VATTENFALL TURBINE TEST STAND

TECHNICAL DESCRIPTION

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1 Tests and services

The following tests and services can be provided by the laboratory.

- Hydraulic efficiency
- Cavitation
- Runaway speed
- Axial and radial thrust measurements
- Pressure pulsations measurements with/without air admission
- Guide vane & runner blade torque
- Time resolved measurements
- Velocity surveys (LDV, pitot tube measurements)
- Design and manufacturing of models,
- Laser scanning, photogrammetry

2 Test codes

The laboratory fulfills the requirements and uses of the international test cods IEC 60193, (Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests) and uses both IEC60193 and IEC 62097 (Hydraulic machines, radial and axial – Performance conversion method from model to prototype) for step up procedures from model to prototype.

3 General description of the test rig

The laboratory has three levels, each level having a total area of approximately 240 m^2 (10 x 24 m), see Figure 3.1.

The test rig with control room and flow diverter (32) for calibration of the flow meter(s) is situated on level 3 (+31.4 m). The turbine model (28) is installed in the test rig between the high-pressure tank (22) and the low-pressure tank (30). The energy from the turbine is absorbed by a dynamometer positioned on a hydrostatic bearing (24). The shaft torque (including friction losses in the turbine bearings), speed, head, and flow are measured.

At the ground floor (+23.3 m) is the weighing tank for calibration of flow meters situated on load cells (34) just below the flow diverter at the upper level. At this level is also the electro-magnetic flow meter (16, 17) situated.

The bottom level (+20.7 m) consists of a low water reservoir (1), which contains 300 m^3 of water. Inside the reservoir, a room has been built containing two large centrifugal pumps (4) and (5), a smaller back up pump, a low flow pump for adjustment of the water level in the system, a water filter and a de-aerator with its centrifugal pump.

Turbine testing is carried out in a closed water circuit. The water is pumped trough the flow meter (16), the high pressure tank (22), the turbine model (28), the low pressure tank (30) and returns to the pumps (4) and (5) via the pipe with the valves (12) and (10). The water level and the air pressure above the water surface in the low-pressure tank (30) can be controlled. The air pressure can adjusted between 70 and 2 000 mBar absolute pressure.

