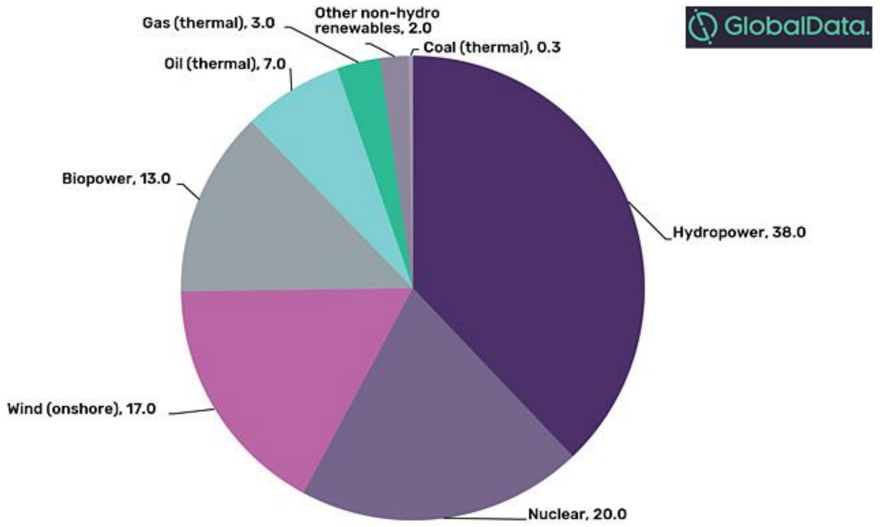
Discharge Measurement Method

- Hydropower in Sweden stands for about 38% of total electricity generation (source: GlobalData 2018)
- Swedish hydropower plants were mostly built during 1950-70s and are now undergoing major refurbishments
- To calculate efficiency, discharge measurement is a necessary parameter to measure and the most challenging (low head plants - head under 50 m)
- The Winter-Kennedy method is widely use in Sweden; a relative method for hydraulic turbines discharge estimation



Method	Type	Development status for low head	Estimated cost (MSEK)	Practical Uncertainty at 95% Confidence level
Winter-Kennedy	Relative	low	0.2	< ± 10% [7] [8] [9]
Pressure-time	Absolute	very low	0.2	< ± 1.4% [10]
Transit time	Absolute	average	1	< ± 0.1% [11]
Scintillation	Absolute	low	1	<± 0.5% [11]
Current meter	Absolute	Very good	1	< ± 1.2% [11]
Dilution	Absolute	Very low	0.2	< ± 3% [12] [13]
Volumetric	Absolute	Very low	0.2	< ± 1.2% [4]*
Model testing	Absolute	Very good	5	< ± 0.2% [4]

**Uncertainty in an artificial basin according to IEC41*

The Pressure-time Method (Gibson)

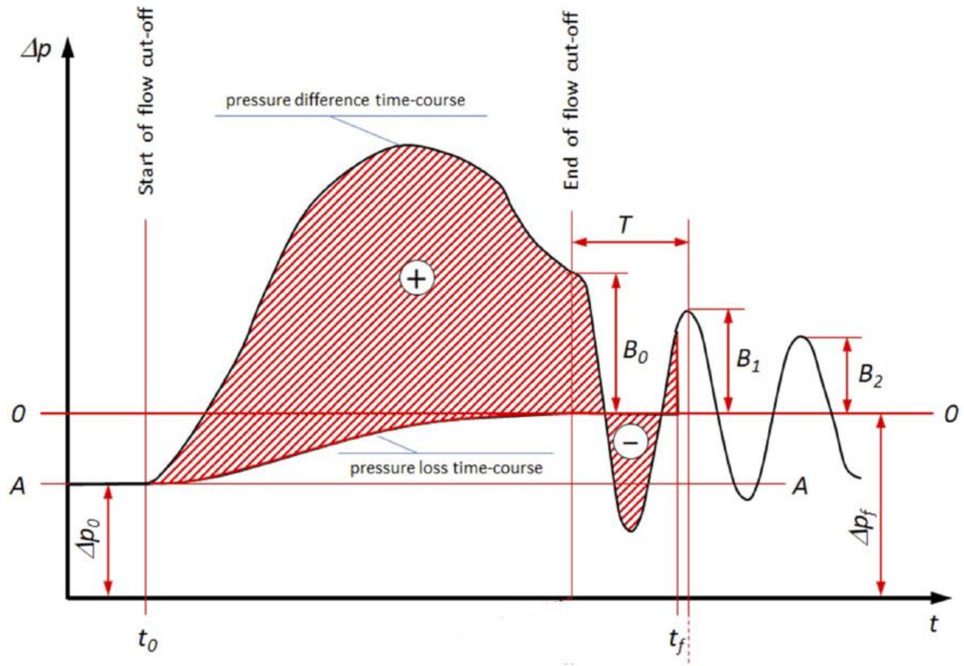
- An absolute method based on the Newton second law; conservation of Momentum. It consists in measuring the differential pressure between 2 cross-sections in a pipe of constant cross-section under a stop (regulated by the closure of the guide vanes)
- Accuracy ±(1.5-2.0)%
- The method cannot be used for continuous measurements
- It can be used to calibrate an inexpensive relative method such as the Winter-Kennedy method
- An alternative method to determine the efficiency step-up between an old and a new configuration after a refurbishment and complete Winter-Kennedy measurements
- The combination of the pressure-time method and the Winter-Kennedy method is attractive because simple to implement, maintain and economically attractive

The Pressure-time Method

The pressure-time method utilizes the inertia force manifesting in the pressure rise during a deceleration of the liquid mass flowing in a closed conduit (penstock in hydropower plant).

IEC major limitation:

- The measuring length with constant cross section must be greater than 10 m
- The measuring length times the initial velocity must exceed 50 m^2/s



$$Q = \frac{A}{\rho L}\int_0^t (\Delta P + \xi)dt + q$$

Q : the discharge
A : the cross-sectional area
ρ : is the water density
L : is the distance between the cross sections

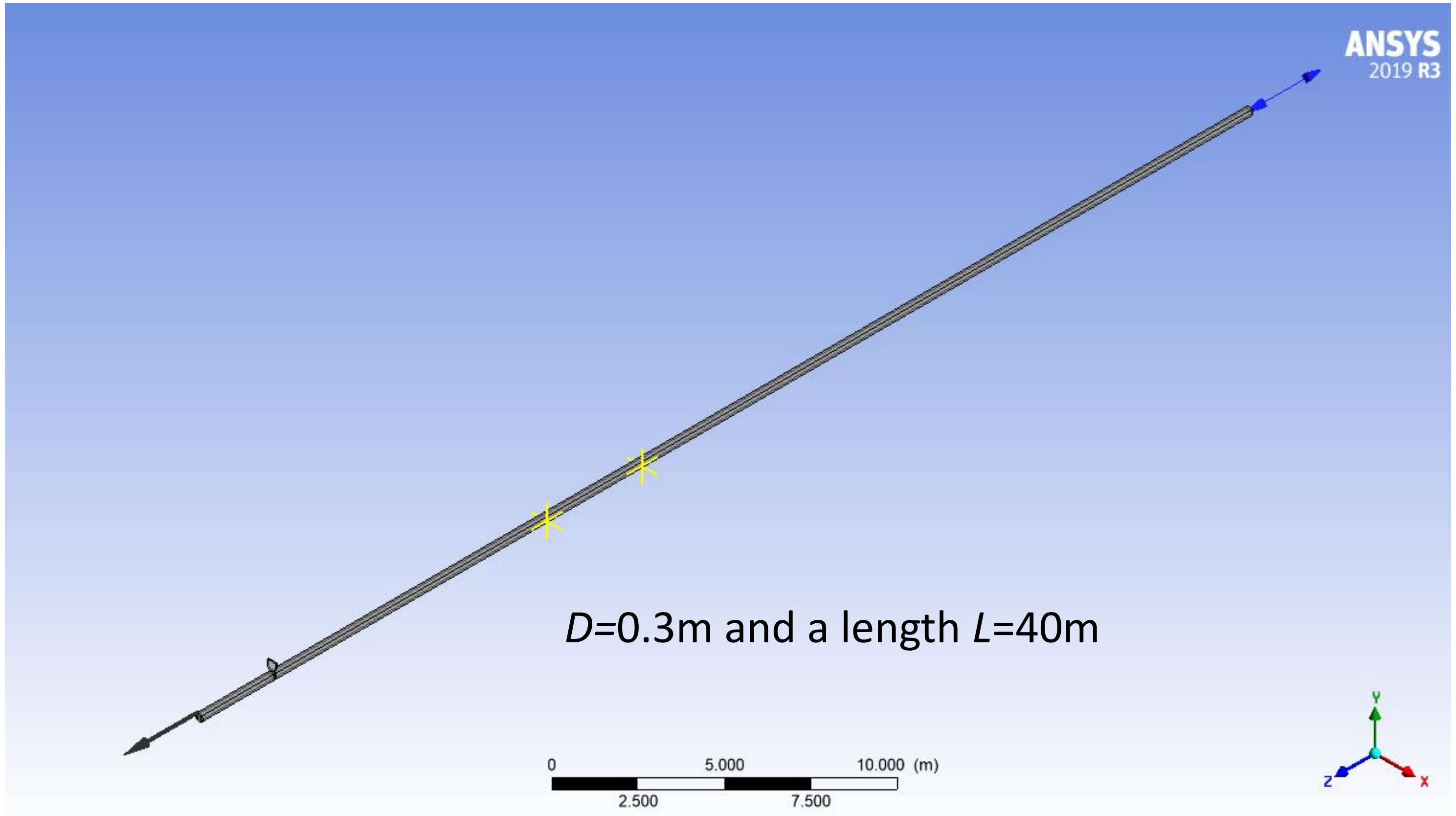
ΔP : the differential pressure
ξ : the pressure loss due to friction
q : the leakage flow after the closure

