NTNU – Trondheim
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Design of a Pelton Model Test Rig at Kathmandu University

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MASTER THESIS

for

Ida Bordi Stene

Spring 2014

Design of a Pelton model test rig at Kathmandu University

Design av Pelton modell test rig ved Kathmandu University

Background

The Turbine Testing Laboratory at Kathmandu University is designed to handle performance testing of model turbines. Model tests should be performed according to the specifications of IEC 60193 which is the standard used in such model tests. In order to achieve required accuracy, one of the most important issues is to establish proper test rig for the model tests of Pelton turbines.

The Pelton test rig at the Waterpower Laboratory, NTNU will be used as the initial design. The adaptations needed for the installation at Kathmandu University will be evaluated, designed and documented in this thesis.

Objective:
Design the Pelton model test rig in the Turbine Testing Laboratory at Kathmandu University

The following tasks shall be considered in the project work:

1. Literature survey
    a. Model test of Pelton turbines
    b. IEC 600193
2. Software knowledge
    a. Get familiar with the CAD-program, Inventor
3. Design the test rig at Kathmandu University with the following components
    a. Detail design of the following components:
        i. Turbine housing with drainage system
        ii. Nozzle with control of the needle position
        iii. Main shaft, bearing and system for the measurement of friction torque in the bearings
        iv. Measurement of pressure, flow rate, speed and torque
    b. Overview of the following components and systems:
        i. Generator
        ii. Frequency transformer
        iii. Electrical system to feed the produced energy back to the main system
4. Development of procedures:
    a. Calibration of the pressure sensors and
    b. Calibration of the flow rate measurements
    c. Efficiency measurement
5. Evaluate the possibility to use the test rig for both Francis and Pelton turbines

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in the Waterpower laboratory
☐ Field work

Department of Energy and Process Engineering, 14. January 2014

Olav Bolland
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Ida Bordi Stene

Ida Bordi Stene
Trondheim, 10.06.2014

Abstract

In this thesis the design of a Pelton model test rig for the Turbine Testing Laboratory at Kathmandu University is presented. The Pelton rig at the Waterpower Laboratory at the Norwegian University of Science and Technology is used as the initial design. The objective of this thesis is to do an evaluation of the different design options and, based on this evaluation, create a detailed conceptual design for the eventual Pelton model test rig. The development of technical drawings and documentations is therefore left for future work.

The initial design is reviewed and the required modifications needed for the installation at TTL are identified and analyzed. The main required changes are modifications to the drainage system, to the frame and to the electrical equipment. Regarding instrumentation, it is recommended that TTL uses instruments of the same type or with the same characteristics as the Waterpower Laboratory. The thesis also evaluates, if the Pelton rig can additionally be used to test Francis model turbines. If the frame is designed with a large rectangular steel plate to which the turbine housing is normally attached, this plate can be used to attach the necessary components that are needed to test a Francis model.

Information and details regarding calibration and testing for the Pelton rig is presented. Procedures for the calibration of flow rate, pressure transducer and generator torque as well as procedures for testing the efficiency and the runaway speed of the turbine are found in the appendices.

The final design is shown in Chapter 6. The presented drainage system is a channel that leads the tail water away on the laboratory floor. For the placement of the flow meter, a permanent placement is recommended. Two flow meters are placed on two separate pipes running in parallel. The flow can be directed to the correct flow meter according to the flow rate. A layout of the laboratory showing the possible placement of both the Francis rig and the Pelton rig is also presented. Two alternative solutions for the placement of the Pelton rig are presented. Since both layouts have positive and negative features, it is concluded that there is no clearly superior option. The eventual choice which option to use will depend on a number of external factors.

Sammendrag

Denne oppgaven omhandler utformingen av en Pelton modell testrigg for Turbine Testing Laboratory ved Kathmandu University. Pelton-riggen ved vannkraftlaboratoriet ved NTNU er brukt som utgangspunkt. Målet med denne oppgaven er å gjøre en vurdering av ulike designalternativer og å komme frem til et endelig design.

Utforming og oppsett av Pelton-riggen ved vannkraftlaboratoriet blir først vurdert og endringene som er nødvendige for at riggen skal kunne installeres på TTL blir gjennomgått. De største endringene gjelder avløpet, rammen og elektrisk utstyr. Det blir anbefalt at TTL har instrumenter av samme type eller med samme egenskaper som instrumentene ved vannkraftlaboratoriet innehar.

Det blir også vurdert om Pelton-riggen kan benyttes til å teste Francis modellturbiner. Dersom rammen er designet med en stor rektangulær stålplate, kan denne platen benyttes til å feste de nødvendige komponenter for å teste en Francis modell når Pelton-turbinhuset fjernes.

Informasjon og detaljer vedrørende kalibrering og testing for Pelton riggen er presentert. Prosedyrer for kalibrering av volumstrøm, trykk og dreiemoment og prosedyrer for testing av effektivitet og rusingshastighet ligger i vedlegg.

Den endelige designet er vist i kapittel 7. Avløpet som presenteres her er en rektangulær kanal som fører vannet vekk på gulvnivå bort til reservoaret. For plassering av volumstrømsmåler er en permanent plassering anbefalt. To separate rør med hver sin volumstrømsmåler og med ulik diameter, ligger parallelt og vannstrømmen ledes til korrekt måler i henhold til om strømningshastigheten er høy eller lav.

Det er presentert to mulige plasseringer av Pelton-riggen i laboratoriet og begge løsningene tar hensyn til Francisriggen. Det konkluderes med at begge løsningene vil fungere godt.

Målet med oppgaven er å utvikle et konseptuelt design. Derfor kommer utvikling av tekniske tegninger og dokumentasjon under videre arbeid.

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List of Symbols

β	Jet angle of attack on bucket	$\circ$
η	Efficiency	
η_H	Hydraulic efficiency	
η_M	Mechanical efficiency	
η_{11}	Reduced rotational speed	$s/\sqrt{m}$
ω	Rational speed	rad/s
ρ	Water density	kg/m^3
σ	Thoma's number	
A	Area	m^2
B	Width of bucket	m
c	Absolute water velocity	m/s
c_u	Speed of the water when it exits the turbine	m/s
D	Diameter of a Pelton turbine	m
E	Specific hydraulic energy	J/kg
Eu	Euler's number	
Fr	Froude's number	
g	Acceleration of gravity	m/s^2
H_e	Effective head	m
n	Rotational speed	rpm
n_{max}	Maximum number of turbine revolutions per minute	rpm
P	Mechanical power minus losses to the bearings	W

p	Pressure	Pa
P_M	Mechanical output power	W
P_M	Net input power	W
p_{abs}	Absolute pressure	Pa
P_{LM}	Mechanical power losses	W
Q	Volumetric flow	kg/m^3
Q_{11}	Reduced rotational flow	$s/\sqrt{m}$
Re	Reynolds number	
T	Temperature	$^\circ C$
u	Pheripheral velocity	m/s
v	Velocity	m/s
We	Weber's number	
Z	Height	m

List of Abbreviations

IEC International Electrotechnical Commision.

KU Kathmandu University.

NORAD The Norwegian Agency for Development Cooperation.

NTNU Norwegian University of Science and Technology.

TTL Turbine Testing Laboratory.

Chapter 1

Introduction

The country of Nepal has a substntial potential for hydropower. However, until recently, Nepal itself has done little research and development in this area. Nepal, as a hydropower country, faces several local challenges. The biggest challenge is sediment erosion which causes extensive damages to turbines and related equipment.

Norway has a long history of hydropower and, over the last few years, the Norwegian University of Science and Technology (NTNU) and Kathmandu University (KU) have worked together closely in this area. In 2011, Kathmandu University inaugurated the Turbine Testing Laboratory (TTL) and plans for installing testing rigs are currently being developed. Having a functional turbine testing laboratory of international standard can have a significant positive impact on the development of the hydropower industry of Nepal. This test facility, which can assist in design modifications and performance analysis, will help to produce turbines that are better equipped to handle the local environment.

Pelton turbines are relevant for Nepalese conditions because of their good results when the head is high and the volume flow relatively low as is often the case for hydropower sites in Nepal. The installation of a Pelton turbine model test rig is therefore an essential step in the development of TTL. The aim of this thesis is to design such a rig using the Pelton model test rig at the Waterpower laboratory at NTNU as a base. It will also be investigated , if this rig can be extended to allow the testing of Francis model turbines.

The objective of this thesis is to do an evaluation of the different design options for the rig, and to develop a detailed conceptual design based on this evaluation. The focus is not on mechanical design which will be left for future work.

Chapter 2

Background

In this chapter the Turbine Testing Laboratory at Kathmandu University will be further presented in addition to the previous work done by students that will be used in the design of the Pelton rig.

2.1 Turbine Testing Laboratory at Kathmandu University

The Turbine Testing Laboratory at Kathmandu University was inaugurated in 2011 and is set up to play a vital role in research, development, training and education for the hydropower industry in Nepal. The blue-roofed laboratory can be seen in Figure 2.1.

Figure 2.1: Turbine testing laboratory at KU

Currently, the laboratory consist of a simplified Francis model test rig and a cross-flow model test rig. The simplified Francis model test rig is not functional, since it lacks vital components and is not connected to a generator.

2.1.1 Layout and Specifications of the TTL

The technical specifications of the turbine testing laboratory are listed in table 2.1.

Feature	**Value**
Open System Head	30 m
Closed System Head	150m
Maximum Flow	500 l/s
Maximum testing Capacity	300 kW
Lower Reservoir	300 m^3
Upper Reservoir	100 m^3
Electric Overhead Traveling (EOT) Crane Capacity	5000 kg

Table 2.1: TTL Specifications [15]

There are two pumps each of a capacity of 250 l/s and head of 75 m. When the pumps are run in parallel mode a flow of 500 l/s is achieved and running the pumps in serial mode gives a head of 150m.

The laboratory spans three floors. It consists of a office floor, a laboratory, a water reservoir and a pump room. The floor area is approximately 18m x 8m according to the drawings of the laboratory. The layout of the laboratory, including the flow circuit, is shown in Figure 2.2 [9].

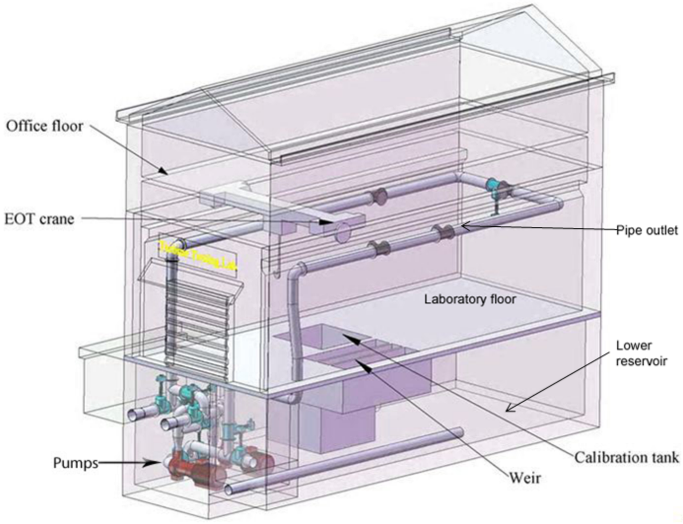


Figure 2.2: Layout of laboratory and flow circuit at KU [9]

The dimensions of the laboratory that will be presented in this thesis are based on dimensions given in the drawings of TTL and on measurements that the author and Inger Johanne Rasmussen took when visiting TTL in the spring of 2014. The placement of the upper pipe circuit and the corresponding flanges could not be accurately determined since the original drawings contained errors and the dimension could only be visually inspected.

2.1.2 Plans

Plans to install more rigs are being developed. Several rigs are being discussed, but the focus lies on getting fully-functional Francis and Pelton model test rigs.

Francis model test rig

Staff and students at TTL have gained knowledge about the Francis turbine through the work related to the simplified rig. Initially the plan was to complete this rig, but now the focus has shifted to installing a new rig that is fully functional and certified by the IEC 60193 standard[5]. Plans for this rig are being drafted and master student Inger Johanne Rasmussen at the Waterpower laboratory at NTNU is writing her thesis on the design of this rig [13]. It will be financed mainly by The Norwegian Agency for Development Cooperation (NORAD) which also was a major contributor to the construction of the laboratory[15].

The Francis rig, including the piping circuit, draft tube, high-pressure tank and low-pressure tank, will require a large section of the available space in the laboratory which will impact the size and placement of other rigs.

Pelton model test rig

The design of the Pelton model test rig is the main focus of this thesis. The Pelton rig will be considerably smaller than the Francis rig and easier to place in the laboratory. Chapter 4 examines the design options and Chapter 6 shows the preferred solutions.

It will also be evaluated if this rig can be used to also test Francis model turbines.

2.1.3 Limitations and challenges

The laboratory faces several challenges with regard to physical size of the laboratory, the current financial situation and the availability of the appropriate equipment and instruments.

Size limitations

The size of the laboratory is a major limiting factor when considering the installation of new rigs. Pumps, water tanks and piping systems require considerable space. Furthermore, with several different types of rigs at the same location, how to design the layout of all required components inside the laboratory is also a challenge.

Pipe circuit limitations

The pipe circuit introduces limitations since it is only possible to run one rig at a time. There are two pumps in the laboratory and these could be used for two independent pipe circuits. This would involve re-construction of the current pipe cycle and pump room layout.

Financial limitations

Nepal is one of the poorest countries in the world and KU has a different financial situation compared to NTNU. This presents new challenges as prioritization regarding new projects and equipment will have to be made.

NORAD financed 60% of the construction of TTL. 20% was financed by KU and the rest by Nepalese industry and institutes. It is expected that NORAD will continue to be a major contributor [15].

Access to Instruments and Equipment

Access to high quality instruments and equipment in Nepal is limited. This means that the TTL would have to either develop their own equipment, or to import equipment and suitable instruments from abroad. The IEC60193 standard [5] contains specific requirements to performance and uncertainty levels for equipment, parts and instruments. These added requirements introduces further limitations to which instruments and equipment to purchase.

Cleanliness of the laboratory

The laboratory is located in a sandy area and this introduces the problem with dust. The dust gets into the reservoir and impacts the density of the water as well as damage equipment and instruments. The IEC60193 standard [5] requires the water to be pure and free of particles, since the particles will give an incorrect results when testing.

