Doc No: LC-4331-5/6/7	Rev: 0	Date: 2006-03-22	
Prepared by: Jørgen Ramdal	Approved by: Ole G. Dahlhaug	Classification: Open	Page: 1 of 5

Substitution calibration of weighing tank

1 General

This procedure describes how the weighing tank system is calibrated in the Waterpower Laboratory.

1.1 Definitions and abbreviations

W	Mass of weights	[kg]
c	Amplifier reading	[kg]
Δc	Difference in amplifier reading before and after upload of calibrated weights	[kg]
a_0, a_1, a_2, a_3, a_4	Parameters in correction equation	

2 The system

2.1 Description

The Waterpower Laboratory makes use of a weighing tank system for calibration of flow meters. The weighing tank is resting on three load cells (type Hottinger RTNC) connected to an amplifier with display (type Hottinger MGC Plus AB22A) The water is guided into or outside the tank through a pneumatically driven guiding system. The weight displayed on the amlifier has to be corrected, and to find the correction equation, a substitution calibration is performed. A number of calibrated weights are used to find the slope in the range of the tank capacity, from which a calibration equation is found. The weights have been calibrated by Justervesenet (Norwegian Metrology Service).

2.2 Equipment used in calibration

- The laboratory piping- and pump system
- Weighing tank system
  - Hottinger RTNC load cells (Reg.nr. 4331-5/6/7)
  - Hottinger MGC Plus AB22A amplifier (Reg.nr. 2755-9)
  - Capacity appr. 86 metric ton -> 73 m^3 water plus weight of tank and calibrated weights.
- Calibrated weights
  - 5126.075 kg (Calibration document: *LS-Sertifikat for lodder og vekter ved VKL*)

3 Calibration

3.1 Preparations

1. Set up the laboratory piping and pump system so that water is directed to the weighing tank system. It is preferred to use the free water surface reservoir.

2. Make sure nothing disturbs the weighing tank or induces unwanted movements. Remove all shafts connected to the tank, and remove all objects not related to the tank. Inspect the tank pit with a flash light, to make sure it is free of water, and that no object is jammed between the tank and the pit wall.

3. Prepare the laboratory crane for operation.

3.2 Calibration

1. Adjust the pump and valves so that the wanted flow is obtained.

2. Record the time and the weight of the tank.

3. Use the laboratory crane to put the calibrated weights on top of the tank, record the amplifier reading [c] and lift off the calibrated weights again.

4. Set the time on the tilting screen controller computer to a time that gives approximately 5 ton per filling. Tilt the screen to start filling the tank.

5. When the filling has stopped, let the tank stabilize and record the weight of the tank.

6. Repeat steps 3, 4 and 5 until full tank capacity is reached.

4 Computations

The amplifier reading is not correct, and an equation has to be found in order to make sure the correct mass is used in flow calibrations.
A function W = f(c) represents the connection between the amplifier reading [c] and the applied weight on the force transducers. This function is assumed to be a fifth order polynom.

$$W = f(c) = a_0 \cdot \frac{c^5}{5} + a_1 \cdot \frac{c^4}{4} + a_2 \cdot \frac{c^3}{3} + a_3 \cdot \frac{c^2}{2} + a_4 \cdot c \qquad (1)$$

The derivate of this function is found by subtracting the amplifier reading after upload from the amplifier reading before, and divide the weight of the calibrated weights by the product of the subtraction.

$$f'(c) = \frac{W}{\Delta c}$$

This relationship is found for every 5 tons in the whole range of the weighing tank and the data is put into a graph with f'(c) along the y axis and c along the x axis. A fourth order polynomial is found by interpolation through the recorded points, giving the parameters a_0, a_1, a_2, a_3 and a_4. The final correction equation is found by integrating the fourth order polynomial.

5 Figures

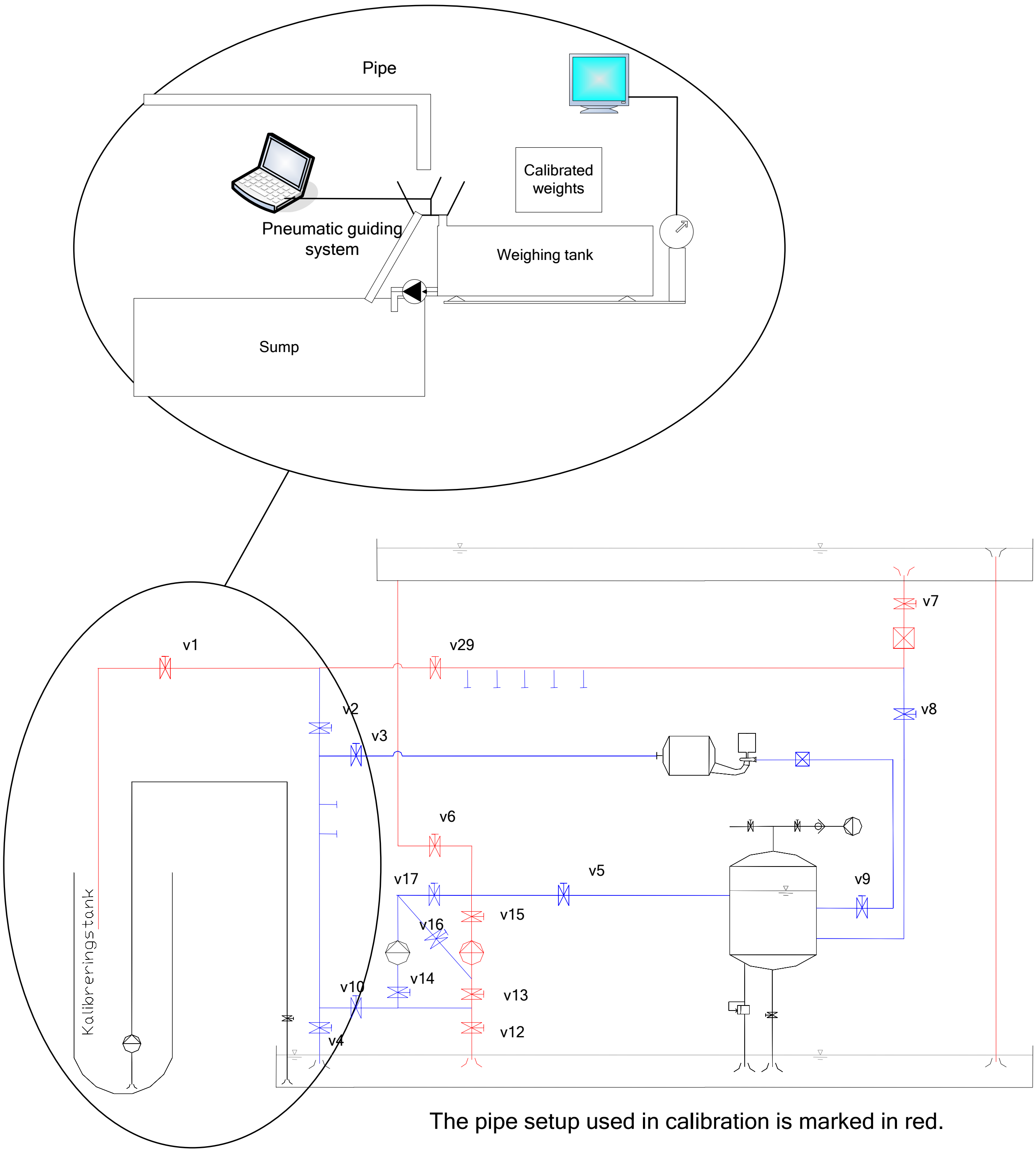

Figure 1: Lab-setup

6 References

- Calibration document for weights at the Waterpower Laboratory issued by Justervesenet (LS-Sertifikat for lodder og vekter ved VKL)
- ISO 4185:1980 Measuring of liquid flow in closed conduits
- Documentation for load cells (Doc IA 4331-5/6/7)
- Documentation for measuring amplifier (Doc IA 2755-9)

Doc No:	Rev:	Date:
LC-4551-1	0	2006-03-22

Prepared by:	Approved by:	Classification:	Page:
Bård Brandåstrø Jørgen Ramdal	Ole G. Dahlhaug	Open	1 of 5

Calibration of oxygen measurement on the Francis Turbine Test Rig.

1 General

This procedure describes how to calibrate the dissolved oxygen (D.O.) measuring system.

1.1 Definitions and abbreviations

D.O. - Disolved oxygen

2 The system

2.1 Description

The oxygen probe in use is a TriOxmatic 700 IQ, which is located at the main pump inlet. The probe is connected to an IQ Sensor Net 182 universal digital signal converter/amplifier system. The amplifier presents the D.O. value in mg/l within a range from 0.0 to 60.0 mg/l. The output signal from the IQ Sensor Net 182 system is fed to the data acquisition system.

2.2 Equipment used in calibration

- Oxygen probe
  - Trioxmatic 700 IQ (Reg. no. 4551-1)
- Signal converter/amplifier
  - IQ Sensor Net 182

3 Calibration

3.1 Preparations

1. Remove the sensor from the pipe, clean and dry the membrane.

2. Position the sensor approximately 2 cm above a water surface in a narrow bucket or similar container with water. (See figure 1.)

3.2 Calibration

1. On the face of the unit, switch to the measured value display with the “M” button

2. Select the sensor to be calibrated with up – down arrows (in the single display the sensor being displayed is always selected at the same time).

3. Call up calibration by pushing on “C”. The message, “*During the calibration, the linked out–puts are frozen*” appears. The maintenance condition is switched on the next time the OK key is pressed. Return to the measured value display without switching on the maintenance condition with “M” button or “ESC” button. By activating the maintenance condition, the linked out-puts remain in their present state. The measured value or status display of the sensor flashes in the measured value display.

4. Confirm with the “OK” button. The maintenance condition is active. **The display will guide you through all steps. Excactly follow all instructions !** A message of the success of the calibration and the determined calibration data appear at the end. Up to this point you can cancel the calibration procedure with the “ESC” button at any time. The system will continue to work with the old calibration data. The maintenance condition, has to be switched off again in any case.

5. Confirm the calibration data with the “OK” button. Calibration is completed with this. The following display message describes the further steps to put the sensor into operation again.

3.3 Complementary work

Putting the sensor onto operation after calibrating:

6. Confirm with “OK” button. The display returns to the measured value display (the measured value flashes as the sensor is still in the maintenance condition).

7. If calibration was successful, immerse the sensor into the test sample.

8. Wait for a stable measured value.

9. Switch off the maintenance condition (highlight sensor and press the “OK” button 3 times).

The measured value has stopped flashing. If calibration was not successful, this is indicated by “ ---“ on the display and a corresponding message with remedial actions appears in the log book. Follow the Instructions and repeat calibration.

4 Computations

This is an absolute measurement, but in order to get the correct values displayed and recorded on the data acquisition unit, the output signal from the amplifier has to be correlated with the value displayed on the amplifier.

$$D.O = a \cdot m.v + b \qquad [\mathrm{mg/l}] \qquad (1)$$

The parameters a, and b are found using linear interpolation for the amplifier reading and the measured volt signal.