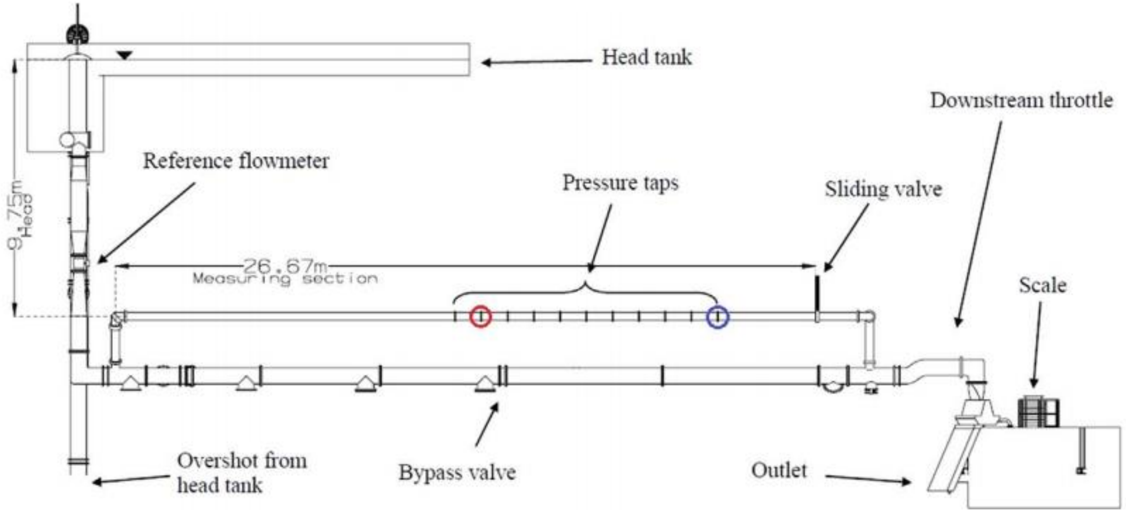
Project Objectives and Goals

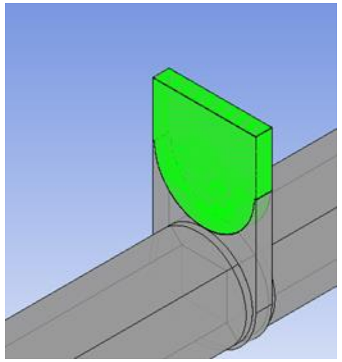
- Develop the pressure-time method for low head machines independent of the intake geometry by combining experiments and numerical methods
    - Develop methodology to predict the flow rate from CFD and pressure measurements
    - Develop a test rig at LTU to test the new evaluation method
    - Validate the new method with measurements performed at Vattenfall test rig
    - Perform full-scale measurements to validate the new methodology
- Couple the new pressure-time method to the Winter-Kennedy method for continuous measurements

CFD

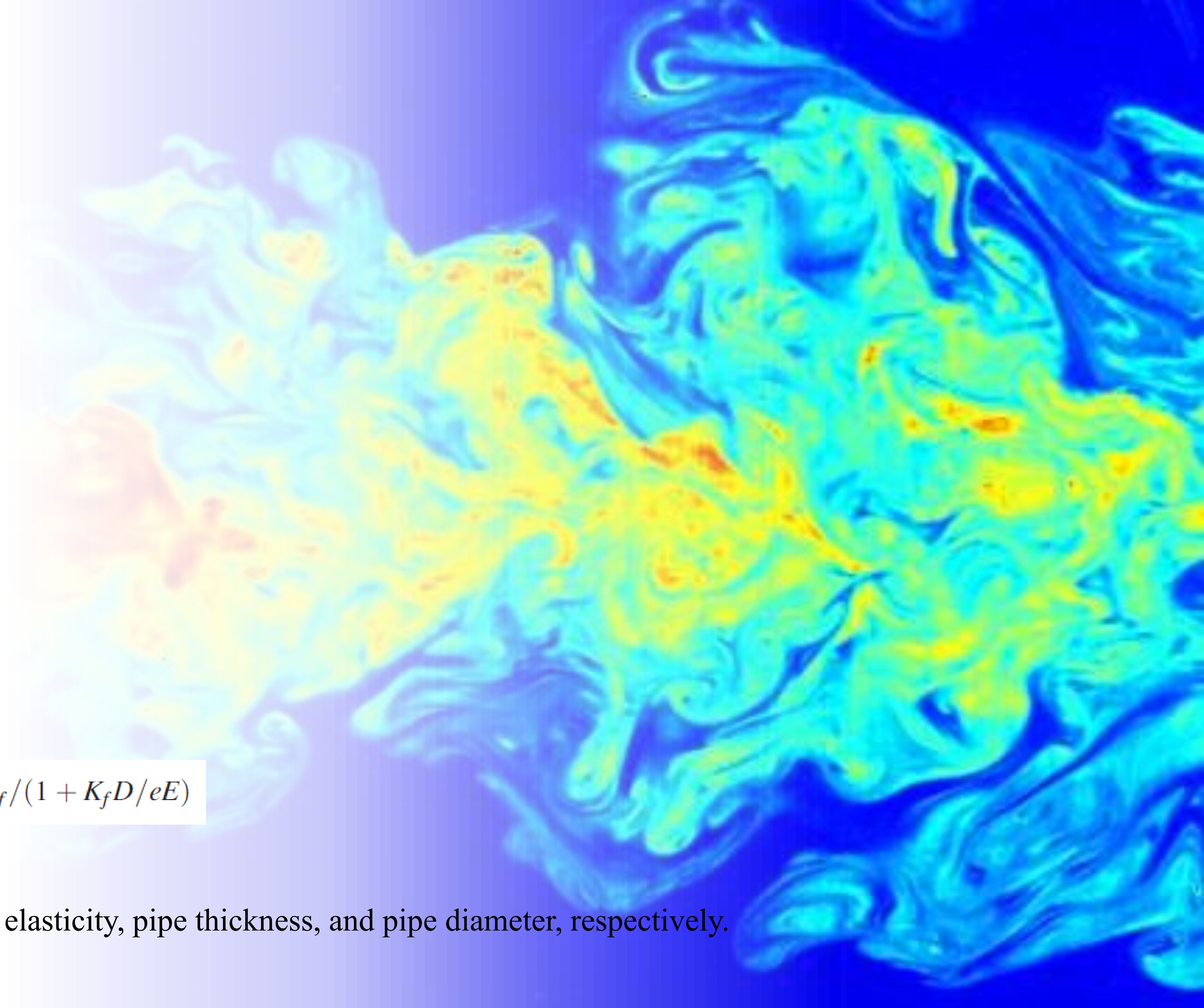
- NTNU Test Rig
- CFX
- Immersed Solid







Turbulence Modelling



SST K-ω

- Freestream sensitivity
- Flow separation from smooth surfaces
- Enhanced wall treatment

