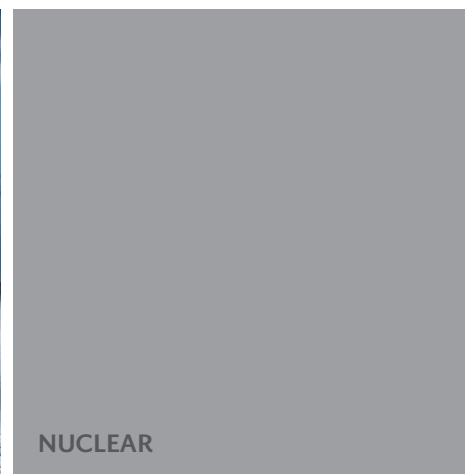


FLUID INDUCED VIBRATIONS IN NEUTRON DETECTION HOUSING

REPORT 2015:160



Fluid induced vibrations in neutron detection housing

Data for Computational Analysis

ERIC LILLBERG, VATTENFALL AB

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Foreword

Flow induced vibrations (FIV) is an important phenomena in the design of fluid conveying systems and components subjected to external or internal fluid flow. As the structure response to the fluid forcing grows in amplitude, the motion of the structure itself changes the flow pattern and the resulting loading significantly and a fluid structure interaction (FSI) of various degree is created.

In the experiment described in this report a synchronized data set is created by simultaneous pressure and in-plane position measurement of a tube in a narrow channel at different flow rates. The geometry is equivalent to the neutron detector housing tube and consists of four fuel box corners and the housing tube.

The data from this experiment will be used in two master thesis works (KTH and CTH) to make computational fluid dynamics calculations. This will increase the knowledge on how the behavior of complex structures can be modelled, which in turn can be used when analyzing different mitigation techniques to solve vibration problems in constructions.

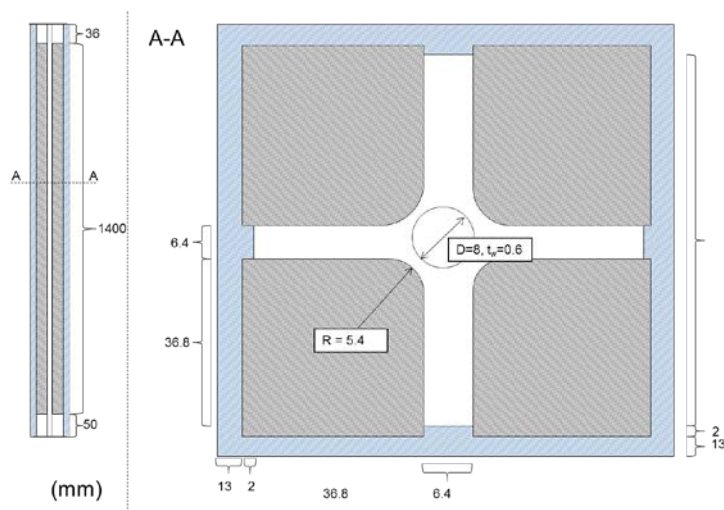
This project has been carried out within the Energiforsk Vibrations research program. The stakeholders of the Vibrations program are Vattenfall, E.ON, Fortum, TVO, Skellefteå Kraft and Karlstads Energi. A reference group consisting of Petri Lemettinen from TVO, Tobias Törnström from OKG, Nicholas Edh and Jerzy Marcinkiewicz from Forsmark have supported the project.

Sammanfattning

Denna rapport sammanfattar resultaten för de experiment av flöde-inducerade vibrationer (FIV) som utförts av Vattenfall AB på uppdrag av Energiforsk.

Experimentet har en geometri som utgörs av de neutronsonrör som är en del av hårdinstrumenteringen i kokarvattenreaktorer. Geometrin har sedan skalats ned för att passa den befintliga testsektion som använts för tidigare FIV experiment utförda av Vattenfall AB.

Geometrin utgörs av ett tunnväggigt rör med 8 mm ytterdiameter centralt placerat i en korsformad kanal med rundade hörn mot kanalens mitt, se figur nedan.



Flödet är axiellt längs med staven genom kanalen och varierar mellan 0 och 15 l/s. På olika höjder i kanalen har tryckfluktuationerna från den turbulenta strömningen mätts med tryckgivare samt det totala tryckfallet över hela testsektionen. Stavens vibration mäts med Particle Tracking Velocimetry (PTV) som är en metod där små prickar på stavens yta följs med höghastighetskameror och efterföljande bildbehandling för att ge en tidsserie för stavens rörelse i ett plan tvärs strömningsriktningen.

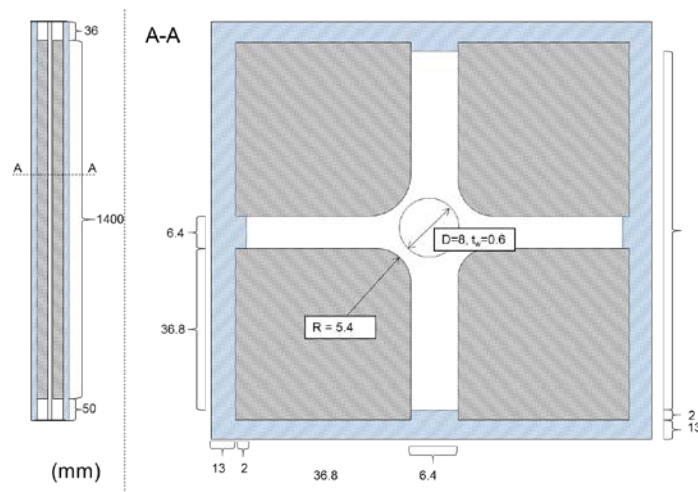
Rapporten tillhandahåller all väsentlig information om experimentets uppställning och hur resultaten dokumenterats samt hur experimentellt data kan tillhandahållas för validering av beräkningsmetoder inom FIV och fluid struktur interaktion (FSI).

Summary

This report summarizes the results of the experiments of flow-induced vibration (FIV) carried out by Vattenfall AB on behalf of the Energy Research Institute.

The experiment has a geometry has been adopted from the neutron flux detectors housing tube which is part of the core monitoring system in boiling water reactors. The geometry has been scaled down to fit the existing test section used by previous FIV experiments performed by Vattenfall AB.

The geometry consists of a thin-walled tube with 8 mm outer diameter centrally located in a cross-shaped channel with rounded corners towards the center of the channel, see figure below.



The water flows axially along the rod through the channel and varies between 0 and 15 l/s. At different heights in the channel pressure fluctuations of the turbulent flow are measured with pressure transducers and the total pressure drop across the test section is also recorded. The rod vibration is measured using Particle tracking velocimetry (PTV) which is a method where small dots on the surface of the rod is tracked in time with high-speed cameras which, after image analysis, results in a time series of the rod movement in a plane perpendicular to the direction of flow.

The report provides all the essential information about the experimental setup and the results documented and how experimental data can be provided for validation of computational methods in FIV and fluid structure interaction (FSI).

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1 Introduction

Flow induced vibrations (FIV) is an important phenomenon in the design of fluid conveying systems and components subjected to external or internal fluid flow. As the structure response to the fluid forcing grows in amplitude the motion of the structure itself changes the flow pattern and the resulting loading significantly and a fluid structure interaction (FSI) of various degree is created. In order to assess FSI phenomena computational fluid dynamics (CFD) is an important tool. Due to the strong coupling simultaneous calculation of both the transient fluid load and the structural response is necessary. Recent development of computational software for coupled fluid/structure analyses has made it possible to address transient flows and complex geometry for industrial applications.

However, the lack of experimental data for validation of available computational tools makes coupled calculations an option that is most often not considered for industrial applications. The experiment presented in this report is designed to create a well-defined benchmark for software validation within relevant industrial applications.

In this experimental setup an important part of a nuclear in-core neutron flux monitoring system is considered. The Average Power Range Monitor (APRM) system consists of a number of in-core neutron flux detectors that are positioned axially inside several guide tubes located in-between the fuel bundles, see figure 1.