5 Figures

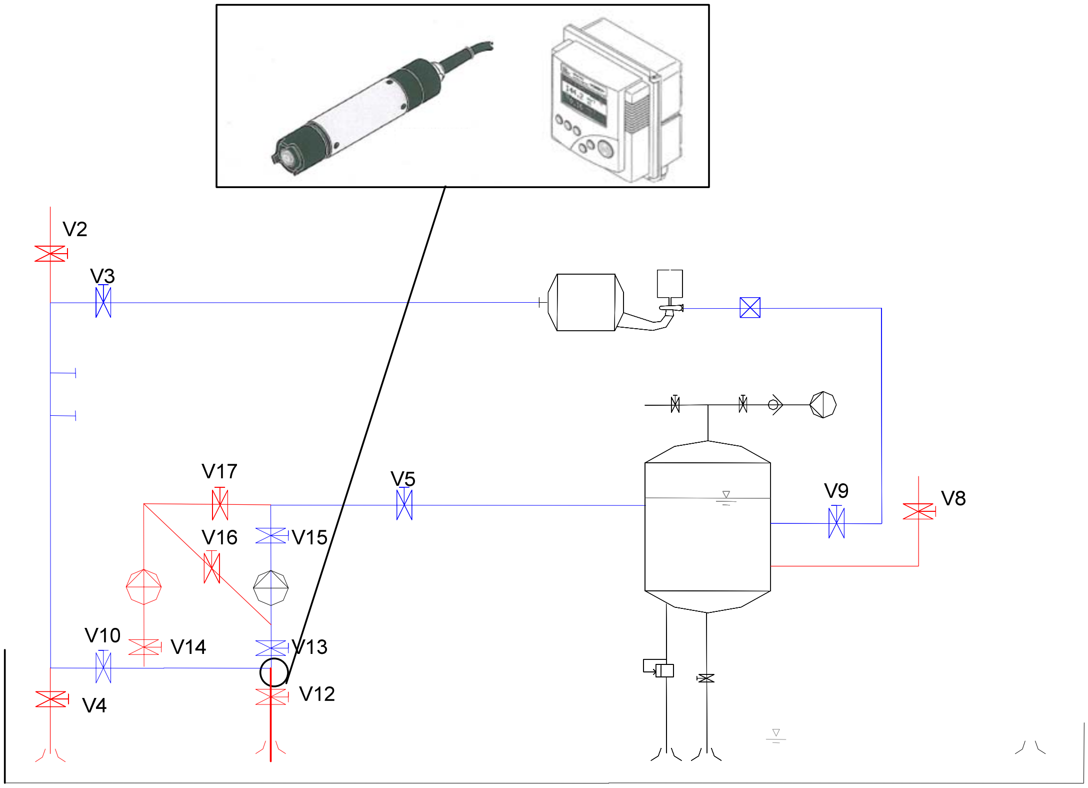

Figure 1: Position of oxygen probe

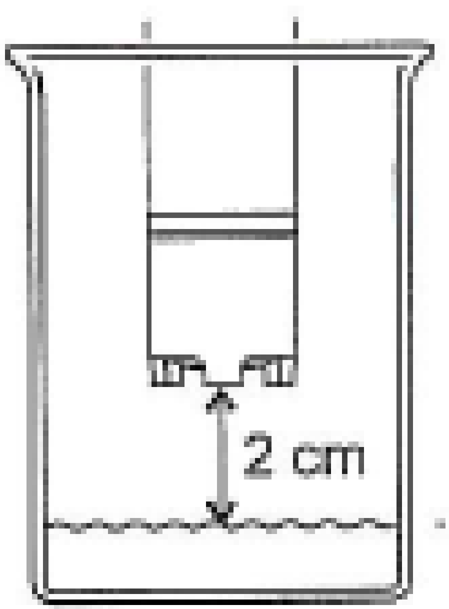

Figure 2: Calibrationposition of oxygen probe

6 References

– Specification for Trioxmatic 700 and DIQ/S 182 signal converter/amplifier. (doc IA-4551-1)

Calibration of differential pressure transducers

1 General

This procedure describes how differential pressure transducers are calibrated using a deadweight manometer.

1.1 Definitions and abbreviations

DPT	Differential pressure transducer
H	High pressure side of differential pressure transducer
L	Low pressure side of differential pressure transducer

2 The system

2.1 General

The measuring system consists of differential pressure transducer, and the Ruska deadweight manometer.

2.2 Equipment used in calibration

- Differential pressure transducer
- Ruska dead weight manometer
- Data acquisition unit

3 Calibration

3.1 Preparations

1. Make sure the signal is present on the data acquisition unit.

3.2 Calibration

1. Start with zero pressure in unit and record the zero point

2. Connect the deadweight manometer, and ventilate all air trapped in the transducer and in the deadweight manometer. Raise or lower either the transducer or the manometer, to find the zero-point recorded in the previous stage.

3. As calibrated weights are loaded onto the manometer piston, record the weight/pressure and the voltage signal induced by the pressure transducer. Make sure the piston and weights are spinning without any friction.

4. When the desired pressure range is obtained, the weights are offloaded and weights and voltage signals are recorded at the same points as in the upload.

5. Repeat the previous step to obtain a minimum of two series of data, from which the calibration curve is found.

4 Computations

The dead weight manometer uses a piston with known area of 80,64036534mm^2 that pressurizes a fluid. A number of calibrated weights follow the manometer. Each weight induces a certain pressure. The pressure (p) as the weights are loaded onto the piston is calculated from:

$$p = \frac{F}{A}$$

And

$$F = m \cdot g$$

The pressure transducer gives an output signal in Volts varying linearly with the load. For each weight applied the average voltage values should be calculated. The calibration equation is determined using linear interpolation.

$$p = a \cdot [m.v.] + b$$

5 Figures

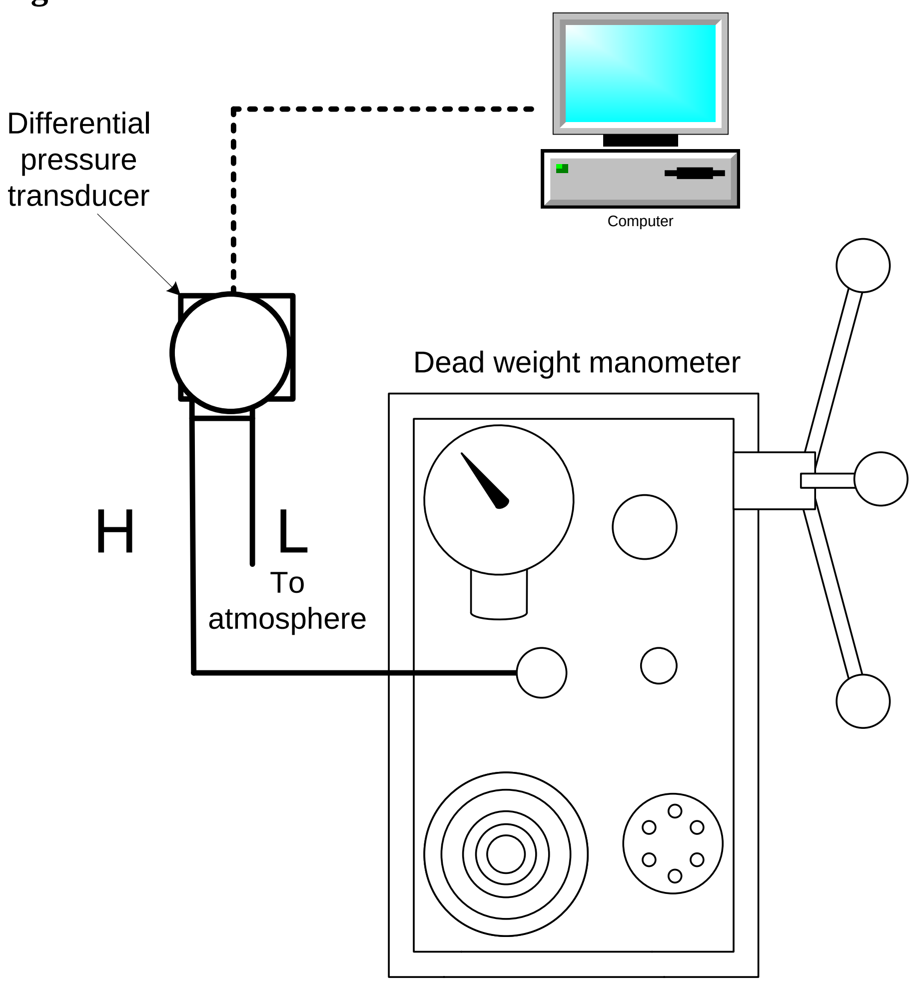

Figure 1: Arrangement

6 References

- Specification for Ruska deadweight manometer serial number 59774.
- Calibration certificate for Ruska deadweight manometer serial number 59774, and weights.
- Specification for Digital pressure transducers (Is found in the instrument archive, IA-4536-…)

Doc No: LC-4536-Supplement		Rev: 0		Date: 2006-03-23	
Prepared by: Jørgen Ramdal	Approved by: Ole G. Dahlhaug		Classification: Open		Page: 1 of 3

Check of differential pressure transducers

1 General

This procedure describes how differential pressure transducers are checked using a secondary method.

1.1 Definitions and abbreviations

DPT	Differential pressure transducer
DPI	Digital pressure indicator
H	High pressure side of differential pressure transducer
L	Low pressure side of differential pressure transducer

2 The system

2.1 General

The measuring system consists of differential pressure transducer, and the Druck DPI 601 pressure indicator.

2.2 Equipment used in calibration

- Differential pressure transducer
- Druck DPI 601 digital pressure indicator
- Data acquisition unit

3 Calibration

3.1 Preparations

1. Connect the DPI to the high pressure side of the differential pressure transducer. Make sure there are no air leaks and that the low pressure side of the DPT is open to atmosphere.

2. Connect the data acquisition unit, and make sure the signal is present.

3.2 Calibration

1. Start with zero pressure in unit and record the zero point

2. Pressurize the DPT using the pump on the DPI. Compare the pressure displayed on the DPI and corresponding volt signal (m.v) and calculated pressure for each point. The signal has to be stable before recorded. A minimum of 5 points over the selected range should be recorded.

3. Release the pressure and repeat the previous steps minimum twice.

4 Computations

5 Figures

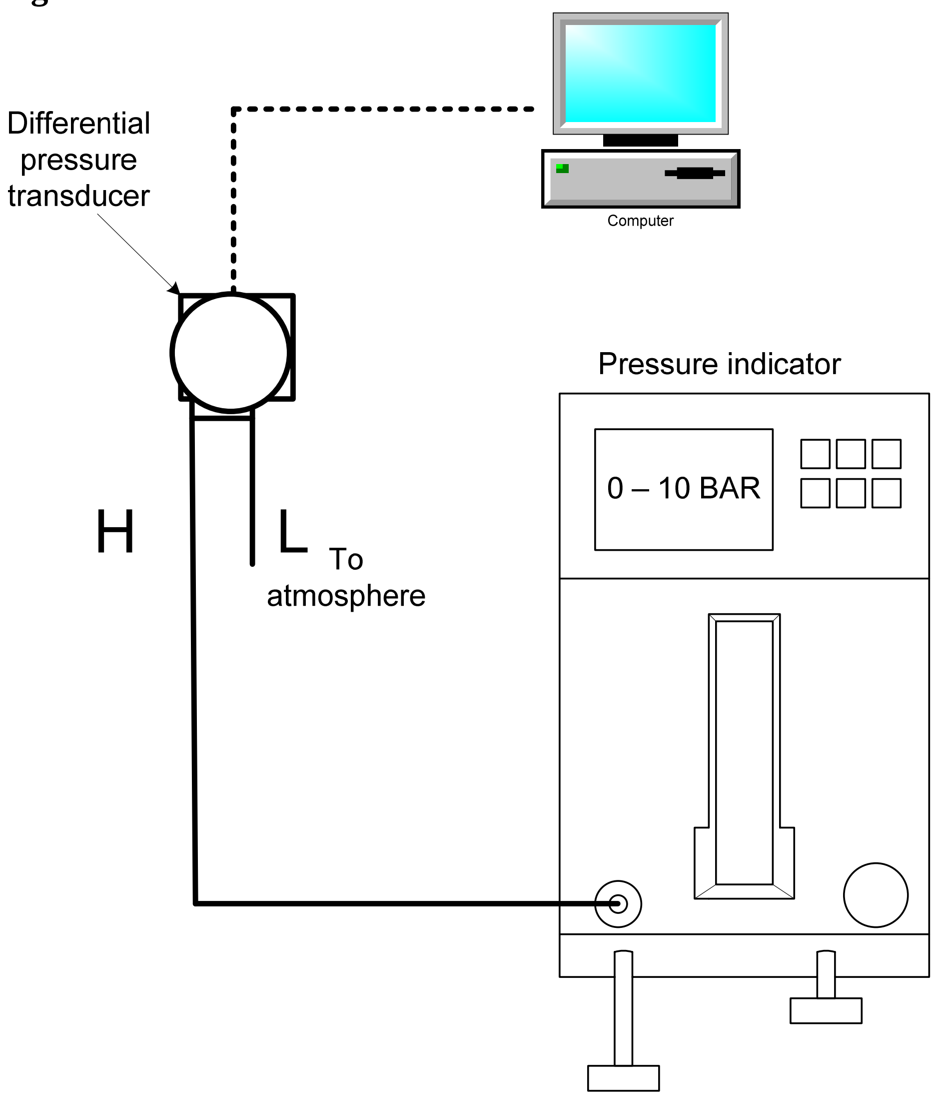

Figure 1: Arrangement

6 References

– Calibration document for Druck DPI 601 (LCd-4539-1)
– Specification for Druck DPI 601. (doc IA-4539-1)
– Spesification for Digital pressure transducers (Is found in the instrument archive, IA-4536-…)

Doc No: LC-4537-4548		Rev: 0		Date: 2006-03-22	
Prepared by: Jørgen Ramdal	Approved by: Ole G. Dahlhaug		Classification: Open		Page: 1 of 3

Calibration of pressure transducers

1 General

This procedure describes how pressure transducers are calibrated using a dead weight manometer.