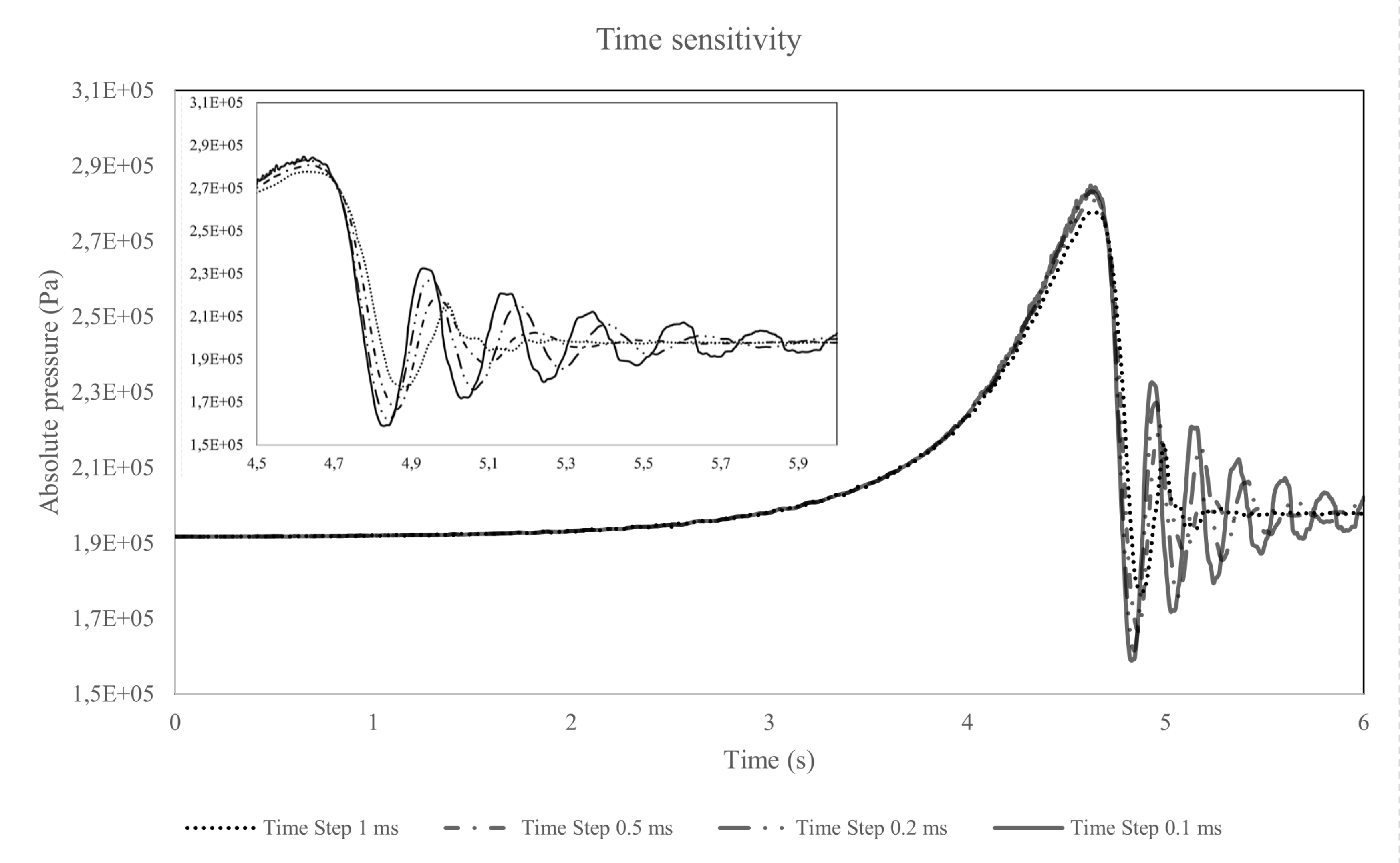
Density variation

$$\rho = \frac{\rho_{\mathrm{ref}}}{\left(1 - \frac{p - p_{\mathrm{ref}}}{K}\right)} \quad (\mathrm{kg\,m^{-3}}) \qquad K_f' = K_f/(1 + K_f D/eE)$$

where E, e, and D are Young’s modulus of elasticity, pipe thickness, and pipe diameter, respectively.

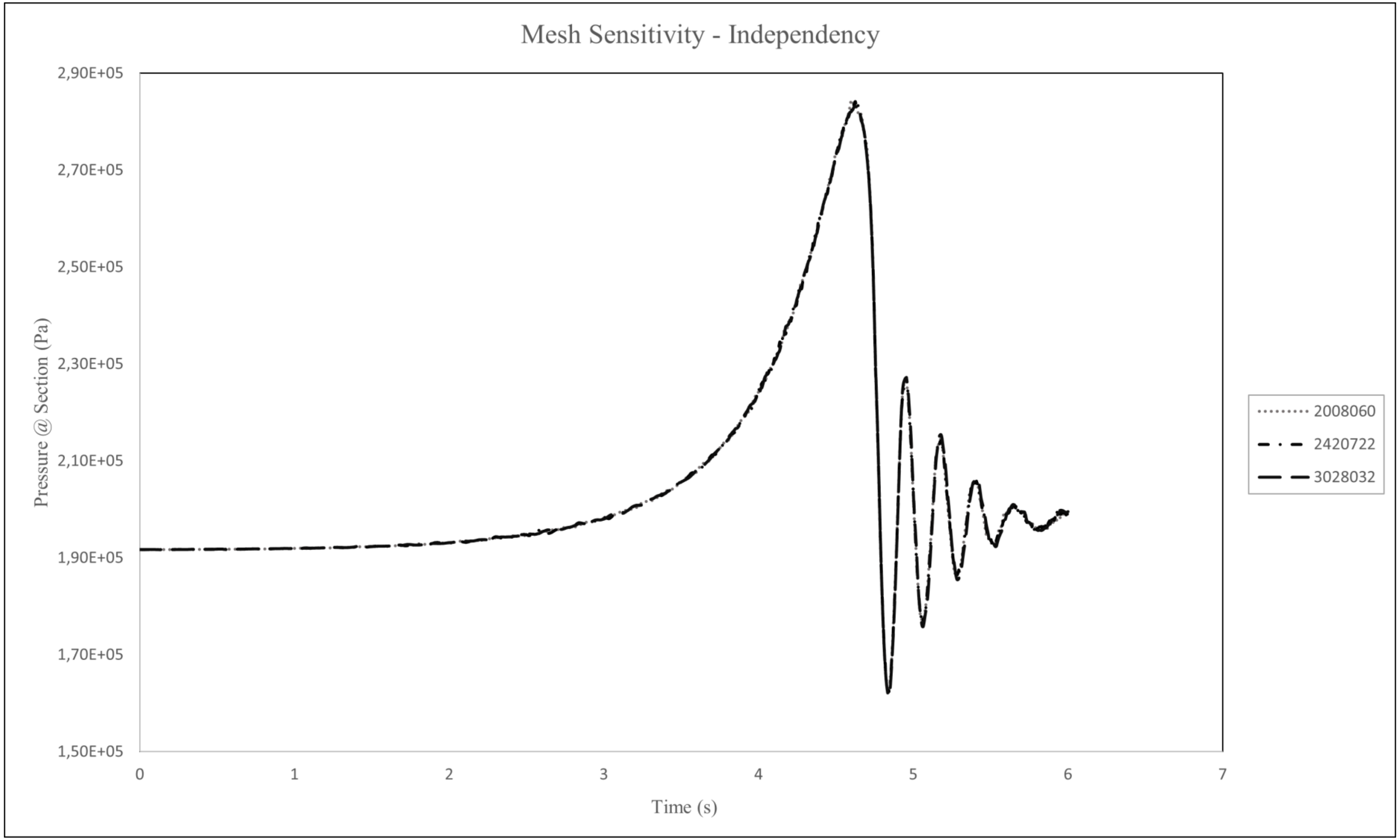
K_f is the fluid bulk modulus of elasticity

