PRESSURE TIME: INFLUENCE OF PRESSURE SENSOR AND CONNECTING TUBING.

HENRI MESPLOU

The flow measurement method known as pressure-time is standardised and chosen as a reference in the I.E.C. 41 for the acceptance of hydraulic machines.

EDF and ALSTOM jointly evaluated this method by means of comparative tests on a double Francis unit of a power of 12.3 MW at a head of 190 m. The results of the application of the thermodynamic method acted as a reference.

Three differential pressure sensors, Siemens, EFFA and Druck, with pass-bands of 10, 100 and 1000 Hz respectively were tested. The Sedeme sensor performed the best with a difference of -0.1 point compared with the mean efficiency measured using the thermodynamic method. This excellent performance must not, however, obscure the mediocre repeatability of the measurement. When this sensor is used, a standard uncertainty was identified due to the repeatability of 0.6 point on the efficiency measurement. This makes it necessary to multiply the number of measurement points in order to increase the accuracy of results.

Two connecting tubings were also tested: one in copper 14/16 and the other, less elastic, in rilsan 11/14. Use of rilsan tubing is not recommended as it resulted in a bias of - 1.8 point on the efficiency measurement.

At the same time, we tested two differens data acquisition devices : one was a A/D card without analogical filter (data acquisition frequency of 200 Hz), the other one was a filtered A/D card with a band width of 500 Hz and a data acquisition frequency of 1280 Hz. Both devices gave same results (discrepency maximal of 0.5% ca between both) and stay in a band of 1% related to the thermodynamic method. It should be noticed that here, the low noise test results help the Gibson calculation in case of non filtered A/D card.

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H. MESPLOU
E.D.F. DTG
21, Avenue de l'Europe - B.P. 41 - 38040
GRENOBLE CEDEX - France
Tel: 33 4 76 20 22 40 Fax: 33 4 76 20 21 94
E-mail: henri.mesplou@edf.fr

O. TRICCA
ALSTOM Hydro
82, avenue Léon Blum- B.P. 75 38041
GRENOBLE CEDEX 9 - France
Tel: 33 4 76 39 33 76 Fax: 33 4 76 39 33 77
E-mail: olivier.tricca@alstom.fr

ABSTRACT

The flow measurement method known as pressure-time is standardised and chosen as a reference in the I.E.C. 41 for the acceptance of hydraulic machines.

EDF and ALSTOM jointly evaluated this method by means of comparative tests on a double Francis unit of a power of 12.3 MW at a head of 190 m. The results of the application of the thermodynamic method acted as a reference.

Three differential pressure sensors, Siemens, EFFA and Druck, with pass-bands of 10, 100 and 1000 Hz respectively were tested. The Sedeme sensor performed the best with a difference of -0.1 point compared with the mean efficiency measured using the thermodynamic method. This excellent performance must not, however, obscure the mediocre repeatability of the measurement. When this sensor is used, a standard uncertainty was identified due to the repeatability of 1.2 point on the efficiency measurement. This makes it necessary to multiply the number of measurement points in order to increase the accuracy of results.

Two connecting tubings were also tested: one in copper 14/16 and the other, less elastic, in rilsan 11/14. Use of rilsan tubing is not recommended as it resulted in a bias of - 1.8 point on the efficiency measurement.

1. INTRODUCTION

The flow measurement method known as pressure-time is standardised and chosen as a reference in the I.E.C. 41 for the acceptance of hydraulic machines.

EDF and ALSTOM jointly evaluated this method by means of comparative tests on a double Francis unit of a power of 12.3 MW at a head of 190 m. The results of the application of the thermodynamic method acted as a reference.

The aim was to test various types of sensor and different types of tubing.

2. APPLICATION

2.1. Eygun power station

Eygun power station is equipped with a double Francis turbine with a power of 12.4 MW under a head of 190 metres.

2.2. Reference method

The method used as a reference was the thermodynamic method. The uncertainty of the efficiency measured using this method was calculated as ± 0.8 point.

2.3. Instrumentation

Two pressure tappings 25.6 m apart were installed on the penstock (Figure 1).

