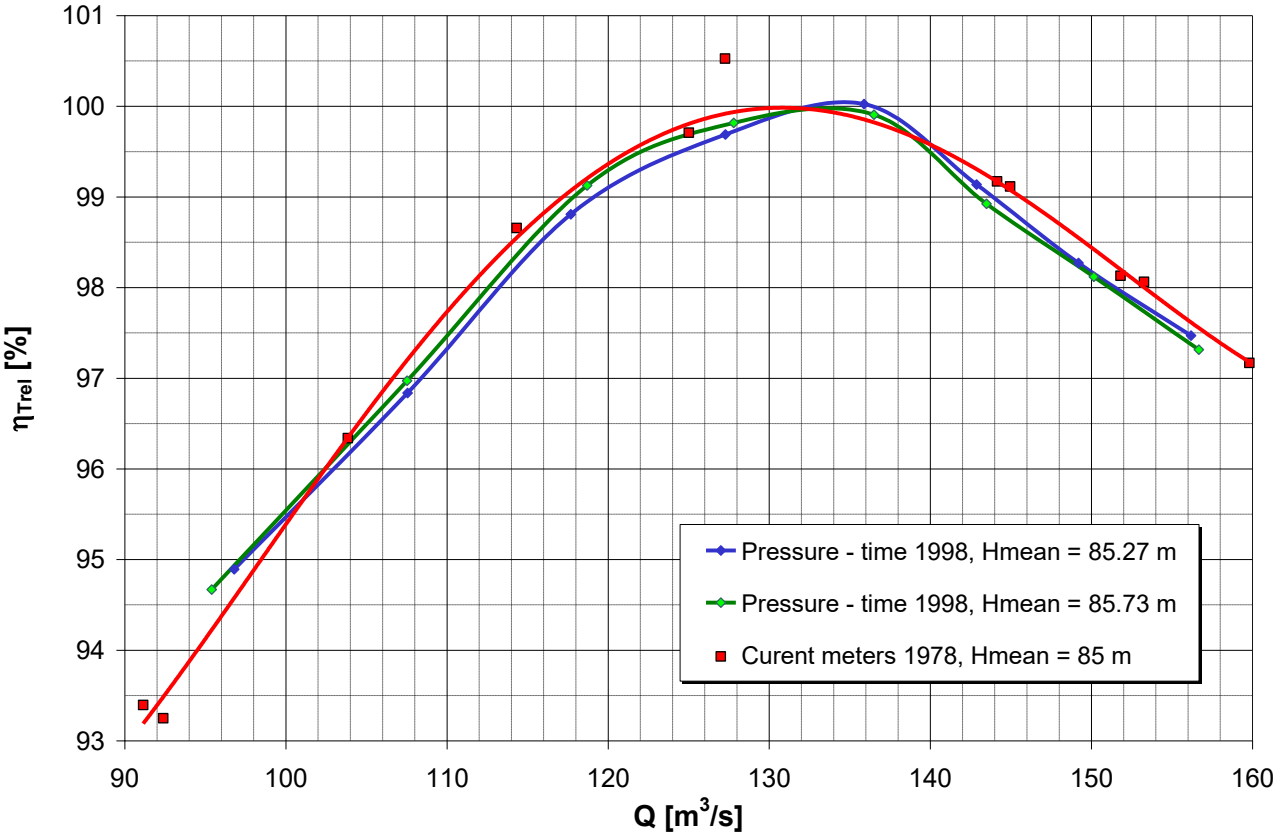


Figure 2: Comparison of TG3 efficiency measured using current meters and pressure – time

2.2 Results comparison

At unit TG3 the runner edges, stay vanes and guide vanes were hydraulically optimized, new runners were also installed at remaining units. All the units have after modernization different design, some of them are optimized for work by lower head, some of them by higher head and they have also different guaranteed efficiencies. But all the units met guaranteed values. All the four units were measured in full operational range in turbine and pump modes after refurbishment / upgrade.

As the measurement credibility marker can be considered also ratio between efficiency in BEP (Best Efficiency Point) in turbine and pump modes. These values for all the units from site tests before and after improvement are available in Table 2. This ratio can't differ too much from value 1.00.