Time Step Sensitivity



Absolute pressure monitoring @ section 12 m upstream of valve

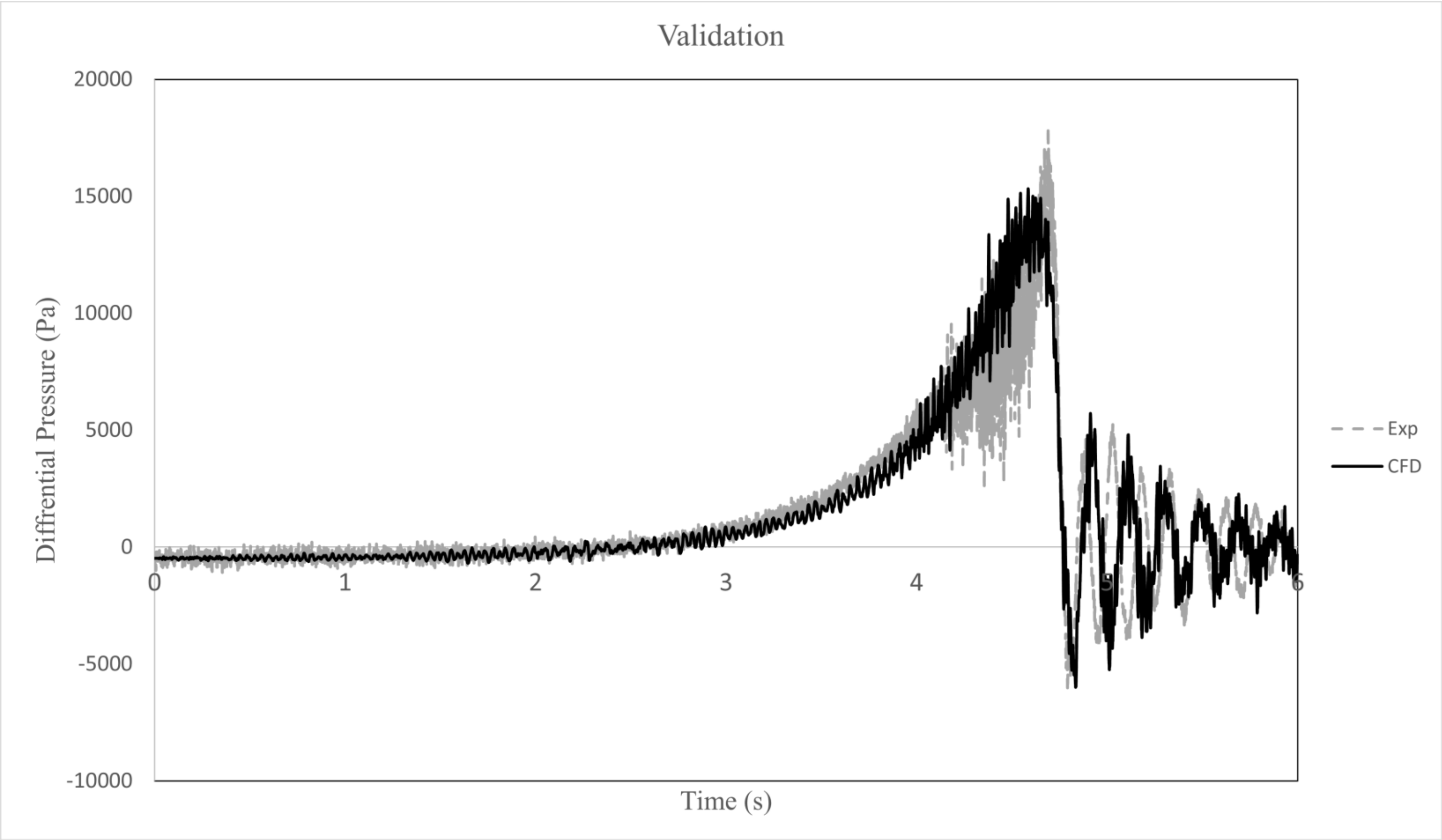
Mesh Independency



Absolute pressure monitoring @ section 12 m upstream of valve

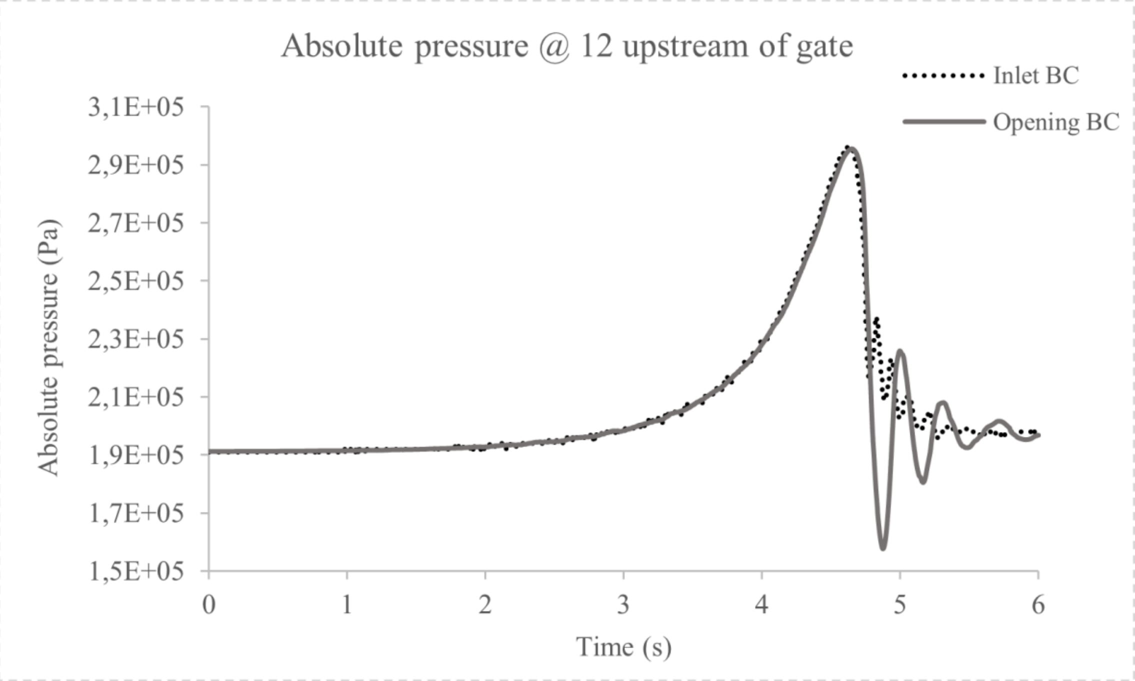
Validation

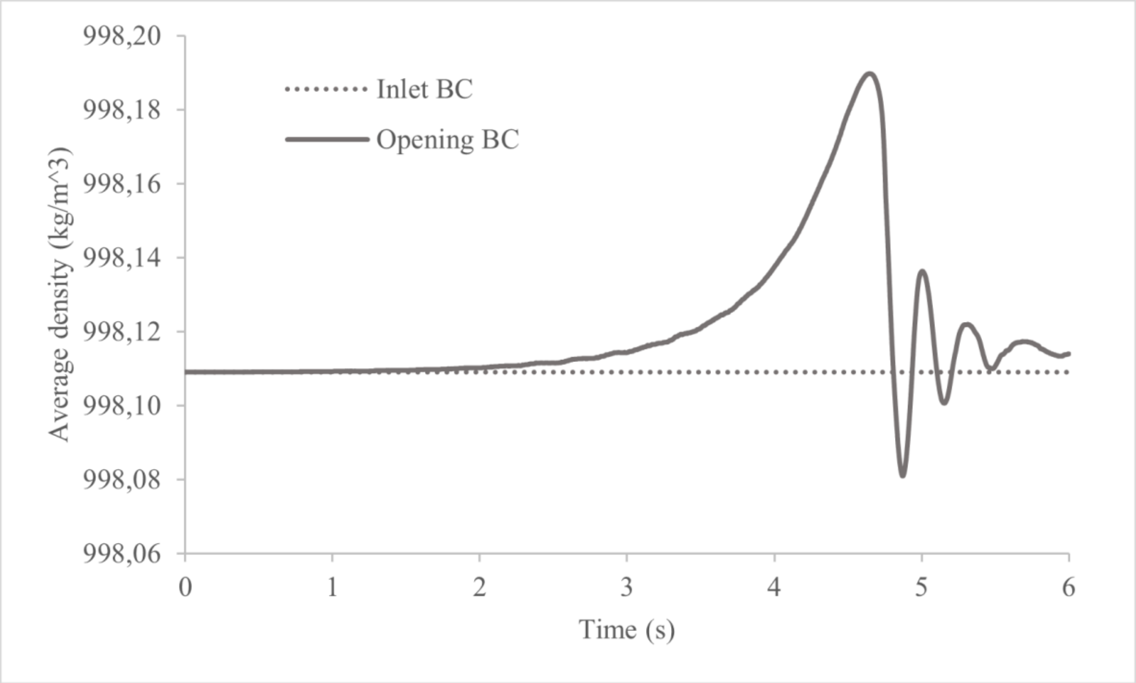
- The experimental setup consists of other components such as fittings, elbows, and pipes with different areas