1.1 Definitions and abbreviations

p	Pressure
F	Force

2 The system

2.1 General

The measuring system consists of an absolute pressure transducer, and the Ruska deadweight manometer.

2.2 Equipment used in calibration

- Pressure transducer
- Data acquisition unit
- Ruska dead weight manometer

3 Calibration

3.1 Preparations

1. Make sure the signal is present on the data acquisition unit.

3.2 Calibration

1. Start without pressurizing the pressure transducer unit and record the point

2. Connect the deadweight manometer, and ventilate all air trapped in the transducer and in the deadweight manometer. Raise or lower either the transducer or the manometer, to find the zero-point recorded in the previous stage.

3. As calibrated weights are loaded onto the manometer piston, record the weight/pressure and the voltage signal induced by the pressure transducer. Make sure the piston and weights are

spinning without any friction.

4. When the desired pressure range is obtained, the weights are offloaded and weights and voltage signals are recorded at the same points as in the upload.

5. Repeat the previous steps to obtain a minimum of two series of data, from which the calibration curve is found.

4 Computations

The dead weight manometer uses a piston with known area of 80,64036534mm^2 that pressurizes a fluid. A number of calibrated weights follow the manometer. Each weight induces a certain pressure. The pressure (p) as the weights are loaded onto the piston is calculated from:

$$p = \frac{F}{A}$$

And

$$F = m \cdot g$$

The pressure transducer gives an output signal in Volts varying linearly with the load. For each weight applied the average voltage values should be calculated. The calibration equation is determined using linear interpolation.

$$p = a \cdot [m.v.] + b$$

5 Figures

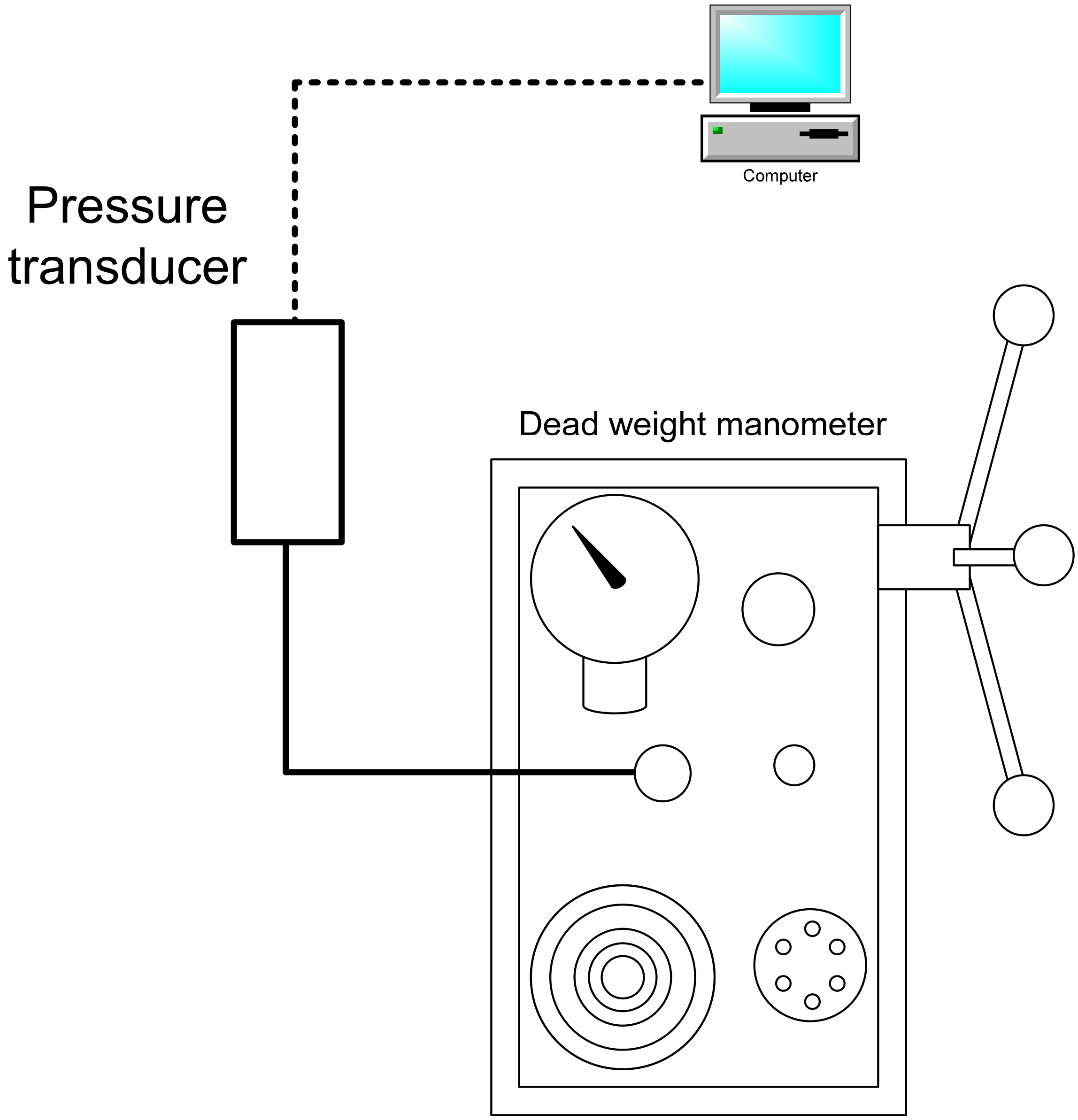

Figure 1: Arrangement

6 Referencesc

- Specification for Ruska deadweight manometer serial number 59774.
- Calibration certificate for Ruska deadweight manometer serial number 59774, and weights.
- Specification for Pressure transducers (Doc. IA- 4537-4548)

Check of pressure transducers

1 General

This procedure describes how pressure transducers are checked using a secondary method.

1.1 Definitions and abbreviations

PT	Pressure transducer
DPI	digital pressure indicator

2 The system

2.1 General

The measuring system consists of pressure transducer, data acquisition unit and the Druck DPI 601 pressure indicator.

2.2 Equipment used in calibration

- Pressure transducer
- Data acquisition unit
- Druck DPI 601digital pressure indicator

3 Calibration

3.1 Preparations

1. Connect the DPI to the pressure transducer. Make sure there are no air leaks.

2. Connect the data acquisition unit, and make sure the signals are present.

3.2 Calibration

1. Start with zero pressure in unit and record the zero point

2. Pressurize the PT using the pump on the DPI. Compare the pressure displayed on the DPI and corresponding volt signal (m.v) and calculated pressure for each point. The signal has to be stable before recorded. A minimum of 5 points should be recorded.

3. Release the pressure and repeat the previous steps minimum twice.

4 Computations

5 Figures

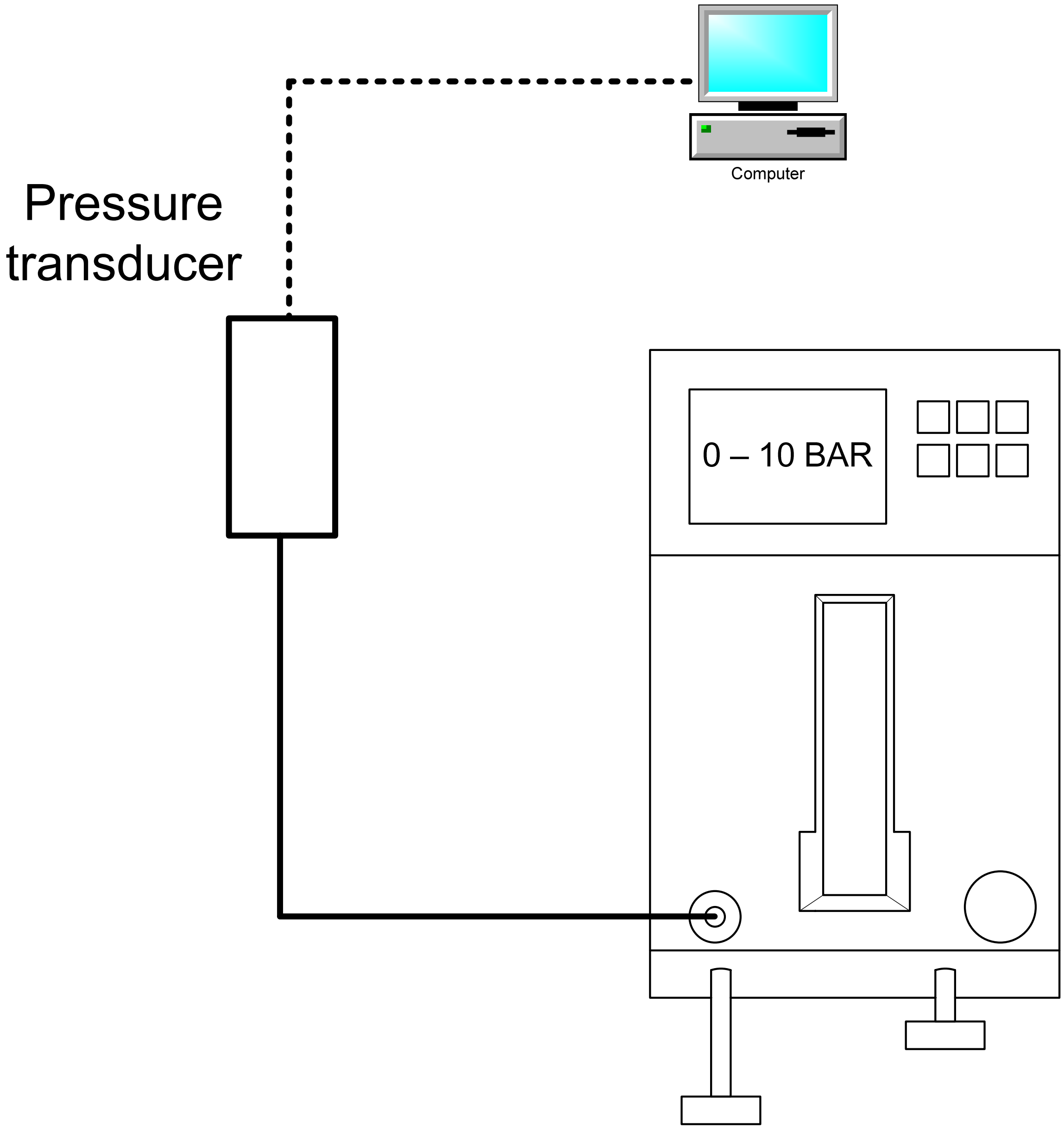

Figure 1: Arrangement

6 References

– Calibration document for Druck DPI 601 (LCd-4539-1)
– Specification for Druck DPI 601. (doc IA-4539-1)
– Spesification for Pressure transducers (Doc. IA- 4537-4548)

Calibration of discharge measurement system in the Francis Turbine Test Rig

1 General

This procedure describes how the flow meter in the Francis Turbine Test Rig is calibrated in the Waterpower Laboratory.

1.1 Definitions and abbreviations

W	Mass	[kg]
Wm	Measured Weight	[kg]
a_0, a_1, a_2, a_3, a_4	Parameters in correction equation	
ρ_w	Density of water	[kg/m^3]
θ_w	Water temperature	[^{o}C]
θ_{amb}	Air temperature	[^{o}C]
t	Time	[s]
p	Atmospheric pressure	[Pa]

2 The system

2.1 Description

The Francis Turbine Test Rig uses an electromagnetic flow meter to determine the discharge. The laboratory is set up so that water is discharged through the flow meter to be calibrated and to the weighing tank system. By recording weight of the tank before and after, and the time of filling, the flow rate through the flow meter is found.