2.2 Previous work

In this section previous work by other students that are relevant for the design of the Pelton rig will be presented. Kyrre Reinertsen and Johanne Seierstad wrote their master thesis at the Waterpower laboratory, while Suman Aryal wrote his project thesis at the laboratory while on exchange from Kathmandu University.

2.2.1 Kyrre Reinertsen: Design of bearing block

Kyrre Reinertsen designed in his master thesis a new bearing block for the Pelton model test rig at the Waterpower laboratory at NTNU including a system for measuring friction torque [14]. Figure 2.3 shows his CAD model of the Pelton rig at NTNU. The CAD models in this thesis are based on Reinertsen's models.

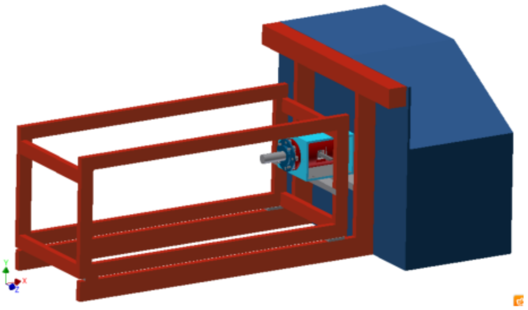
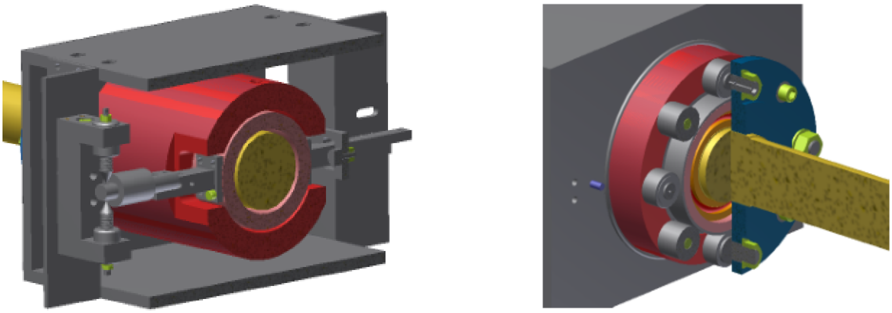


Figure 2.3: Inventor drawing of the Pelton model test rig at NTNU [14]

In the bearing block the shaft is coupled to an inner cylinder with two roller bearings. The inner cylinder is fixed to an outer cylinder with eight roller bearings, four on each end. Figure 2.4 shows the bearing block and Reinertsen's design for measuring friction torque.



(a) Method of calibrating and measuring the friction

(b) Section view of the bearing casing

Figure 2.4: Bearing block [14]

The friction torque is measured by attaching the inner cylinder to a force cell.

2.2.2 Suman Aryal: Design of Pelton model test rig at KU

Suman Aryal developed preliminary plans for the design a Pelton model test rig for TTL [1]. He used the rig at NTNU as the initial design, but changed the design of the drainage system. His design and placement within the laboratory is shown in figure 2.5.

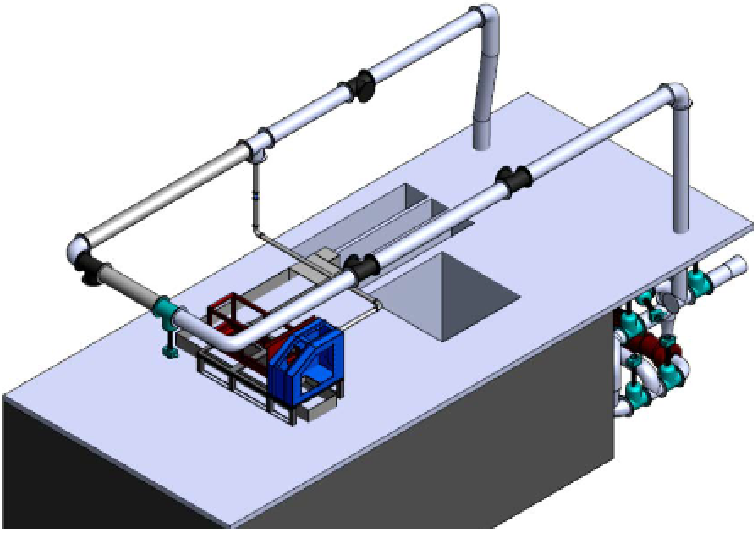


Figure 2.5: The Pelton rig placed within TTL [1]

2.2.3 Johanne Seierstad: Design of system for flow calibration

Johanne Seierstad designed in her master thesis a system for calibrating flow rate at TTL [16]. In her design the flow rate is calibrated using a volumetric method and the whole system is dimensioned to fit the simplified Francis test rig.

Figure 2.6 shows the calibration facility. The flow meter is attached to the pipe coming from the pump room. A deflector mechanism directs the water into the calibration tank or to the reservoir when the desired level in the tank is reached.

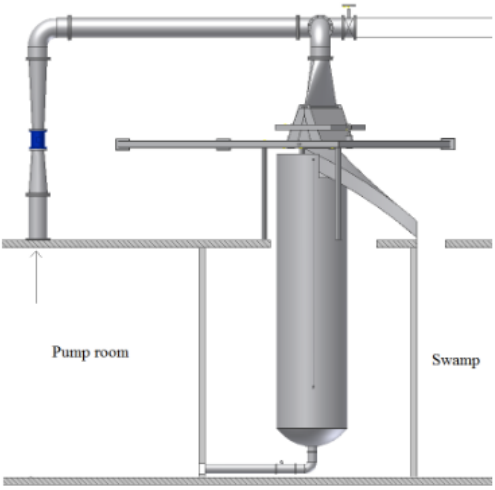
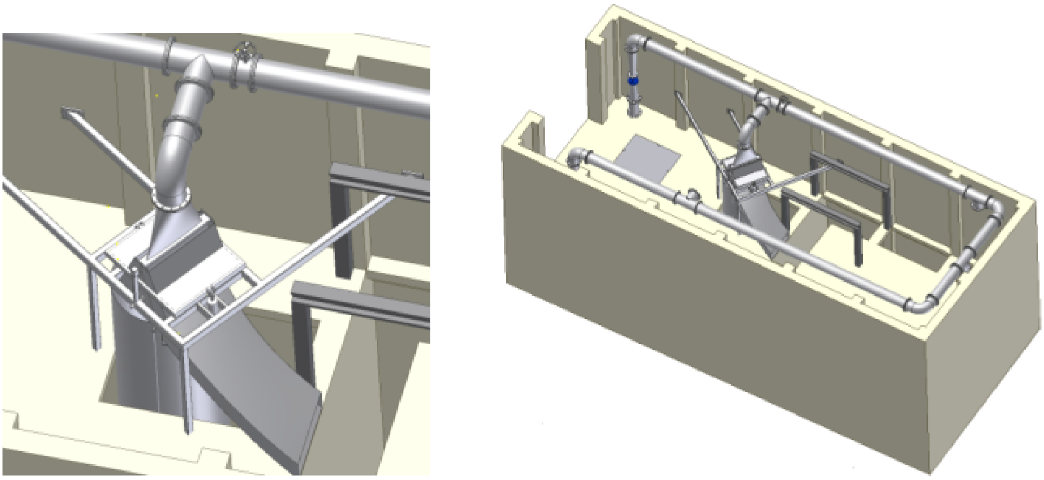


Figure 2.6: The volumetric calibration rig [16]

Figure 2.7 shows the calibration facility when placed in the laboratory. The frame of the simplified Francis test rig can be seen to the right of the calibration facility.



(a) Close view of the calibration rig [16]

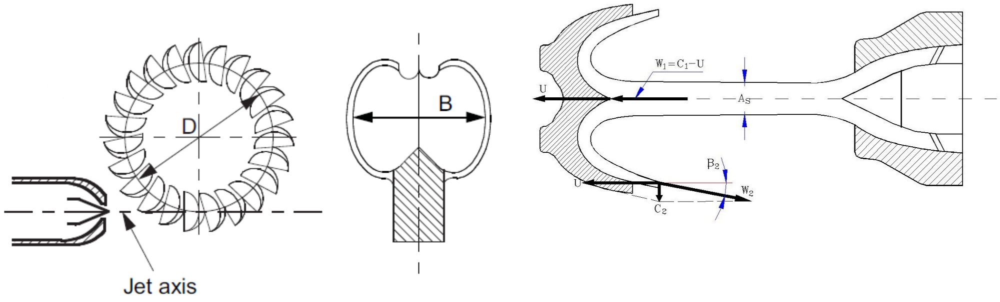
(b) The calibration rig installed in the laboratory [16]

Figure 2.7: Placement of the rig in the laboratory

Chapter 3

Theoretical background

The Pelton turbine is categorized as an impulse turbine since it extracts energy from the impulse of the moving water. This is done by converting the water's potential energy into kinetic energy. Discharging the water through the nozzle creates a free jet, which is directed to buckets fixed on the runner. The water jet impinges onto the bucket and is split by the ridge in the center. After a 180 ° turn, the water is dropped to the ground. The reaction force from the water transfers energy to the runner. Figure 3.1a shows the main dimensions for a Pelton turbine and the runner diameter where the water jet hits the bucket. In Figure 3.1b the resulting velocity vectors can be seen.



(a) Main dimensions of a Pelton turbine [3] (b) Velocity vectors for a Pelton turbine [2]

Figure 3.1: Main dimensions of a Pelton turbine

The Pelton turbine is suitable for medium to high heads with relatively low volume flow. The Pelton turbine either has a horizontal or a vertical shaft. A Pelton turbine with a horizontal shaft normally has a maximum of two jets, while a vertical turbine can have up to six jets. If the turbine is run on part-load, more jets will increase the efficiency [7].

3.1 Power

Power is the rate at which energy is transferred. Mechanical power P_M [W] in a Pelton turbine is the power that is transmitted from the runner to the shaft. P_{LM} [W] is the mechanical power loss due to friction in the bearings and in the shaft seals. P [W] is the mechanical power after deducting the losses.

$$P = P_M - P_{LM} = T \cdot \omega \tag{3.1}$$

The net input power, P_H [W], is the hydraulic power which is available from the water that enters the turbine.

$$P_H = \rho \cdot g \cdot H_e \cdot Q \tag{3.2}$$

Specific hydraulic energy E $[\frac{J}{kg}]$ is the energy that is available between the high and low pressure reference sections 1 and 2 of the machine. Equation 3.3 shows its definition according to the IEC60193 standard [5].

$$\begin{gathered} E = P_H \cdot (Q \cdot \rho)_1 = \frac{p_{abs1} - p_{abs2}}{\overline{\rho}} + v_1^2 - v_1^2 + g \cdot (z_1 - z_2) \\ \overline{\rho} = \frac{\rho_1 + \rho_2}{2} \end{gathered} \tag{3.3}$$

3.2 Efficiency

The efficiency of a turbine is the ratio between the mechanical output power and the net input power. The hydraulic efficiency is the overall efficiency of the turbine without losses in the generator or the bearings being included.

For the calculation of the optimal efficiency, it is usually assumed that the speed of the water when it exits the turbine, c_{u2}, is zero, i.e. that all the energy from the water is transferred to the runner. As u_1 converges towards $\frac{1}{2}$ c_1 and c_{u2} goes towards zero, η_H reaches is maximum value [7]. Hydraulic efficiency is defined as the ratio of power transfer to the runner to the potential energy available from the flow.

$$\eta_H = \frac{\rho \cdot Q(u_1 \cdot c_{u1} - u_2 \cdot c_{u2})}{\rho \cdot Q \cdot g \cdot H_e} \tag{3.4}$$

The hydraulic efficiency can also be expressed as

$$\eta_H = \frac{\text{Mechanical output power}}{\text{Net input power}} = \frac{P_M}{P_H}. \tag{3.5}$$

The mechanical efficiency η_M is defined as:

$$\eta_M = \frac{P}{P_M} \tag{3.6}$$

The total efficiency η for the turbine is defined as:

$$\eta = \frac{P}{P_H} = \eta_H \eta_M \tag{3.7}$$

A Pelton turbine has a higher available efficiency at a larger operational range compared to Francis and Kaplan turbines, but both of the latter have higher maximum efficiencies . The maximum efficiency for the best Pelton turbines η is about 92% [7]. Figure 3.2 shows the efficiency characteristics for five types of turbines as functions of capacity ratio.

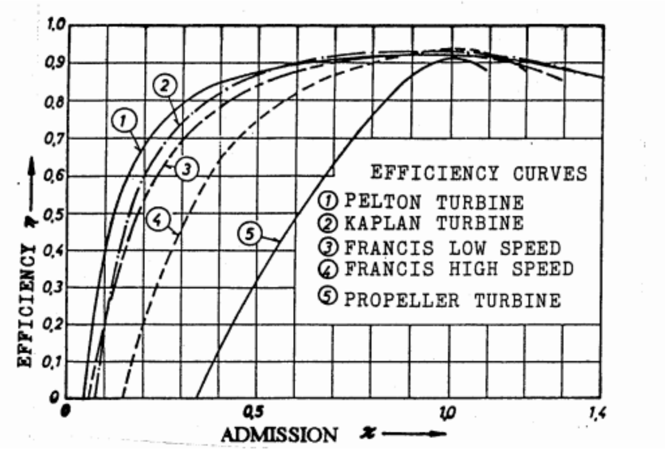


Figure 3.2: Efficiency characteristics of different types of turbines as functions of capacity ratio. [7]

3.3 Model Testing

The purpose of turbine testing is to determine performance parameters and to check if the turbine is performing according to the specifications from the manufacturer. A full scale prototype of a turbine is large and challenging to test compared to a scaled down model. Laboratories often have size limitations and testing the model can help to improve design and performance before the installation of the prototype.

When scaling down the turbine, it is important to follow international standards in order to ensure the accuracy of the results. The international standard IEC 60193[5] applies to laboratory models of any type of hydraulic turbine, storage pump or pump-turbine. The objective of the IEC 60193 standard is to determine if the main hydraulic performance contract guarantees are satisfied, for example the guarantees for hydraulic performance. The standard also defines terms, quantities and methods to be used for testing, measuring and computations [5].