- The frequency of oscillation has been affected by total length of piping pulse length of reservoir tank which is unknow
- Immersed Solid can give "leakage" through the immersed solid (less than 1%)

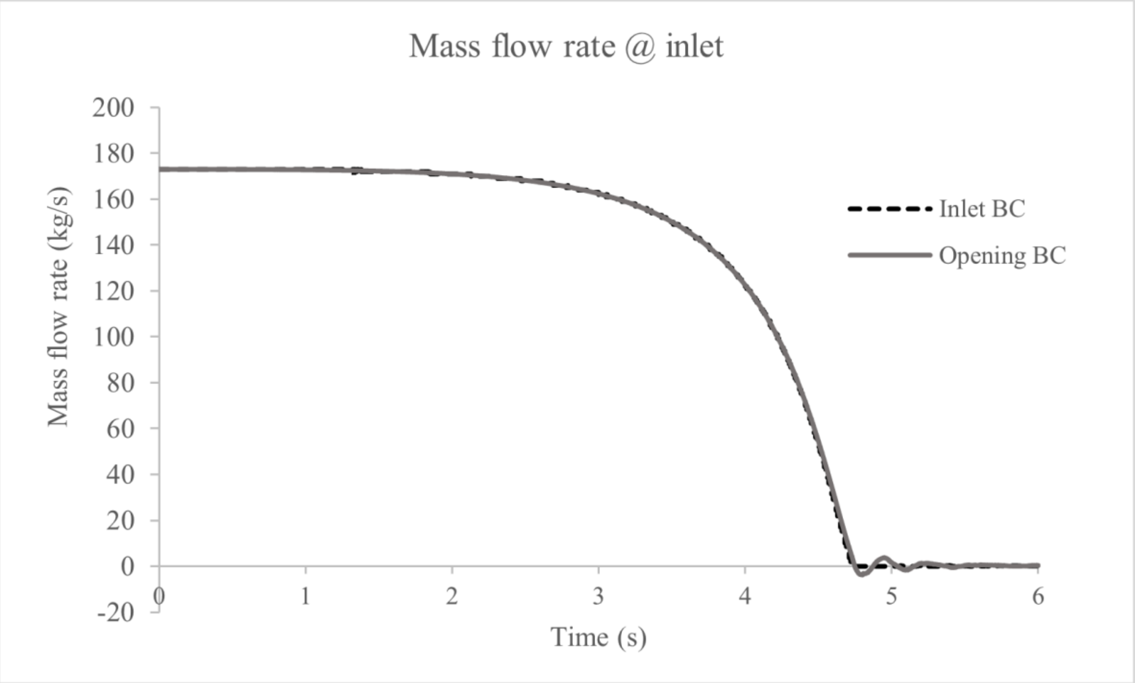


Differential pressure sensor are located 36.67*D* and 50*D* upstream of the valve