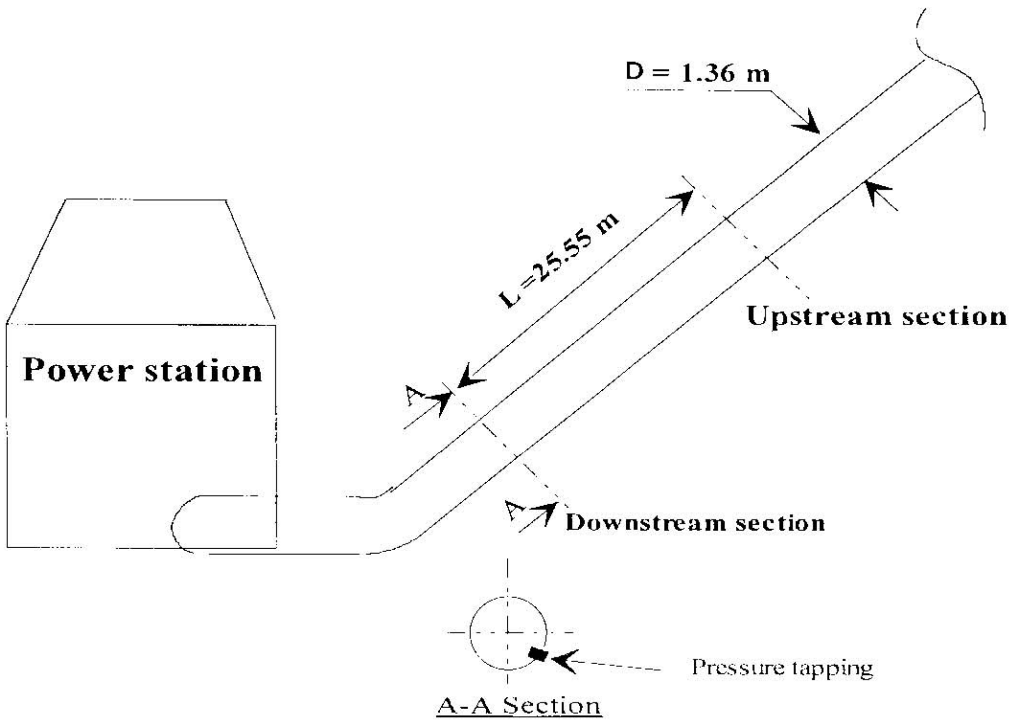

Figure 1: Eygun power station

2.4. Pressure sensors

The following pressure sensors were installed and tested:

	Range	Pass-band given by the manufacturer	Remarks
Sedeme (EFFA G63)	-500 to +500 mBar	100Hz	No rangeability – no temperature compensation
Druck	0-600 mBar	1000 Hz	No rangeability – no temperature compensation – restricted off-setting of zero
Siemens	0-600 mBar	10 Hz	Good rangeability - temperature compensation

The choice of sensors tested was made to cover the widest possible range of pass-band.

2.5. Connecting tubing

Two types of connecting tubing were installed on the penstock:

1) copper tubing 14/16, which has the advantage of being very rigid.

2) rilsan tubing 11/14, less rigid but has the advantage of being easier to install.

2.6. Leakage flow

The leakage flow was determined by draining the penstock. The variation in the water level in the penstock was measured for 2 installation configurations:

- guide vanes closed, foot valve open and head valve closed (flow measured = 70 l/s);
- guide vanes closed, foot valve closed (the seal of this valve has recently been renovated to make it completely leakproof) and head valve closed (flow measured = - 34 l/s); hence, this flow corresponds to the leakage flow of the head valve.

This finally gives a leakage flow of 36 l/s via the guide vanes.

2.7. Load shedding performed

During load shedding, Francis Double turbines generate sudden overpressures. To avoid affecting the measurements, we decided to set up the following method of load shedding:

- unit connected to the network until opening corresponding to speed-no-load operation;
- inactive relief valve (the unit is equipped with a relief valve that has a relatively long closing time);
- guide vane closure in 18 s. To achieve good amplitude of the pressure signal, the target was between 7 and 10 seconds but this could not be achieved because of the capacity of the oil circuit of the guide vanes.