IEC 60193 contains several requirements for the scaling down from a prototype to a model. Most of these requirements can be split into the following categories:

Geometrical Similarity

Similarity in physical shape and dimensions. IEC 60193 provides detailed procedures that assure geometrical similarity. Surface waviness and roughness of the model compared to the prototype must also be checked and be within the allowed deviation.

Hydraulic Similitude

To ensure hydraulic similitude two conditions must be met:

- Geometrical similarity as described above.
- Identical ratios of forces acting between the fluid and the turbine with its connected components.

Table 3.1 shows the most significant of these ratios, defined by their similitude numbers.

Similitude number (symbol)	**Ratio of forces**	**General definition**
Reynolds (Re)	$\frac{\text{inertia}}{\text{viscosity}}$	$\frac{v_c \cdot L_c}{\nu}$
Euler (Eu)	$\frac{\text{pressure}}{\text{inertia}}$	$\frac{\Delta p_c}{\rho v_c^2}$
Thoma (σ)	-	$\frac{\text{NPSE}}{E}$
Froude (Fr)	$\frac{\text{inertia}}{\text{gravity}}$	$\frac{v_c}{(g \cdot L_c)^{0.5}}$
Weber (We)	$\frac{\text{inertia}}{\text{surface tension}}$	$\frac{p_c \cdot L_c \cdot v_c^2}{\sigma^*}$

Table 3.1: Similitude numbers [5].

Achieving hydraulic similarity can be challenging. Often it is impossible for all ratios of forces to be identical at the same time. In this case, it has to be considered which ratio should be prioritized for the given circumstances.

3.3.1 Model and Test Requirements

Table 3.2 shows minimum values for a number of parameters for both Pelton and Francis turbines according to IEC60193.

Parameter	**Pelton**	**Francis**
Reynolds number Re	$2 \cdot 10^6$	$4 \cdot 10^6$
Specific hydraulic energy E $(J \cdot kg^{-1})$	500	100
Reference diameter D m	-	0.25
Bucket width B m	0.08	-

Table 3.2: Minimum test parameter values by model [5]

3.3.2 Condition of the Water

The water used during tests should be free of impurities and without air or gas bubbles since all of these can have an influence on the water properties. The water temperature should not exceed 35 °C, and should not vary significantly during the tests. There should be no leakage in or addition of water to the flow circuit, as this could impact results [5].

3.3.3 Calibration

Calibration is done to ensure a correct relation between sensor output, i.e. V or mA, and the physical value in question. The results from the calibration are used to convert the results from testing which leads to a more accurate overall result. According to IEC60193, calibration should be executed before and after testing to check if any changes were made to the sensors during testing. Calibration should also be performed *in situ* when possible[5].

The procedures and requirements for calibration relating to the Pelton model test rig are further described in Section 5.1.

3.3.4 Testing

Testing is done to determine performance parameters for the turbine. The different turbine types require different sets of tests depending on the properties being tested. For the Pelton turbine, it is standard to test turbine efficiency and runaway speed. The standard tests for the Francis turbine also includes both of these assessments as well as tests for cavitation and pressure pulsations.

Model testing for Pelton turbines is described in detail in Section 5.2.

3.3.5 Reduced Values

Reduced values make it easier to compare the results for different models. The modified parameters Q_{11} $[\frac{s}{\sqrt{m}}]$ and η_{11} $[\frac{s}{\sqrt{m}}]$ are used to present test results for flow rate and rotational speed.

$$\eta_{11} = \frac{n \cdot D}{\sqrt{H_e}} \tag{3.8}$$

$$Q_{11} = \frac{Q}{D^2 \cdot \sqrt{H_e}} \tag{3.9}$$

When the reduced values Q_{11} $[\frac{s}{\sqrt{m}}]$ and η_{11} $[\frac{s}{\sqrt{m}}]$ are the same for the prototype and the model, this shows hydraulic similarity.

$$(\eta_{11})_{prototype} = (\eta_{11})_{model} \tag{3.10}$$

$$(Q_{11})_{prototype} = (Q_{11})_{model} \tag{3.11}$$

Chapter 4

Design of the Pelton Model Test Rig

The initial design of the rig for TTL is based on the Pelton model test rig at the Waterpower laboratory at NTNU. In this chapter the initial design will be presented along with required modifications for installation at TTL. Instrumentation, electrical equipment and other features relevant for the design of the rig will also be presented.

4.1 Initial Design

The Waterpower laboratory has been operating since 1920, and currently contains a number of state of the art rigs and associated equipment. It was built according to a multi-purpose concept which makes it ideal for running a range of experiments both on standardized rigs and on specially designed ones. Currently, the lab contains rigs for running experiments on Francis model turbines, Pelton model turbines, cross-flow turbines, pump-turbines and a rig for running experiments on swirl.

The Pelton model test rig at the Waterpower laboratory is fully automated and has a capacity of 100 meter effective head and a discharge of 100 liters per second using one pump. The rotational speed of the pump, the discharge, and the rotational speed of the runner are set from the control room. Figure 4.1 shows the Pelton model test rig.

(a) Frontal view

(b) Side view

Figure 4.1: The Pelton model test rig at the Waterpower Laboratory at NTNU

As part of the initial design, the turbine housing, drainage system, the bearing block and the nozzle of the Pelton model test rig at the Waterpower Laboratory at NTNU are presented in detail. The pipe circuit at TTL and at the Waterpower Laboratory have few similarities and therefore the pipe circuit at the Waterpower Laboratory is not presented.

4.1.1 Turbine Housing and Drainage System

In Figure 4.1, the turbine housing is shown from the front and from the side. The housing is made from steel and coated with paint. Parts of the turbine housing have been cut out and the steel there has been replaced with plexiglass. This makes it possible to visually inspect the runner in motion. The plexiglass also makes it possible take photographs or film the model turbine. A drainage is connected vertically under the turbine housing and leads the water straight down into the reservoir.

4.1.2 Bearing Block

Figure 4.2 shows the bearing block from the side with the torque meter placed in the coupling between the generator and the turbine side of the rig.

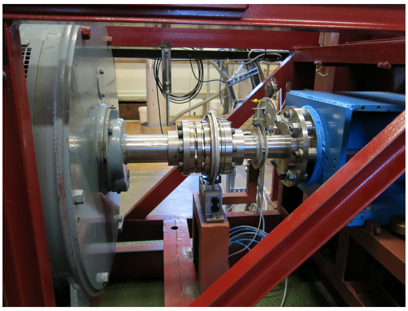


Figure 4.2: Side view of bearing block

The shaft is made from stainless, tough hardened shaft steel with a diameter of 0.078m. The bearing block is further describe is Section 2.2.1.

4.1.3 Nozzle

The nozzle at NTNU uses water hydraulics to change the nozzle opening and it was constructed at the Waterpower laboratory. The nozzle opening is changed by adjusting the water content in the chambers inside the nozzle which changes the position of the needle. This makes the needle either move forward and decrease the flow rate, or retract and increase the flow rate.

The nozzle uses tap water or water from the circuit to control the opening. It is normally operated using water from tap. A challenge with this arrangement is, that when running at high heads the pressure from outside the nozzle is greater than the pressure from the tap water. This makes it impossible to decrease the nozzle opening and the head needs to be lowered to decrease the outside pressure.

Figure 4.3 shows a section view of the needle and the first out of three pistons. The needle and the pistons are kept in position by a stationary cylinder. The water is led past the outside of the cylinder to be directed towards the runner buckets.

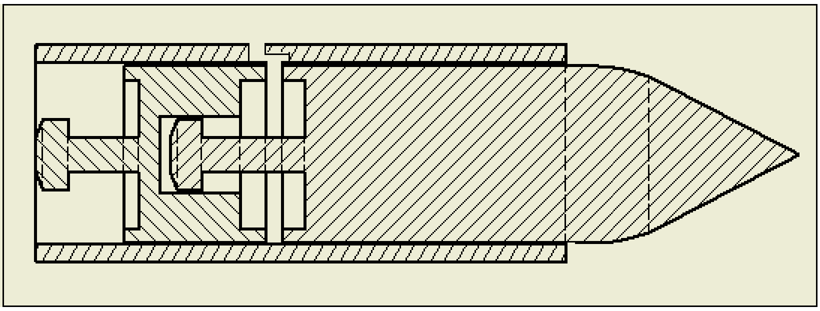


Figure 4.3: Sketch of the needle and the first piston

Pipes are connected to the cylinder and supply the respective chamber with tap water. The first entry point in the cylinder is illustrated in the sketch. The pistons move, and therefore the entry point for the water needs to be adjusted. When the water enters, the piston is pushed forward and the nozzle opening is increased. The piston is held back from entering into the chamber by screws which are not depicted in the sketch. Water is removed through the same pipe to make the nozzle opening decrease.

It is important that the nozzle is correctly placed for the water jet to hit the buckets in the center and with the correct diameter. The nozzle should also be positioned as close to the runner as possible without disturbing the flow.

4.2 Modifications of the Initial Design

The initial design taken from the Pelton model test rig at the Waterpower laboratory at NTNU has to be modified to TTL.

Staff at TTL have stated that a flexible rig that has the potential to be used for a range of heads and flow rates is ideal. Most of the initial design can be directly re-used for the Pelton rig at TTL, since the rig at the Waterpower Laboratory is small of size, deliver good results and is flexible in terms of adjusting head, generator rotational speed and nozzle opening.

A main objective for the design of the rig at TTL is to have a set-up that is flexible and that consists of high-end components and instruments. The initial design itself will be basic, but can be adjusted to fit multiple uses at a later stage. The chosen strategy is to start with a basic small rig which can be upgraded at a later stage. Staff and students can then gain initial knowledge for operation and maintenance with an easier set-up. Furthermore, upgrading the rig in increments allows a more gradual financial investment.

The main differences between the initial design from NTNU and the new design at TTL will be the drainage system, the frame, the piping circuit and electronic equipment such as generator and frequency transformer. The design of the turbine housing, the nozzle and the shaft with adjacent bearings and the friction measurement system is retained, along with most of the instrumentation.

4.2.1 Shaft Orientation

The rig at NTNU is installed with a horizontal shaft. For TTL, both a vertical and horizontal installation should be considered.

The main benefit of having a vertical installation is that it requires less laboratory floor space than having a horizontal installation. On the other hand, a horizontal rig can be placed very close to the wall of the laboratory which means it takes up less space.

A vertical installation requires a solid frame. This makes the rig less flexible, since it requires more effort to move when compared to a horizontal installation. The horizontal rig also has the benefit of making it easier to observe the model turbine during testing if plexiglass is installed as in the initial design.

The main argument for choosing a horizontal installation is flexibility. The rig can relatively easily be moved around and, at a later stage, be made into a vertical installation if needed. This change would have little effect on the rig itself, except that a new frame will have to be designed for it and the bearings will have to be chosen with this in mind.

4.2.2 Turbine Housing and Drainage System

A Pelton rig in a hydroelectric plant will normally have a water surface below the turbine since tail water is led away using a channel. When there is a water surface under the turbine, foam can start to develop and potentially cause disturbances. For a rig to imitate real-life conditions as closely as possible, re-creating this water surface is therefore of interest.

For TTL, there are three potential solutions for the drainage system. The first option is to use the same solution as the one at NTNU, i.e. to have a vertical pipe connected under the turbine housing. The turbine housing will have to be placed directly above the reservoir.

Another option is to use a channel to lead the tail water away on the laboratory floor and to the reservoir. The rig can then be placed anywhere that is deemed appropriate, but placing the rig far way from the reservoir will require extra use of floor space for the channel. The rig will have to be elevated to fit the channel underneath it. Suman Aryal described a similar channel in his project thesis which can be seen in Figure 2.5.

The cross-section of the channel needs to be decided according to the maximum flow rates than can be expected. If the channel is too small, the tail water starts to gather in the turbine housing and can cause damage. The necessary cross-section for the channel can be calculated using Equation 4.1.

$$A = \frac{Q}{c} \tag{4.1}$$

The velocity of the water is derived from Bernoulli's equation. This derivation is described in more detail in Appendix B.3.

$$c = \sqrt{2 \cdot g \cdot H} \tag{4.2}$$

The head is the difference in height between the bottom of the turbine housing and the laboratory floor. The maximum flow rate given the nozzle design from the Waterpower laboratory is 50 l/s. With a safety factor of 0.2 for the flow rate and a head of 0.2 m, the minimum value for the area is 0.3 m^3. Increasing the head decreased the area.

The third option for the drainage system is to have a turbine housing without a base and directly placed on top of a channel with the same cross-section. This channel leads the water away in the same way as described above. The water in the channel level needs to be adjustable. This can be done by attaching a metal plate across the channel next to the reservoir and by using a crank device to adjust the height of the plate. This will produce a water-surface below the runner.

4.2.3 Frame

The frame for the rig at NTNU was initially designed for an older version of the rig. The frame was made to be able to withstand oscillations, a feature which is not necessary for the rig as it is used today.

The frame designed for TTL will have a basic design, since the weight will be evenly distributed. The frame needs to provide support for the generator, the torque meter and the bearing block. To increase flexibility, a rectangular steel plate can be attached to the frame. The turbine housing will again be attached to the plate on the other side. Having this plate in place, the Pelton turbine housing canpotentially be removed and other turbines could instead be installed and tested.

If the channel is chosen as the solution for the drain, an additional frame to elevate the rig is needed.

4.2.4 Nozzle

The nozzle at NTNU is well-functioning, has a simple design and requires little maintenance work. It will therefore be recommended for the Pelton rig at TTL to have a nozzle constructed according to the same principles.

Since the rig is designed with simplicity in mind, TTL design will have one horizontally oriented nozzle. At a later stage, the rig can be altered to have an additional nozzle or to change the orientation of the original nozzle. As mentioned in Chapter 3, the orientation of the shaft dictates the suitable number of nozzles. If the shaft orientation is changed to vertical, the nozzle number could be further adjusted.

To increase flexibility, two rubber pipe sections can be assembled on the inlet pipe. This will provide a few degrees of flexibility in the horizontal or vertical plane and makes it easier to change the position of the nozzle.