The electromagnetic flow meter has an internal amplifier and power supply and gives an output signal from 2-10 V that varies linearly with the discharge.

2.2 Equipment used in calibration

- The laboratory piping- and pump system
- Flow meter
    - Krohne Aquaflux IFS 4000 (Reg. nr. 4624-4)
- Weighing tank system
    - Hottinger RTNC load cells (Reg. nr. 4331-5/6/7)

- Hottinger MGC Plus AB22A amplifier (Reg. nr. 2755-9)
- Capacity appr. 86 metric ton -> 73 m^3 water plus mass of tank and calibrated weights.

3 Calibration

3.1 Preparations

1. Set up the lab piping and pump system so that water is discharged through the flow meter, and to the weighing tank system. It is preferred to use the free water surface system if possible.

2. Make sure nothing disturbs the weighing tank or induces unwanted movements. Remove all shafts connected to the tank, and remove all objects not related to the tank. Inspect the tank pit whit a flash light, to make sure it is free of water, and that no object is jammed between the tank and the pit wall.

3. Make sure that a measuring signal from the flow meter is present.

3.2 Calibration

1. Adjust the pump, guide vanes and valves so that wanted flow is obtained. Ten calibration points should be recorded. First record 5 points at regular intervals within the expected flow rate of the following test, then repeat the same points again.

2. Record the time, weight of the tank, the atmospheric pressure, water temperature and air temperature, into the recording scheme. (FCd-4624-4)

3. Set the tilting time on the screen controller computer to 120 seconds. Tilt the screen to start filling the tank, and at the same time start recording the volt signal.

4. When the filling has stopped, let the tank stabilize and record the weight of the tank.

5. Repeat steps 1, 2, 3 and 4 until tank capacity is reached. On full tank, empty the tank using the pumps.

6. Repeat steps 1, 2, 3 and 4 until all points are recorded.

4 Computations

To find the correct mass [W] for each recorded point, the measured mass [Wm] has to be corrected using the parameters a, b, c, d and e found in the substitution calibration. (See Calibration document for Substitution calibration of weighing tank)

$$W = a_0 \cdot \frac{mW^5}{5} + a_1 \cdot \frac{mW^4}{4} + a_2 \cdot \frac{mW^3}{3} + a_3 \cdot \frac{mW^2}{2} + a_4 \cdot mW$$

Density of water has to be corrected using formula

$$\rho_w = \frac{10^3}{(1-4,6699 \cdot 10^{-10} \cdot p) + 8 \cdot 10^{-6} \cdot (\theta - 4 + 2,1318913 \cdot 10^{-7} \cdot p)^2 - 6 \cdot 10^{-8} \cdot (\theta - 4 + 2,1318913 \cdot 10^{-7} \cdot p)^3}$$

And the density of air is corrected

$$\rho_{\mathrm{amb}} = \frac{(p_{amb} \cdot 3,4837 \cdot 10^{-3})}{(273,15 + \theta_a)}$$

The mean discharge Q is found by using the corrected weights (W), the corrected density of water (ρ_m) and air (ρ_{a}), and the time (t)

$$Q = \frac{W_2 - W_1}{\rho_w \cdot t \cdot (1 - \frac{\rho_{amb}}{\rho_w})} \qquad [\mathrm{m^3/s}]$$

The calibration equation, giving the relationship between measured volt signal (m.v) and discharge is a linear equation

$$Q = a \cdot (m.v) + b \qquad [\mathrm{m^3/s}]$$

The parameters a, and b, is determined using linear interpolation.

5 Figures

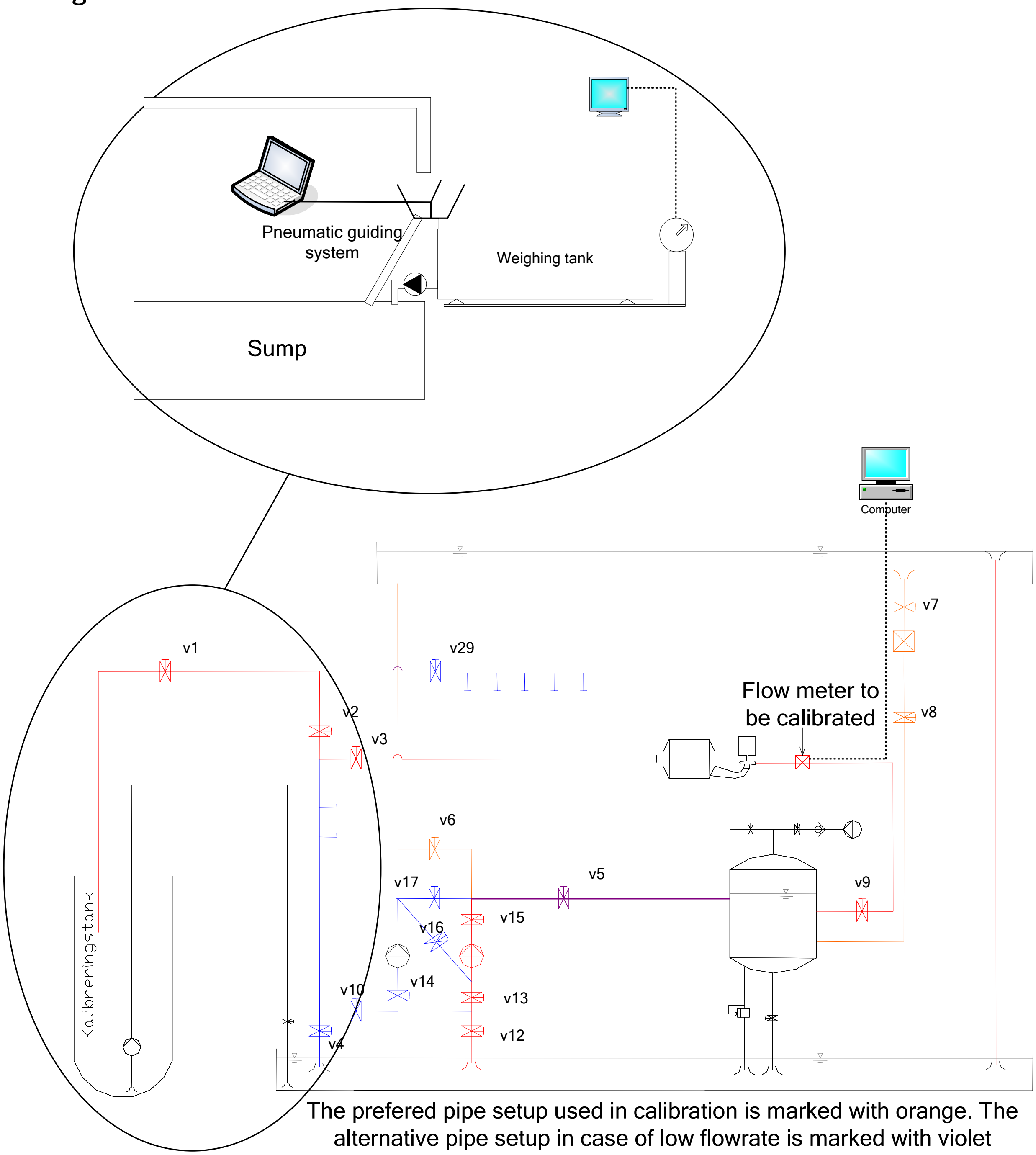

Figure 1: Lab setup

6 References

- Calibration document for Substitution calibration of weighing cells (LCd-4331-5/6/7)
- Specification for flow meter Krohne Aquaflux IFS 4000 (Doc IA-4624-4)
- ISO 4185:1980 Measuring of liquid flow in closed conduits
- Documentation for load cells (Doc IA-4331-5/6/7)
- Documentation for measuring amplifier (Doc IA-2755-9)

The Waterpower Laboratory

Doc No:	Rev:	Date:	
FC-4331-4	0	2006-03-22	
Prepared by:	**Approved by:**	**Classification:**	**Page:**
Jørgen Ramdal/Pål-Tore Storli	Ole G. Dahlhaug	Open	1 of 4

Calibration of generator torque measuring transducer

1 General

This procedure describes the calibration of the generator torque transducer.

1.1 Definitions and abbreviations

T	Shaft torque	[Nm]
m	Mass of weights	[kg]
l	Length of torque arm	[m]
m.v.	Measured value	[V]
a	Slope in calibration equation	[Nm/V]
b	Intersection constant in calibration equation	[Nm]
g	Gravity	[m/s^2]

Constant of gravity (g) is 9.8215 m/s^2.

2 The system

2.1 General

The measuring system consists of a hydraulic bearing and a load cell of type Hottinger Z6FC3. The weight range for the weighing cell is 0 to 500 kg. The load cell output signal is amplified using an external amplifier to a 0-10 V signal.

The torque is generated by using weights supplied to a tackle and hanging fixture on the arm. The carrier fixture is attached to the generator torque arm via a hydrostatic bearing with virtually zero friction. The generators torque arm has a known length from the centre of the generator shaft. (See document “FCd-4331-4 Supplement Calibration of Torque Arm Length”)

2.2 Equipment used in calibration

- Calibrated carrier fixture
- Oil hydraulic pump unit for feeding oil to bearing.
- Calibrated weights ($39 \cdot 5$ kg weights, marked VKL NTNU)

3 Calibration

3.1 Preparations

1. In order to cancel out oil temperature differences in the hydrostatic bearing the oil pump should be started at least one hour before the rest of the calibration is performed.

2. Connect the data acquisition unit, and make sure the signals are present. Ensure the computer is on and that the signal is present.

3.2 Calibration

1. Record the voltage without any weights added. Attach the weight holding fixture onto the torque arm. Record the voltage.

2. Place the weights one by one onto the holding fixture. The weight holding fixture and the weights in use all have a known weight and are calibrated by Justervesenet.(Norwegian metrology service)

3. For every 40 kg weight applied the voltage reading from the weight cell is recorded. The voltage reading is presented on the computer screen. Make sure the weights have no pendulum motion or no rotation when the recording is made.

4. When the final amount of weights has been placed onto the holding fixture, record the reading of the voltage value. Then add a little force by slightly pressing down on the weights for a few seconds. After releasing, record the reading again.

5. Remove the weights one by one. Note the voltage signal at the same points as when the weights were put on.

6. Perform the procedure a total of two up- and offloads.

4 Computations

The torque (T) on the shaft, as a known mass (m) is added is calculated by:

$$T = m \cdot g \cdot l \qquad \text{[Nm]} \qquad (1)$$

Gravity (g) and length (l) is already known.

The load cell gives an output signal in Volts varying linearly with the torque/weights applied. For each load applied the average voltage values should be averaged. The calibration equation is determined using linear interpolation.