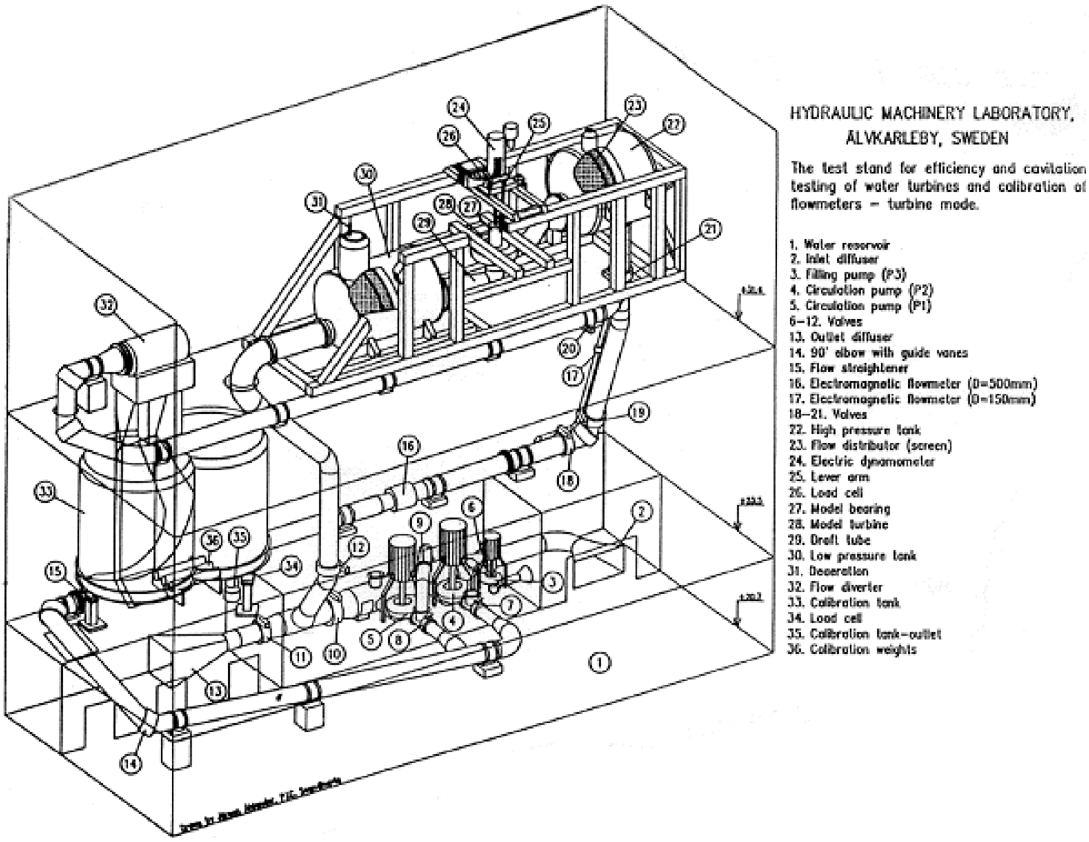


Figure 3.1 Layout of turbine test stand.

3.1 Main parameters

- Model turbine dimensions usually D_M=340-400 mm.
- Water reservoar, 300 m^3.
- 80 m^3 calibration tank for flowmeters.
- In the existing design, the rig is adapted for the testing of model turbines with vertical axis; see figure 3.2 and figure 3.4. The dynamometer is a direct current machine capable of operating in all four quadrants (i.e. can be operate in brake or motor mode in both directions). The brake power is 140 kW for speeds between 600 and 2 500 rpm.
- The speed of the main pumps (2 x 250 kW) is controlled (direct current operation, variable speed, 4Q operation). In parallel operation, the maximum flow is 1.8 m^3/s at a pressure of 20 m head.
- The turbine bearing is hydrostatic. The maximum speed is 3 000 rpm, maximum downward axial force is 23 000 N, maximum radial force is 1 500 N and maximum torque is 1 950 Nm.
- The high-pressure tank can be continuously moved vertically 2 600 mm. An eccentric flange provides further possibilities of adjustments both vertically and horizontally.
- The low-pressure tank (with an eccentric flange for sideways adjustments) can be continuously moved horizontally 3 150 mm. This provides an available space for the encapsulation of the models between 4 010 and 6 750 mm.