4.3 Monitoring Instruments

It is preferable for the Pelton rig at TTL to consist of high-end components and instruments. The instruments at NTNU are approved certified by the IEC 60193 standard [5] and the Waterpower laboratory has well-established routines for calibration and operation. Given these considerations, it is advisable to use instruments of the same type that are used at the Waterpower laboratory or with the same characteristics.

All the instruments connected to the test rig at NTNU are connected through a National Instruments logging card to a computer in the control room. A specialized logging software created with LabView is used to record the obtained data.

This section presents the necessary instrumentation and the principles behind measuring the quantity. Furthermore, a list of the instrumentation used at the Waterpower laboratory is presented.

4.3.1 Pressure

The pressure is measured using a pressure transducer. The mechanical effects created by the pressure are converted into electrical signals by the transducer. IEC60193 [5] states, that for the pressure measuring sections there should be minimal disturbance of the flow. For circular sections, four pressure taps are needed. The taps must be equally spaced around the pipe with taps 45 ° from the top, bottom and the side to avoid air bubbles or dirt gathering in the taps. Figure 4.4 illustrates the principle.

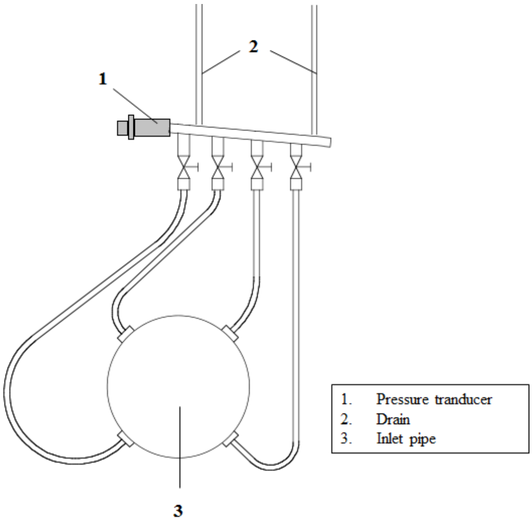


Figure 4.4: Pressure measured just before nozzle inlet

The resulting pressure is the average value of measured pressure at the four locations around the pipe.

4.3.2 Flow Rate

At NTNU, the flow rate is measured using an electromagnetic flow meter. Water is a conductive fluid and a voltage is induced when water moves through a magnetic field. The voltage is proportional to the speed of the moving fluid, this way the flow rate can be measured [11].

To get correct measurements it is important the flow is undisturbed by bends or junctions in the pipe. Because of this, placing the flow meter can be a challenge.

Options for placement of the flow meter is presented in section 5.1.1.

4.3.3 Torque

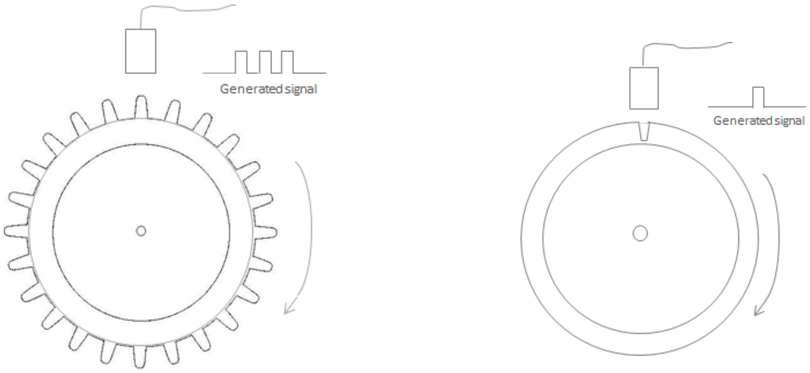
Generator torque is measured using a torque meter. It is placed in the coupling between the generator and the turbine. The torque meter at NTNU uses shear stress as a measure of torque and also measures rotational speed. This is done optically by using infrared light and a metallic slotted disc [8]. Only the rotational speed is measured, it is not possible to tell the exact position of the shaft during a rotation.

4.3.4 Friction Torque

The friction torque is measured using a load cell. Figure 2.4a shows how the friction torque measurement works.

4.3.5 Rotational Speed

At NTNU, the rotational speed can be measured in two ways: using the torque meter and using a self-designed optical rotameter. A circular disc with a cut-out is attached to the shaft. A photo cell sends out infrared light and, when the cut-out on the disc passes, the light passes through and signal is sent to a logging computer. Because of this, the rotameter has the ability to tell the exact position of the shaft during a rotation.



(a) Rotational sensor with several measuring points

(b) Rotational sensor with one measuring point

Figure 4.5: Turbine housing and drain

The principle behind the torque meter and the rotameter is illustrated in Figure 4.5a and in Figure 4.5b. In the illustration, the sensor is placed above to show the principle, in reality it is placed next to the disc.

4.3.6 Temperature Sensor

The temperature sensor measures temperature and is placed on the inlet pipe. The Waterpower laboratory at NTNU uses Platinum Resistance Thermometers (PTs), which measure the resistance of a platinum element.

4.3.7 Oxygen Sensor

An oxygen sensor is used to measure the oxygen content in the water. This is especially important if the rig is run using a closed loop pipe circuit, since the water is whirled around and hardly ever calm. The motion increases the oxygen content.

The Pelton rig does not use a closed loop and the water is taken from and led back to a large reservoir. When the water is still, the accumulated oxygen leaves the water. Therefore, it is not necessary for the Pelton rig to have a separate oxygen sensor. An oxygen sensor will be purchased as a part of the instrumentation for the Francis rig and this will suffice for measuring oxygen for the Pelton rig.

4.3.8 Table of Instruments

The instruments used in connection to the Pelton rig at the Waterpower laboratory are presented in Table 4.1.

Intrument type	**Model**	**Producer**	**Upper limit**
Flow meter	Optiflux F	Krohne	100 l/s
Pressure transducer	3276.076.001	Tecsis	16 bar
Generator torque transducer	T10F/FS	HBM	500 Nm
Friction torque transducer	Z6 beam force cell	HBM	12.5 Nm
Temperature sensor	PT100	-	-
Oxygen sensor	DIQ/S 182	WTW	-

Table 4.1: Instruments used for testing

4.4 Generator and Frequency Transformer

The generator and frequency transformer chosen for TTL must both be of high quality. In Nepal, power outages happen regularly and the electrical equipment must be able to handle the subsequent strain. It is also important to have proper electrical grounding, and all electrical work and installations must be carried out by qualified personnel.

4.4.1 Generator

When choosing a generator, the preferred range of power outputs should be investigated along with the range of rotational speeds the rig will be operating at. There is a linear relationship between rotational speed and power output. Running the rig outside the linear curve could make the generator go on over-speed. A generator should be chosen that matches the operational area of the rig.

For the generator, it must be decided if it should be direct current (DC) or alternating current (AC). The Waterpower Laboratory has DC generators which have low noise levels, but are more expensive. AC generators have higher noise levels, but, when correctly installed using high quality components, the noise level can be acceptable. Noise levels should be kept low to provide a better and safer work environment for the staff and students.

For laboratory experiments, it is necessary to be able to control the rotational speed of the generator. The generator rotational speed can then be changed to correspond with a given flow rate and head. A synchronous generator runs at a given rotational speed and phase angle. An asynchronous generator runs according to the input values it is given, and it is necessary to have a frequency transformer to control these inputs.

With an asynchronous generator, the rotational speed can be controlled by using a frequency transformer. For these reasons, an AC asynchronous generator will be recommended for TTL.

Power

The nozzle opening dictates the flow with the nozzle at NTNU giving 0.05 m^3/s of water at maximum nozzle opening and 70 m head. As the flow is largely affected by nozzle opening, this flow will be used to calculate the maximum available power. Using Equation 3.2 with $\rho = 1000 kg/m^3$, $g = 9.81 m/s^2$ and the maximum head set to be 100 m, this results in $P_H = 49kW$.

Restrictions in the system should also be investigated. The HBM torque meter at NTNU has a range of 0 - 500 Nm. Adding a safety effect of 1.4 gives a maximum of 700Nm. The highest torque occurs at low rotational speed and the rotational speed is therefore set to be 100 rpm. Both the rotational speed and the safety factor are approximations. Using equation 3.1, the calculated power P is 73kW.

Rotational Speed

The maximum rotational speed that the generator should account for must be investigated. The highest rotational speeds would occur if either the turbine is disconnected from the grid and begins to rotate freely, or if this scenario is recreated during a runaway speed test.

A runaway speed test done at the Waterpower laboratory indicated that at 70 m head, the rotational speed would be 1200 rpm. Following the trend from the results from this test, at 100 m head the rotational speed would be approaching 1500 rpm [18]. Since the rig designed for TTL is similar to the rig at NTNU, the results from these tests at NTNU can be used. The generator should therefore be able to handle rotational speeds above 1500 rpm. A generator with maximum rotational speed of 2000 rpm would thus include a sufficiently buffer.

The theoretical rotational speed is calculated using Equation 4.3.

$$n_{runaway} = \frac{c}{R} \cdot \frac{60}{2\pi} \tag{4.3}$$

Equation 4.3 can also be used to find a relation between the smallest allowed radius R and the upper limit for the generator rotational speed.

4.4.2 Frequency Transformer

The main requirement for the frequency transformer is that it is of high quality. It will create substantial noise and cause disturbances for sensitive instruments. If possible, the frequency transformer should be placed outside the laboratory. Placing the frequency transformer at too great a distance will introduces small losses to the system. The laboratory includes a separate a room on the far side of the laboratory's long-side wall where the frequency transformer could potentially be located.

4.5 Placement of Rig

The planned Francis model test rig will require a significant amount of laboratory space and is also likely to be installed before the Pelton rig. The placement of the Pelton rig is therefore dependent on the placement of the Francis rig.

In Figure 4.6, the laboratory can be seen from above, with the Francis rig in place. The CAD model of the Francis rig was created by Inger Johanne Rasmussen as part of her master thesis [13]. The floor space that is available for placing the Pelton rig is marked red.

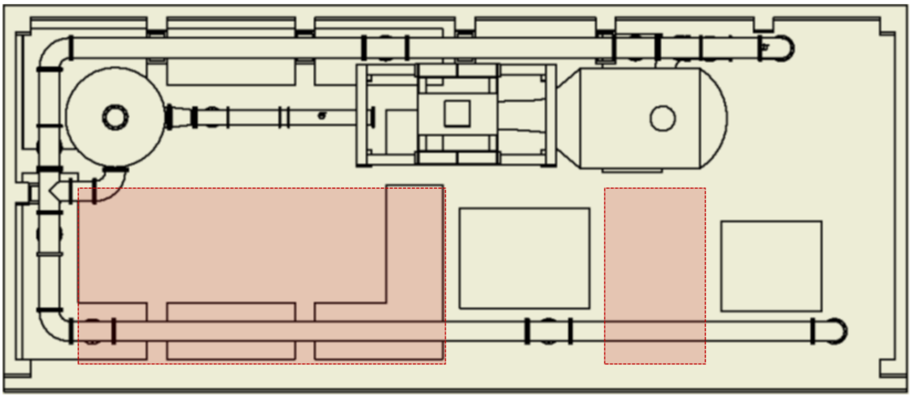


Figure 4.6: Options for placement of the Pelton model test rig

For connecting the inlet pipe to the flow circuit, both the existing flanges and potential future flanges should be considered. Once both the financially expensive IEC 60193[5] certified Francis rig and the additional Pelton rig are installed, potential modifications of the existing pipe circuit should be discussed in order to achieve the best possible result.
Four options for connecting the inlet pipe are deemed the most suitable. These are shown in figure 4.7. The pipe that is shown in the figure, is the pipe coming up from the pump room, the same pipe that is seen at the bottom of figure 4.6.

Option 1 and option 2 both require the installation of an extra flange. These options are part of the suggested solutions for the calibration circuit presented in Section 5.1.1 and are explained in more detail there.

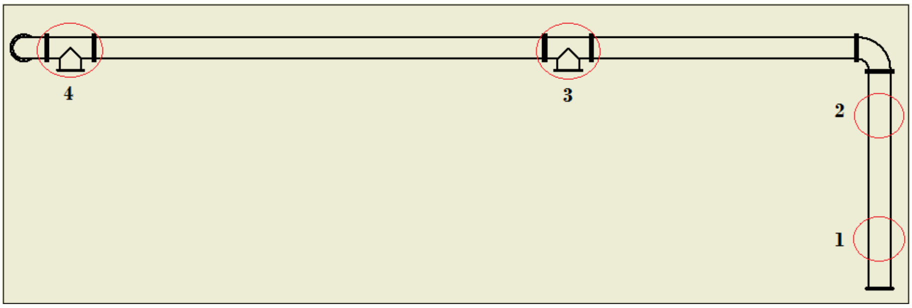


Figure 4.7: Potential flanges for connecting the inlet pipe

The flange suggested in option 3 is currently not in use. This option could reduce the use of space in the laboratory since the flange is placed in the middle of the laboratory and would therefore likely require a shorter inlet pipe. This flange is however also part of the suggested calibration rig in Johanne Seierstad's master thesis.

Option 4 uses the flange that is currently used by the simplified Francis rig. As this rig would likely be removed, the flange would become available.

The inlet pipe connecting the the rig with the chosen flange can be manufactured using PN 16 steel, which is dimensioned according to rated pressure. The choice of steel type dictates the thickness of the pipe walls.

Placement of the Francis rig and the chosen solution for flow calibration will be the major influences on the placement of Pelton rig. The Pelton rig requires sufficient space in front of the turbine housing to enable torque calibration and to ensure the runner can be maintained or changed.

4.6 Feedback System

Electricity is produced when model turbines are tested and ideal this generated power is used. TTL has currently no system in place for the use of this energy, but students at the electrical department are doing research on the subject as part of their thesis work.

At NTNU, the generated energy is fed back to the grid at the laboratory, which is connected to the national grid, at the right frequency. This would also be ideal for TTL. Connecting to the national grid will require special permits and will likely prove problematic due to strict regulations.

4.7 Costs

A list of instruments and equipment necessary for the Pelton rig with price estimations is presented in Appendix D. The price estimates are based on conversations with professor Ole Gunnar Dahlhaug and Bård Brandåstrø, the budget proposal for the IEC60193 approved Francis rig sent to NORAD and the prices stated in Reinsertsen's master thesis [14]. The estimated prices for the steel components are based on the offer Inger Johanne Rasmussen received from Nepal Hydro Electric regarding the budget for the Francis rig.