Effects of Boundary Condition

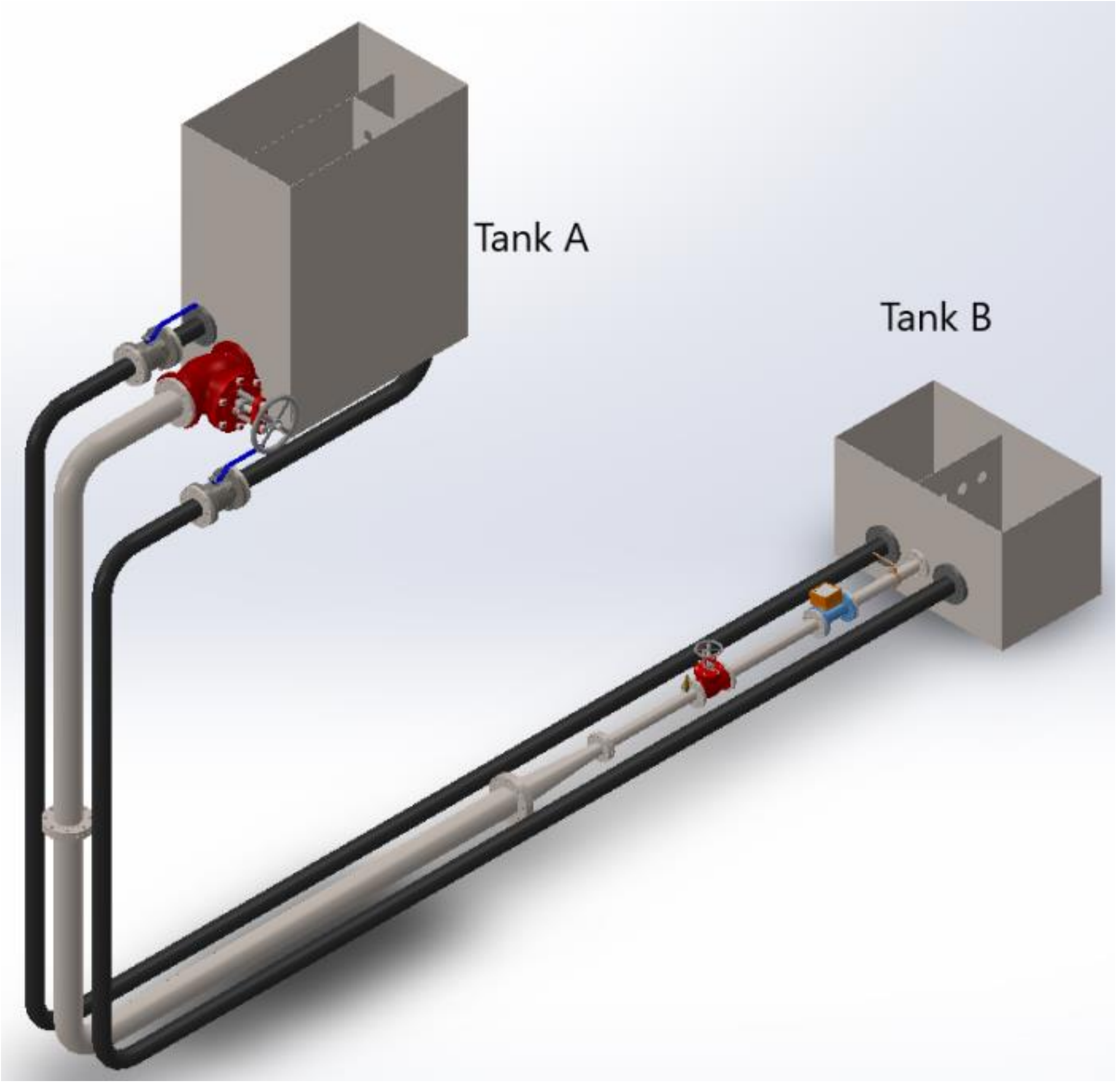






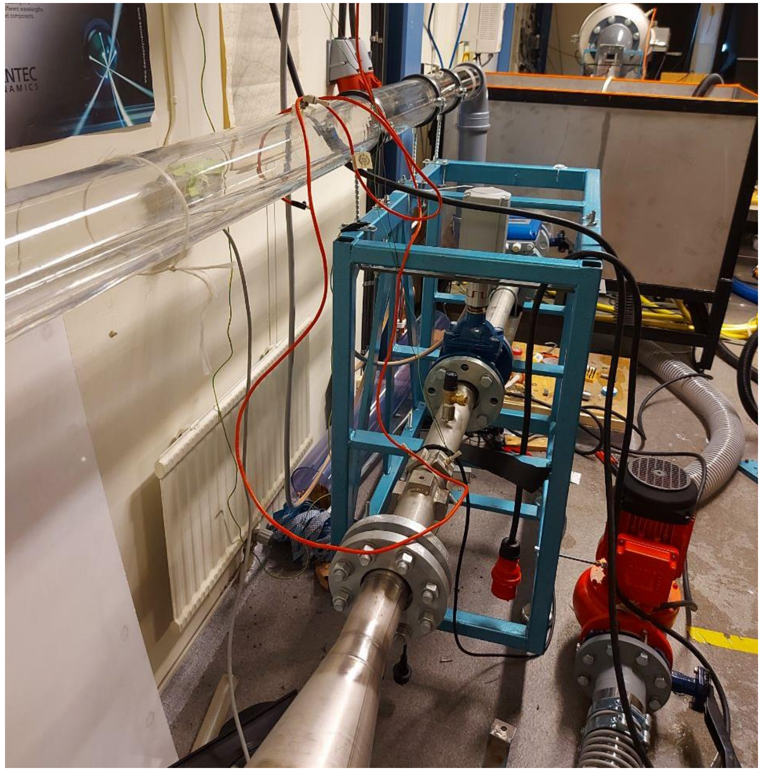
Test Rig Design

- Test Flow Rate : 10 l/s
- Max Flow Rate : 15 l/s
- 1.5kW VFD
- AC Servo Motor with Driver for valve closure (0.5 s)



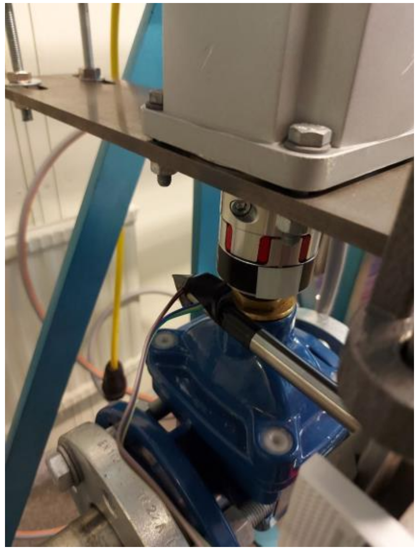
Test Rig

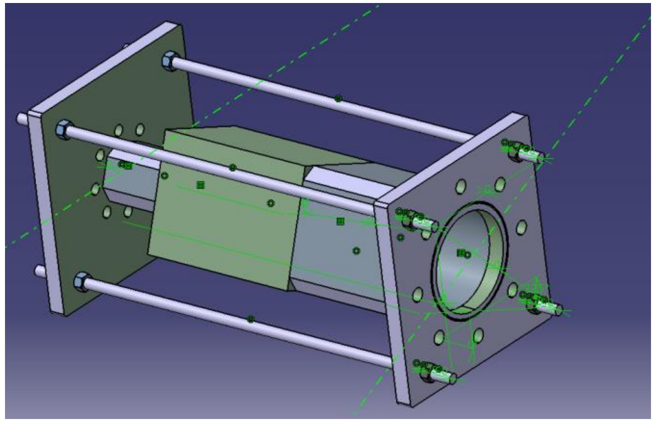
- Main piping : Stainless steel
- Pump and overflow line flexible pipe and plexiglass

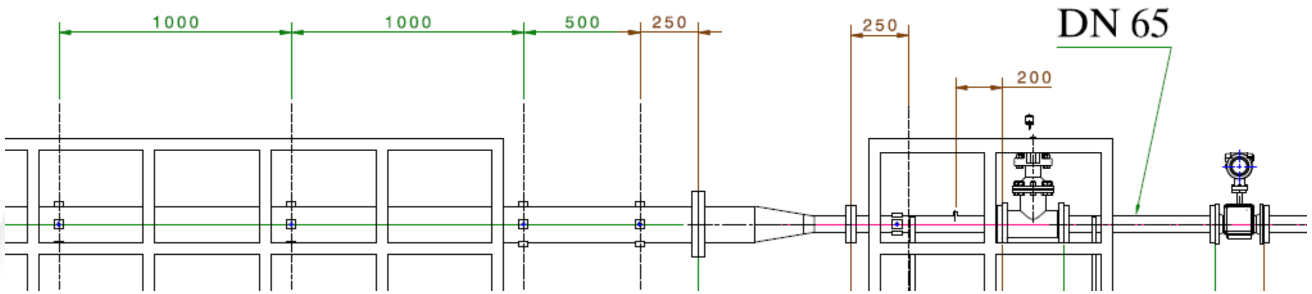


Sensors

- Differential Pressure Transducers
  - Range of ±0.5 bar
- Electromagnetic Flow Measurement
- Photomicrosensor (Reflective)
- PIV
- 16-bit DAQ