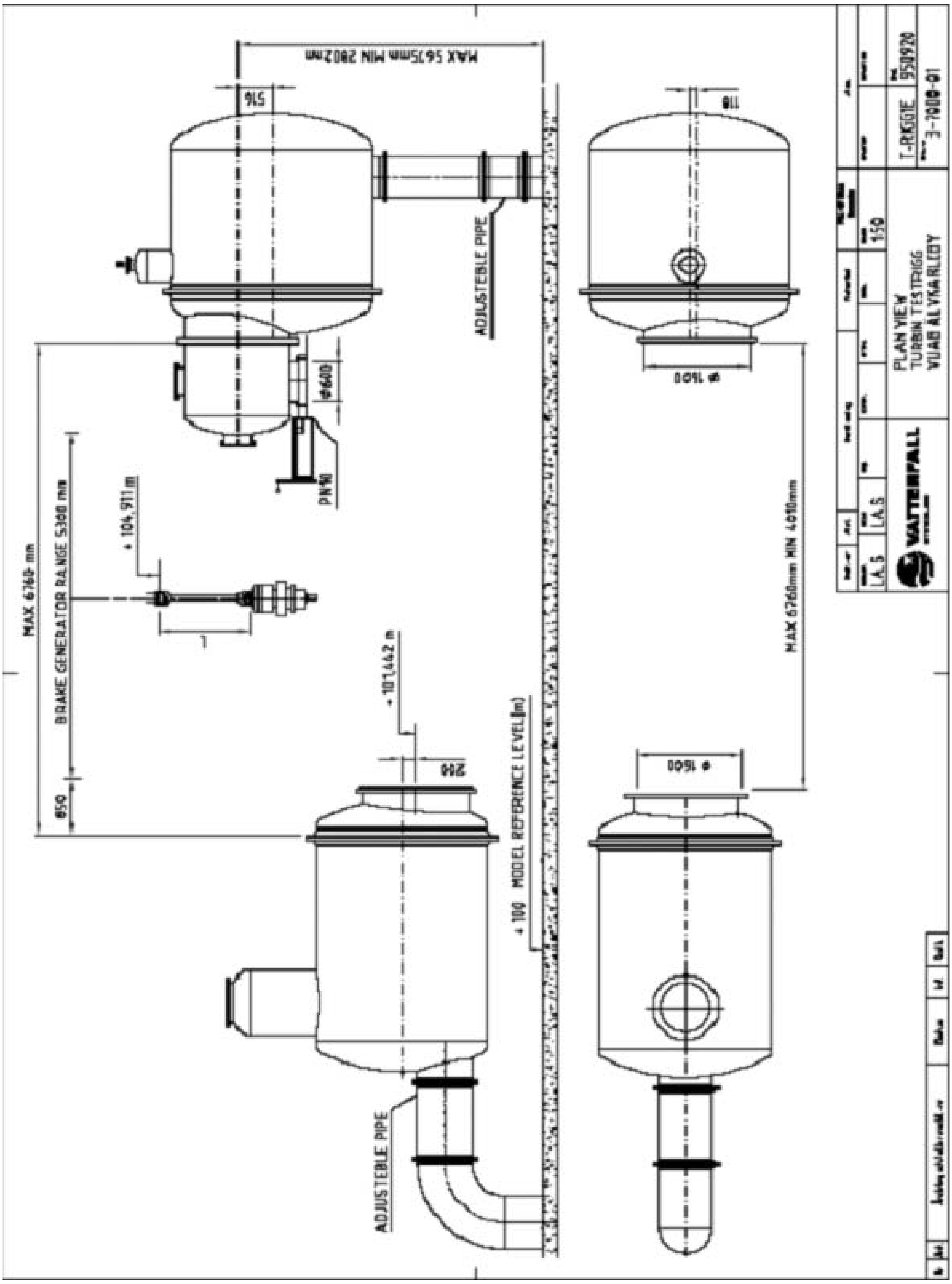


Figure 3.2 Turbine test rig – model installation area.

Figure 3.3 An example of a Kaplan model turbine installed in Vattenfall test rig.

3.2 General system function

All maneuvers during the test are made from a control room and control system. Automatic governors and safety equipment facilitate the operation of the test stand.

A speed governor is controlling the dynamometer speed. The main pumps can either run at a fixed pump speed or with a head governor controlling the main pumps to get the desired test head. The free water surface in the low-pressure tank is regulated by a valve-governor controlling the amount of water in the test loop. A governor controls the air pressure above the free water surface by means of vacuum (pump) and compressed air (compressor). All automatic governors can if necessary be operated in manual mode during the test period.

A control safety system with alarms and interlocks prevents the operator from making mistakes while maneuvering the system.

Signals from all permanent measuring equipment are found at the control desk. A PC-based system (based on LabVIEW) handles data acquisition, presentation on screen and storage in a database. Measurements are performed continuously and both latest values and mean values may be presented on the screen.

Different presentation layouts and control routines are run at calibration and data acquisition.

For evaluation of the hydraulic efficiency, the following parameters have to be measured:

- Rotational speed rpm
- Torque Nm
- Head Pa
- Discharge m^3/s
- Water temperature °C

Measurements of other parameters (such as axial thrust, draft tube pressure etc.) are made simultaneously with the same computer.