Some items of expenditure have been left without a price estimate since it has been challenging to give a reliable estimation at this stage. The budget proposal sent to NORAD was provided by professor Ole Gunnar Dahlhaug, the report has not yet been published. The prices stated in the budget are European prices, except for the steel components which are Nepalese prices.

Chapter 5

Calibration and Testing

In this chapter, information related to the calibration and testing of the planned Pelton model test rig at TTL is presented.

5.1 Calibration

Calibration is done to ensure a correct relation between sensor output and the physical value in question. A primary method of measurement uses fundamental quantities such as mass, length and time according to the IEC 60193 standard [5]. Devices that use secondary methods of measurement must be calibrated against a primary method. Here, further information about the calibration of flow, pressure, torque and friction torque is presented.

Appendix A contains detailed procedures for calibration of the flow meter, the pressure sensor and the torque meter.

5.1.1 Flow Rate

When the flow rate is measured using an electro-magnetic flow meter, this counts as a secondary method for measuring according to the IEC 60193 standard [5] and the flow rate needs to be calibrated against a primary method.

Johanne Seierstad designed a system for calibrating the flow rate at TTL in her master thesis [16]. This system is presented in Section 2.2.3 under previous work. She designed the tank seen in Figure 2.6 for the simplified Francis test rig. This tank has an adequate size for the Pelton rig, but will be too small for the planned Francis rig due to increased flow rates. Further information on this topic can be found in Inger Johanne Rasmussen's master thesis [13].

The manual for the Krohne flow meter provides guidelines for the distances that the flow meter requires upstream and downstream from disturbances in flow. The manual states that the flow meter should be placed at a distance greater than 5 times the pipe diameter after a 2-dimensional bend and 10 times the pipe diameter after a 3-dimensional bend or after a t-section [6]. Downstream of the flow meter, there should be a distance greater than twice the pipe diameter before a bend. According to professor Ole Gunnar Dahlhaug, a rule of thumb is to place the flow meter at a distance of 10 times the pipe diameter upstream and downstream from any changes in the flow.

If the length of the pipe before and after the flow meter is too short, a flow straightener can be installed inside the pipe. This is shown in figure 5.1. The principle behind a flow straightener is to fill the pipe in question with several smaller pipes, which in turn will help to create a steady flow.

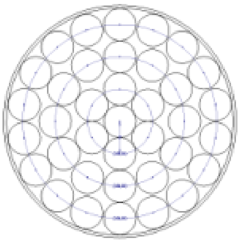


Figure 5.1: Flow straightener [16]

For the placement of the flow meter, there are several options. After discussions with with Inger Johanne Rasmussen, professor Ole Gunnar Dahlhaug and Bård Brandåstrø, two primary possibilities were identified. A high-level view of these two options is presented in figure 5.2 and figure 5.3. The inlet that is marked by an arrow in both figures is the pipe coming from the pump room.

In order to reduce uncertainty in the measurements, it is important that the velocity through the flow meter is high enough. For the Krohne Optiflux 2000, the velocity should be close to 5m/s or higher [6]. A permanent pipe circuit can be designed where the water can either be led through a pipe designed for larger flows or a pipe designed for smaller flows, and each of the pipes has a flow meter attached. With this installation, two flow meters can be used for a range of rigs, resulting in a flexible solution. After passing though the flow meter the water is either led to the relevant rig or to the calibration facility.

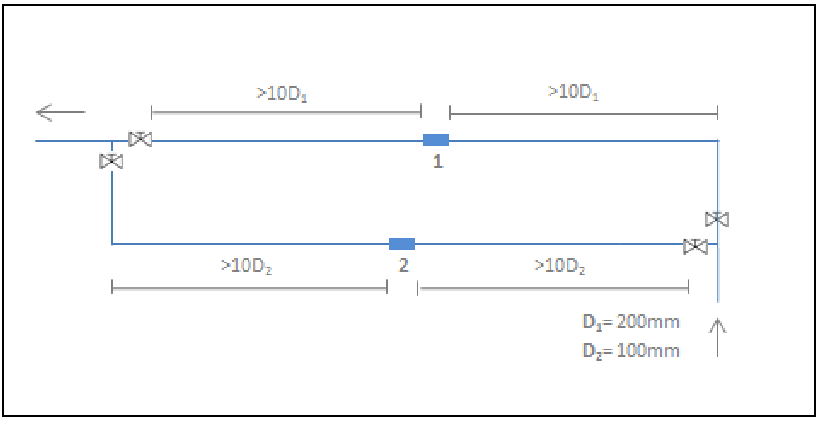


Figure 5.2: Option 1: Permanent placement of the flow meter

Running the Pelton rig requires lower flow rates than running the planned Francis rig, and the bottom flow meter would be used.

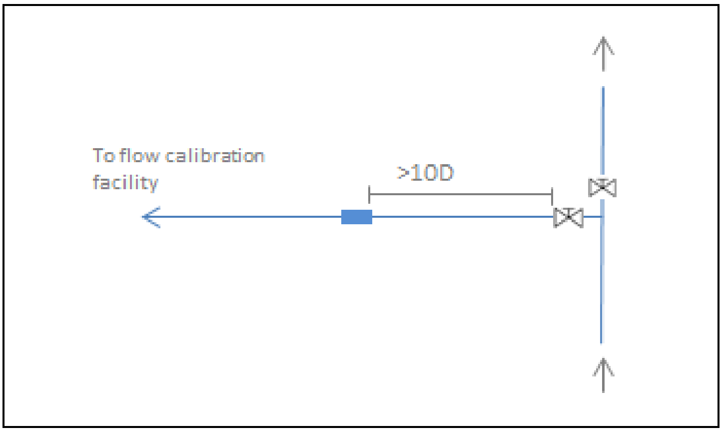


Figure 5.3: Option 2: Movable flow meter

The second option is to put a flange on the pipe coming up from the pump room. Depending on which rig is being calibrated, a corresponding pipe with the flow meter attached will be fixed to the flange. The flow meters will need to moved from their original position to the calibration pipe. The Pelton rig can use the same flange for the inlet pipe and, when in normal mode, direct the water past the calibration rig. This pipe would have to be dismantled when another rig needs to be calibrated.

5.1.2 Pressure

Pressure transducers are electromechanical devices and fall into the category of secondary methods of measurement. A deadweight manometer is classified as a primary method of measurement since it uses only measurements of length and mass and can be used to calibrate the pressure transducer. The principle behind the deadweight manometer is further described in Appendix A.1.

The differential pressure transducer for the Pelton rig at NTNU is calibrated using a deadweight manometer from GE Sensing model 3223-1.

5.1.3 Torque

The torque meter is located in the coupling between the generator and the turbine. It is calibrated by applying torque to the turbine side using weights. A lever-arm is used to create distance, and weights are rested on a weight pan attached to the lever-arm. On the opposite side of the lever arm,the weight of the lever arm is counter-balanced by a steel structure. On the generator side, the shaft is kept from rotating. Figure 5.4 shows the set-up for the calibration of the generator torque.

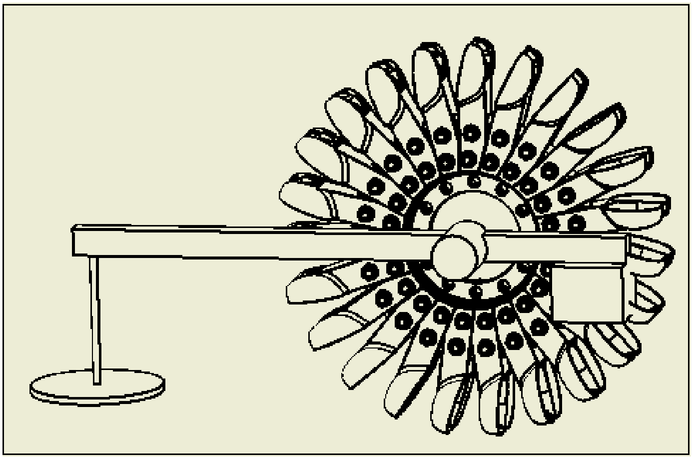


Figure 5.4: Set-up for calibrating torque

5.1.4 Friction Torque

The friction torque is measured using a load cell, which counts as a secondary method of measurement. It can be calibrated by applying torque and using calibrated weights, the same procedure as for the generator torque. In his master thesis, Reinertsen wrote a procedure for calibrating friction torque which can be used for the Pelton rig at TTL[14]. One necessary change is an adjustment of the weights used during calibration, since these will differ due to wear and tear of weights used at NTNU. The set-up for calibrating the friction torque can be seen in Figure 5.5

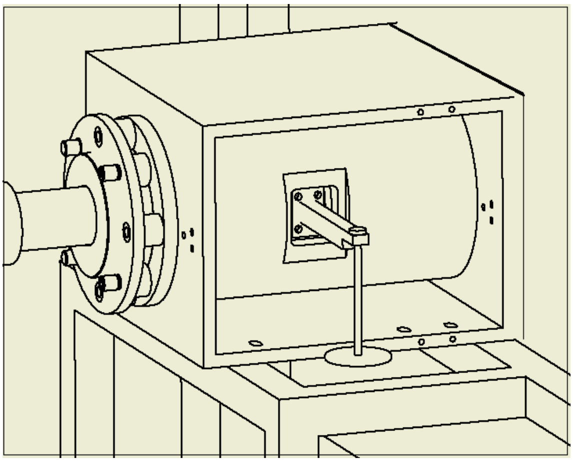


Figure 5.5: Set-up for the calibration of the load cell

5.2 Testing

Two standard tests for a Pelton model turbine are to test the runaway speed and the efficiency of the turbine. In Appendix B, a detailed procedure for testing the efficiency and runaway speed can be found.

5.2.1 Efficiency Testing

Efficiency testing is done to determine the best operating point and operating region for the model turbine. When testing for efficiency, the turbine is tested at different operating points. The head is kept constant, while the rotational speed of the runner and the nozzle opening is varied.

The data from testing is presented using a Hill chart. Hill charts show how the efficiency changes at different volume flows and rotational speeds. It is presented as a contour plot. An example of a Hill chart can be seen in figure 5.6.

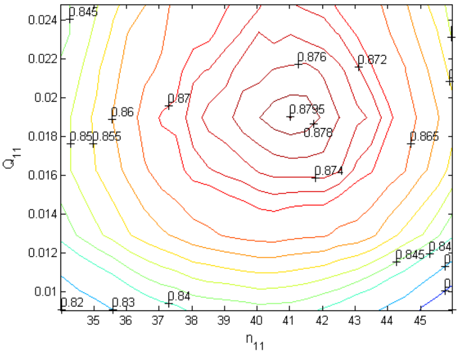


Figure 5.6: Example of a Hill Diagram showing the efficiency for reduced rotational speed n_{11} $[\frac{s}{\sqrt{m}}]$ and for reduced flow Q_{11} $[\frac{s}{\sqrt{m}}]$ [18]

5.2.2 Runaway Speed Testing

Runaway speed testing is done to simulate the real-life scenario where the turbine is disconnected from the grid and starts spinning uncontrollably. This can lead to damage to the generator, bearings and seals. Therefore, it is important to find the rotational speed that the runner would reach for a given head if this were to happen.

During testing, the generator can either be switched off, or it can be kept running in order to increase control. If it is kept on, the total torque must be kept at zero in order to simulate the correct conditions. This is done by adjusting the generator rpm. The rotational speed of the runner is then found at different heads while the total torque is kept at zero.

Chapter 6

Results

There are several possible design solutions for the Pelton model test rig. In this chapter, the design solutions that are deemed the most suitable for the rig as of today will be presented. The design solution is basic, but with room for further upgrades and changes at a later stage.

6.1 The Laboratory

The dimensions used for the layout of the laboratory floor is taken from drawings available at TTL and from the author's own measurements when visiting the laboratory in the spring of 2014. The laboratory floor with main dimensions and without any rigs installed can be seen in Figure 6.1.

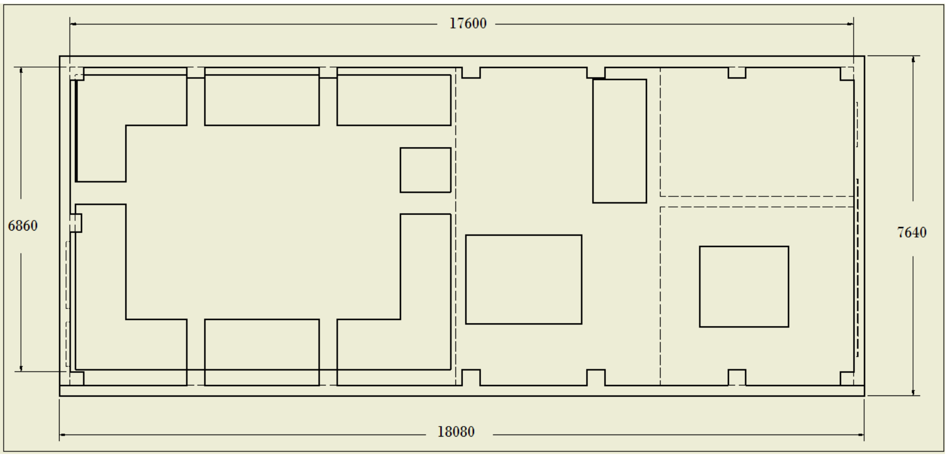


Figure 6.1: Laboratory floor with dimensions [mm]

The reservoir can be seen to the left in Figure 6.1 and is marked by a stapled line.

The steel rectangles seen on top can be removed to gain access to the reservoir. Figure 6.2 shows a side-view of the laboratory where the two closest walls have been removed to provide a better view of the laboratory floor.