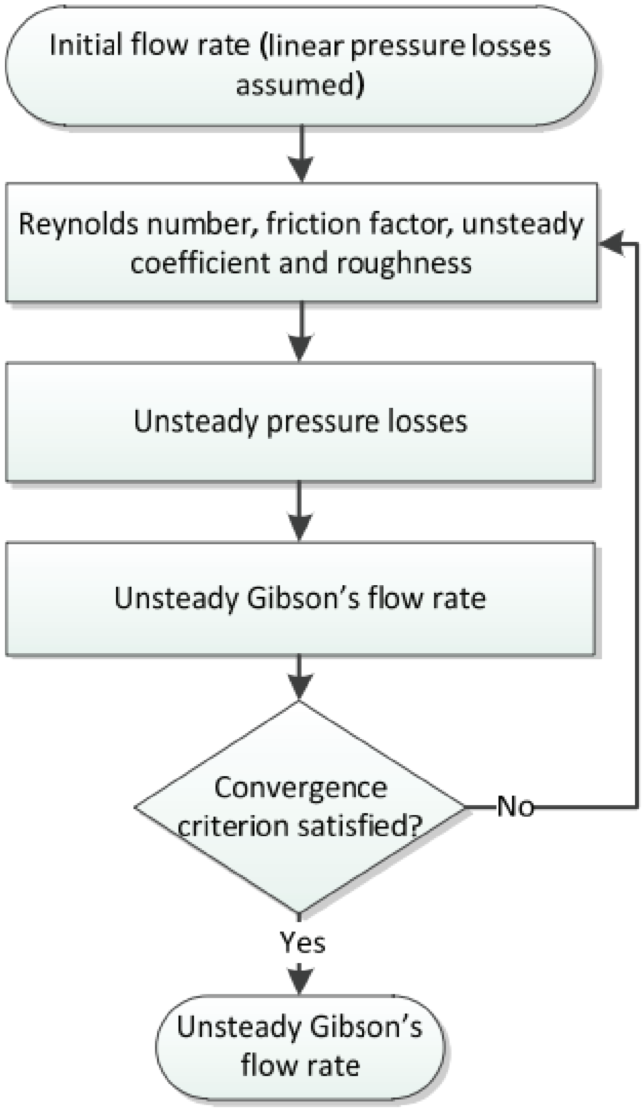




Pressure-Time Method

$$Q = \frac{A_c}{\rho L}\int_0^{t_f}(\Delta p + \Delta p_f)dt + q$$

$$P_{loss} = kQ_i^2$$



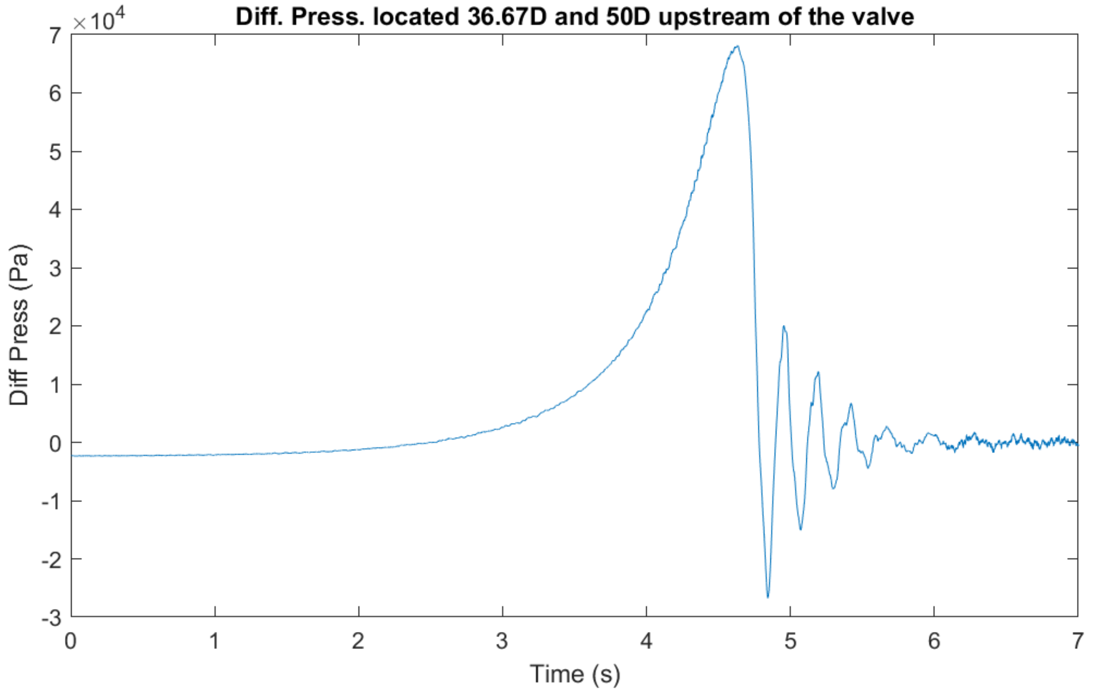
End point

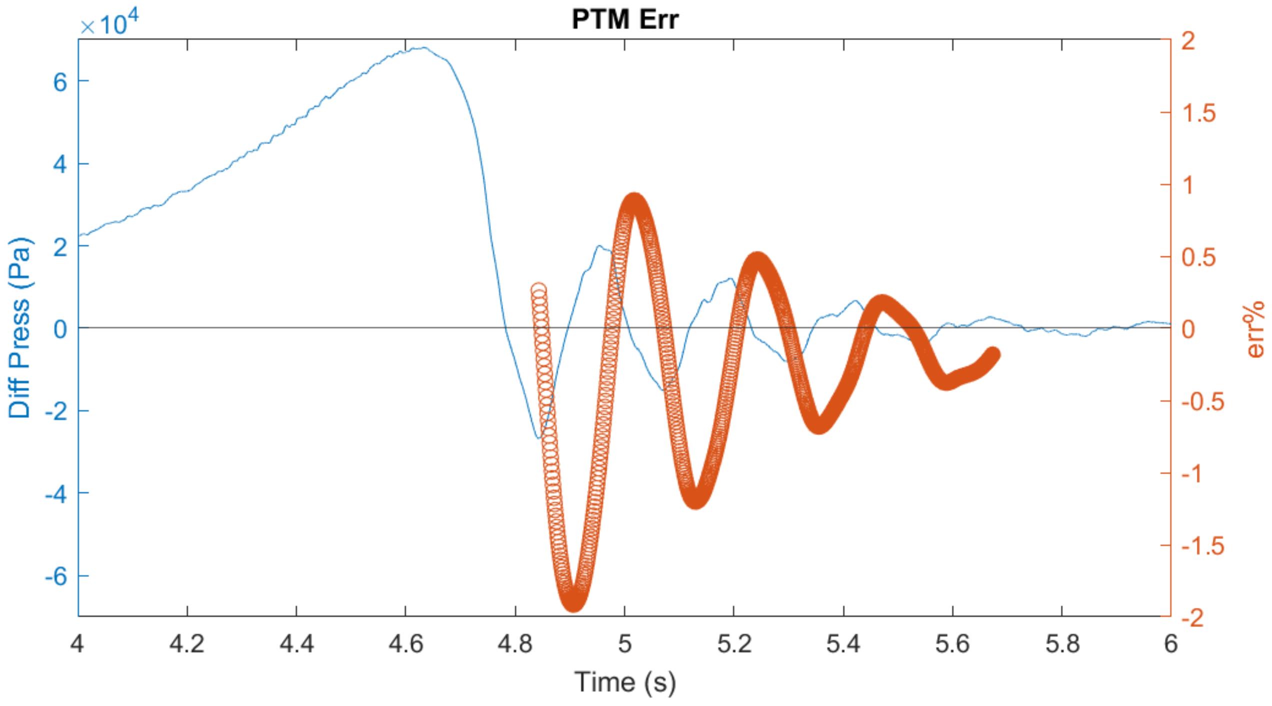
- Near the top of the pressure peaks
- IEC 41
- Adamkowski
- Using randomly distributed end points