3.3 Special system functions

3.3.1 Torque measurement / Hydraulic bearing

The energy from the turbine is absorbed by a dynamometer on a hydrostatic bearing. Shaft torque, friction torque, speed, and axial thrust are measured within the system.

The main parts according to the overview in figure 3.4 are from top to bottom:

- Dynamometer (1)
- Dynamometer bearing (2)
- Flexible axle coupling (4)
- Universal joint shaft (5)
- Hydrostatic turbine bearing (3)

In addition there are some parts vital to the torque measurement:

- Bearing friction torque lever arm (6)
- Deflection roller (7)
- Counter weight (8)

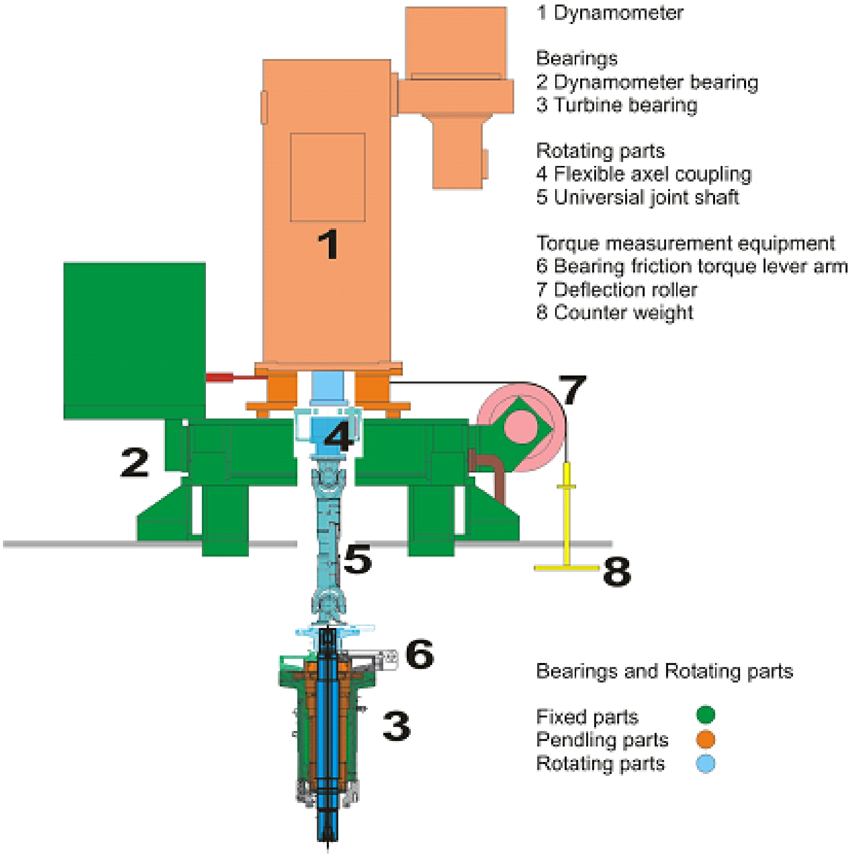


Figure 3.4 Overview of the torque transmission system.

The dynamometer is situated on two carriages, one that can be continuously moved lengthways and the other sideways within the area between the tanks. There is an arrangement for the cables that eliminates any effect on the torque measurement.

The axis between the turbine bearing and the dynamometer consist of two parts, a universal joint shaft and a flexible axle coupling, see figure 3.4. The flexible axle coupling limits the transfer of axial thrust from the runner to the dynamometer.

Both bearings (dynamometer and turbine bearings) are hydrostatic and consist of a fixed, a swinging and a rotating part. The rotating part (the axis) transfers the momentum to the dynamometer. The swinging part is hydrostatically supported and transfers any friction losses to the torque measurement system.