3. APPLICATION CONDITIONS

The conditions for applying the pressure-time method are summarised in the table below:

	Criteria to be respected	Criteria respected?
D = 1.36 m	D > 1 m	yes
L = 25.55 m	L > 10 m	yes
q = 36 l / s	q < 5 % Q	yes
u(q)/q = 0.1 % Q	u(q)/q < 0.2 % Q	yes
L V = 114 m²/s	LV > 50 m²/s	yes
Tf = 18 s	Tf > 5 s	yes
$\Delta P_{average}$ = 0.7 mWC	$\Delta P_{average}$ > 1 mWC	no
$\Delta H_{initial} \approx 35\ \%\ \Delta P_{average}$	$\Delta H_{initial} < 20\ \%\ \Delta P_{average}$	no

Where:

- Tf: closing time of guide vanes;
- L: distance between the two measurement sections;
- D: internal diameter of the penstock;
- Q: flow to be measured;
- Qmax: flow to be measured at full load;
- q: leak rate via the guide vanes;
- u(q): uncertainty of the measurement of the flow q;
- V: average velocity in the penstock at full load;
- $\Delta P_{average}$: average value of the measured overpressure;
- $\Delta H_{initial}$: load losses before closing the operating mechanism between the 2 sections.

The application conditions of the pressure-time method were rather poor: the amplitude of the pressure signal is lower than the acceptable limit and the load losses in the penstock were too great. It can be seen below that these conditions allowed a better comparison to be made between the performances of the different pressure sensors.

4. RESULTS

4.1. Pressure sensors

4.1.1 Comparison of pressure-time and thermodynamic methods

The results obtained using the pressure-time and thermodynamic methods are given in the table below:

Mechanical power (kW)	5041	6714	7323	9709	11156	**Average**
Efficiency deviation pressure-time Druck/Thermo (point)	-2.0	-5.4*	-2.4	-2.5	-2.3	**-2.3 ± 0.8** point**
Efficiency deviation pressure-time Sedeme/Thermo (point)	-0.3	-0.0	-0.4	+0.3	-0.1	**-0.1 ± 0.8**point**
Efficiency deviation pressure-time Siemens/Thermo (point)	-0.8	-1.8	-0.7	-1.3	-0.4	**-1.0 ± 0.8** point**

*the sensor was saturated because pressure fluctuations were too great; the average of the variations was calculated without this measurement point.

** this uncertainty corresponds to the uncertainty of the average efficiency measured using the thermodynamic method (± 0.8 point).

For the 3 pressure sensors, the deviations measured are within the uncertainty announced by the standard IEC 41 [1, §2.4], i.e. approx. ± 1.8 point of efficiency. In spite of unfavourable application conditions, the results obtained by the pressure-time method are consistent, for the three pressure sensors, with the standard IEC 41.

4.1.2 Repeatability errors

However, the good results observed before hide important repeatability errors. These repeatability errors were quantified in the form of standard deviations for each of the pressure sensors used.

	Standard deviation caused by repeatability
Druck pressure-time	1.7 point of efficiency
Sedeme pressure-time	0.6 point of efficiency
Siemens pressure-time	1.3 point of efficiency

The Sedeme pressure sensor with a pass-band of 100 Hz has the smallest error due to repeatability.

4.1.3 Analysis of time signals

Siemens pressure sensor:

The analysis of the time signal shows that some fluctuations in the pressure signal are truncated (Figure 2). The frequency of these fluctuations is of the order of 7 Hz. For a sensor whose pass-band announced by the manufacturer is 10 Hz, this should not be the case. In reality, a frequency analysis of the pressure signal shows that the real pass-band of the sensor is in the order of 3 to 5 Hz, which is insufficient for the application of the pressure-time method and explains the large error of repeatability observed.

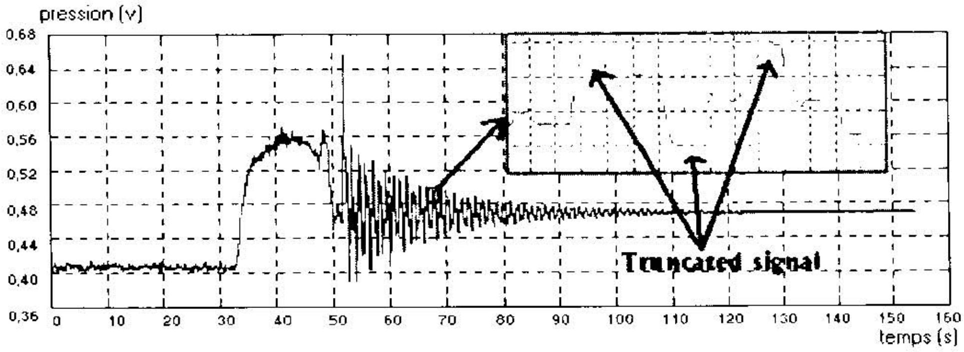

Figure 2: Pressure signal measured by the Siemens sensor

Druck pressure sensor:

