# Exact zero determination and integration termination for pressure – time method

Petr Ševčík
Hydro Power Group Leading Engineer
OSC, a.s., Brno, Czech Republic
e-mail: sevcikp@osc.cz

**ABSTRACT**

This paper presents engineering approach to exact pressure difference zero determination and termination of integration which is based on following physical facts:
The person performing the flow measurement usually knows, which flow rate can be expected after unit shut down. The discharge can't grow or drop, if the valve in front of turbine is closed and tight, because in this case the flow rate is zero. Similar situation occurs if small leakage through guide vanes or other closing apparatus remains after unit shut down. In this case the final leakage is almost constant and it can change with pressure / head oscillation. The mean value of leakage $Q_0$ has to be determined other way than pressure – time procedure. But the water mass oscillation in penstock after guide vane closing is presented as small flow oscillations with constant mean value $Q_0$.
Algorithm based on mentioned phenomenon evaluates the pressure difference part after guide vane or main intake valve closing.

## 1 INTRODUCTION

Two types of experts perform usually the site tests, scientific oriented research workers and practically oriented engineers. Engineering approach to solving any problem is based on knowledge of tested device and on feedback. I.e. the test result plausibility is compared with the real possibility. Scheme of such test evaluation procedure is presented in Fig. 1.

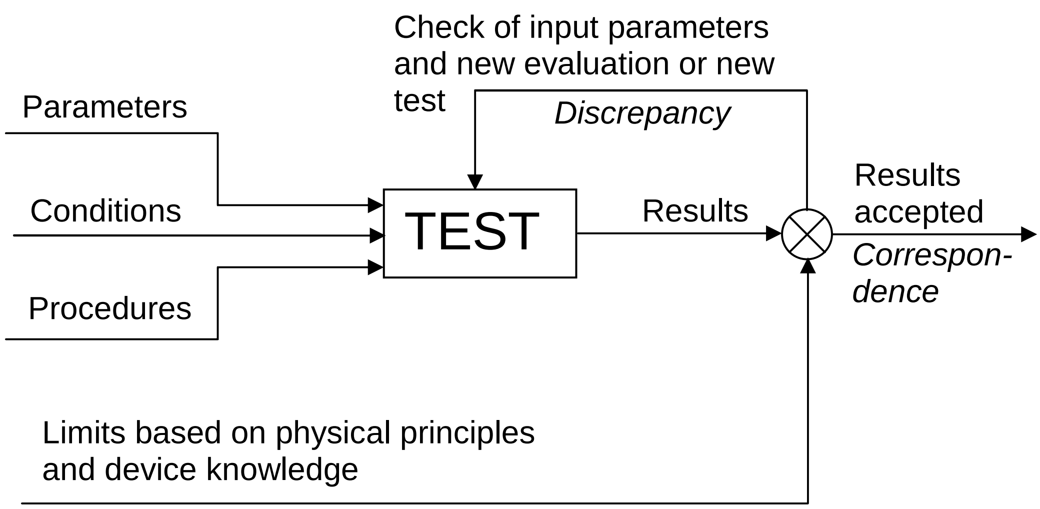


**Fig. 1 –** Scheme of evaluation procedure based on feedback

## 2 MAIN FEEDBACK PHENOMENA

The person performing the flow measurement usually knows, which flow rate can be expected after unit shut down. Following phenomena have to be taken into consideration by evaluating of flow waveform plausibility:

### 2.1 Trend of flow rate after valve closing

The flow rate after closing of tight valve (e.g. nozzles of Pelton turbines, butterfly valves, spherical valves) is zero. The calculated flow rate can oscillate symmetrically around zero, but the trend of mean value has to be zero.

### 2.2 Trend of flow rate with residual flow

The residual flow is usually caused by leakage through guide vanes of Francis or Kaplan turbine. It's mean value is usually almost constant, but the influence of slow waves on the lake surface or oscillation of pendulum lake – surge tank can cause the changes of residual flow.