For the main (shaft) torque measurement a lever arm is connected to the swinging part of dynamometer. The end of the arm is connected to a precision thickness gauge strip that transfers the shaft torque of the turbine to the load cell. The other end of the steel strip is connected to a counter weight that ensures that there always is a minimum load at the load cell. The counter weight can be increased when necessary e.g. during runaway tests. The steel strip lies over a hydrostatic deflection roller that transfers the force from vertical to horizontal. The shaft torque measurement system is shown in figure 3.5.

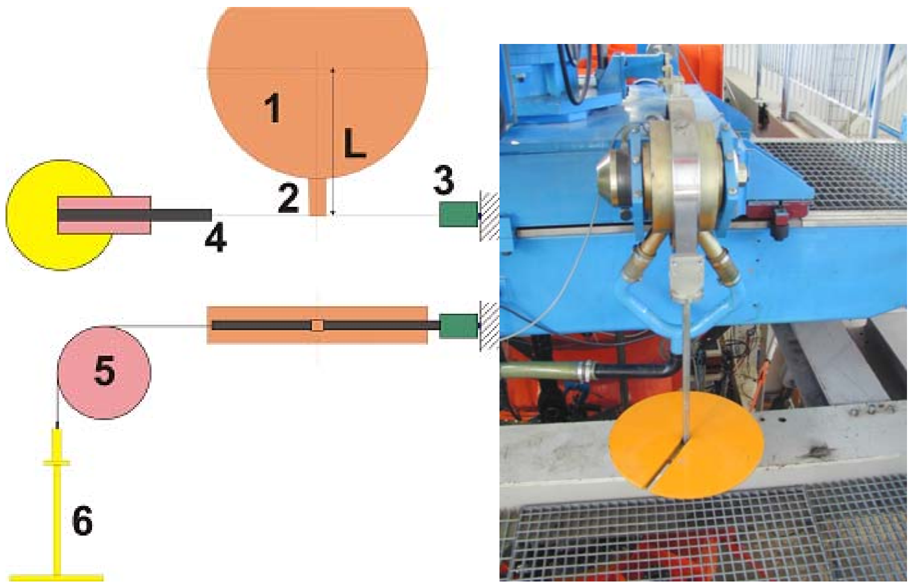
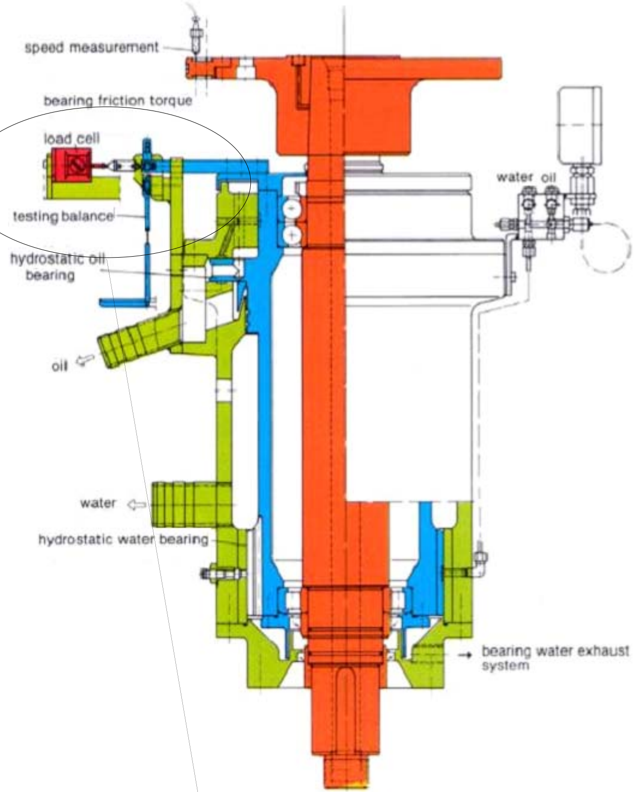


Figure 3.5 Overview of the shaft torque measurement system. 1 Dynamometer, 2 Lever arm, 3 Load transducer, 4 Steel cord, 5 Deflection roller, 6 Counter weight.