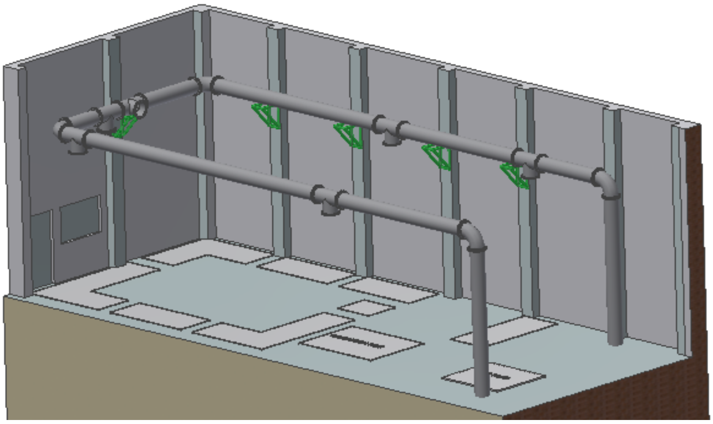


Figure 6.2: The laboratory seen from the side

6.2 The Pelton Model Test Rig

Here the final design of the Pelton model test rig is presented. The Pelton runner, which can be seen in the following figures, was designed and drawn by Bjørn Winther Solemslie as a part of his doctoral work at the Waterpower Laboratory. Figure 6.3 shows the rig seen at an angle. The rig is presented with channel solution for the drainage system.

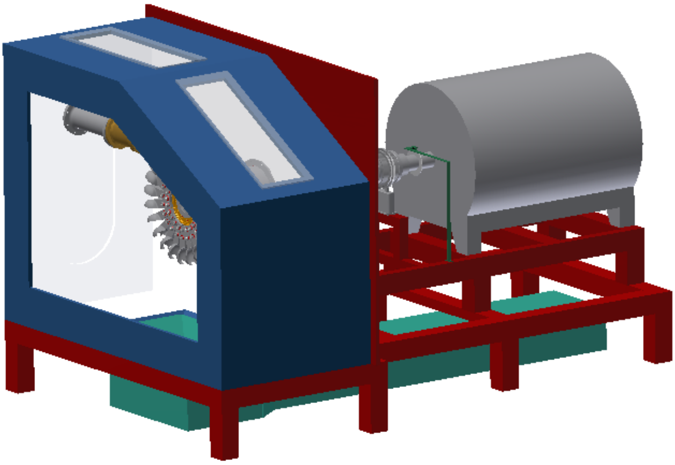
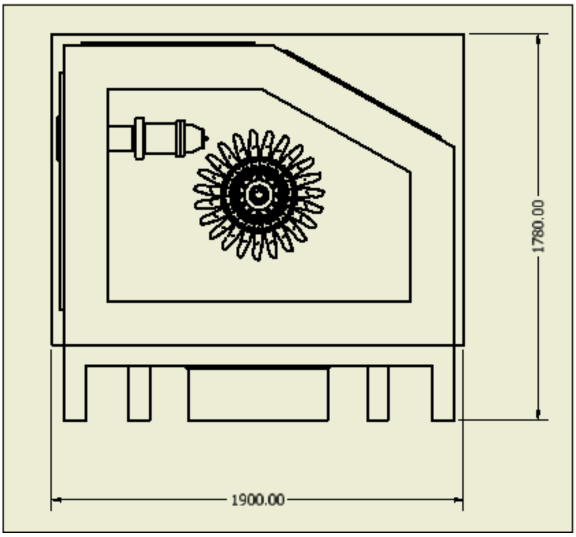
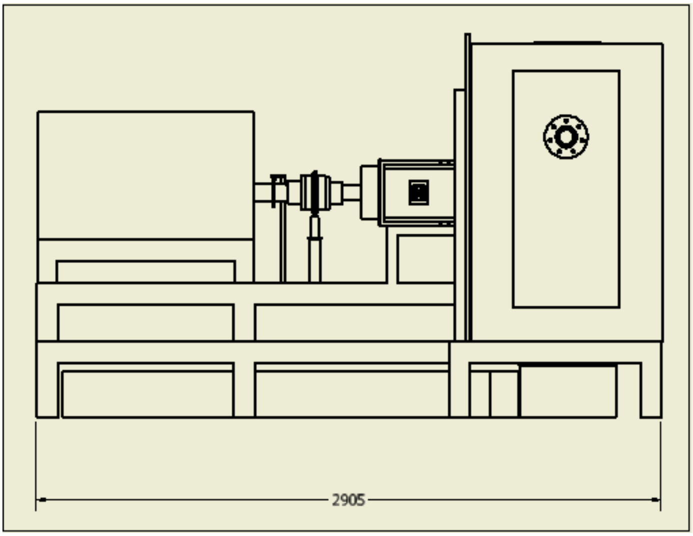


Figure 6.3: Sideview of the Pelton model test rig

In Figure 6.4, the Pelton model test rig can be seen from the front and from the side with the main dimensions displayed. In Figure 6.4a, the part of the drain that will be below the laboratory floor level can be seen.



(a) Front view



(b) Side view

Figure 6.4: The Pelton model test rig with main dimensions [mm]

6.2.1 Turbine Housing with Drainage System

The turbine housing seen in Figure 6.5 is created according to the same specifications as the turbine housing at the Waterpower Laboratory. The inlet is on the opposite side, making the features mirrored to the ones at the Waterpower Laboratory. The housing contains cut-outs in the front, on the top and to the side. These are covered with plexiglass that is sufficiently strong to withstand the force of the water. This gives the operator better control of the operation of the rig as well as introducing the possibility of photography and filming. Around the inlet, there is also a cut-out in the steel covered by a movable steel plate. This makes it easier to adjust the position of the nozzle which varies with the different runners being tested.

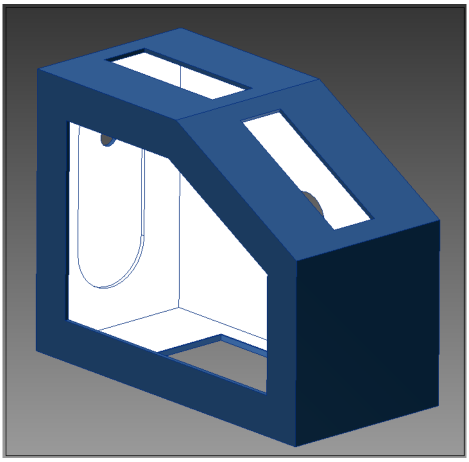


Figure 6.5: Turbine housing

Figure 6.6 presents the channel solution for the drainage system. The drainage system is designed to be a flexible solution for leading the water away from the rig to the reservoir.

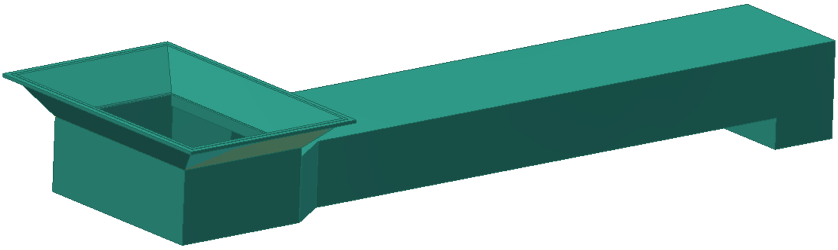


Figure 6.6: Drainage system

The drainage system can at a later stage be upgraded to the third suggested solution with the water surface below the runner. Figure 6.7 shows this design. The drainage channel is covered in plexiglass to make it possible to observe potential foam development and the flow in the channel.

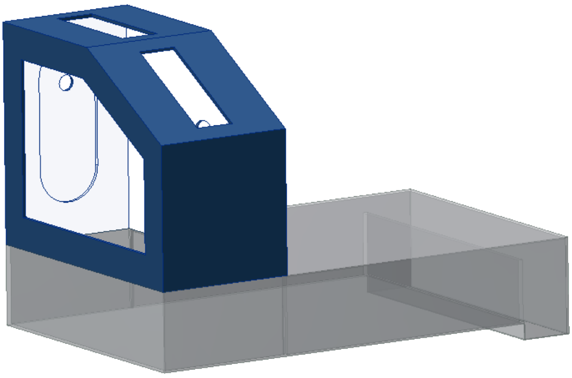


Figure 6.7: Turbine housing

6.2.2 Frame

The frame is split into two parts, a top and a bottom frame. This is done to increase the flexibility of the rig and enables re-using parts of the rig for testing other model turbines. Adding the rectangular steel plate to the top frame structure adds the possibility of removing the Pelton turbine housing and instead attaching other model turbine types. The upper frame can be seen in Figure 6.8.

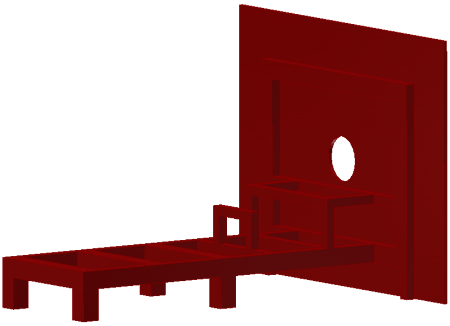


Figure 6.8: Upper Frame

The upper frame has to provide support for the generator, the torque meter and the friction torque measuring system. The drainage channel introduces the requirement of an additional frame structure that would not be required if the drain was a vertical pipe as seen at the Waterpower Laboratory. The required support is provided by the bottom frame, which must support the weight of the bearing block and the turbine housing as well as elevate it high enough to make the drain fit underneath. The bottom frame can be seen in figue 6.9.

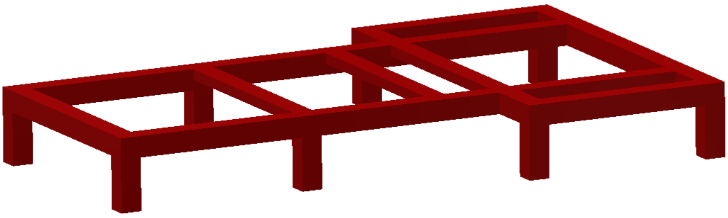


Figure 6.9: Lower frame

6.2.3 Nozzle

The nozzle is designed according to the outside dimensions of the nozzle at Waterpower Laboratory. There are no drawings of the interior of the nozzle available. In Figure 6.10 the nozzle is seen when it is installed.

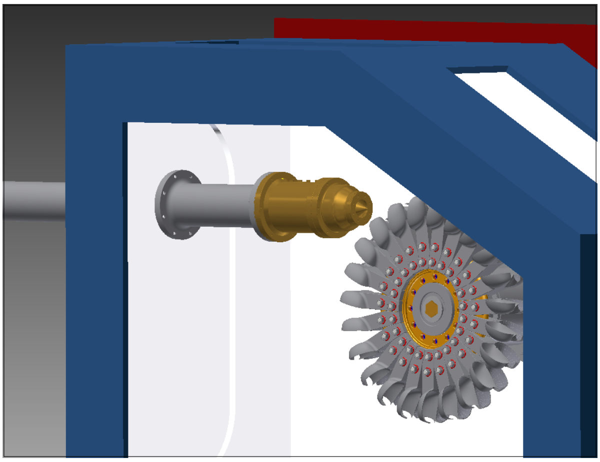


Figure 6.10: The nozzle when installed

Figure 6.11 and Figure 6.12 show the nozzle from different directions. The placement of the nozzle has a large impact on the efficiency. The nozzle must be placed at an appropriate height for the water jet to hit the buckets at the right runner diameter and the tip of the needle must be perfectly aligned with the center-line of the buckets.

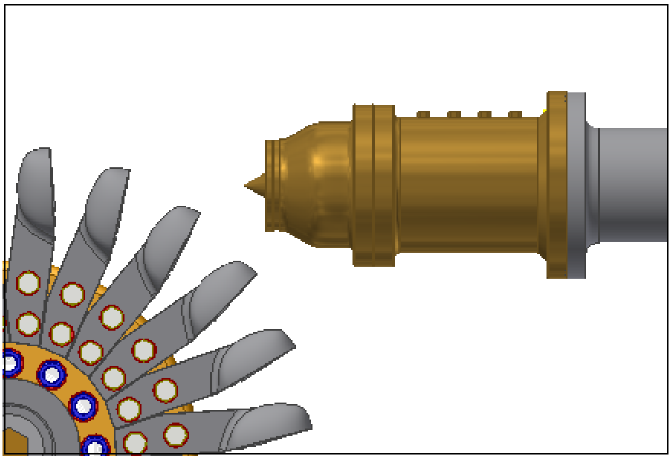


Figure 6.11: The nozzle seen from the side

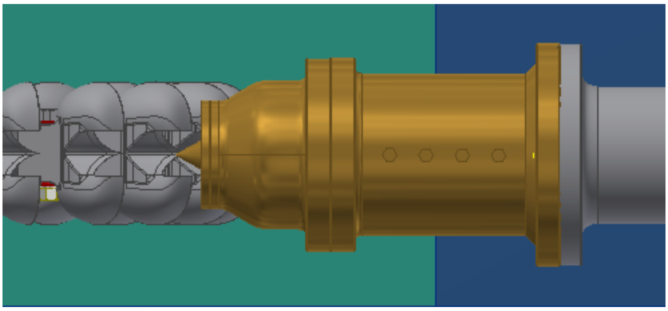


Figure 6.12: The nozzle seen from the top

The nozzle opening and thereby the flow is changed by using water hydraulics. On the top of the nozzle, four taps can be seen. These are connected to plastic pipes which in turn are connected to tap water.

6.2.4 Bearing Block

The bearing block is similar to the one at Waterpower Laboratory. A cover has been designed to protect the visible bearings from dust and other particles as this is a big problem at TTL.U. The bearing block is shown in Figure 6.13 and the cover for the bearings is seen up-close in Figure 6.15.