### 2.3 End of integration

The mean value of final residual flow after closing of all closing elements has to be set by integration termination to zero or to residual flow determined by other method.

## 3 ASSESSMENT OF PARTICULAR EFFECTS

Calculation procedure used by author and his measuring group is based on formulas presented in standards IEC 60041 and IEC 62006.

$$Q_G = \frac{1}{\rho \cdot c_{pst}} \cdot \int (\Delta p + \xi) \cdot dt + Q_0$$

where

- $c_{pst}$ = geometrical penstock factor
- $\Delta p$ = pressure difference on the penstock section used for measurement during abrupt maneuver
- $\xi$ = sum of pressure loss by friction and speed head difference between both sections G1 and G2; $\xi(t) = k_G * Q(t)^2$
- $Q_0$ = residual flow

Differential pressure $\Delta p$ can be measured directly by differential pressure transducer or by separately installed sensors in cross sections G1 and G2 at the beginning and end of the measuring section. In both the mentioned cases the differential pressure $\Delta p$ used for flow rate calculation is calculated according to following formulas:

$$\Delta p = p_{2G} - p_{1G} - p_{offset} \quad \text{for separate sensors}$$

$$\Delta p = \Delta p_{meas} - p_{offset} \quad \text{for differential pressure sensor}$$

Value $p_{offset}$ performs the correction of differential sensors position for separately installed sensors and also correction of sensors zero offsets in both the cases. This value proves to be principal variable for correct flow determination.