The bearing friction torque measurement is performed in the same manner as the shaft torque, with the difference that the bearing friction can be measured bi-directional. The system is also smaller and the deflection rolls have ordinary bearings (figure 3.6).



Main components

- Rotating shaft & coupling
- Roller/ball bearings
- Bearing casing
- Friction torque measuring device
- Oil static bearing
- Water static bearing
- Outer casing
- Adaption piece to model turbine head cover

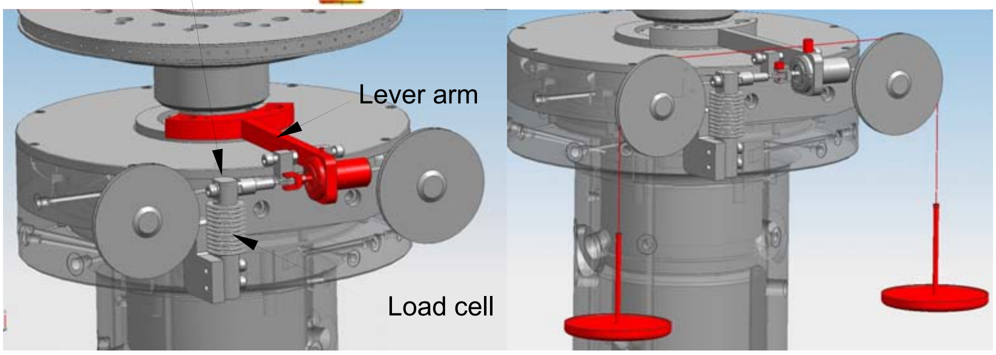


Figure 3.6 Overview of the bearing friction torque measurement system. The set-up is equivalent to the torque measurement with the difference that the bearing friction is bi-directional hence two deflection rollers and counter weights. Left: Operational set up. Right: Calibration set up.

3.3.2 Flow calibration / Flow diverter

The discharge is calibrated by the *Weighing method* described in ISO 4185, [3]. During the calibration the test stand is operated as an open circuit that takes water from the reservoir in the basement. The water is then pumped passed the flow meter at the bottom floor and up to the flow diverter on the upper floor. The flow diverter either diverts the flow back to the reservoir, or into the weighing tank. During calibration the time for the diversion into the weighing tank and the accumulated weight during this period, is measured to get the discharge, see figure 3.7.