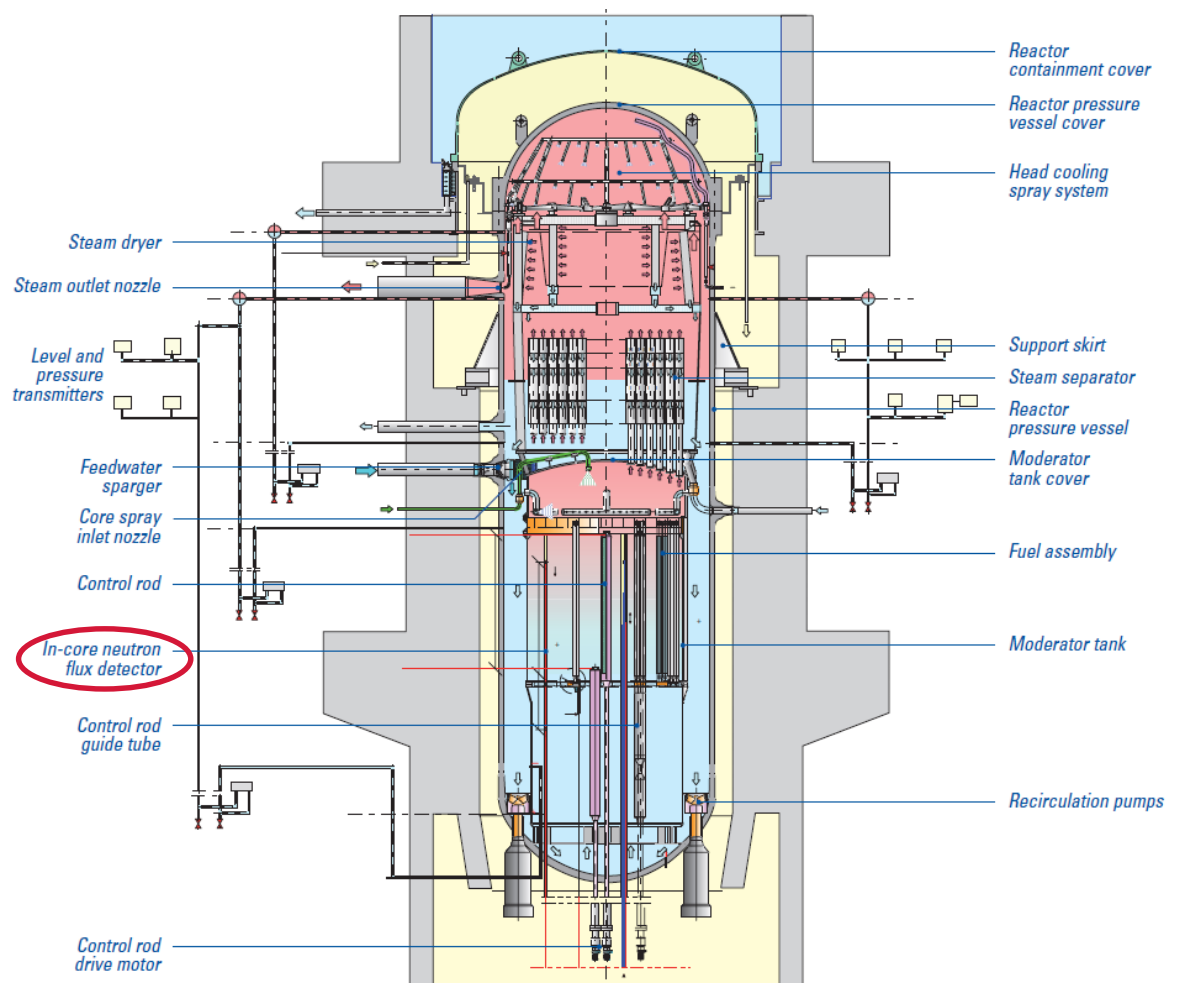


Figure 1: Section of a BWR showing the location of the in-core neutron flux detector system

In this section in-between the fuel boxes the bypass water, approximately 13-15% of the total flow in the main recirculation loop, flows axially upwards along the guide tube outer surface in the channel formed between four fuel boxes. The guide tube is only 19 mm in diameter and 4040 mm tall which makes it weak and susceptible to fluid forces. The flow path between the fuel boxes and the guide tube is only 15 mm wide so even small deflections of the guide tube from its centered position will significantly alter the shape of the flow path and the resulting forcing on the guide tube, see figure 2.

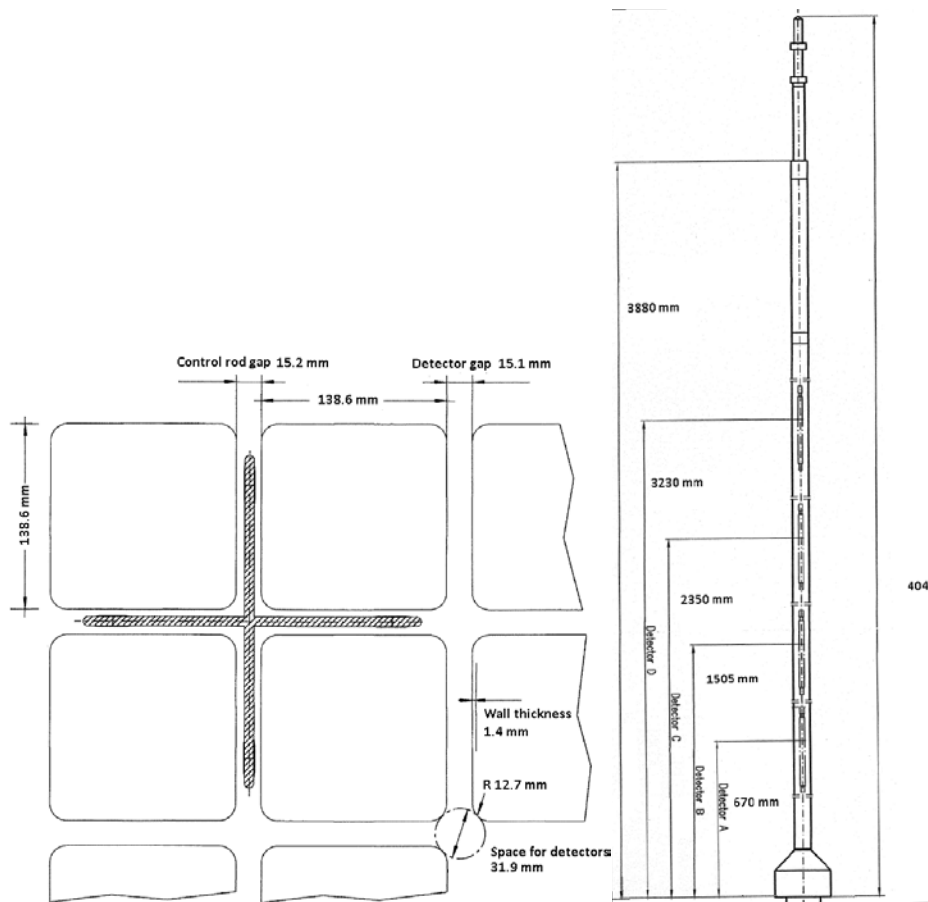


Figure 2: Schematic of the core fuel boxes and detector guide tube position (left) and dimensions (right)

The lower end of the guide tube is fixed in the core support plate while the upper end is fastened in the core grid with a spring. The resulting mechanical system typically has a fundamental frequency in the range of 2-3 Hz.

For a large boiling water reactor (BWR) the bypass flow is as large as 1000-1800 kg/s divided into 125-169 channels, one for each super cell (four fuel bundles) in the core. With an average density $\rho=762 \text{ kg/m}^3$ at a temperature of $T=286 \text{ }^\circ\text{C}$ the resulting average flow velocity is in the range of 2 m/s.

2 Scaling of the experiment

Geometric scaling of the experimental setup is necessary due to the limited length of the available test section. The length of the in-core neutron flux detector tube is 4040 mm and the fundamental frequency is 3-4 Hz. The test section is approximately 1500 mm long which gives a length ratio of 0.37 between the real life application and the experimental setup. In order to have a good frequency resolution for the vibration measurements the fundamental frequency of the rod should be as low as possible. Hence, only geometric scaling of the mechanical system is made for the experimental setup, no dynamic scaling is performed here. The fundamental frequency, f_{s0} for a beam with uniformly distribute mass is given by [1]

$$f_{s0} = \frac{1}{2\pi} \frac{K_N}{L^2} \sqrt{\frac{EI}{\rho_s}}$$

Where E is the Young's modulus, L is the tube length, I is the area moment of inertia and ρ_s is the mass density (mass/length). For "fixed-pinned" boundary conditions the constant is $K_N=15.4$ [1], c.f. Table 1.