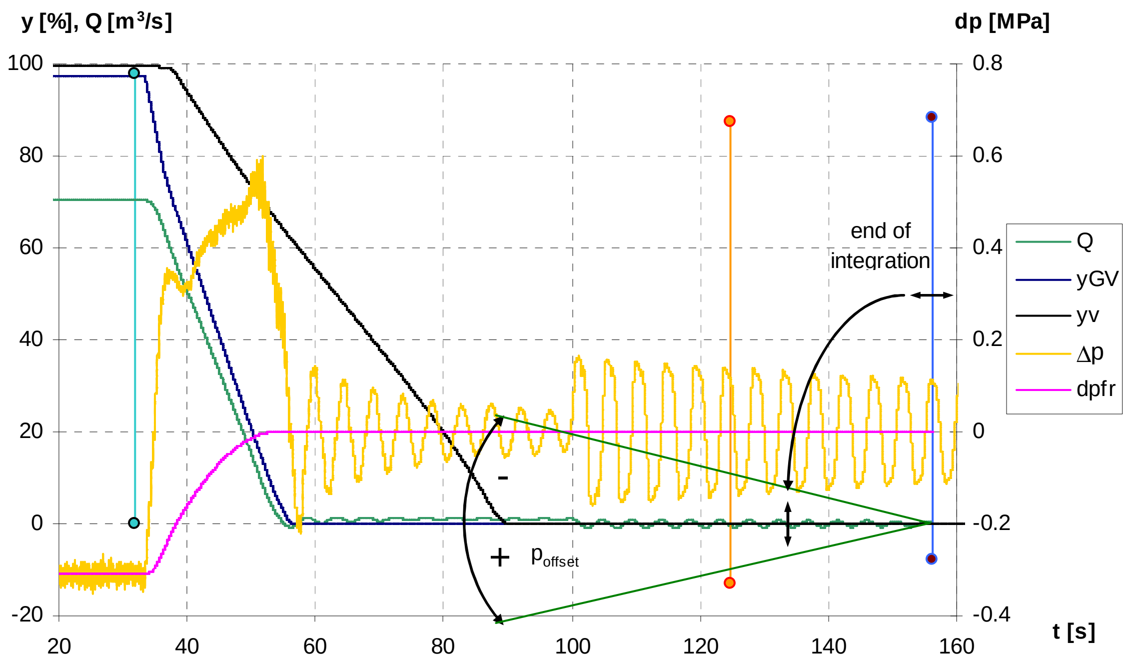


**Fig. 2** – Impact of $p_{offset}$ and integration termination on final flow waveform

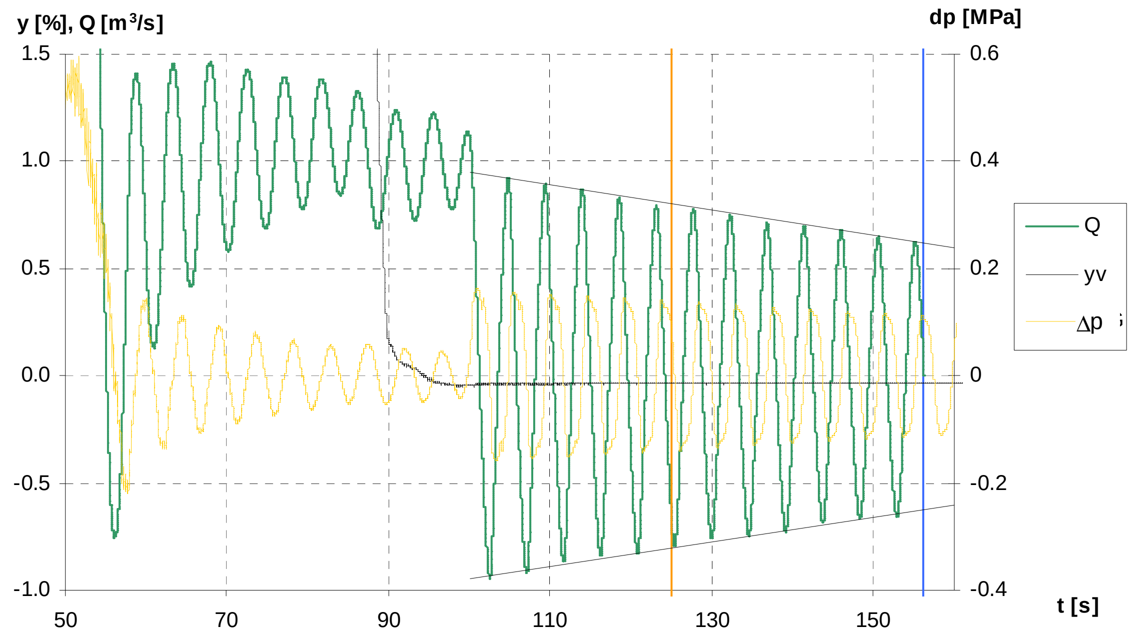


**Fig. 3** – Detail of flow waveform oscillation

Schematic explanation of pressure offset $p_{offset}$ impact and also integration termination on flow waveform is presented in Fig. 2. Detail of flow stabilization after guide vane and also spherical valve closing is presented in Fig. 3. The auxiliary envelope curves of oscillating flow rate signal are inserted into this graph. Such curves have usually following equations:

$$Q_{e+/-} = Q_0 \pm A \cdot e^{-\frac{t}{\tau}}$$

where

| | | |
|---|---|---|
| $Q_{e+}$ / $Q_{e-}$ | = | upper / bottom envelope curve |
| $Q_0$ | = | residual flow |
| A | = | initial amplitude of flow rate signal oscillation (for t = 0) |
| t | = | time |
| $\tau$ | = | damping time constant |

No leakage through spherical valve after closing ($Q_0$ = 0) was in the case presented in Fig. 3. Sometimes is possible to substitute the exponential function by a simpler curve. Important is the symmetry of oscillation. Impact of wrong determined $p_{offset}$ is presented in Fig. 4.