$$T = a \cdot [m.v.] + b \qquad \text{[Nm]}$$

5 Figures

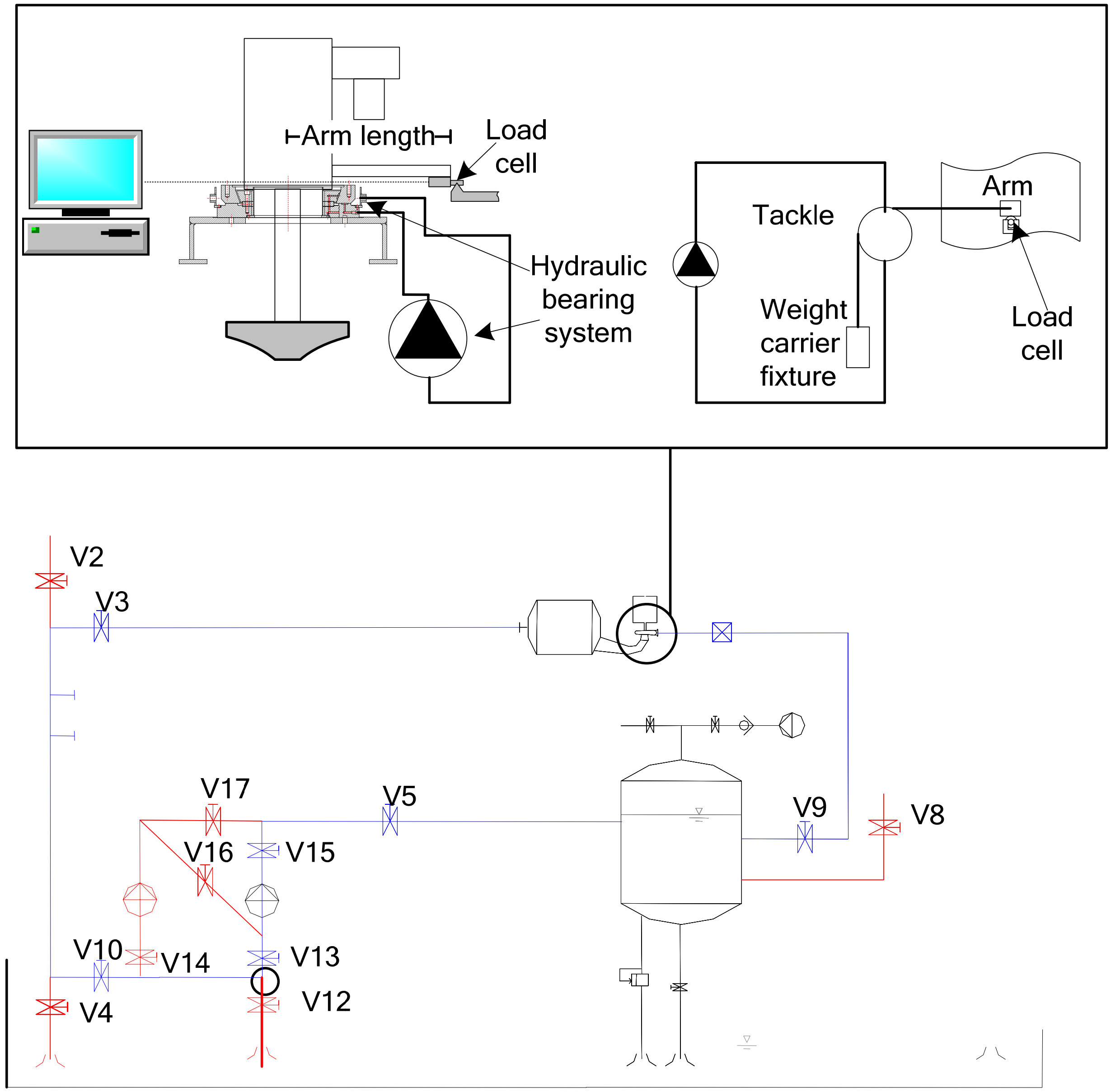

Figure 1: Arrangement

6 References

- Calibration document for weights marked VKL NTNU (LS-Sertifikater på lodder og vekter ved VKL)
- Calibration document for the torque arm length (FCd-4331-4 Supplement)
- Specification for weighing cell (doc IA-4331-4)
- Documentation of gravity from NGU (LS-Sertifikat for målt “g” ved VKL)

Calibration of friction torque measurement in the Francis Turbine Test Rig

1 General

This procedure describes calibration of the generator friction torque in the Francis Turbine Test Rig.

1.1 Definitions and abbreviations

T	Torque	[Nm]
m	Mass of weights	[kg]
l	Length of torque arm	[m]
m.v.	Measured value	[V]
a	Slope in calibration equation	[Nm/V]
b	Intersection constant in calibration equation	[Nm]
g	Gravity	[m/s^2]
hct	Holding clamp thickness	[m]
d	Shaft diameter	[m]
L	Total length measured with micrometer	[m]

Constant of gravity (g) is 9.8215 m/s^2.

2 The system

2.1 Description

The system consists of a hydraulic bearing, and a weighing cell of type Hottinger Z6FC3 with external amplifier. Two mechanical bearings connected to the generator shaft are absorbing all radial and axial movement in the turbine. These two bearings are inserted into a hydraulic bearing/thrust block that makes it possible to measure axial thrust and radial friction. The load cell, connected to the hydraulic bearing unit and a mechanical stop, is absorbing all friction in the two bearings connected to the generator axle. The weight range for the weighing cell is 0-10 kg and an external amplifier in connection with the weighing cell gives an output signal from 0-10 V that is sent to the data acquisition unit for post processing.

The torque for calibration is generated by using weights supplied to a scale pan on the arm. The scale pan is attached to the generator torque measuring rig via a roller bearing. The generators torque arm length from the centre of the generator shaft, is found using a micrometer.

2.2 Equipment used in calibration

- Load cell
    - Hottinger Z6FC3 (Reg. no. 4331-2)
- Measuring amplifier
    - Hottinger ME30 (Reg. no.
- Hydraulic thrust block
- Data acquisition unit
    - National Instruments data acquisition unit
    - LabView for computation and presentation of data.
    - External 24 V power supply
- Hanging fixture
- Calibrated weights
- Micrometer

3 Calibration

3.1 Preparations

1. In order to cancel out oil temperature differences in the hydrostatic bearing the oil pump should be started at least one hour before the rest of the calibration is performed.

2. Connect the data acquisition unit, and make sure the signals are present. Ensure the computer is on and that the signal is present.

3. Find the torque arm length using a micrometer.

3.2 Calibration

1. Start the generator and let it run on 100 rpm. This is done to cancel out effects that occur because friction behaves differently when a system is still.

2. Record the voltage without any weights added. Attach the scale pan to the torque arm. Record the voltage.

3. Place the weights one by one onto the scale pan. The scale pan and the weights in use all have a known weight and are calibrated by Justervesenet.(Norwegian metrology service)

4. For every 2 kg weight applied the voltage reading from the weight cell is recorded. The voltage reading is presented on the computer screen. Make sure the weights have no pendulum motion or no rotation when the recording is made.

5. When the final amount of weights has been placed onto the scale pan, record the reading of the voltage value. Then add a little force by slightly pressing down on the weights for a few seconds. After releasing, record the reading again.

6. Remove the weights one by one. Note the voltage signal at the same points as when the weights were put on.

7. Change the direction of rotation on the generator, but keep the same rotational speed. Perform the prior steps once again. It is assumed that averaging the voltage values for both rotational directions will give the correct offset. This is checked during computations.

4 Computations

The friction torque (T) as a known mass (m) is added is calculated by:

$$T = m \cdot g \cdot l \qquad \text{[Nm]} \qquad (1)$$

Gravity (g) is already known.

The arm length (l) is found by using a micrometer to measure the length (L) from the furthermost side of the shaft to the end of the load cell holding clamp. Then half the shaft diameter (d), and half the holding clamp thickness (hct) is subtracted from the total length.

$$l = L - (\frac{d}{2}) - \frac{hct}{2} \qquad \text{[m]} \qquad (2)$$

The load cell gives an output signal in Volts varying linearly with the torque/weights applied. Voltage values are averaged for each weight point, and the calibration equation is determined using linear interpolation.

$$T = a \cdot [m.v.] + b \qquad \text{[Nm]} \qquad (3)$$

For both rotational directions the slope (a) should be approximately the same. The offset (b) is correct if the difference between the voltage signals in both rotational directions is the same in all reading points.

5 Figures

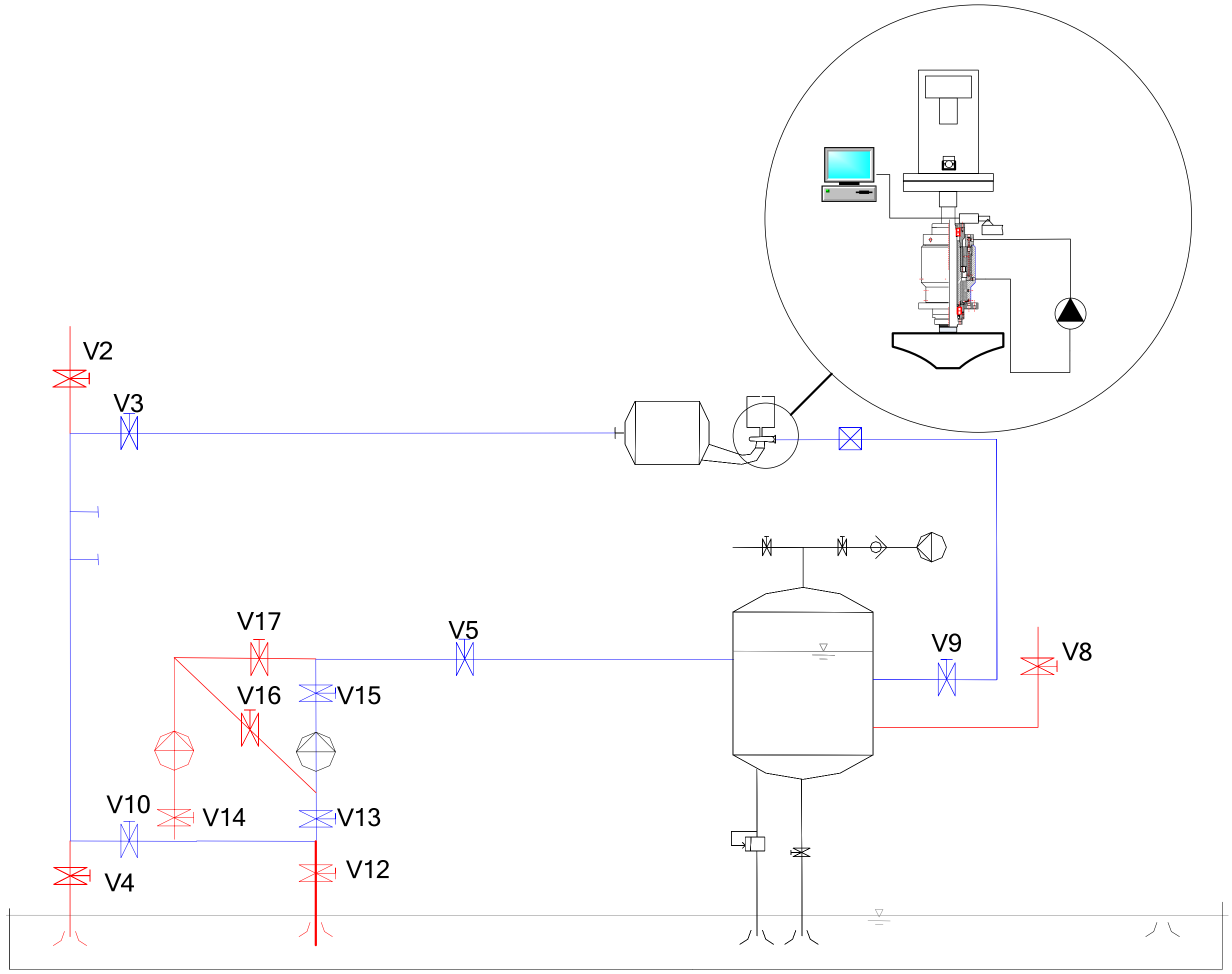

Figure 1: Arrangement

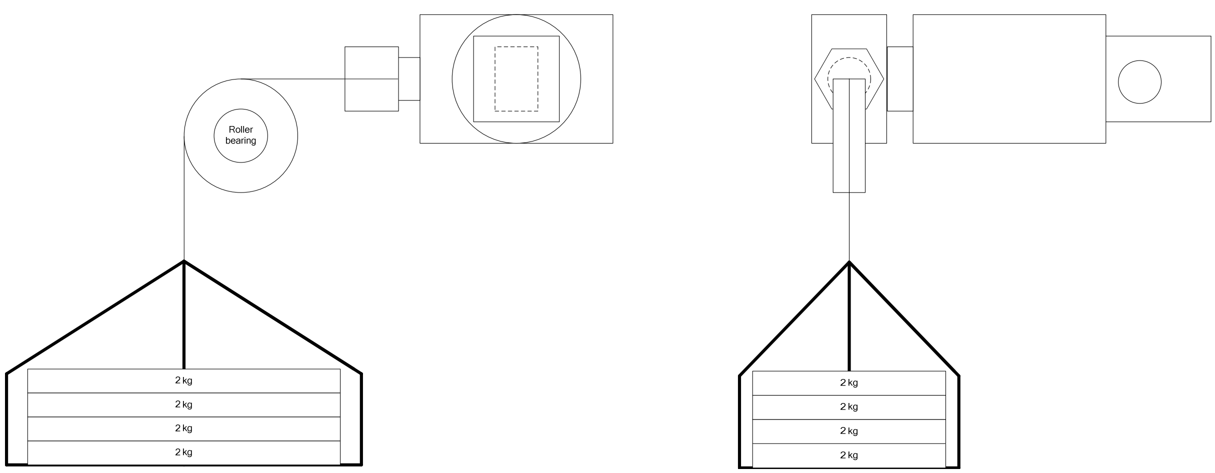

Figure 2: Calibration setup

6 References

- Specification for Hottinger load cell. (doc IA-4331-2 in the instrument archive)
- Specification for Hottinger ME30 amplifier. (doc IA-2763-28)
- Calibration document for weights marked VKL NTNU (LS-Sertifikater på lodder og vekter ved VKL)
- Documentation of gravity from NGU (LS-Sertifikat for målt “g” ved VKL)

Calibration/measurement of generator torque arm length

1. General

This procedure describes how to measure the length of the arm on the torque measurement system at the Francis turbine test rig.