Mode	K_n	Nodal position/L					
1	15.4	0.0	1.0				
2	50.0	0.0	0.557	1.0			
3	104	0.0	0.386	0.692	1.0		
4	178	0.0	0.295	0.529	0.765	1.0	
5	272	0.0	0.239	0.428	0.619	0.810	1.0

Table 1: Natural frequency of a fixed-pinned beam

The area moment of inertia for a tube is $I = \frac{\pi}{4}(r_{outer}^4 - r_{inner}^4)$ where $r_{outer/inner}$ is the outer and inner tube radius respectively. As seen from these expressions the tube radius is the most important parameter for decreasing the frequency of the tube in the test section. Also, choosing a different material, e.g. Aluminum, gives both lower density as well as Young's modulus which results in no or little change to the fundamental frequency. One important factor though is that the density ratio between the fluid and the tube is then changed.

Using a stainless steel tube with 8 mm diameter and 0.6 mm wall thickness, $E = 197$ GPa, $\rho = 7863$ kg/m³, $\rho_s = 0.11$ kg/m and $L = 1.486$ m the "fixed-pinned" fundamental frequency is then 14.6 Hz. Using the same boundary conditions for the housing tube its fundamental frequency becomes 4,6 Hz which yields a frequency ratio between the real life application and the experiment of approximately 0.32.

With smaller tube diameter the channel width need also to be reduced since the tube diameter to channel width ratio together with the flow velocity governs the amplitude and frequency content of the pressure oscillations. Also, the narrow channel defines the flow path as the tube moves and the effect of boundary layer displacement thickness on the added mass. The detector housing tube is 19 mm in diameter, the channel width is 15.1 mm and the fuel bundle corner radius is 12.7 mm. Scaling with the 8 mm diameter test tube the fuel bundle corner radius is 5.4 mm and channel width 6.4 mm leaving a total space for the test tube equal to the area of a 13.4 mm diameter circle.

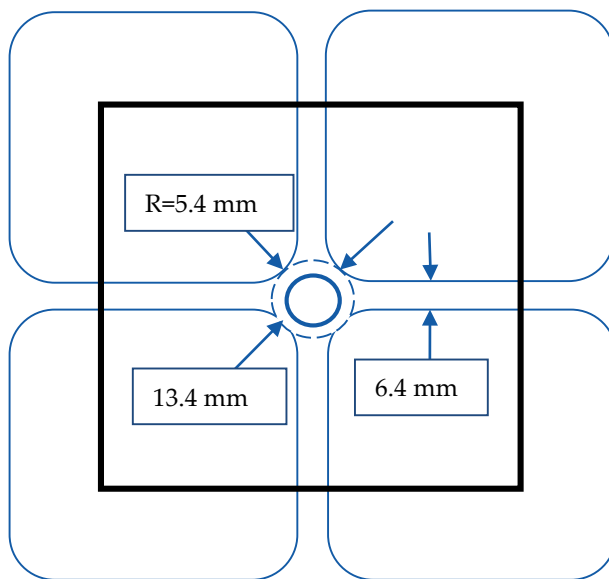


Figure 3: Dimensions of the scaled test section using 8 mm diameter tube. Black contour is the square test section 80 x 80 mm.

The tube chosen for the experimental setup has a low natural frequency which puts less demand on the frame rate of the PTV system.

3 Boundary conditions

The test tube is fixed at its lower end, which is close to real life situation where the in-core neutron flux detector housing tube is positioned in the core support plates. At the upper end the detector tube is attached to the core grid with a spring. In the experimental setup the previously used “fixed-pinned” boundary conditions is used. At the top four set-screws at 90° angle are used, c.f. figure 4. The set-screws have ball tips to create zero moment at contact point. At the bottom end the tube is welded into a rigid cross which is then tightened into the steel inlet part of the test section with adjustment screws. The cross shaped tube holder is seen in figure 5.



Figure 4: Upper fixation with four ball tip set-screws at 90°

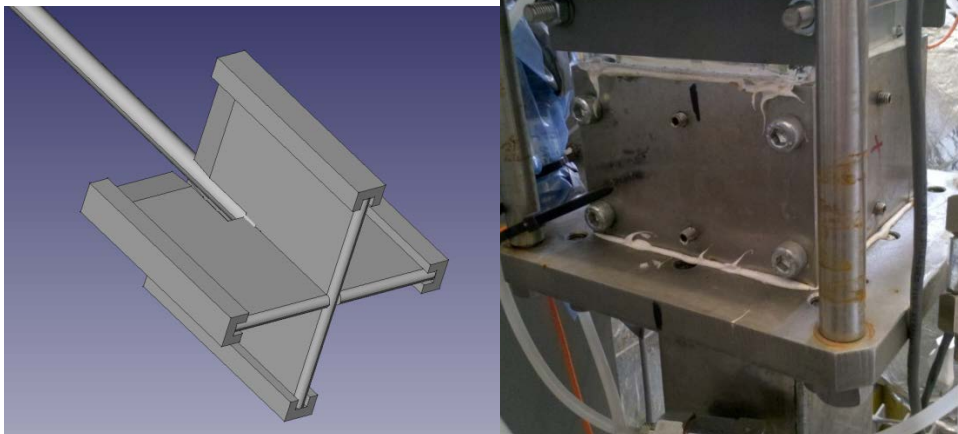


Figure 5: Bottom fixation for the tube (left) and the steel inlet part with the adjustment screws for the cross (right)

The inflow region is defined by the corners of the fuel bundles. The narrow channel between the bundles will act as a contraction reducing any swirl or large scale

turbulence in the flow through vortex stretching. A vena-contracta and consequently a small recirculation zone will form at the entrance due to the sharp corners. This can be reproduced with good accuracy by most CFD methods why this situation is preferred. Due to the narrow channels re-laminarisation of the boundary layer might occur at lower flow velocities. The inflow is defined by the mass flow ranging from 0-15 kg/s. The outflow boundary and piping is connected to a reservoir at constant pressure.

Property	Value
Rod length (between BCs)	1.486 m
Rod diameter	0.008 m
Rod wall thickness	0.0006 m
Rod density	7863 kg/m ³
Young's modulus	197 GPa
Water density	998 kg/m ³
Temperature	20 °C
Rod upstream support	Fixed
Rod downstream support	Pinned (Hinged)
Boundary layer	Not tripped
Inflow boundary	Flowrate 0-15 l/s
Outflow boundary	Fixed pressure

Table 2: Structure and fluid properties and boundary conditions summary

4 The test rig

A schematic of the test rig is shown in figure 6. The centrifugal pump circulates the water from the storage tank upward through the test section and out through a sparger in the storage tank where the free surface remains constant during the experiment. The flow rate is varied by controlling the rotational speed of the pump without flow regulation. Downstream of the test section a valve is placed to control the pressure in the test section.

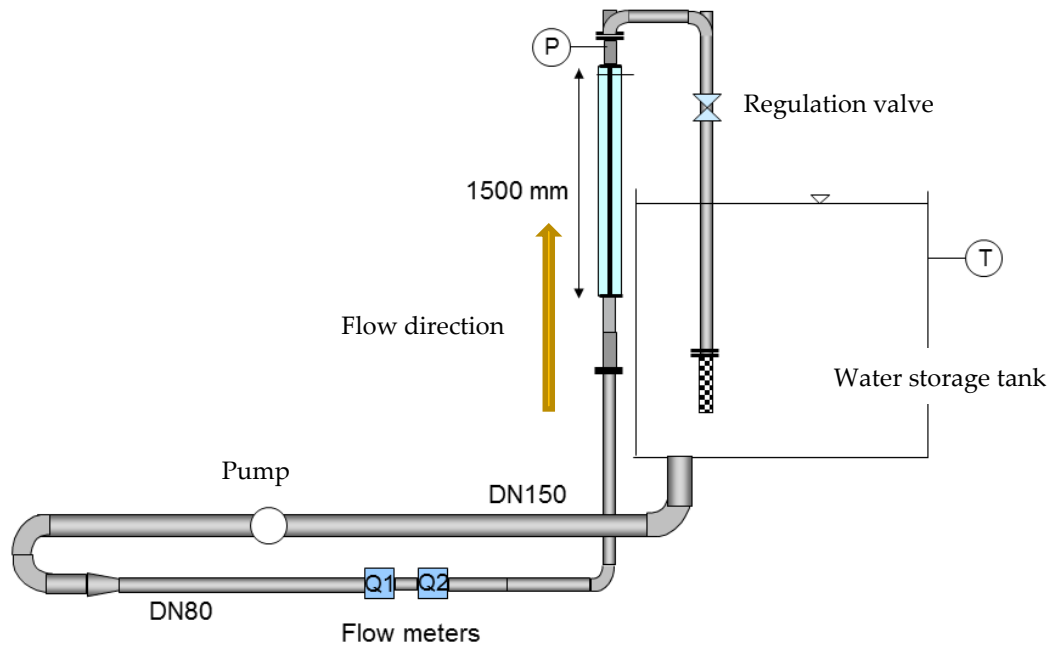


Figure 6: Schematic of the test rig.