The great inconvenience of this sensor is that its zero can only be moved slightly. Signal saturation may result (Figure 3). However, the pass-band, which is of the order of kHz, does not filter the parasite frequencies due to some methods of penstock vibration (frequency of the order of 50 to 70 Hz) that can be superimposed on the "useful" signal. This could explain why this sensor offers the greatest deviation in comparison with the reference method and the worst repeatability.

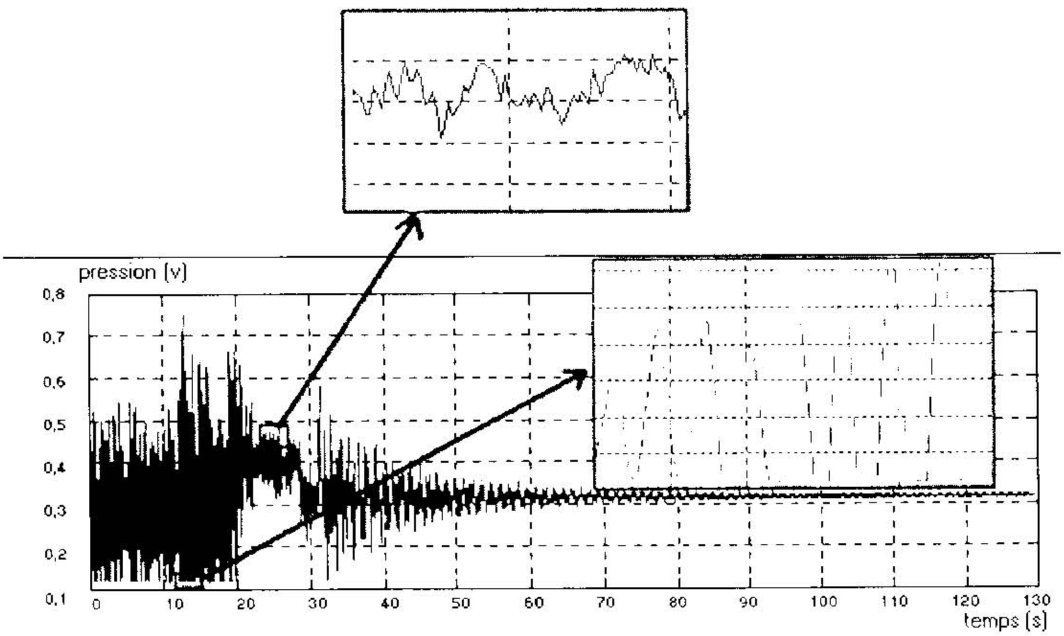

Figure 3: Pressure signal measured by the Druck sensor

Sedeme pressure sensor:

The pass-band of this sensor according to the manufacturer is 100 Hz. A frequency analysis shows that it is close to 50 Hz. This sensor is the most accurate and repeatability performances of the three sensors tested. Nevertheless, its absolute repeatability is not very good and seems to be caused by pressure fluctuations from the penstock vibrations (Figure 4).

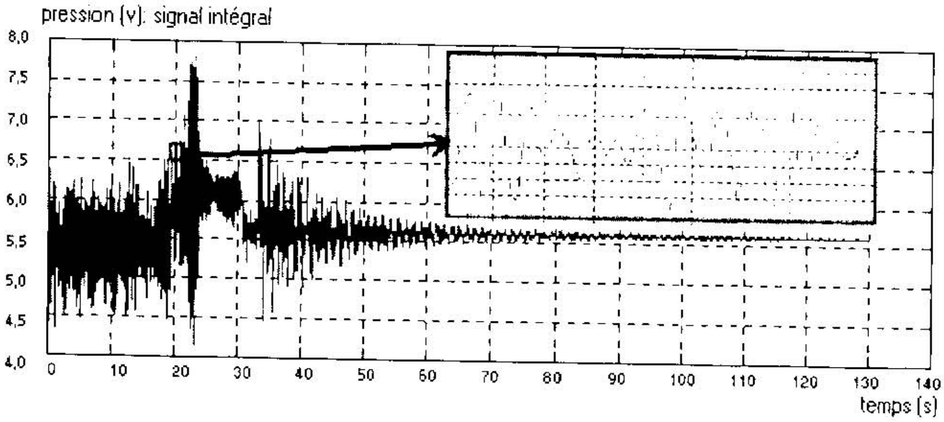

Figure 4: Pressure signal measured by the Sedeme sensor

The use of a physical filter (for example, hydropneumatic) installed between the pressure tappings and the pressure sensor could allow the repeatability of the measurement to be improved.