Unit		**TG1**	**TG2**	**TG3**	**TG4**
Kind of improvement		upgrade	upgrade	refurbishment	upgrade
Before	$\eta_Č / \eta_T$	1.007	not measured	1.012	1.024 *)
After	$\eta_Č / \eta_T$	0.996	0.988	1.008	0.997

*) Reduced scope of efficiency tests before upgrade

Table 2: Ratio $\eta_Č / \eta_T$ for BEP before and after units improvement in PSHP Dalešice

3 PSHP Dlouhé Stráně

3.1 Plant description

Pumping storage plant Dlouhé Stráně is equipped by 2 reversible one stage Francis turbines with nominal output 325 MW working with the head approx. 495 ÷ 532 m. Each unit has own penstock with diameter 3.6 m and length of measuring section approx. 1 400 m. Power Plant has been put into operation in 1996 and runners have recently been replaced by new ones. Thermodynamic method is suitable for Power Plants with similar head, but there is no access to draft tube end for thermometers installation. Therefore Pressure – Time method was utilized for this plant.

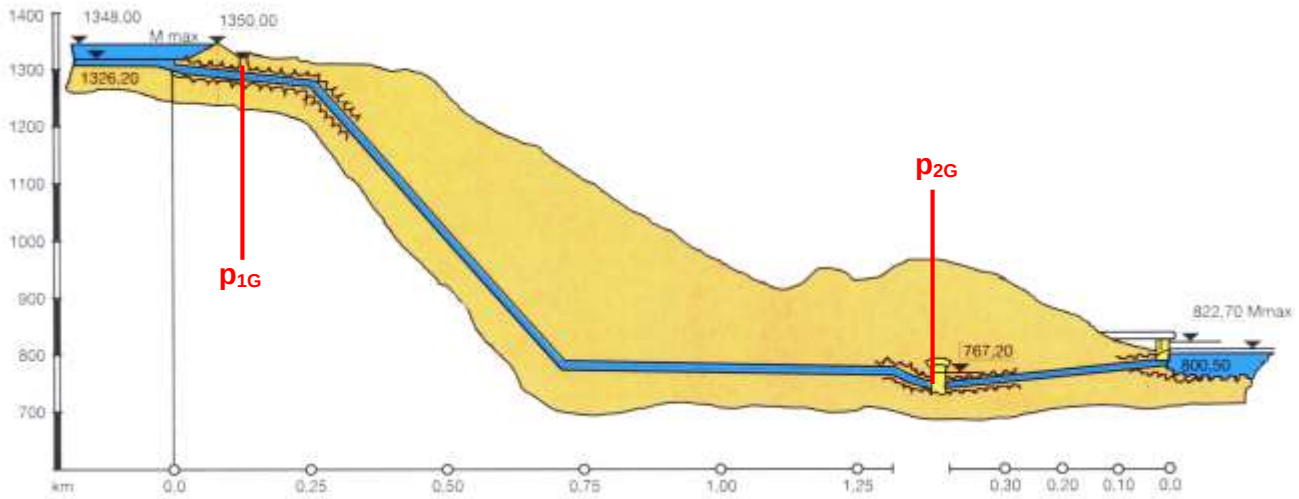


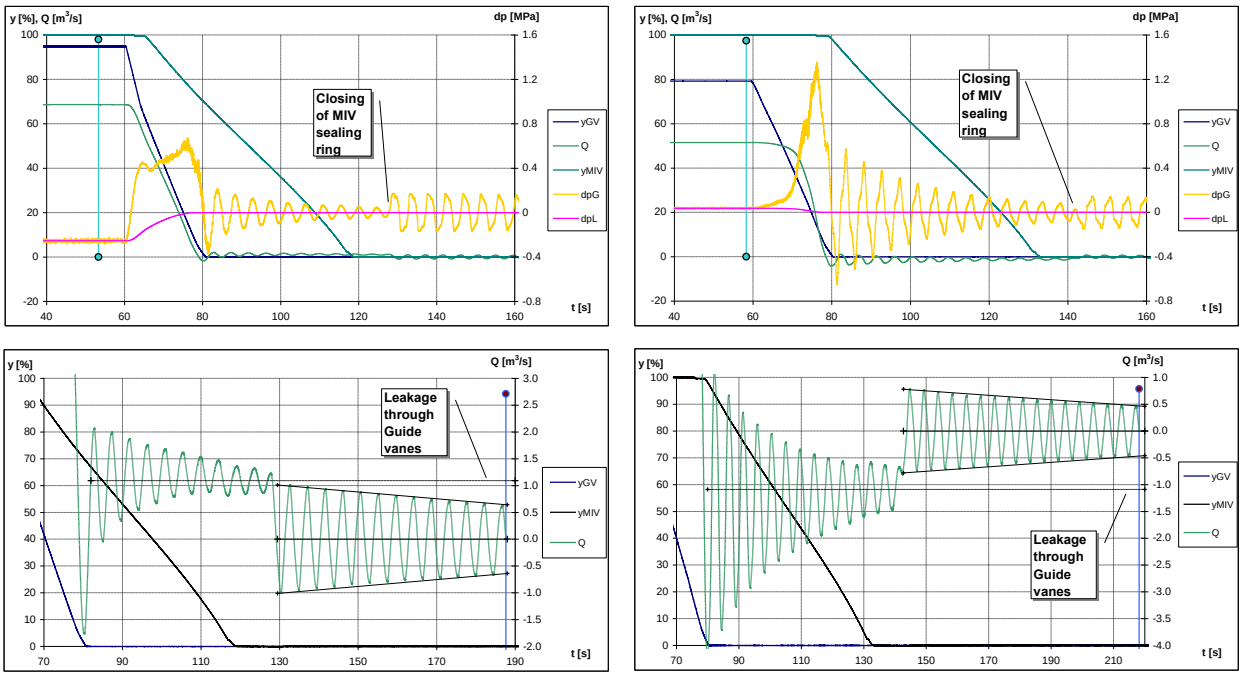
Figure 3: Longitudinal section through PSHP Dlouhé Stráně

3.2 Pressure – Time in turbine and pump modes

Example of Pressure - Time evaluation for both operational modes are presented in Figure 4. These records come from this year's TG2 test before upgrading. Following differences between the two modes of operation are evident from the records:

- The water column speed deceleration is caused not only by closing guide vanes but also by gravity during unit stop from pump mode. Maximum of pressure difference on measuring section is significantly higher than by stop from turbine mode.
- The pressure oscillations are higher during unit stop from pump mode than from turbine mode.
- Identical leakage through closed guide vanes was before spherical valve (MIV) closing.
- The recovery curve dp_L includes not only friction losses in the measuring section but also the difference in velocity heads in different upstream and downstream cross sections.
- "Engineering approach" for Pressure –Time flow rate evaluation described in detail in [2] was applied.

Here presented examples are typical for documentation of difference between flow rate evaluations in the both operational modes for reversible turbines.



Turbine, Q = 68.642 m^3/s Pump, Q = 51.470 m^3/s

Figure 4: Comparison of signal waveforms for turbine and pump operation

3.3 Results comparison

The guarantee measurement using current meters installed in upper horizontal part of penstocks was performed after units start to operation. Efficiency tests on both the units using Pressure – Time were performed before upgrade. At unit TG1 also the guarantee measurement of reversible turbine with new runner was performed. Author participated on all the above mentioned tests and the results are summarized in Table 3. It is obvious that the efficiency ratio between the pump and turbine mode varies minimal with the method used and with the time. Considering the credible measurement in turbine mode, it follows from the above that the measurement in the pump mode is equally plausible.