The pump is a Grundfos CRN 90-2-2 three stage centrifugal pump with 7 blades in each impeller. The pump is run at constant speed from 800 rpm for the 2.35 l/s flow rate up to 2920 rpm for the maximum flow rate 14.8 l/s. The pump produces a stable flow and the multistage configuration reduced the pressure fluctuations due to the blade passing frequency.

5 Geometry

The geometry of the computational domain is given in figure 7 below.

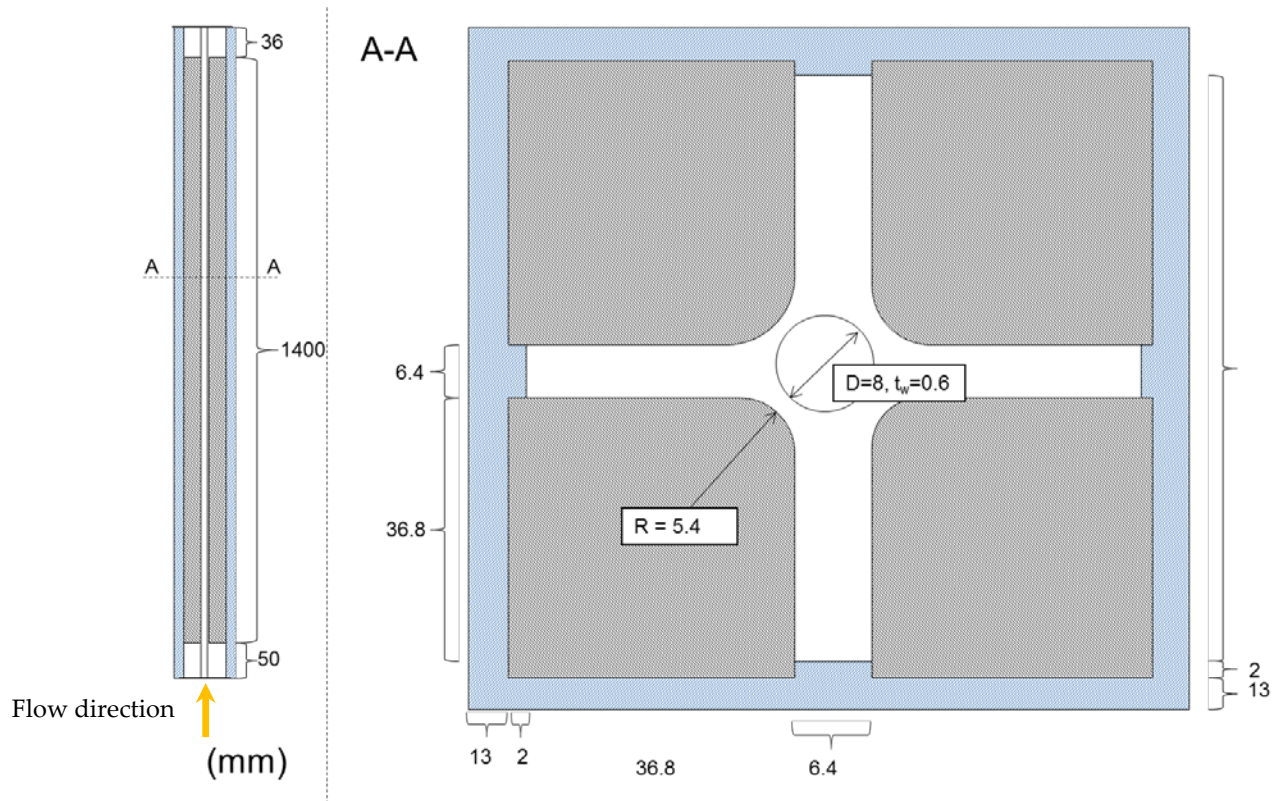


Figure 7: Geometry of the computational domain

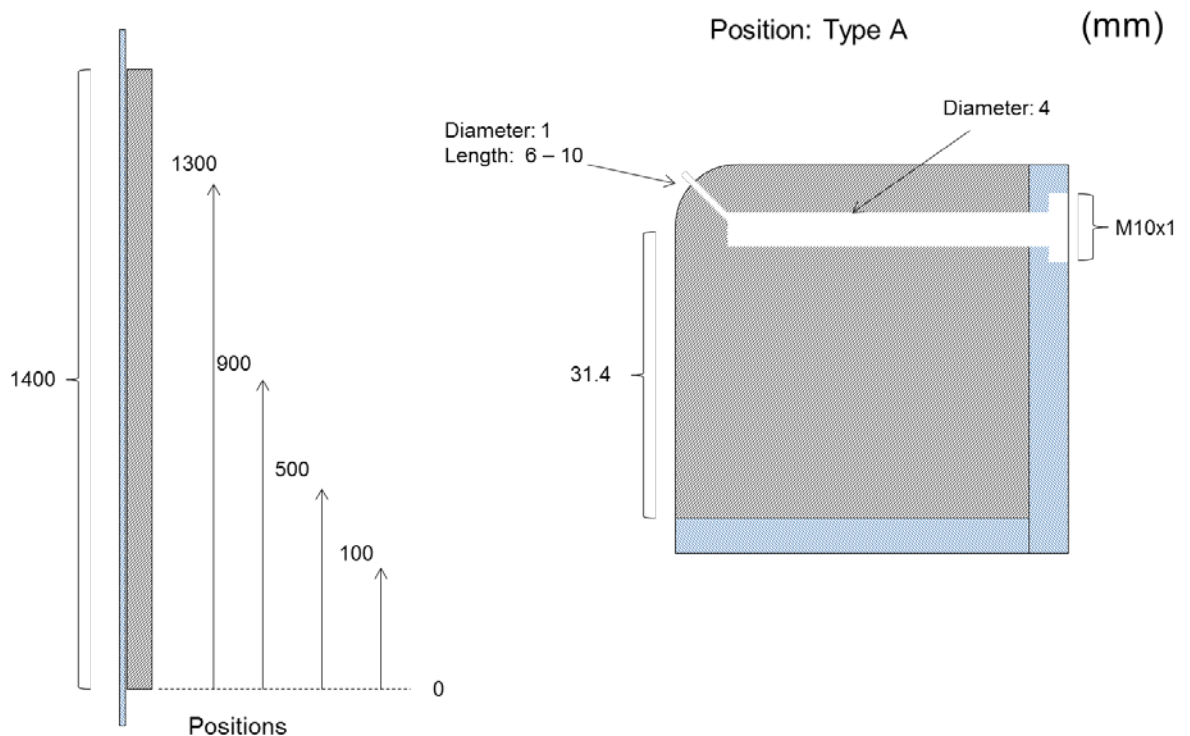
6 Pressure measurement

In order to estimate the loading on the tube in the central channel of the experimental setup pressure transducers are placed in the narrow flow path between the tube and the plates forming the corners of the fuel bundles. Pressure measurement are made at the level of the vibration measurements along the channel.

The differential pressure transducers used, BD Sensors DMD331, have a range of 100 mbar, an uncertainty $\leq \pm 0.5\%$ of Full Scale Output (FSO) (corresponding to 0.5 mbar) and a response time < 5 ms. The positive side of the pressure transducers are connected to the test section with short tubes, < 10 cm, to get a good frequency response and the negative side are collected to a common tube, with a valve, at the same level as the transient pressure measurements. The valve is kept open until the flow rate and static pressure is stabilized and then closed while the transient measurements are made. In this way it was possible to use sensitive differential pressure transducers although the background pressure at some measurement points was as high as 3 bars for the highest flow rates due to the high pressure drop over the test section. The sampling rate of the pressure transducers was set to 1 kHz.