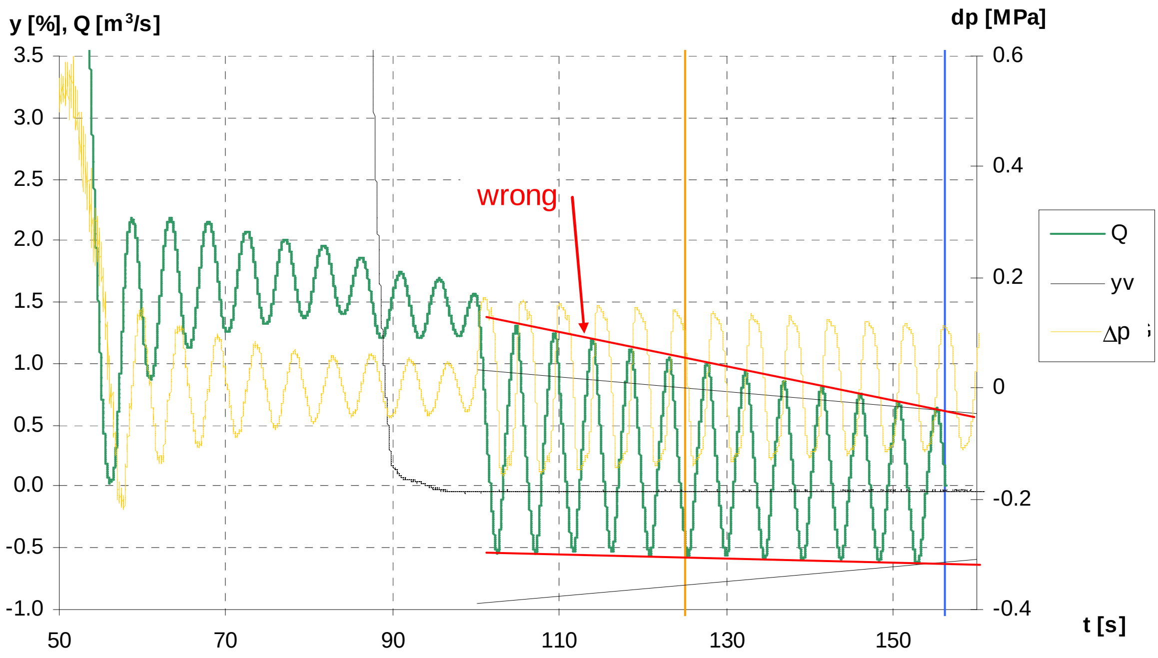


**Fig. 4** – Impact of wrong determined $p_{offset}$

| **Case** | ***p<sub>offset</sub>* deviation** | ***Q*** | ***ΔQ*** |
|---|---|---|---|
| | ***% of $dp_{max}$*** | ***$m^3/s$*** | ***%*** |
| ***Correct $p_{offset}$*** | 0.00 | 70.280 | 0.0 |
| ***Wrong $p_{offset}$*** | -0.18 | 71.351 | 1.5 |

**Tab. 1** – Comparison of flow rate calculation with correct and wrong $p_{offset}$ determination

Evaluation of wrong determined $p_{offset}$ value is presented in Tab. 1. Deviation corresponding with sensor accuracy class causes approximately ten times higher flow rate error. That means it is necessary to devote maximum effort to establish the $p_{offset}$ value correctly. The error based on integration of small deviation is proportional to the integration time.

On the other hand the end of integration determination is easier comparing with $p_{offset}$ adjusting. It is also based on the oscillation symmetry but the potential error is independent on integration interval – see Fig. 2.

## 4 DESCRIPTION OF THE CALCULATION PROCEDURE

As mentioned above the calculation procedure is based on the equation from standards [7] and [8]. The procedure works as several mutually nested iterative loops – see Fig. 5. The internal basic calculation loop works automatically, loop runs for integration error minimizing (adjusting of $p_{offset}$) and integration end determination are started manually.