1.1. Definitions/Abreviations

L	Length of torque arm	[m]
d	Generator shaft diameter	[m]
mr	Length of measurement rod	[m]
ee	Length from end of measurement rod to end of torque arm	[m]
bt	Band thickness	[m]

2. General

2.1 Description

The torque measurement system is calibrated using weights applied to a carrier fixture attached to an arm, and the distance from the centre of the generator axle to the weight carrier system has to be determined in order to get a correct torque calibration.

2.2 Equipment used in calibration

- Calibrated micrometer
- Calibrated measuring rod
- Calibrated machinists scale with resolution 1/100 mm

3 Calibration

3.1 Preparations

Take off the bottom generator cover in order to expose the generator shaft.

3.2 Calibration

1. Measure the diameter of the generator shaft with a calibrated micrometer, take a minimum of two measurements to be sure that the measured value is correct.

2. Insert the measurement rod through hole in the generator body in order to reach the generator shaft.

3. Measure the distance between the end of the measurement rod and the end of the torque arm with a calibrated machinist scale with a minimum resolution of 1/100mm.

4. Measure the thickness of the band attached to the carrier fixture.

4 Computations

The length of the arm is found by adding half the axle diameter, the length of the measuring rod, the length from the end of the measurement rod to the end of the torque arm, and half the band thickness.

$$L = d/2 + mr + ee + bt/2 \quad [\mathrm{m}] \tag{1}$$

5 Figures

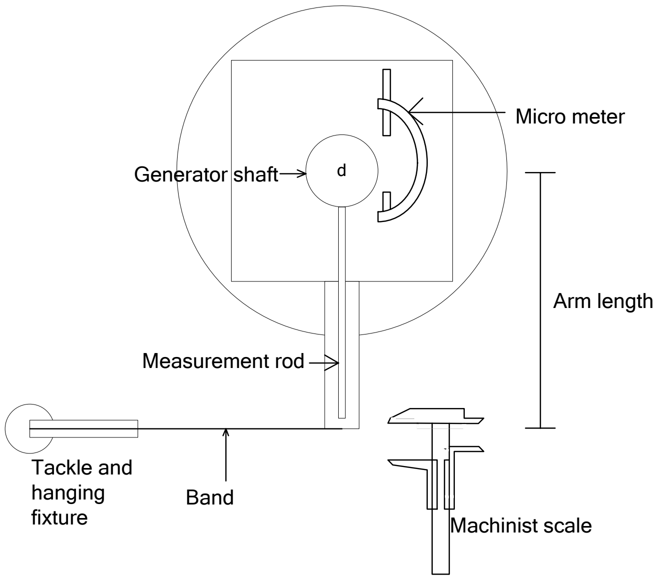

Figure 1: Measurement overview

6 References

- Calibration document for micrometer. (LS Sertifikat for … micrometer)
- Calibration document for measurement rod (FS Lengde på målestav målt av Sintef IPK)
- Calibration document for machinist scale (LS Sertifikat for … skyvelære)

Doc No: FC-4536-8	Rev: 0	Date: 2006-01-31	
Prepared by: Jørgen Ramdal	Approved by: Ole G. Dahlhaug	Classification: Open	Page: 1 of 5

Calibration of axial force measuring system on the Francis Turbine Test Rig.

1 General

This procedure describes the calibration of the axial force measuring system on the Francis Turbine Test Rig.

1.1 Definitions and abbreviations

W	-	Weight	[kg]
m.v.	-	Measured value	
a	-	Slope in calibration equation	
b	-	Intersection constant in calibration equation	
g	-	Gravity	[m/s^2]
F	-	Force	[N]
p	-	Pressure	[kPa]
A	-	Area	[m^2]

Gravity (g) is 9,8215 m/s^2.

2 The system

2.1 Description

The measuring system consists of a hydraulic thrust bearing (Figure 1) and a differential pressure transducer (Figure 2)

Oil pressure is fed to the differential pressure transducer from the two sections of the axial thrust bearing, and the differential pressure is directly dependent on the hydraulic axial thrust.

The output signal from the pressure transducer is 4 – 20 mA. The signal is being transformed into 2-10 VDC using a drop resistor before the data acquisition system.

The pressure range for the transducer is 0 to 3000 kPa which gives a weight range from 0 to app. 1230 kg.

2.2 Equipment used in calibration

- Differential pressure transducer
    - Fuji Electric FKCW38V4AKCYYAE. (Reg. no. 4536-8)
- Drop resistance
    - Type Econsistor 8E16 500 ohm
- Hydraulic axial thrust bearing
- Calibrated weights
- Oil hydraulic pump unit for feeding oil to bearing

3 Calibration

3.1 Preparations

1. Turn on oil hydraulic pump unit.

2. Make sure the display for visualization of the measured volt signal is present on the data acquisition system

3.2 Calibration

1. Record the volt signal with no weights on.

2. Connect the equipment necessary to suspend weights to the end of the generator shaft.

3. Load on the weights one by one and record the total weight (W) and corresponding measured volt signal (m.v) for each weight suspended to the generator shaft. The volt signal should be stable before the reading is taken. A minimum of 5 points are needed to find a satisfying calibration equation and the whole range (0-1230 kg) has to be covered.

4. Load off the weights one by one and record the volt signals for each weight again. For each point a minimum of 4 points should be read.

5. Repeat 1., 2. 3. and 4 obtaining minimum two sets of data

4 Computations

The relation between the force and the pressure measured by the differential pressure transducer is

$$F = W \cdot g = \frac{p}{A} \qquad \text{[N]} \tag{1}$$

Since A is constant in the hydraulic axial thrust bearing, the force is determined directly by using the voltage signal from the pressure transducer.

The calibration equation is a linear equation

$$F = (a \cdot (m.v) + b) \cdot g \qquad \text{[N]} \tag{2}$$

and the relationship is determined using linear interpolation.

5 Figures

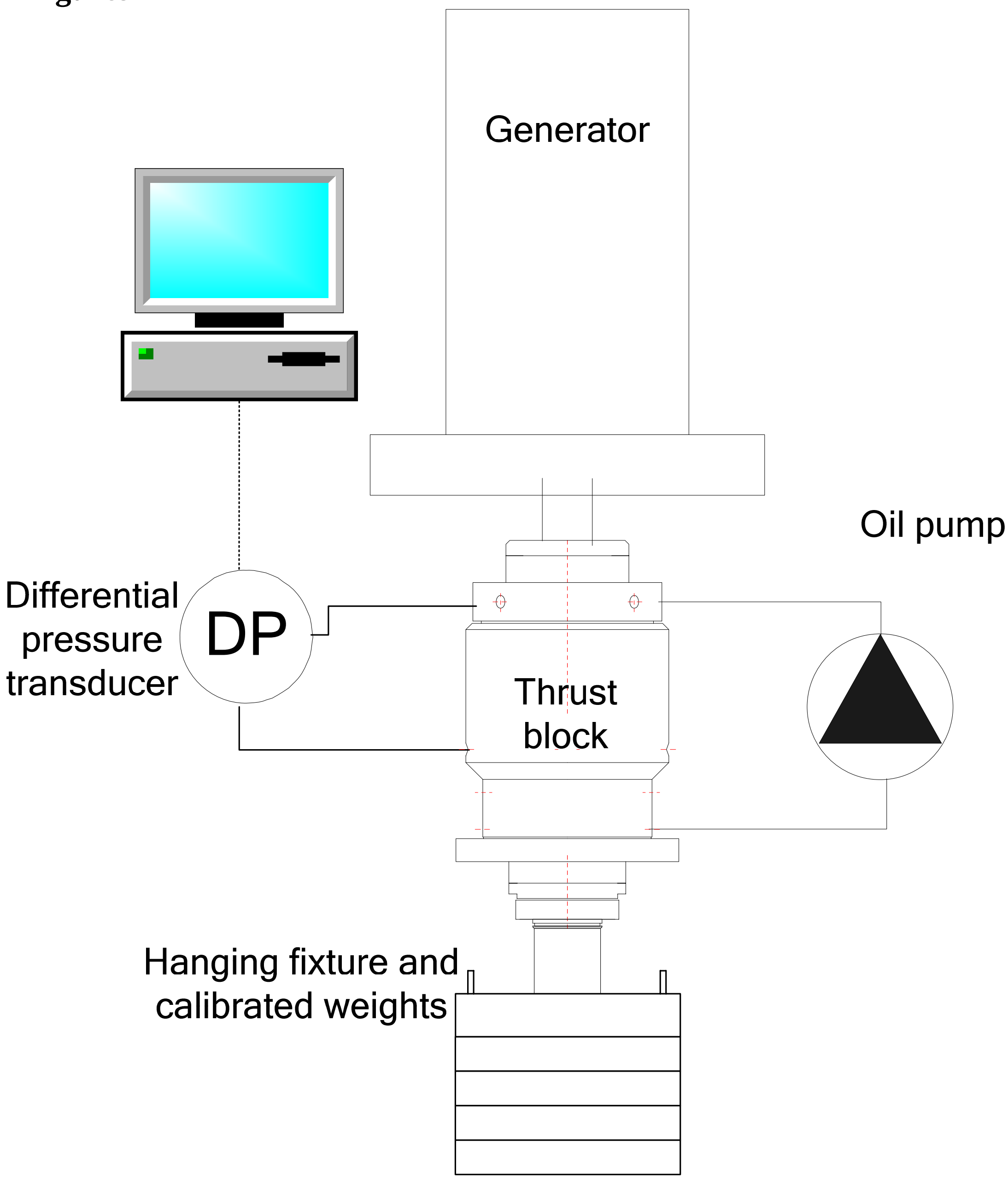

Figure 1: Arrangement

6 References

- Calibration document for calibrated weights and hanging fixture from Justervesenet (Norwegian Metrology Service) (LS-Sertifikat på lodder og vekter ved VKL)
- Documentation for gravity at the Waterpower Laboratory from NGU (LS-Sertifikat på målt "g" ved VKL)
- Specification for Fuji Electric FKCW38V4A differential pressure transducer. (doc IA-4536-1/2/4/5/8)

Doc No:	Rev:	Date:
FC-4624-4-Supplement	0	2006-10-3

Prepared by:	Approved by:	Classification:	Page:
Jørgen Ramdal	Ole G. Dahlhaug	Open	1 of 5

Calibration of discharge measurement system in the Francis Turbine Test Rig without the runner installed

1 General

This procedure describes how the flow meter in the Francis Turbine Test Rig is calibrated in the Waterpower Laboratory.

1.1 Definitions and abbreviations

W	Mass	[kg]
Wm	Measured Weight	[kg]
a_0, a_1, a_2, a_3, a_4	Parameters in correction equation	
ρ_w	Density of water	[kg/m^3]
θ_w	Water temperature	[^{o}C]
θ_{amb}	Air temperature	[^{o}C]
t	Time	[s]
p	Atmospheric pressure	[Pa]

2 The system

2.1 Description

The Francis Turbine Test Rig uses an electromagnetic flow meter to determine the discharge. The laboratory is set up so that water is discharged through the flow meter to be calibrated and to the weighing tank system. By recording weight of the tank before and after, and the time of filling, the flow rate through the flow meter is found.

The electromagnetic flow meter has an internal amplifier and power supply and gives an output signal from 2-10 V that varies linearly with the discharge.

2.2 Equipment used in calibration

- The laboratory piping- and pump system
- Flow meter
  - Krohne Aquaflux IFS 4000 (Reg. nr. 4624-4)
- Weighing tank system
  - Hottinger RTNC load cells (Reg. nr. 4331-5/6/7)

- Hottinger MGC Plus AB22A amplifier (Reg. nr. 2755-9)
- Capacity appr. 86 metric ton -> 73 m^3 water plus mass of tank and calibrated weights.