6.1 PRESSURE MEASUREMENT POSITIONS

The transient pressure measurements are made at the locations defined in figure 8.



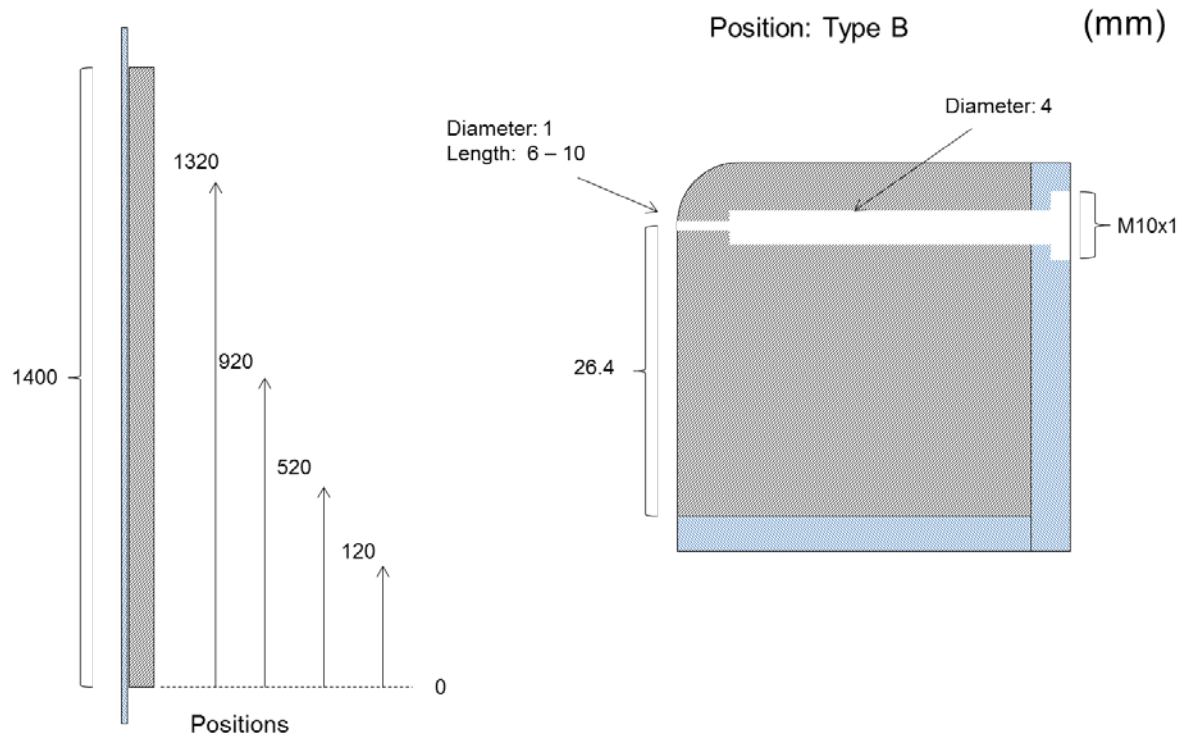


Figure 8: Positions for transient pressure measurements

In addition the differential pressure over the test section was measured with a differential pressure transducer with a range of 20 bars and accuracy $\leq \pm 0.5\%$ FSO.

7 Velocity measurement

Velocity is measured using electromagnetic flow meters, Krohne Optiflux 4000. The water flow rate is between 0-15 l/s which corresponds to a bulk velocity of approximately 0-15 m/s in the test section. The time variation of the flow is low compared to the frequency of the rod motion and pressure fluctuations. The accuracy of the flow measurements is $\leq \pm 0.3$ % FSO.

8 Vibration measurement

Two high speed cameras are located at 90 degree angle at two different locations along the tube axis captures the in plane motion in two directions simultaneously. The cameras are synchronized in time using a common trigger. The steel tube is painted black at the measurement locations and white dots are sprayed onto the black surface.

The cameras use a 2/3" 2080x1044 pixels CCDs which gives a pixel resolution of 5 μm . As the tube moves the dots are tracked using a Particle Tracking Velocimetry (PTV) algorithm based on the 'matPIV' Matlab® software described in [2]. The favorable dot size for the algorithm is 3-50 pixels so the dots on the tube surface are almost too small to be visible to the human eye. The cameras use tele-centric lenses with 1X magnification, a fixed working distance of 65 mm and the region of interest (ROI) covers 288x100 pixels of the total CCD area. This allows for a frame rate of 750 fps.

The PTV algorithm was calibrated using a "manufactured solution" procedure where computer generated images with particles of different sizes move along prescribed trajectories. By this procedure the accuracy of the algorithm could be established with good precision to within 5 μm or 0.5% of the measurement range.

To establish a relation between the real world coordinates and the measured coordinates of the camera pixels a reference frame was chosen for each camera setup where a predefined distance was correlated to the image of the measurement. This is a source of error in the position measurement which is constant for each camera position and is of the same magnitude as the pixel size $\sim 5 \mu\text{m}$.

The test rig vibrates slightly during the tests, especially at high flow rates, which could impact the cameras and the position measurement. The vibration of the cameras was reduced by using special attachments directly on the rigid Plexiglas structure which resulted in very small vibration amplitudes at the cameras. The vibrations of the cameras was measured by a handheld vibration monitoring equipment at different flowrates and due to the mechanical properties of the rigid test section and the camera mounts the dominant frequencies were $> 400 \text{ Hz}$ which is well above the interesting range of the measurements. However, errors from camera vibrations cannot be completely excluded since there was no simultaneous measurement on the cameras but they are estimated to be small in comparison to the motion of the tube in the test section.

The synchronization signal of the cameras is sampled together with the pressure measurements to create a fully time synchronized coupled data set with pressure loads and the resulting motion of the tube. An example of the time synchronized data with in-plane position and pressure is seen in figure 9.

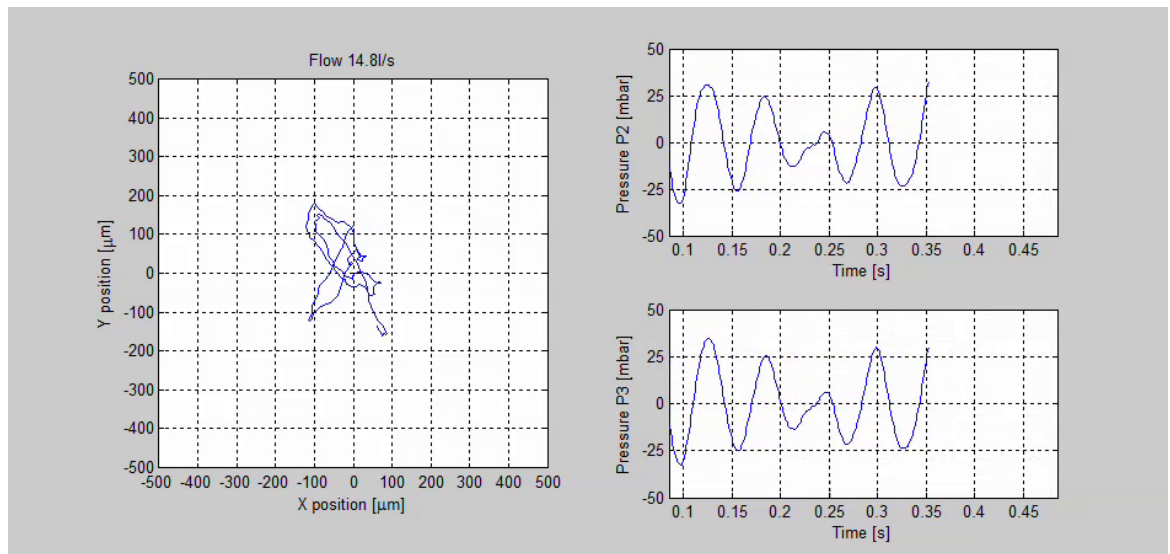


Figure 9: Time synchronized data with pressure and in-plane position measurements

The in-plane position of the rod was measured at the same position as the pressure measurements "Type A", c.f. figure 8.

9 Test Matrix

The data points measured are shown in Table 3. The corresponding data files are found in the tesrun.xlsx file on the data server as described in paragraph 10.