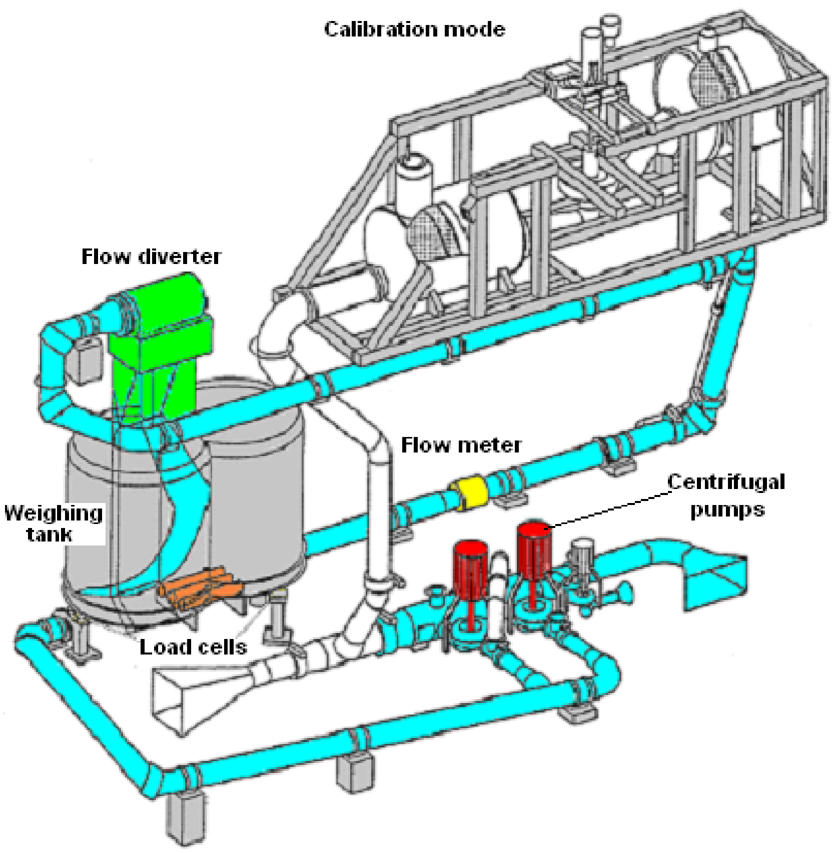


Figure 3.7 The test circuit for flow calibration (pipes – blue, flow meter – yellow, flow diverter – green and weighing tank – grey).

In the beginning of the calibration procedure the flow diverter knife is flipped from one side to the other diverts the flow. The transition time of the knife is approximately 0.2 seconds. The pressure inside the diverter can be regulated with an adjustable nozzle and is kept constant at 0.2 bar during calibration to get a well-defined jet that hits the knife.

The weighing tank has a volume of 80 m³ (LxWxH 6.7x3.8x4.45 m³) and weighs approximately 10 tons. Water enters from the top (from the flow diverter) and pours down into two channels/baffles that secure a smooth flow into the tank. The water is emptied with a valve at the bottom of the tank.

The weighing tank is positioned at 3 double load cells that give the weight of the weighing tank. The load cells are calibrated with calibrations weights that are positioned under the weighing tank are automatically loaded on/off by the control system.

3.3.3 Data acquisition system

The hydraulic laboratory uses a PC-based measurement system. The outline of the standard hardware of the measurement system is shown in figure 3.8.