3 Calibration

3.1 Preparations

1. The thrust block and turbine axle is removed, and the upper cover is sealed using a blind flange.

2. Set up the lab piping and pump system so that water is discharged through the flow meter, and to the weighing tank system. The water is guided through the pressure tank. The guide vanes are set at maximum opening in order to minimize swirl in the draft tube.

3. Make sure nothing disturbs the weighing tank or induces unwanted movements. Remove all shafts connected to the tank, and remove all objects not related to the tank. Inspect the tank pit whit a flash light, to make sure it is free of water, and that no object is jammed between the tank and the pit wall.

4. Make sure that a measuring signal from the flow meter is present.

3.2 Calibration

1. Adjust the pump to obtain wanted flow. The operator has to be cautious to run the rig in a manner that minimize the back flow due to swirl and pressure pulsations due to swirl.

2. Ten calibration points should be recorded. First record 5 points at regular intervals within the expected flow rate of the following test, then repeat the same points again.

3. Record the time, weight of the tank, the atmospheric pressure, water temperature and air temperature, into the recording scheme. (FCd-4624-4)

4. Set the tilting time on the screen controller computer to 120 seconds. Tilt the screen to start filling the tank, and at the same time start recording the volt signal.

5. When the filling has stopped, let the tank stabilize and record the weight of the tank.

6. Repeat steps 1, 2, 3 and 4 until tank capacity is reached. On full tank, empty the tank using the pumps.

7. Repeat steps 1, 2, 3 and 4 until all points are recorded.

4 Computations

To find the correct mass [W] for each recorded point, the measured mass [Wm] has to be corrected using the parameters a, b, c, d and e found in the substitution calibration. (See Calibration document for Substitution calibration of weighing tank)

$$W = a_0 \cdot \frac{mW^5}{5} + a_1 \cdot \frac{mW^4}{4} + a_2 \cdot \frac{mW^3}{3} + a_3 \cdot \frac{mW^2}{2} + a_4 \cdot mW$$

Density of water has to be corrected using formula

$$\rho_w = \frac{10^3}{(1-4,6699 \cdot 10^{-10} \cdot p) + 8 \cdot 10^{-6} \cdot (\theta - 4 + 2,1318913 \cdot 10^{-7} \cdot p)^2 - 6 \cdot 10^{-8} \cdot (\theta - 4 + 2,1318913 \cdot 10^{-7} \cdot p)^3}$$

And the density of air is corrected

$$\rho_{\mathrm{amb}} = \frac{(p_{amb} \cdot 3,4837 \cdot 10^{-3})}{(273,15 + \theta_a)}$$

The mean discharge Q is found by using the corrected weights (W), the corrected density of water (ρ_m) and air (ρ_{a}), and the time (t)

$$Q = \frac{W_2 - W_1}{\rho_w \cdot t \cdot (1 - \frac{\rho_{amb}}{\rho_w})} \qquad [\mathrm{m^3/s}]$$

The calibration equation, giving the relationship between measured volt signal (m.v) and discharge is a linear equation

$$Q = a \cdot (m.v) + b \qquad [\mathrm{m^3/s}]$$

The parameters a, and b, is determined using linear interpolation.

5 Figures

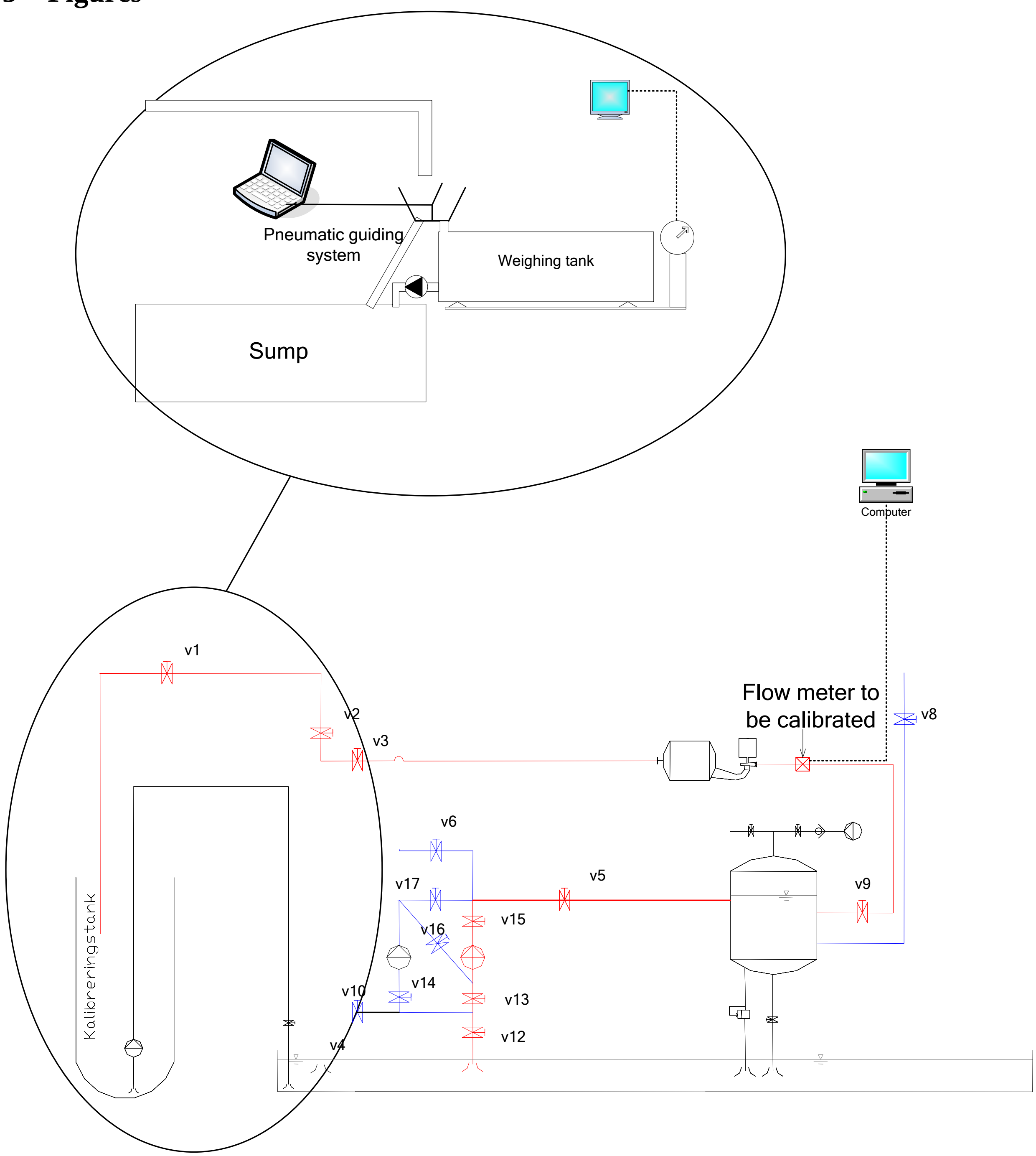

Figure 1: Lab setup

6 References

- Calibration document for Substitution calibration of weighing cells (LCd-4331-5/6/7)
- Specification for flow meter Krohne Aquaflux IFS 4000 (Doc IA-4624-4)
- ISO 4185:1980 Measuring of liquid flow in closed conduits
- Documentation for load cells (Doc IA-4331-5/6/7)
- Documentation for measuring amplifier (Doc IA-2755-9)

Doc No: FC-4514-3	Rev: 0	Date: 2006-05-24	
Prepared by: Jørgen Ramdal	Approved by: Ole G. Dahlhaug	Classification: Open	Page: 1 of 4

Calibration of water temperature measuring system in the Francis Turbine Test Rig

1 General

This procedure describes calibration of the water temperature measurement in the Francis Turbine Test Rig.

1.1 Definitions and abbreviations

m.v.	-	Measured value
a	-	Slope in calibration equation
b	-	Intersection constant in calibration equation
θ	-	Temperature [^{o}C]

2 The system

2.1 Description

The measuring system consists of a temperature probe, with internal amplifier/signal converter. The temperature probe is a PT 100 element. The signal converter gives an output signal that varies from 4-20 mA, which is converted into a 2-10 V signal via a 500 ohm resistance before the data acquisition system. The temperature range is from 0 to 100 ^{o}C. However the calibration range is from 0-32 degrees ^{o}C.

The Waterpower Laboratory has no opportunity to use a primary method to calibrate temperature measurement systems. Therefore a Seabird SBE 38 is used as reference. The Seabird has an accuracy of 0,001 ^{o}C, stability of 0,001 ^{o}C and is calibrated every 2nd year.

2.2 Equipment used in measuring

- Temperature probe
  - (Reg. no. 4514-3)
- 500 ohm resistance
  - Type Econsistor 8E16
- Data acquisition unit
  - National Instruments data acquisition unit
  - LabView for computation and presentation of data.
- Seabird SBE 38 temperature probe.

– Reg. no. 4514-2

3 Calibration

1. Dismount the temperature probe from its position in the pipe, and place it into a bucket with cold water together with the Seabird.

2. Record the temperature measured by the Seabird, and the voltage signal given by the temperature probe.

3. Heat the water, and wait for the signal to stabilize. The temperature probe needs longer time to find the new temperature and stabilize than the Seabird. The temperature and the voltage signal is recorded at certain intervals. A minimum of three points is needed to get a calibration curve.

4 Computations

The relationship between the measured volt signal and the temperature is a linear equation

$$\theta = a \cdot (m.v) + b \qquad [^{o}\mathrm{C}] \qquad (1)$$

The parameters a, and b are found using the least square method.