Flow rate l/s	Media
0.00	Air
0.00	Water
2.35	Water
5.00	Water
7.00	Water
10.00	Water
12.00	Water
14.80	Water

Table 3: Test matrix

For the tests at 0 m/s with air and water the tube was exited using a jet of water (using a syringe) through one of the "Type A" pressure taps. This way no additional vibration was introduced in the rig which would shake the cameras. For the rest of the measurements the pump was set at a constant rotational speed and the system was left at that state for at least 10 minutes. After this initialization period all measurements were made simultaneously during the 20 seconds sampling time for the PTV cameras.

The raw data was saved into ASCII text files and the movies for the PTV algorithm were post processed using the PTV algorithm supplied together with the data. The resulting tube velocities were also saved into ASCII text files.

10 Data format

The data is organized as time series of pressure, flow rate, rod position and rod velocity. The RAW data is post processed and output format is ASCII for simplicity. A collection of Matlab® scripts are also supplied to facilitate post processing.

The data is located on a cloud service on the internet for easy access and is organized into three directories containing Matlab® scripts, processed and the RAW data from the measurement system.

The top level of the data directory is shown below in figure 10.

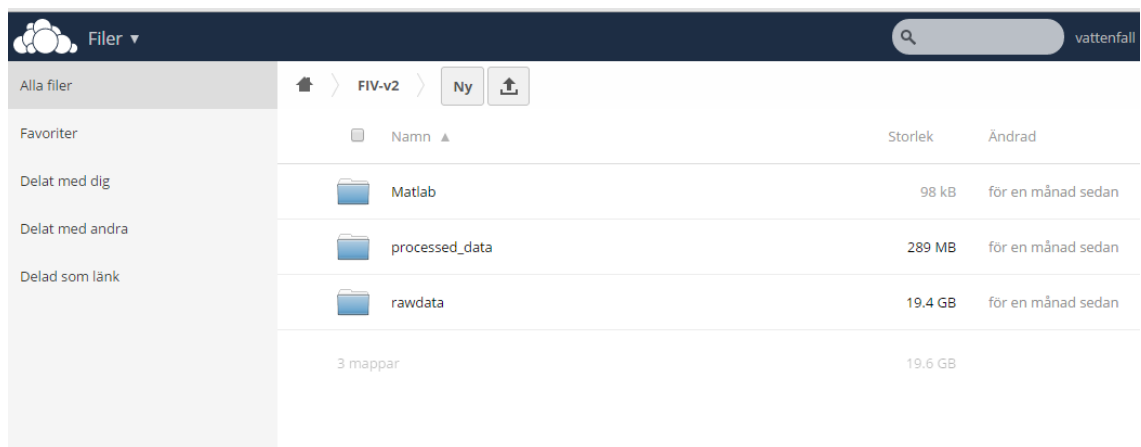
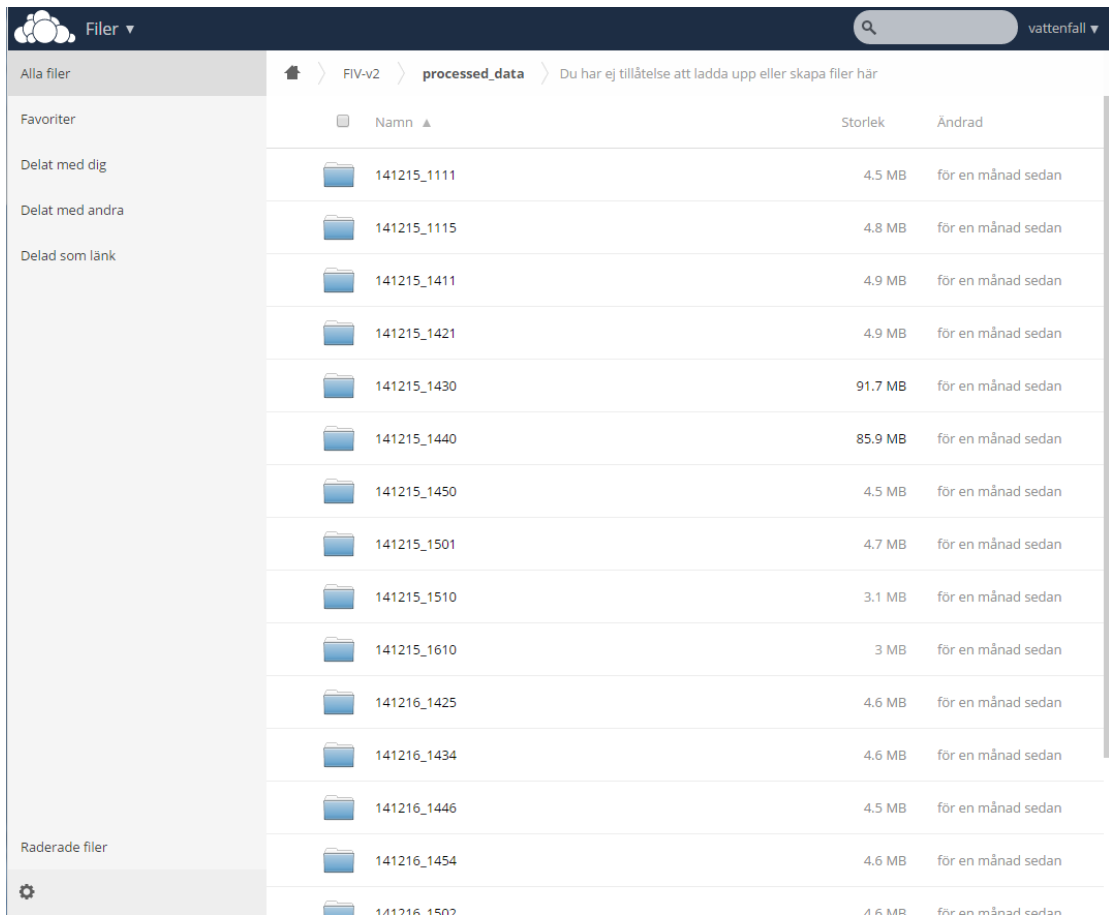


Figure 10: Top level of the data directory

The ASCII data files are located under 'processed_data' and the corresponding RAW data under 'rawdata'.

The 'processed_data' directory is shown below in figure 11.



Namn	Storlek	Ändrad
141215_1111	4.5 MB	för en månad sedan
141215_1115	4.8 MB	för en månad sedan
141215_1411	4.9 MB	för en månad sedan
141215_1421	4.9 MB	för en månad sedan
141215_1430	91.7 MB	för en månad sedan
141215_1440	85.9 MB	för en månad sedan
141215_1450	4.5 MB	för en månad sedan
141215_1501	4.7 MB	för en månad sedan
141215_1510	3.1 MB	för en månad sedan
141215_1610	3 MB	för en månad sedan
141216_1425	4.6 MB	för en månad sedan
141216_1434	4.6 MB	för en månad sedan
141216_1446	4.5 MB	för en månad sedan
141216_1454	4.6 MB	för en månad sedan
141216_1502	4.6 MB	för en månad sedan

Figure 11: The directory containing the processed data in ASCII format.

The data files corresponding to each measurement point is described in the file 'testruns.xlsx' which resides in the 'rawdata' folder.

Access to this cloud service is granted by sending an e-mail to any of these addresses:

eric.lillberg@vattenfall.com
 kristian.angele@vattenfall.com
 gustav.lundqvist@vattenfall.com
 johan.westin@vattenfall.com