4.2. Connecting tubing

We compared the results obtained with copper and rilsan tubing for the whole power range of the turbine. We observed a deviation that was almost constant for the whole range:

Average efficiency deviation Sedeme pressure-time Rilsan/Copper (point)	**-1.8** point of efficiency
Average efficiency deviation Siemens pressure-time Rilsan/Copper (point)	**-1.8** point of efficiency

The rilsan tubing reduces performances and results in an under-estimation of the efficiency of approximately 1.8 point. By comparing the time signals (Figure 5), a strong attenuation is observed in the measured pressure fluctuations, particularly for frequencies in the order of 7 Hz. These fluctuations particularly affect the repeatability but affect measurement accuracy less.

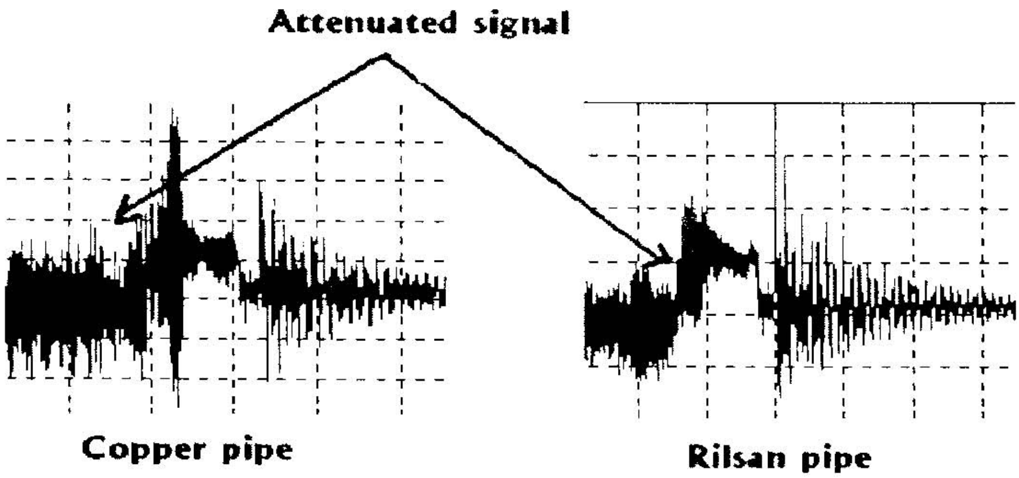

Figure 5: Pressure signals measured with copper and rilsan tubing

Rilsan tubing has a frequency that tends towards low frequencies (approx. 3 Hz) and tends to amplify the average signal (this is of interest for the flow calculation). This is shown by a slight over-estimation of the flow and hence an under-estimation of the efficiency. The choice of tubing is important and the following must be ensured:

$$\frac{a}{4 \times L} > 10\,\text{Hz}$$

Where:

- L: tubing length (from the pressure tapping to the sensor);
- a: speed of sound in the water in the tubing.

5. CONCLUSION

Tests carried out in poor application conditions for the pressure-time method, enabled the performances of three differential pressure sensors to be tested. Extrapolation of the obtained results indicates that the performances of the pressure sensors can be classified according to their pass-band:

- f < 5 Hz: poor repeatability that can be improved by using physical filters (this still has to be proved);

- 5 Hz < f < 50 Hz: best performances; however, under critical application conditions, the errors of repeatability are still great;

- f > 50 Hz: worst performances; there is no point in using sensors with such a wide pass-band (degradation of the signal/noise ratio).

Note that the pass-bands announced by the manufacturers are sometimes approximate.

The choice of tubing type to be used is important and should have a frequency above 10 Hz.

References

[1] **Title:** Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pumps-turbines - **Author**: International Electrotechnical Commission - **Reference:** IEC 41 - **Edition**: November 1991 (third edition).