5 Figures

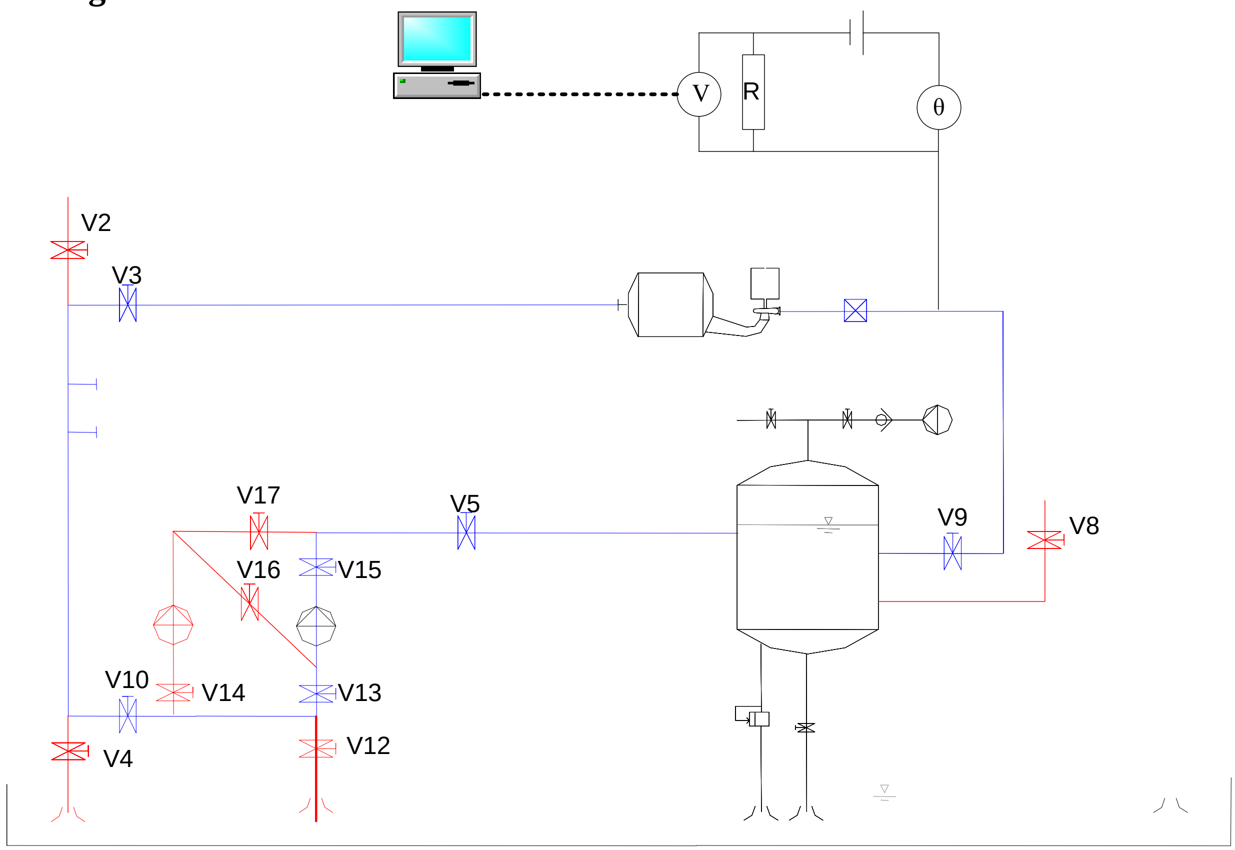

Figure 1: Arrangement

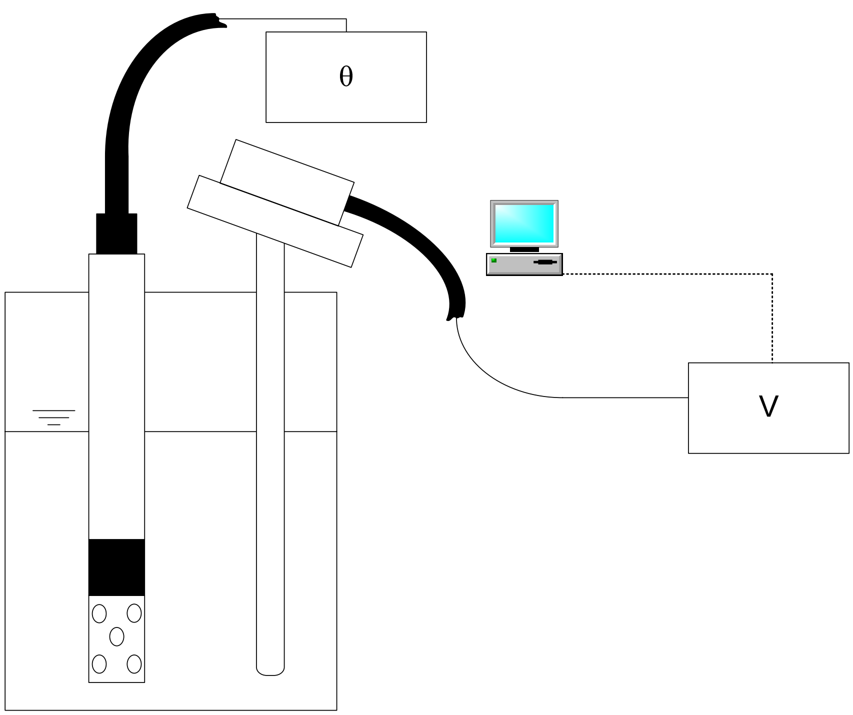

Figure 2: Calibration setup

6 References

- Specification for temperature probe. (doc IA-4514-3)
- Documentation for 500 ohm drop resistance.
- Specification for Seabird SBE 38 (doc IA-4514-2)
- Calibration document for Seabird SBE 38 (Cd-4514-2)

Calibration of guide vane torque in the Francis Turbine Test Rig

1 General

This procedure describes calibration of the guide vane torque in the Francis Turbine Test Rig.

1.1 Definitions and abbreviations

T	Torque	[Nm]
m	Mass of weights	[kg]
l	Length of torque arm	[m]
m.v.	Measured value	[V]
a	Slope in calibration equation	[Nm/V]
b	Intersection constant in calibration equation	[Nm]
g	Gravity	[m/s^2]

Constant of gravity (g) is 9.8215 m/s^2.

2 The system

2.1 Description

The measuring system consists of four especially made guide vanes located one in each quadrant of the turbine. The guide vanes have strain gauges attached. A voltage signal that is sent from an external amplifier and through the strain gauges will vary as the guide vane shafts are stressed due to influence from the water on the guide vanes. The voltage signal is recorded by the data acquisition unit.

The torque for calibration is generated by using a calibration jig, and weights supplied to a scale pans connected to an arm via roller bearings. The generators torque arm length from the centre of the generator shaft, is found using a micrometer.

2.2 Equipment used in calibration

- Strain gauges
    - Hottinger

- Measuring amplifier
    - Spider amplifier and data acquisition unit
- Data acquisition unit
    - Spider amplifier and data acquisition unit
    - National Instruments data acquisition unit
    - LabView for computation and presentation of data.
    - External 24 V power supply
- Hanging fixture
- Calibrated weights
- Micrometer

3 Calibration

3.1 Preparations

1. Mount the guide vane into the calibration jig.

2. Connect the data acquisition unit, and make sure the signals are present.

3. Find the torque arm length using a micrometer.

3.2 Calibration

1. Record the voltage without any weights added. Attach the scale pans to the torque arm. Record the voltage.

2. Place the weights onto the scale pans. The scale pans and the weights in use all have a known weight and are calibrated by Justervesenet.(Norwegian metrology service)

3. For every weight applied the voltage reading from the weight cell is recorded. The voltage reading is presented on the computer screen. Make sure the weights have no pendulum motion or rotation when the recording is made.

4. When the final amount of weights has been placed onto the scale pans, record the reading of the voltage value. Then add a little force by slightly pressing down on the weights for a few seconds. After releasing, record the reading again.

5. Remove the weights. Note the voltage signal at the same points as when the weights were put on.

6. Perform the previous steps once again, but this time with opposite torque direction. This is done because the guide vane torque can work in both directions depending on gate opening.

4 Computations

The torque (T) as a known mass (m) is added is calculated by:

$$T = m_1 \cdot g \cdot l_1 + m_2 \cdot g \cdot l_2 \qquad \text{[Nm]} \qquad (1)$$

Gravity (g) is already known.

The arm lengths (l_1 and l_2) is found by using a micrometer.

The strain gauge gives an output signal in Volts varying linearly with the torque/weights applied. Voltage values are averaged for each weight point, and the calibration equation is determined using linear interpolation.

$$T = a \cdot [m.v.] + b \qquad \text{[Nm]} \qquad (3)$$

5 Figures

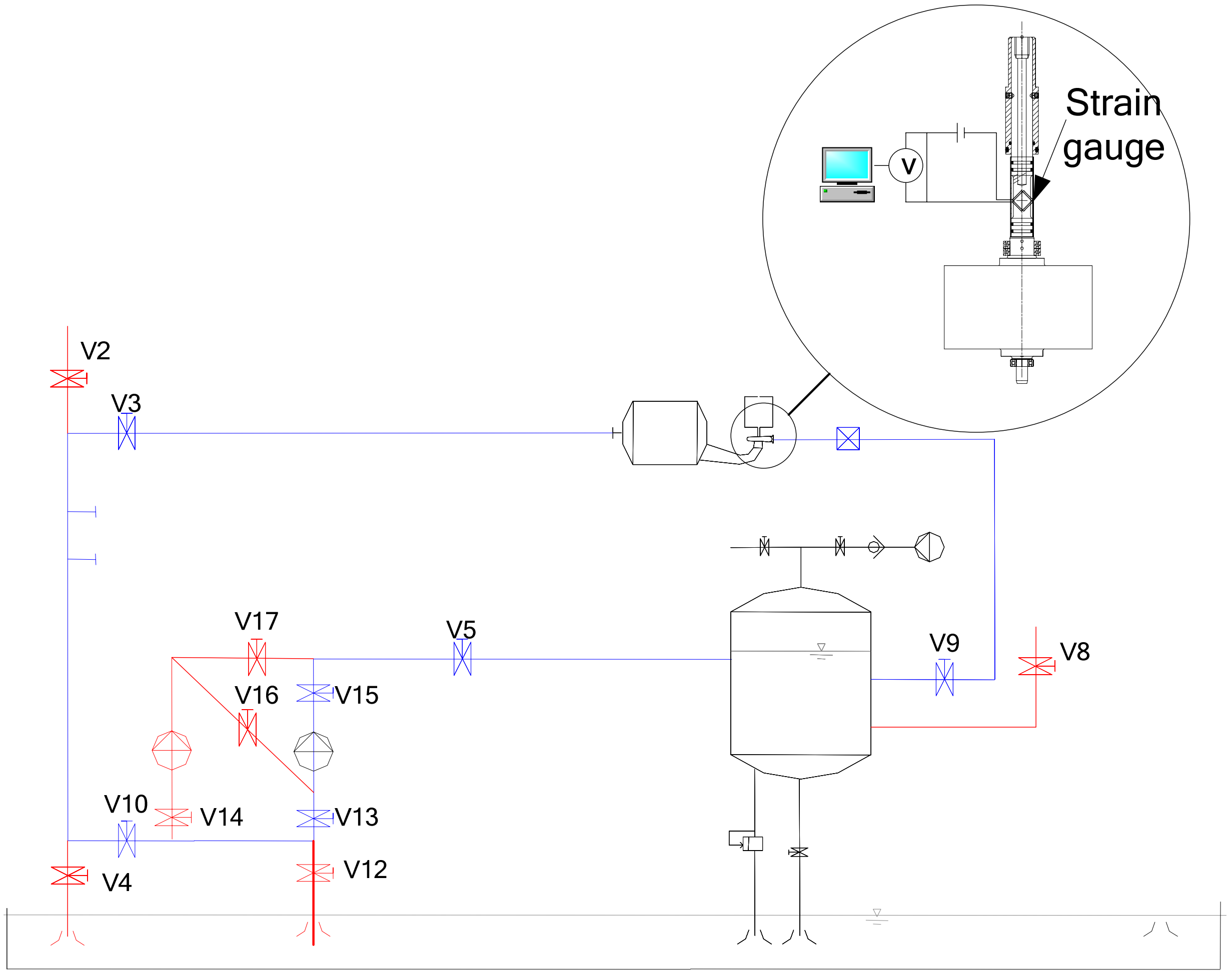

Figure 1: Arrangement

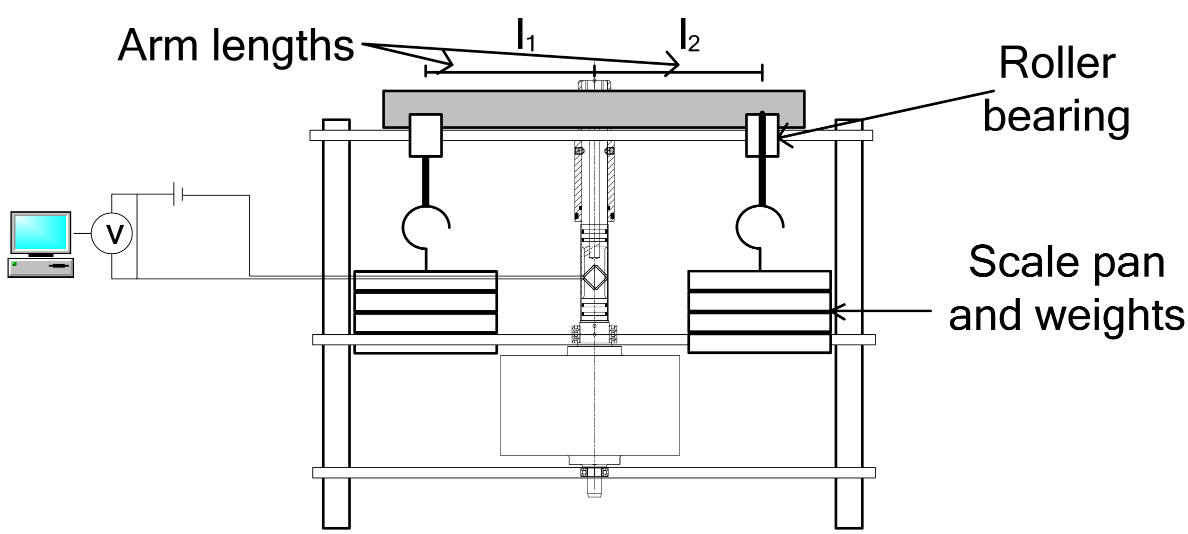

Figure 2: Calibration setup

6 References

- Specification for strain gauges
- Specification for Spider amplifier and data acquisition system (IA-2768-…)
- Calibration document for weights marked VKL NTNU (LS-Sertifikater på lodder og vekter ved VKL)
- Documentation of gravity from NGU (LS-Sertifikat for målt “g” ved VKL)