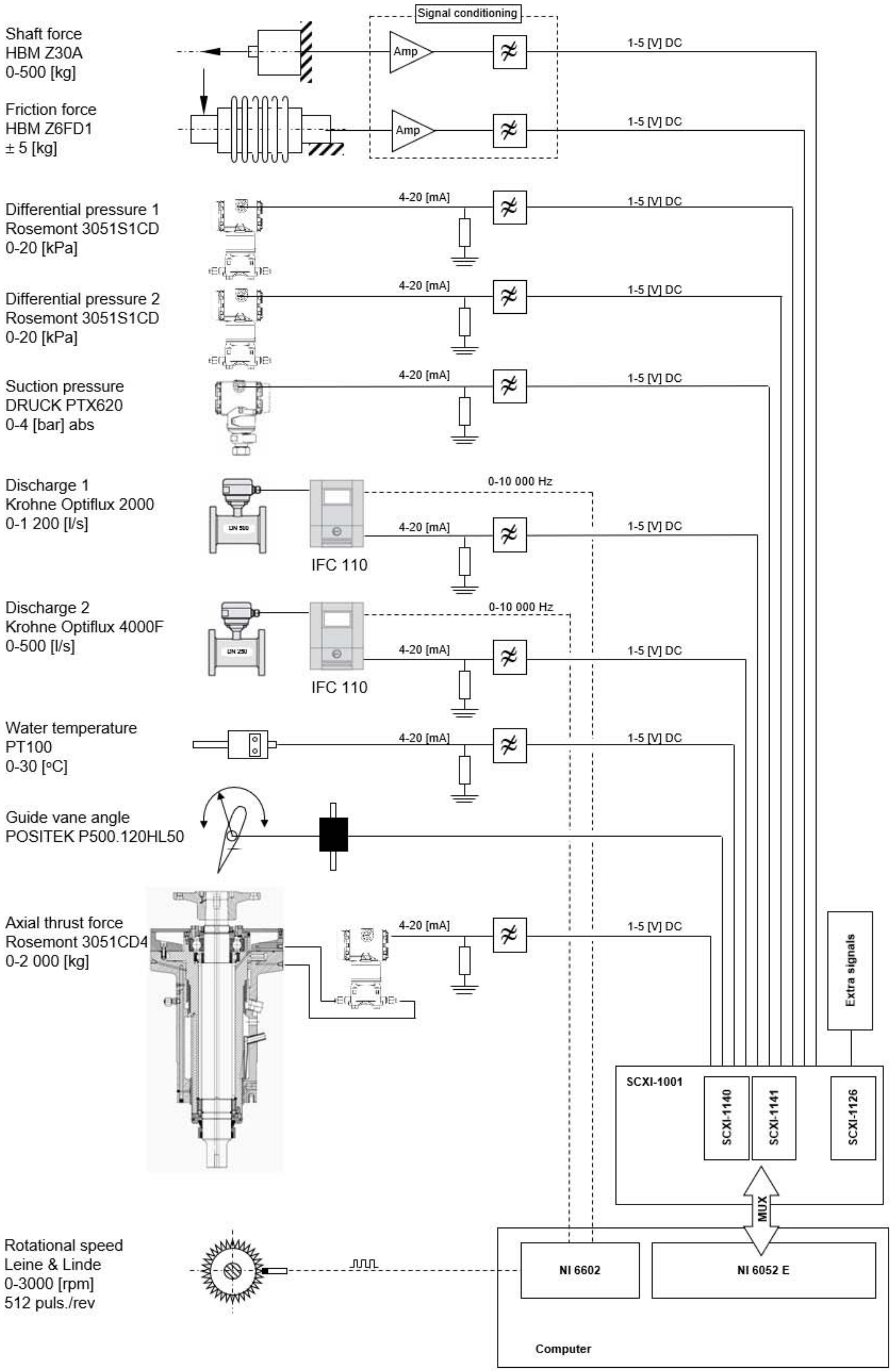


Figure 3.8 Outline of the measurement system.

4 Test stand accuracy

The measurement error with respect to hydraulic efficiency is in general about ± 0.20 %.

Error analysis

Term	Symbol	Unit		Error [%]
	$$f_{\eta_{h,M}} = \sqrt{f^2_{\eta\_rand} + f^2_{\eta\_syst}}$$ $$f_{\eta\_syst} = \sqrt{f^2_{P_{h,M}} + f^2_{P_{m,M}}}$$			
Hydraulic efficiency	$\eta_{h,M}$	-	**Total**	**0.191%**
			Random	**0.068%**
			Systematic	**0.178%**
	$$f_{P_{h,M}} = \sqrt{f^2_{Q_{1,M}} + f^2_{H_M}}$$			
Hydraulic Power	$P_{h,M}$	**W**		**0.169%**
Discharge	$Q_{1,M}$	m³/s		0.132%
Head	H_M	Pa		0.105%
	$$f_{P\,h,M} = \sqrt{f^2_{T_{Lm}} + f^2_{N_M} + f^2_{g_M}}$$			
Mechanical power	$P_{m,M}$	**W**		**0.056%**
Torque	$T_{m,M}$	Nm		0.054%
Rotational speed	N_M	rpm		0.016%
Gravitational acceleration	g_M	m/s²		0.000%
	$$f_\sigma = \sqrt{f^2_{NPSH_M} + f^2_{H_M}}$$			
Thoma number (Sigma)	σ_M	-		**0.318%**
Net positive suction head	$NPSH_M$	m		0.300%
Head	H_M	m		0.105%
Axial load	Fa_M	N		**5.123%**

Figure 4.1 Example of test stand measurement errors.

5 Contact information and location

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The Vattenfall laboratory is located in Älvkarleby, Sweden approximately 110 km north of Stockholm and Arlanda airport.