End Point

- Uniformly distributed end points

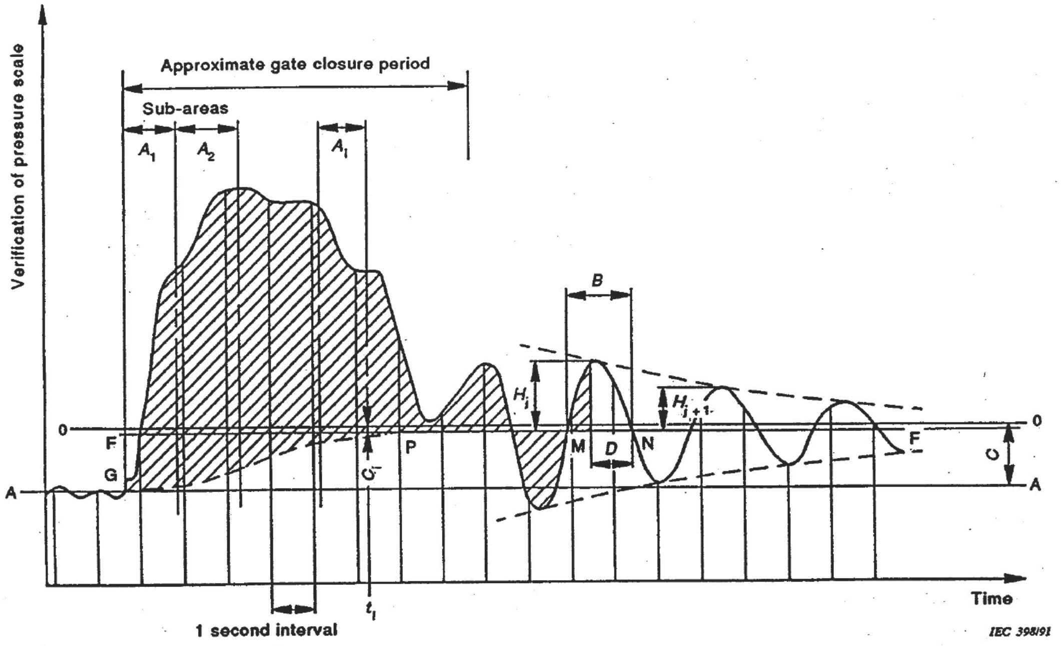
Mean error = 0.22%

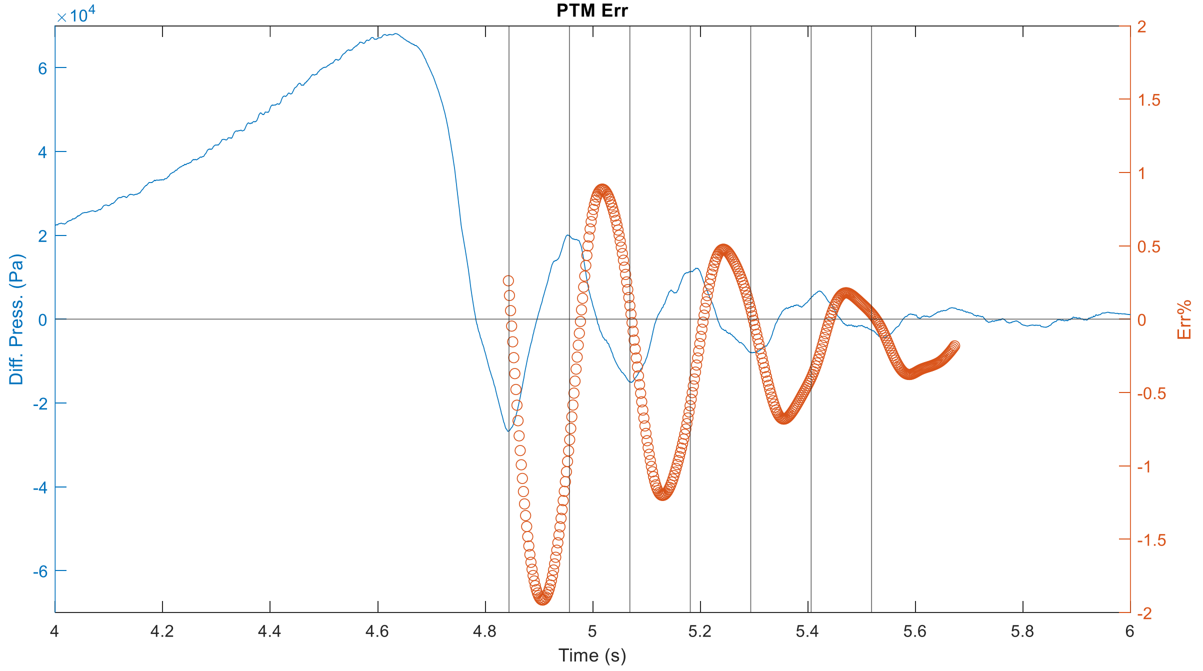




PTM end Point Standard IEC -CFD

Time (s)	Error %
4.84298	0.2616
4.95498	-0.8972
5.06698	0.1471
5.18098	-0.5901
5.29298	0.0797
5.40498	-0.4098
5.51698	0.04519





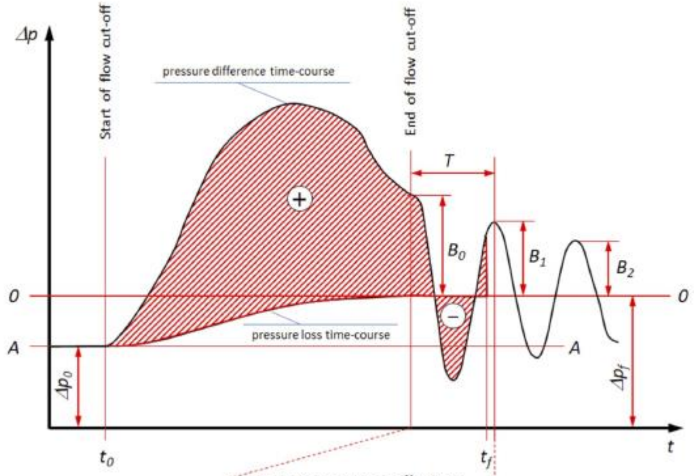
PTM end Point Adamkowski -CFD

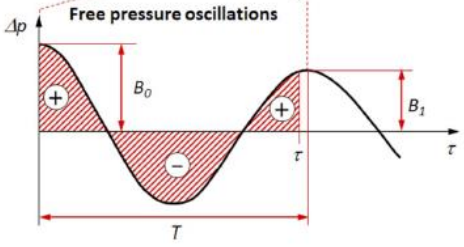
$$\int B_0\, e^{-ht}\ \cos(\omega t)\ dt=$$

$$= B_0 \frac{e^{-ht}}{h^2+\omega^2}[-h\cos(\omega t) + \omega \sin(\omega t)]$$

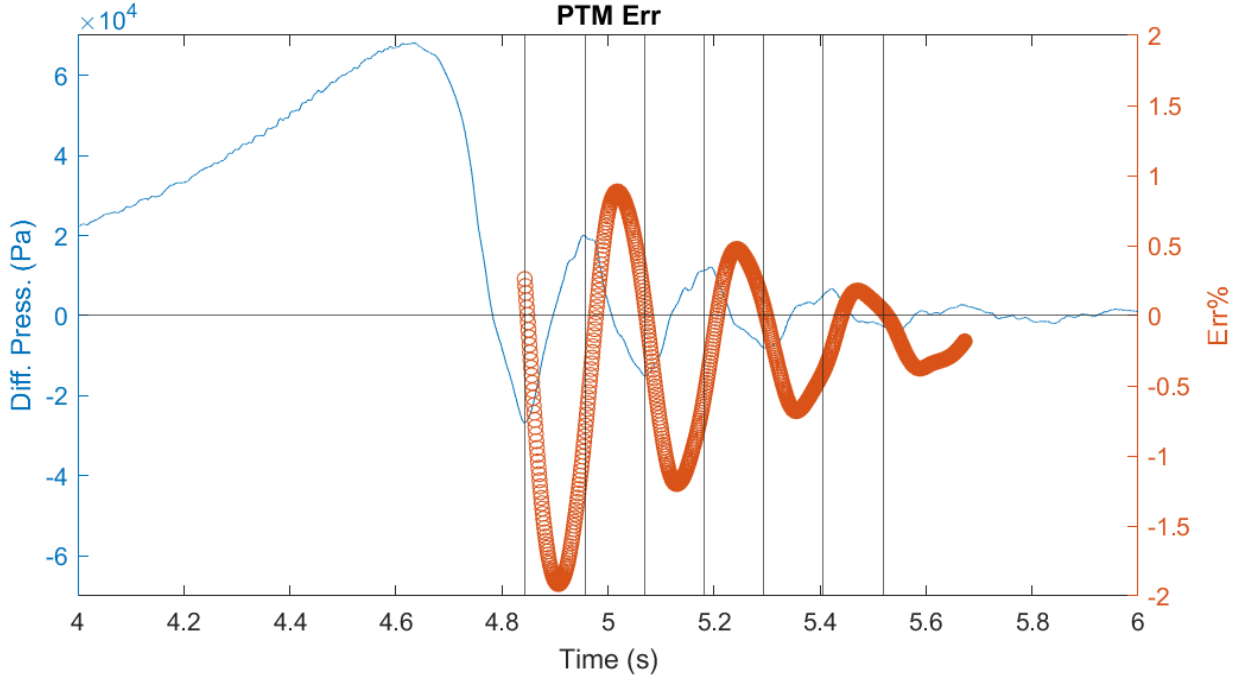
$$\tau = n\frac{T}{2} + \frac{T}{2\pi}\operatorname{arctg}\left(\frac{\ln(B_i/B_{i+1})}{2\pi}\right), \quad \text{for } n = 0,1,2,3,....$$

Time (s)	Error %
4.8362	0.406
4.9556	-0.768
5.0750	0.040
5.1944	-0.260
5.3138	-0.257
5.4331	-0.13





$$h = \frac{1}{T}\ln\left(\frac{B_0}{B_1}\right)$$
$$\omega = \frac{2\pi}{T}$$



Next Steps

- Troubleshooting of LTU test rig
- Validate methodology to predict the flow rate from CFD result in deceleration flow for pipe with variable cross section
- Validate the new method with measurements performed at Vattenfall test rig
- Perform full-scale measurements to validate the new methodology
- Couple the new pressure-time method to the Winter-Kennedy method for continuous measurements