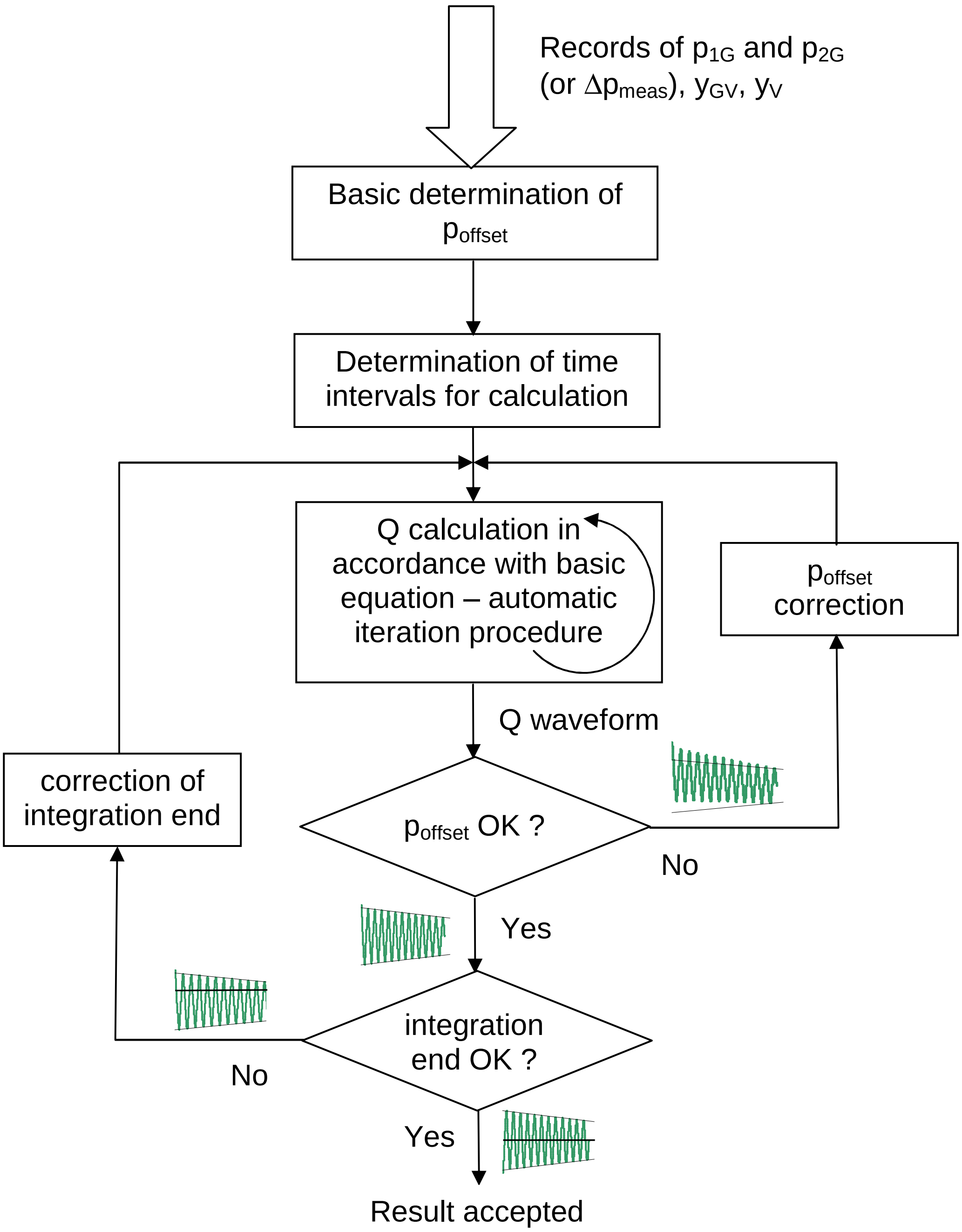


**Fig. 5** – Principal scheme of calculation procedure

# 5 COMPARISON WITH OTHER CALCULATION PROCEDURES

Many measurements (over 100) were evaluated using above described procedure. Statistic evaluation of deviation between guaranteed and measured turbine efficiency [1] was presented on last IGHEM session in 2012 in Trondheim. Couple of comparative tests of pressure – time method with other physical methods was carried out during last years – see [2], [3]. Some of such experiments were performed recently and the results can be presented in the future.

Very interesting is comparison of flow rate evaluation performed by 4 different procedures from identical record. Data was provided through the kindness of Mr. Adam Adamkowski from his test and it was evaluated according to differential procedures – see Tab. 2.