Stage	**Unit**	**TG1**	**TG2**
GM after start up – current meters	$\eta_Č / \eta_T$	0.988	1.007
Before upgrade - Pressure - Time	$\eta_Č / \eta_T$	0.994	1.011
GM after upgrade - Pressure - Time	$\eta_Č / \eta_T$	0.992	-

Table 3: Ratio $\eta_Č / \eta_T$ for BEP in PSHP Dlouhé Stráně

4 Other tests

4.1 PSHH Ziarnowiec

PSHH Ziarnowiec is a large plant with four reversible Francis turbines with nominal output approx. 190 MW located in north Poland close to Baltic Sea. Each unit is equipped by own 1 100 m long and almost straight penstock. Guarantee measurement performed here IMP Gdansk (Institute of Fluid-Flow Machinery Polish Academy of Sciences) and the author here acted as a supplier's consultant. Some records were evaluated independently on IMP. The correlation was very good. Hydro Power Group of IMP also carried out a number of Pressure – Time tests on reversible turbines in pump mode with good results.

4.2 Pumping station Trei Ape

Pump station Timis Trei Ape is part of hydro system Resita in west part of Romania. Two standard pumps transport the water between two lakes with geodetic head approx. 180 m. Nominal pump parameters are as follows: H_n = 212 m, Q_n = 0.3 m^3/s. The difference compared to reverse turbine measurement in the pump mode is the immediate function of the non-return valve held in open position by water only. Therefore the water hammer has significantly higher pressure peaks but the flowrate evaluation is without problems as evident from example presented in Figure 5. Procedure described in [2] was also used for this case.

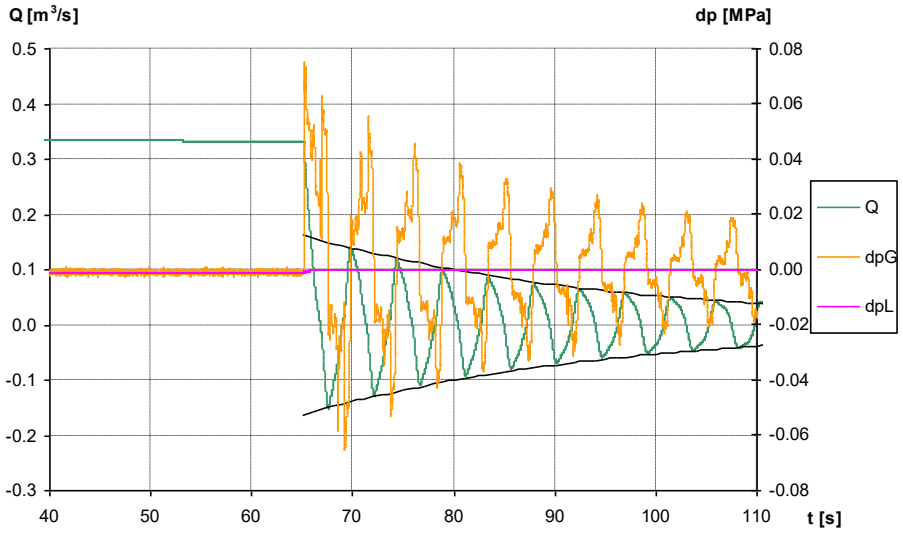


Figure 5: Signal waveforms for pump shut down at Trei Ape pump station

5 Conclusion

Results of tests at reversible turbines in pump mode and at standard pumps using Pressure – Time method performed by author and colleagues from his team are presented in this paper. All the flow rates were evaluated by algorithm described in detail in [2]. Main findings can be summarized as follows:

- There is no obstacle to apply Pressure – Time method on pumps according author's experience.
- Measurement accuracy in pump mode doesn't differ from measurement in turbine mode.
- The ratio pump efficiency / turbine efficiency can be considered as criterion of correct flow rate measurement. This ratio should be close to the guaranteed values ratio and should not be too different from 1.
- Not only OSC Hydro Power Group regularly performs Pressure – Time at pumps. See chap. 4.1.

6 References

[1] Standard IEC 60041: *"Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump turbine"*. IEC, 3rd edition, 1991.

[2] Ševčík P.: "*Exact zero determination and integration termination for Pressure - Time method*". Contribution IGHEM 2014.

[3] Ševčík P.: "*Statistic evaluation of deviation between guaranteed and measured turbine efficiency*". Contribution IGHEM 2012.

[4] Ševčík P.: "*Statistic evaluation of deviation between guaranteed and measured turbine efficiency*". Contribution Hydro Turbo 2016.