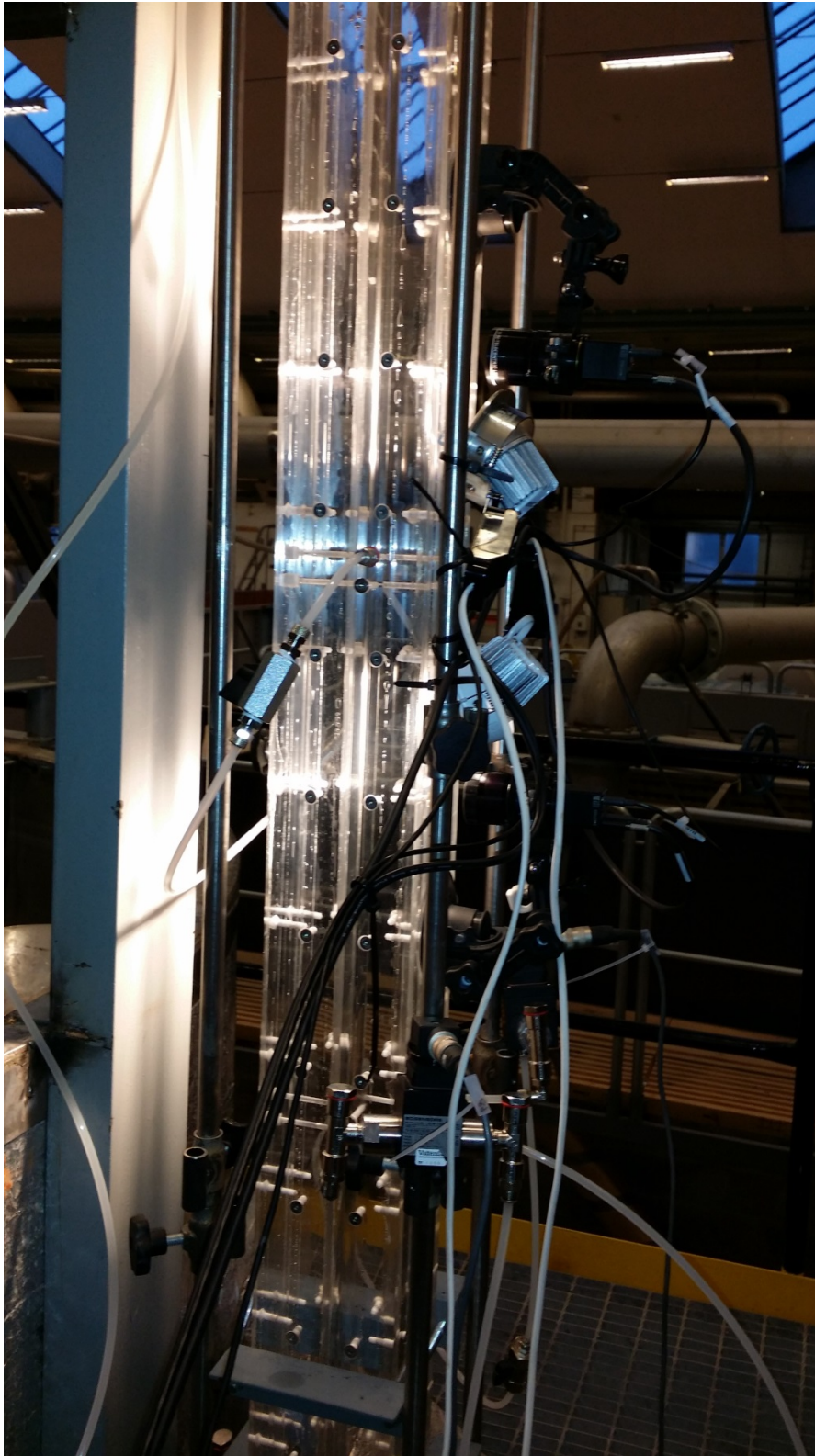
11 References

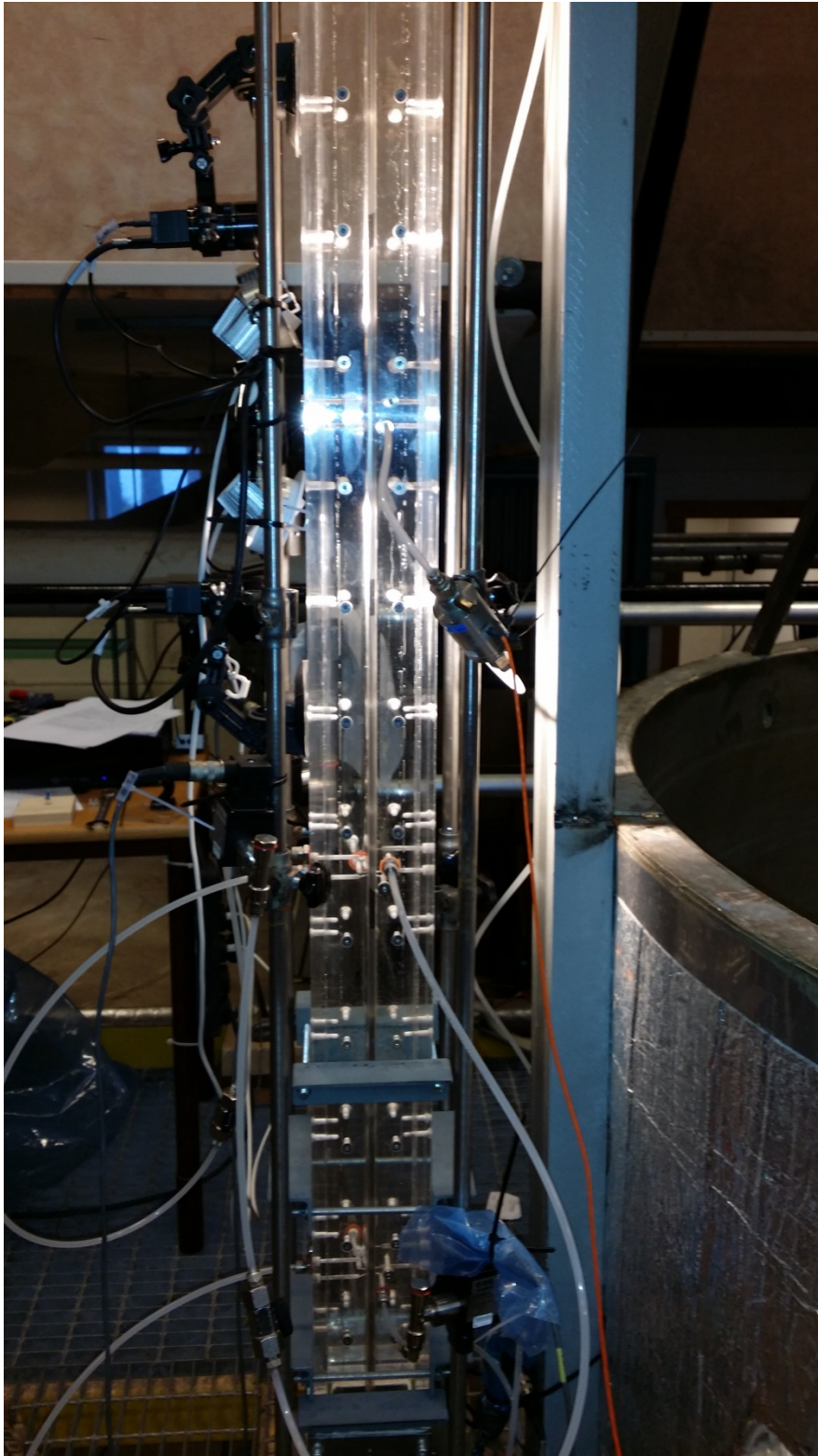
- [1] WARREN C. YOUNG, RICHARD G. BUDYNAS, "Roark's Formulas for Stress and Strain", 7th Edition
- [2] J. Kristian Sveen: "An introduction to MatPIV v. 1.6.1", eprint series, Dept. of Math. University of Oslo, "Mechanics and Applied Mathematics", NO. 2 ISSN 0809-4403, August 2004

Appendix 1

In this section pictures of the physical experimental setup is shown.







Appendix 2

In this section calibration protocols for all measurement equipment is shown.

Vattenfall Research and Development AB

Sid 1(1)

KALIBRERINGS PROTOKOLL FÖR TRYCKGIVARE.**1. Provobjekt**

Benämning:	Tryckgivare 0-10 bar g	Inv.nr:	1143
Fabrikat:	WIKA	Typ:	9013547
2. Mätområde:	0 – 10 bar g	Se.nr:	3677121
Kalibrerat område:	0 – 10 bar g		

3. Kalibreringsintervall

Kalibreringsintervall: 12 mån

4. Kalibreringsnormal

Benämning:	Kalibrator DPI 605	Inv.nr:	1854
Fabrikat:	DRUCK		
Mätområde:	-1bar till 20bar (e)	Tillverkn.nr:	2143195-2

5. Spårbarhet

För att säkra spårbarheten kalibreras kalibreringsnormalen med ett intervall på 1 år vid FFA riksmätplats för tryck.