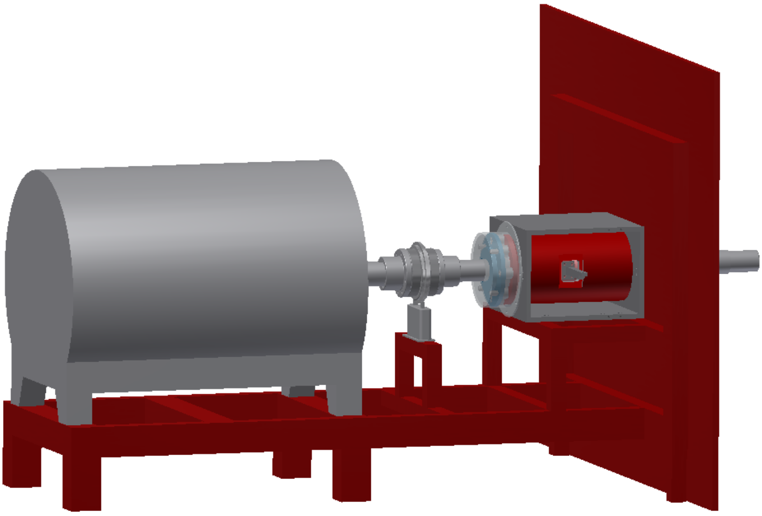
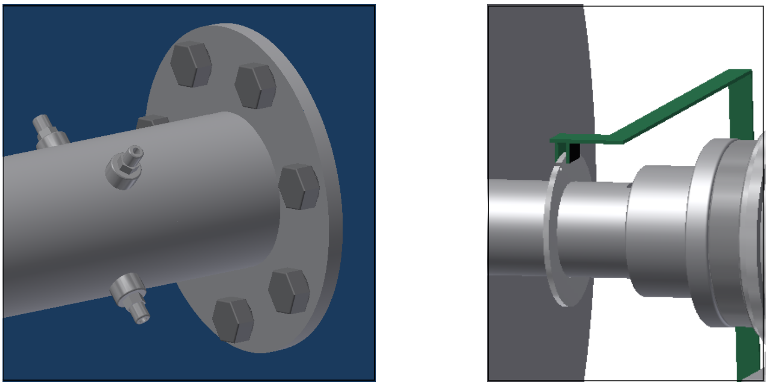


Figure 6.13: Upper frame and bearing block

6.2.5 Monitoring Instruments

This section elaborates on the placement and the physical appearance of the instruments involved in the design.

The pressure is measured just before of the inlet to the nozzle as shown in Figure 6.14a. Four pressure taps are placed at equal distances around the inlet pipe, and for each tap a plastic tube is connected. These four tubes are in turn connected to a manifold as shown in Figure 4.4 where the average pressure is recorded.



(a) Pressure taps

(b) Rotational speed sensor

Figure 6.14: Monitoring instruments

In Figure 6.14b, the optical rotameter is illustrated. It is attached on shaft at the generator side of the coupling. This way, if there is a desire to re-use the generator and connected torque meter, the rotational sensor would also follow.

The torque meter and friction torque measuring system can be seen in Figure 6.15.

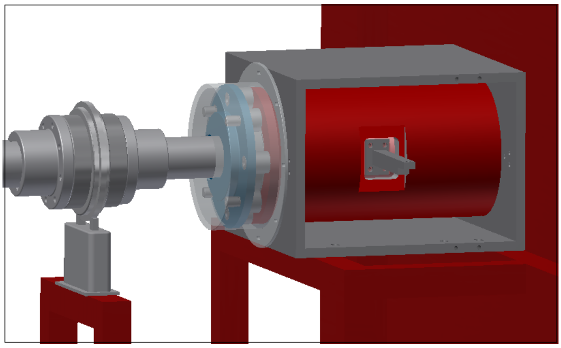


Figure 6.15: Torque meter and friction torque measuring system

In Figure 6.16, option 1 for placing the flow meter is shown. This is chosen as the best solution and is therefore illustrated here in detail as well as being included in the pipe circuit in subsequent figures. Placement of the flow meter is further discussed in Section 7.2.

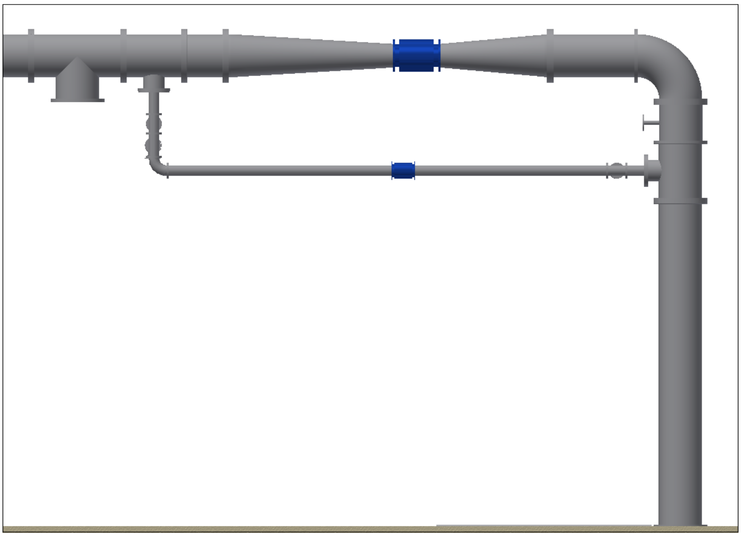


Figure 6.16: Placement of flow meter

This would be a permanent part of the new pipe circuit. The flange seen at the very left is where the pipe to the flow calibration facility is connected. When performing flow calibration for the Pelton rig, the water would be led through the lower flow meter, up through the vertical pipe section and down through the mentioned flange into the calibration tank. For normal operation of the rig, the placement of the rig decides where the water will be lead.

6.3 Placement of the Pelton Rig within the Laboratory

The planned Francis rig will use a large section of the available space at TTL. The Pelton rig will likely be installed after the Francis rig and must therefore be placed within the space that remains available. Two possible layouts of the laboratory are presented below.

6.3.1 Layout 1

Instead of leading the water water up and into the main circuit after the flow meter, the flange can be fixed onto the vertical pipe after the flow meter. This way, the water is led directly to the Pelton rig. This arrangement is illustrated in Figure 6.17.

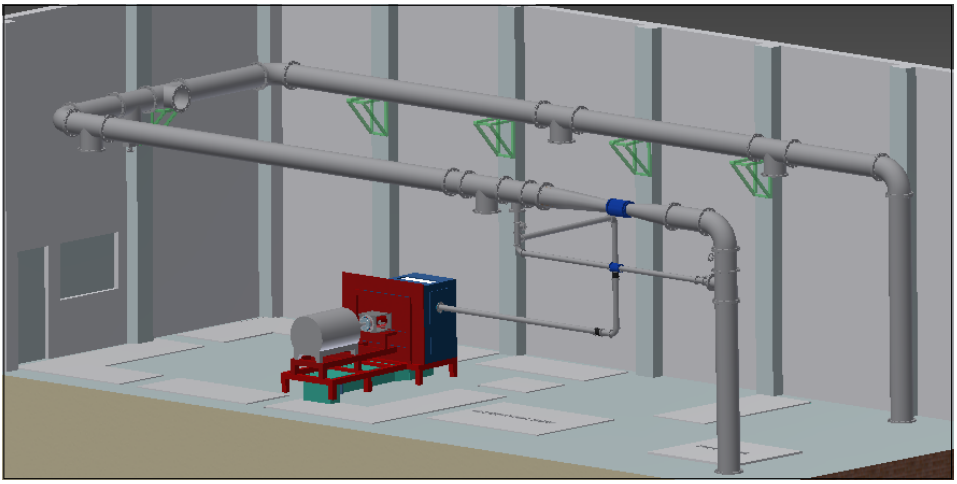


Figure 6.17: The first layout option for placing the rig

On the inlet pipe, two rubber pipe sections are placed as shown in Figure 6.18. These give a few degrees of flexibility in both in horizontal and vertical direction for adjusting the placement of the inlet pipe and the nozzle.

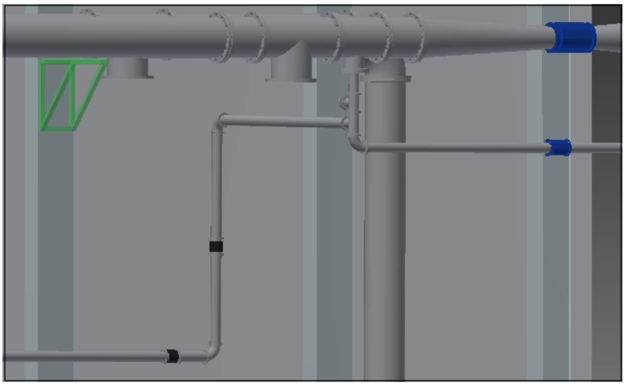


Figure 6.18: Pipe circuit

Figure 6.19 shows the laboratory with both Pelton rig and Francis rig in place. All the drawings of the Francis rig were done by Inger Johanne Rasmussen as part of her master thesis [13]. Some components of the calibration facility drawn by Johanne Seierstad in her master thesis are also depicted in the figure [16]. She designed the facility with the simplified Francis test rig mind, but since this rig is not a part of the design presented here, some components of her design must be left out as they are not relevant for this case.

With this layout, at the closest point the two rigs are 1m apart. There is space above to Pelton rig where equipment can be moved using the crane.

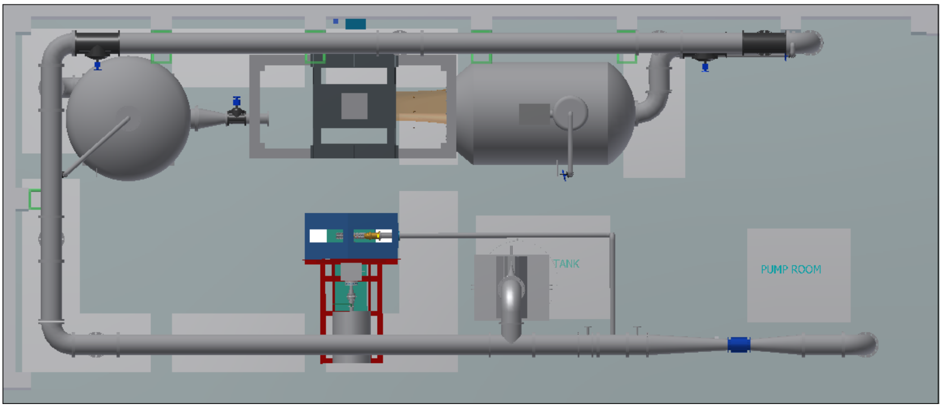


Figure 6.19: Option 1 placed with the Francis rig in place

Figure 6.20 shows the laboratory with both rigs placed within from an angle.

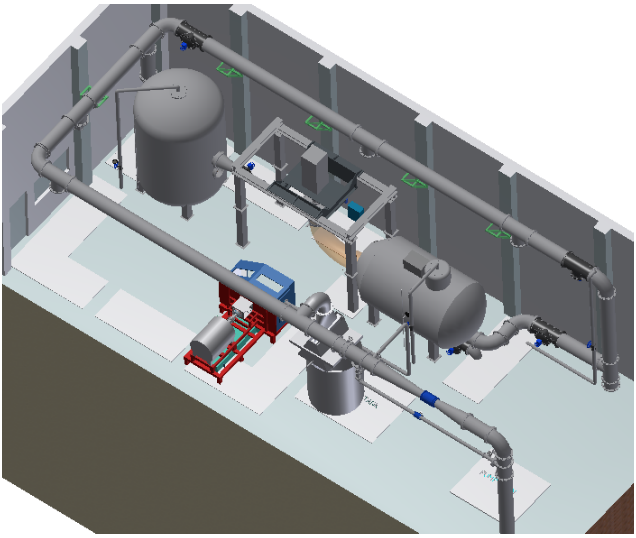


Figure 6.20: Layout 1 with the Francis rig installed

6.3.2 Layout 2

The second possibility for placing the Pelton rig is to use another flange for connecting the inlet pipe. With this solution, the rig is placed with the plexiglass side facing the control room.

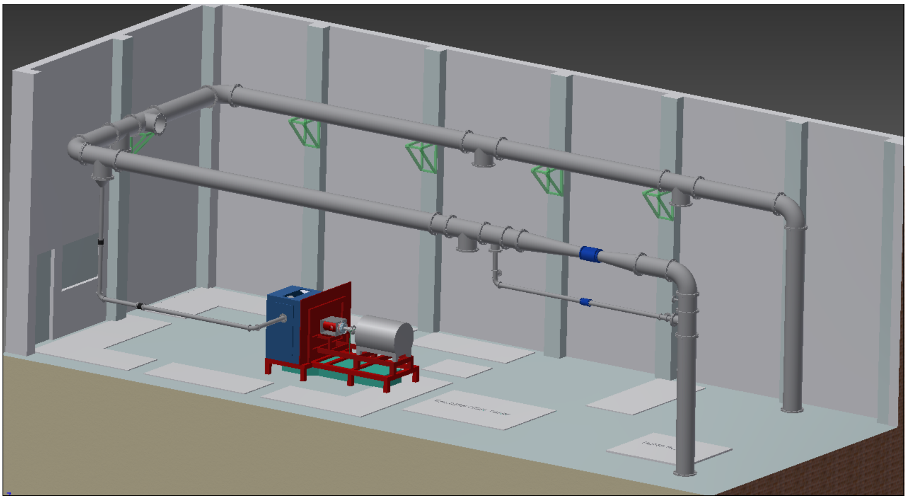


Figure 6.21: Layout 2

Figure 6.21 shows how the rig would be placed within the laboratory. The inlet is placed on the opposite side of what is seen in Figure 6.2and the other features of the rig are mirrored. Figure 6.22 shows the second option for placing the Pelton rig together with the Francis rig.

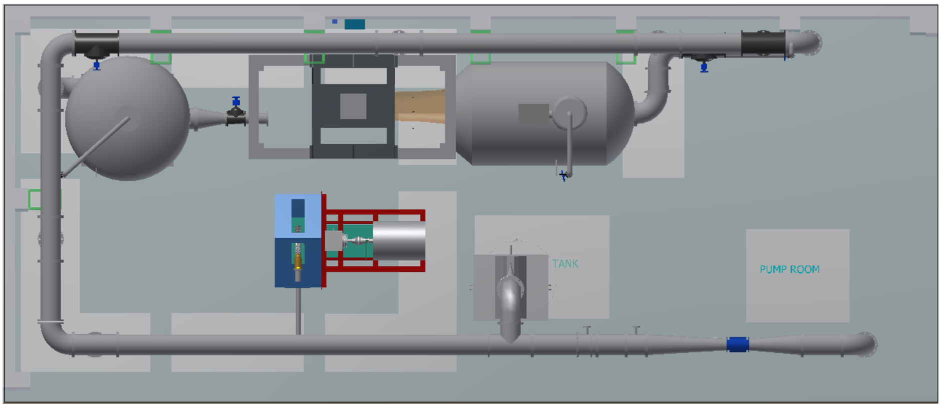


Figure 6.22: Option 2 placed with the Francis rig in place

Figure 6.23 shows the Pelton rig and the Francis rig placed together from the side.