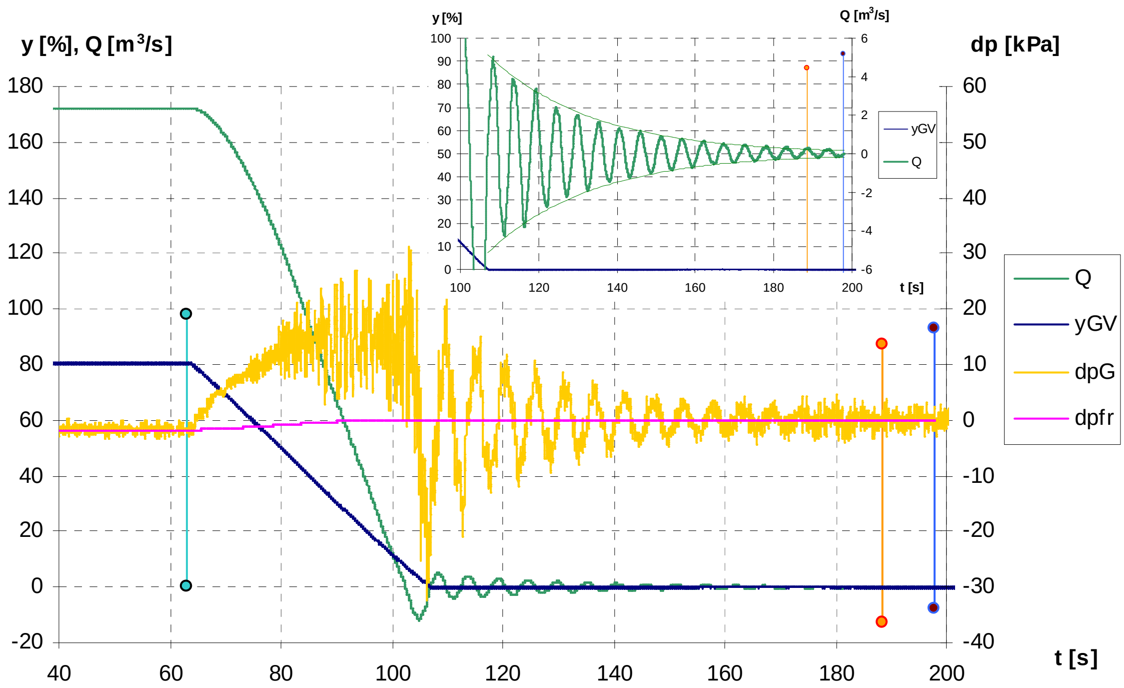


**Fig. 6 –** Flow waveform calculation based on data provided by Mr. Adamkowski

| *Author* | *Calc. procedure* | *Q [m$^3$/s]* | *Deviation* |
|---|---|---|---|
| By Mr. Sevcik, OSC | Q_GIB-SEV: | 171.998 | - |
| By Mr. Adamkowski, IMP PAN | Q_GIB-ADAM: | 171.868 | 0.08% |
| By Mr. Jonson, NTNU | Q_GIB-MOC: | 171.904 | 0.05% |
| According to IEC 60041/1991 | Q_GIB-IEC: | 172.365 | -0.21% |

**Tab. 2 –** Comparison of different calculation procedures

## 6 SUMMARY

Nowadays it exists couple of advanced algorithms for pressure – time method which seems to be better than the procedure performed exactly according to IEC 60041 / 1991 code. Above described “engineering” procedure provides almost identical results as calculation procedure improvements prepared by well known above mentioned authors. Here described procedure is easy to perform and has regards to real behaviour of tested equipment. High number of tests performed using this procedure and experience with mutual comparison with other physical methods and also with other experts for pressure – time method guarantee high plausibility of here presented algorithm.

**Acknowledgments**
The author would like to thank Mr. Adamkowski for providing of recorded data and also for the results evaluated by other procedures.

## 7 REFERENCES

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