6. Kalibreringsinstruktion UI 1062**7. Omgivningstemperatur**

Omgivningstemperatur: 22,7°C

8. Protokoll för kalibrering

1	2	3	4	5
Mätning	Insignal	Utsignal		
NR	Enhet: bar	Enhet: Volt	Enhet:	Enhet:
1	0,00	0,99482		
2	2,5	1,9928		
3	5,0	2,9949		
4	7,5	3,9971		
5	10,0	4,9984		
6	0,00	0,9928		
7				
8				
9				
10				
11				
12				
13				
14				
15				

Anmärkningar:

Kalibreringen utförd av: Underskrift:

Namnförtydligande: Tim Bergseth Datum: 2009-07-01

\\oden.eur.corp.vattenfall.com\Usersej\ejli\Documents\Elforsk\FTV\Kalibreringsprotokoll\1143_09.doc 15-05-11



KALIBRERINGSBEVIS

utfärdat av riksmålsplats 01

Kontaktperson
Thomas Franzén
Mätteknik
010-516 59 19
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Datum
2015-02-02
Beteckning
MTv5F000143-K01

Sida
1 (2)

RMP
01

Vattenfall AB
Business Strategy R&D Nordic
Laboratorievägen 1
814 26 ÄLVKARLEBY

Kalibrering av induktiv flödesmätare, intnr 5281

Identifiering

Objekt Induktiv flödesmätare Krohne Optiflux 4000, DN 80, serienr A0900845 med intnr 5281, förstärkare IFC300, serienr A0900845 med intnr 5285.
Givarkonstanter GK 2,4342 och GKL 4,8173.
Analog utgång, 4 – 20 mA, som motsvarar 0 – 25 l/s.
Upplösning flödesvisning på display 0,01 l/s.
Objektets tillstånd Vid ankomsten var objektet utan synliga skador.
Ankomstdatum 2015-01-23
Kalibreringsort Borås
Kalibreringsdatum 2015-02-02

Mätmetoder och -rutiner

Mätaren har kalibrerats med flygande start och stopp mot SPs mastermätare med minsta provtid 2 minuter.

Mätförhållanden

Rum 6:232
Rumstemperatur ca. 20 °C
Provvätska vatten

Resultat

Flödesvisning display

Flöde [l/s]	Tryck [MPa]	Temperatur [°C]	Avläst flöde [l/s]	Felvisning [%]	Mätosäkerhet [%]
25,13	0,3	40	25,01	-0,47	±0,1
15,08	0,2	40	15,02	-0,36	±0,2
5,05	0,2	38	5,03	-0,41	±0,3

Analog utgång, 4 – 20 mA

Flöde [l/s]	Tryck [MPa]	Temperatur [°C]	Uppmätt ström [mA]	Felvisning [%]	Mätosäkerhet [%]
25,13	0,3	40	20,019	-0,39	±0,2
15,08	0,2	40	13,625	-0,25	±0,2
5,05	0,2	38	7,221	-0,29	±0,2

Resultaten i tabellerna ovan anges som medelvärde av tre prov.

SP Sveriges Tekniska Forskningsinstitut

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501 15 BORÅS

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033-13 55 02
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Riksmålsplats utses av regeringen enligt lagen (2011:791) och förordningen (2011:811) om teknisk kontroll. SP tillämpar kvalitetsystem enligt SS-EN ISO/IEC 17025 under överinseende av SWEDAC. Detta dokument får endast släpas i sin helhet om inte SP i förväg skriftligen godkänt annat.

5-Points-Measurement Report

Company:

Paab Tekno Trading AB

OC Number:

21070298

Specification of the device:

Manufacturer:	BD Sensors s.r.o	Start signal output:	4,00	Lower range:	0,00
Serial number:	1757237	End signal output:	20,00	Upper range:	100,00
Type:	DMD 331	Unit signal output:	mA	Unit range:	mbar
Ordering code:	730-D-1000-1-E-100-JCC-1-000	Pressure:	differential		

Specification of the calibration equipment:

Ambient temperature:	20,3 °C	Medium:	N2
Pressure reference:	Manufacturer: GE Druck Accuracy: <1...10 bar->0,03%RDG+0,01%FS	Type:	DPI 515
		Serial number:	51502197
Multimeter:	Manufacturer: Agilent Accuracy: 0...100 mA->0,05%RDG+0,005%FS	Type:	34401 A
		Serial number:	M/Y 47009157

Measured values:

Input	Input	Output target	Output values actual			
			measured	deviation	measured	deviation
in %	mbar	mA	mA	%FSO	mA	%FSO
			rising	rising	falling	falling
0,0	0,000	4,000	4,021	0,13	4,323	0,14
25,0	25,000	9,000	8,029	0,16	9,021	0,19
50,0	50,000	12,000	12,032	0,20	12,032	0,20
75,0	75,000	15,000	15,035	0,22	15,032	0,20
100,0	100,000	20,000	20,325	0,16	20,027	0,17

Evaluation according to IEC 60770

Target
1,00Actual
0,22

Measured and logged by:

Service 12

Date:

10.11.2014

BD SENSORS GmbH
B.D. Sensors s.r.o.

Tel.: +49 (0) 42 35 195 - 1 - 0

www.bdsensors.de

5-Points-Measurement Report

Company: Paab Tekno Trading AB OC Number: 21070296

Specification of the device:

Manufacturer:	BD Sensors s.r.o	Start signal output:	4.00	Lower range:	3.00
Serial number:	1757238	End signal output:	20.00	Upper range:	133.00
Type:	DMD S61	Unit signal output:	mV	Unit range:	mbar
Ordering code:	730 B-1000-1-B-100-JCC-1-000	Pressure:			differential

Specification of the calibration equipment:

Ambient temperature:	20.0 °C	Medium:	N2
Pressure reference:	Manufacturer: GE Druck Accuracy: -1...10 bar => 0,03%RDG+0,01%FS	Type:	DPI 515
		Serial number:	51502157
Multimeter:	Manufacturer: Agilent Accuracy: 0...100 mA => 0,05%RDG+0,005%FS	Type:	34401A
		Serial number:	MY 4/003157

Measured values:

Input	Input	Output target	Output values actual			
			measured	deviation	measured	deviation
In %	mbar	mA	mA rising	%FSO rising	mA falling	%FSO falling
0.0	0.000	4.000	3.995	-0.13	3.994	-0.14
25.0	25.000	8.000	7.998	-0.25	8.003	0.02
50.0	50.000	12.000	12.005	0.03	12.007	0.04
75.0	75.000	16.000	16.001	0.01	16.003	0.02
100.0	100.000	20.000	20.003	0.02	20.002	0.01

Evaluation according to IEC 60770

Target: 1.00
Actual: 0.04

Measured and logged by: Service 12

Date: 17.11.2014



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5-Points-Measurement Report

Company: Paab Tekno Trading AB OC Number: 21070298

Specification of the device:

Manufacturer:	BD Sensors s.r.o.	Start signal output:	4.00	Lower range:	0.00
Serial number:	1757239	End signal output:	20.00	Upper range:	100.00
Type:	DMD 331	Unit signal output:	mA	Unit range:	mbar
Ordering code:	750-B-1000-1-3-100-J00-1-000				
		Pressure:	differential		

Specification of the calibration equipment:

Ambient temperature:	23.0 °C		Medium:	N2
Pressure reference:	Manufacturer:	GE Druck	Type:	DP1515
	Accuracy:	-1...10 bar → 0.03%RDG+0.01%FS	Serial number:	51532187
Multimeter:	Manufacturer:	Agilent	Type:	34401A
	Accuracy:	0...100 mA → 0.05%RDG+0.005%FS	Serial number:	MY 47009157

Measured values:

Input	Input	Output target	Output values actual			
			measured	deviation	measured	deviation
In %	mbar	mA	mA	%FSO	mA	%FSO
			rising	rising	falling	falling
0.0	0.000	4.000	4.021	0.13	4.023	0.14
25.0	25.000	8.000	8.028	0.18	8.031	0.15
50.0	50.000	12.000	12.039	0.20	12.032	0.20
75.0	75.000	16.000	16.056	0.22	16.032	0.20
100.0	100.000	20.000	20.025	0.16	20.027	0.17

Evaluation according to IEC 60770

Target
1.00

Actual
0.22

Measured and logged by: Service 12

Date: 17.11.2014



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FLUID INDUCED VIBRATIONS IN NEUTRON DETECTION HOUSING

The experimental setup described in this report provides valuable data sets for validation of computational tools, e.g. CFD, with fluid structure interaction (FSI). The fluid elastic vibration of the tube is an important case since it directly addresses the fundamental challenges with structural verification of components subjected to external axial flow. The experiment is also tailored so to have simple and well defined boundary conditions which is fundamental for validation purposes.

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