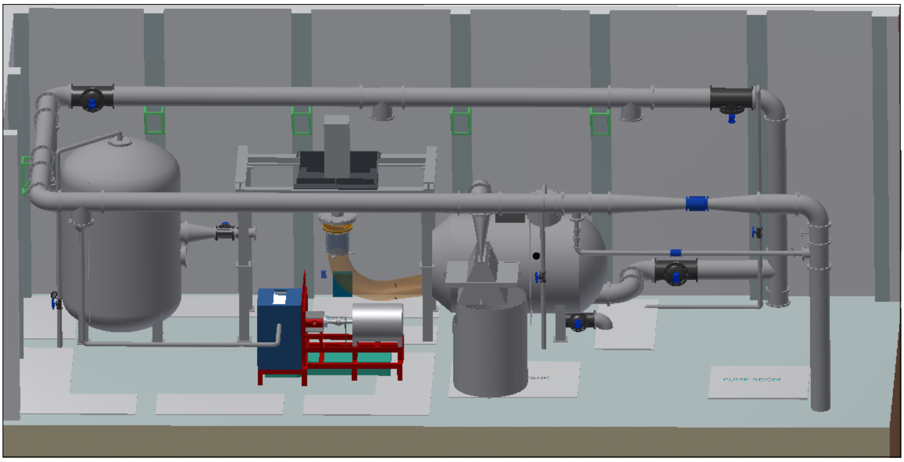


Figure 6.23: Option 2 placed with the Francis rig in place

6.4 Pelton-Francis Model Test Rig

If the turbine housing and the bottom frame are removed from the Pelton rig, what is left can also be used to test Francis model turbines. Figure 6.24 shows the principle behind how the the Pelton rig could be used for Francis model turbines.

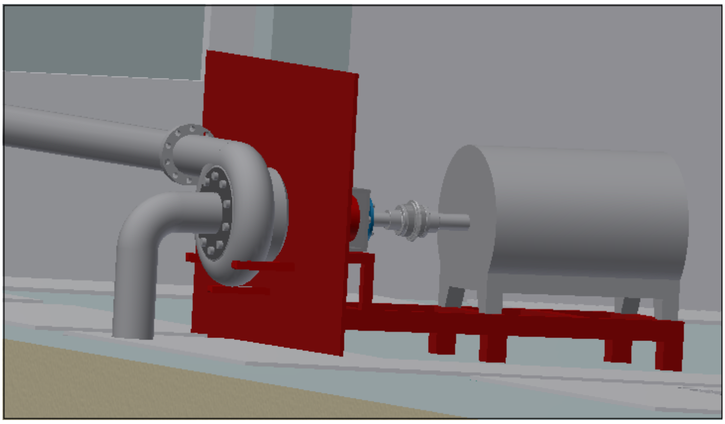


Figure 6.24: Pelton-Francis rig

Figure 6.25 shows the Pelton-Francis rig placed within the laboratory where today the simplified Francis test rig is located. The Pelton-Francis rig is illustrated as using the same inlet as the simplified rig uses today. The inlet pipe is rotated slightly, to be able to place the rig as close to the wall as possible.

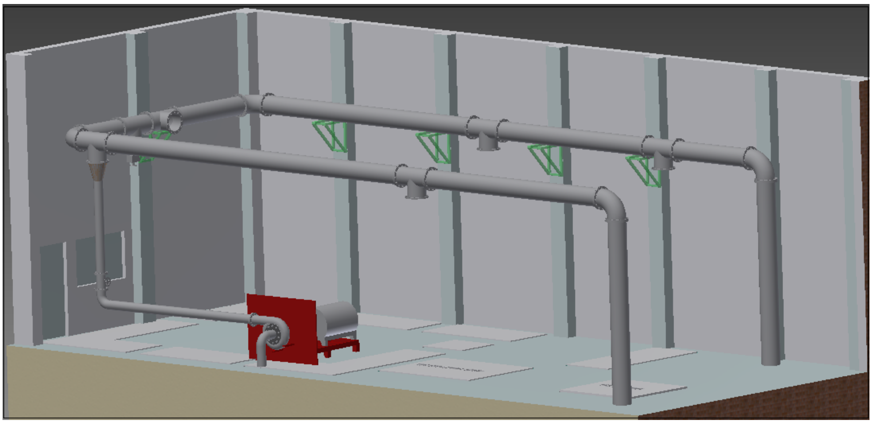


Figure 6.25: Pelton-Francis rig placed in the laboratory using parts from simplified rig

6.5 Procedures for Calibration and Testing

Procedures for the calibration of pressure, flow and torque are presented in Appendix A and procedures for efficiency and runaway speed testing are presented in Appendix B.

Chapter 7

Discussion

In this section, design choices and other aspects relevant to the Pelton model test rig as presented earlier are discussed in detail.

7.1 The Laboratory

There are several drawings of the laboratory available. One complicating factor was, that the drawings contained dimensions that differed from the actual dimensions of the laboratory. When a dimension proved to be wrong, this was resolved by re-doing the measurement where possible.

The dimensions for the laboratory floor have been validated and are correct. Measurements related to the pipe circuit and the flanges could not be easily validated, as the pipe circuit is elevated close to 4 meters above the laboratory floor. The placement of the flanges is therefore based on a combination of the available drawings and visual validation and estimates which might have led to errors.

7.2 Pelton Model Test Rig

The design of the Pelton model test rig for TTL is closely related to the initial design. The facilities at the Waterpower Laboratory that the initial design is based upon have proven to be versatile, reliant and flexible. These are all desired attributes for the rig design for TTL, and therefore few significant changes were made.

The drainage system is the biggest change from the initial design and the solution with the channel is chosen as the optimal design at this stage. With this design, the rig can be placed nearly anywhere on the laboratory floor which gives the rig added flexibility. If the rig is permanently placed with direct access to the reservoir, a solution with vertical pipe and valve as described in Section 4.2.2 can be chosen. This option makes the bottom frame redundant. The suggested solution which is seen in Figure 6.7 represents a potential upgrade at a later stage.

It will be recommended for TTL to have the nozzle manufactured at NTNU. There are currently no available drawings of the nozzle interior, but it possible to dismantle the nozzle and create new drawings. This was not done for this thesis due to the nozzle being used by other students for running tests and because of the risk of damaging the nozzle.

In the initial phase after installing the new rig, using the torque meter as a measure of speed will be sufficient for TTL. Having an optical rotameter, such as the one at NTNU, is helpful for more advanced uses of the rig,such as for example filming or photography using a high-speed camera. When there is a requirement to take a photo at a set time during one rotation, this function becomes necessary. Such additions are however expensive and should not be prioritized at this stage.

7.3 Placement of the Pelton Model Test Rig

Both options for placing the Pelton rig that are presented in this thesis have their advantages and disadvantages.

Layout 1 utilized the available space optimally. It is positioned close to the wall and close to the calibration tank, which leaves space for other small rigs to be installed if that should be desired. In Figure 6.19, the Pelton inlet pipe is shown close to the calibration tank. Installing the rig this way with the generator side as close to the wall as possible, gives the maximum possible distance from the Francis rig. It could, however, be a conflict between the placement of the inlet pipe and the calibration tank. Extending the inlet pipe would likely solve this potential problem, but this would again result in a smaller distance between the two rigs. The plexiglass side of the rig is also not visible from the control room with this option, which makes it difficult for the operator to visually inspect the operation of the rig. This could be solved by placing mirrors strategically or by using a camera. Being able to see the runner during operation and observe how it reacts to changes in head is beneficial for student education.

With Layout 2, the plexiglass side is placed in front of the control room, thereby giving the operator a perfect view of the model turbine. This placement is, however, more space consuming than layout 1 since the rig is placed in the middle of the available space and the inlet also hinders the installation of new rigs. The inlet pipe can be made to go higher to reduce use of space close to the laboratory floor. This would introduce addition bends to the inlet pipe. This option also only allows for a short inlet pipe. After the final bend before the nozzle, the distance is around 15 D. This is, however, higher than the rule of thumb to have 10 D distance between the flow meter and a bend, which also require developed flow.

7.4 Placement of the Flow Meter

In Chapter 6, two primary options for placing the flow meter were presented. The first option gives a permanent solution where the extra pipes that are introduced are elevated and do not consume laboratory space. The other option requires rearranging the pipes leading to the calibration rig, depending on which rig is being calibrated. Additionally, the flow meter in question has to be dismantled and moved over to the calibration pipe. This is both time-consuming and takes up laboratory floor space. The permanent solution was therefore deemed the best.

7.5 Pelton-Francis Test Rig

The Pelton rig is, with practically possible adjustments, found to be useable for testing Francis model turbines. The rearranging from Pelton rig to Francis rig will however require time and effort. If the Francis rig is unusable because of maintenance work or other factors, then students can use the Pelton-Francis rig to gain knowledge and experience with the Francis turbine.

Staff at TTL want to re-use parts from the simplified test rig if possible and for the Pelton-Francis this is a possibility. The simplified test rig at TTL was most recently run by having the pump on and letting the shaft spin freely as there is no generator in place. This resulted in significant problems with leakages and with strong vibrations. Because of these issues, the components would have to be checked and possible repaired before re-using them. All the parts on the simplified test rig are designed and manufactured either directly at the laboratory or otherwise locally. Because of this, using these components in a functional rig which provides reliable results, would be view as an accomplishment by the staff and students.

7.6 Power Output

The rig is designed for a power output of 49kW, as described in Section 4.4.1. TTL has a higher capacity for flow rate and head than the rig is designed for. If an increased power output is desired, the rig will have to be scaled up. Up-scaling would require a different generator, a different frequency transformer and also a different torque meter, since suggested HBM torque meter is limited to 500 Nm.

7.7 Condition of the Water

One challenge at TTL is the dust and sand that enters the laboratory. If dust and sand enters the water, equipment will be damaged over time and the IEC 60193 [5] requirements for clean water will not be met.

To be able to solve this challenge, several measures will have to be taken. At the moment, the floor of the laboratory is made of concrete that has not been treated with any form of coating. This makes it difficult to remove the particles that enter the laboratory. This could easily be solved by adding a coating. This coating should also be applied to the walls for the reservoir to prevent concrete particles from entering the water.

Introducing daily routines for cleaning the laboratory would also be beneficial. Cleaning with water instead of only sweeping with a broom will help remove particles. This again requires the floor to be coated.

Installing a filtration system that the water in the reservoir could pass through on a regular basis would greatly benefit the water quality. This would likely bring the particle level down to a level within the requirements of the IEC 60193 standard, which states that the test water should be free of impurities [5]. The standard does not, however, provide any exact numbers to go by to determine if the test water is approved. Looking at installing a filtration system will be suggested for future work.

7.8 Costs Connected to the Pelton Model Test Rig

A budget proposal is found in Appendix D. To fund the rig, TTL will apply for financial support from NORAD. The application needs to contain a budget proposal and the prices listed will be the upper limit for required funds. The overall budget proposal is therefore based on the upper limit of the cost estimates.

For some of the budget posts, no price estimate is given, because it is difficult to estimate the expense at this time. The total price of the rig listed in the budget is therefore below the actual final cost.

It is likely, that the Francis rig will be installed first. Some of the instruments listed in the budget will be purchased as a part of the installation of the Francis rig and can be therefore be excluded from the Pelton rig budget. The total cost of the rig as listed in the budget is 914 000 NOK and, excluding the shared instruments, the cost is 769 000 NOK. Adding the total estimated cost for the missing budget post of 200 000 NOK gives a final cost of 969 000 NOK.

High-end instrumentation and electrical equipment are recommended for TTL and these items represent a major part of the budget. The financial situation for TTL is, however, significantly different to the one at the Waterpower Laboratory. The reason for recommending high-end products is that the Waterpower Laboratory has had good experience with the products in question. They show high reliability, produce high quality results and have long life spans.

Chapter 8

Conclusion

In this thesis, design options for the main components of a Pelton model test rig have been evaluated and the preferred options have been described in detail. The design of the rig, the choice of instrumentation and equipment along with the development of procedures for calibration and testing have been done in accordance with the IEC 60193 standard [5].

The final solution for the design is close to the initial design with the main changes being to the drainage system, the frame and the electrical equipment. For the drainage system, the solution that uses a channel on the laboratory floor is chosen as the optimal one, since this solution gives the rig additional flexibility.

Two options for placing the Pelton rig have been presented. Both options have positive and negative features. The eventual choice which option is used depends on the future plans for the laboratory and what the staff at TTL prefer.

The possibility of using the Pelton rig to test Francis model test turbines has also been evaluated in this thesis. It can be concluded, that the Pelton rig, after some adjustments, can be used to test Francis model turbines.

Some work still has to be done before the rig can be installed. Provided that further design details are specified, technical drawings are created and the required systems are developed, the rig can be ready for installation within a few years if the financial situation allows for it.

Chapter 9

Future Work

This chapter presents the next steps that are required in the process of getting a fully functional Pelton model test rig that is approved by the IEC 60193 standard [5].

Technical Documentation

The main purpose of the drawings made in this master thesis is to illustrate the different design options for the Pelton model test rig. Detail designs and technical documentation needs to be developed for all the components of the rig. Technical documentation of pipes, flanges and valves connected to the rig must also be developed.

For the frame, the beam cross-sections should be further evaluated and calculations on beam deflection and stresses should be done.

Drawings of the nozzle interior need to be made. Either a new design with new technical drawings have to be devised, or the nozzle at NTNU hast to be dismantled and technical drawings based on it have to be created.

Data Acquisition

A system for obtaining and treating the inputs from the different sensors is necessary. If the choice is to use LabView, logging programs for testing and calibration must be developed.

Power Output

It should be further evaluated, if a power output of 49 kW is satisfactory for the rig. If the staff at TTL decide to maximize the laboratory's potential for testing, the rig will need to be scaled up.

Electrical System and Instrumentation

Specific models need to be chosen for the generator and the frequency transformer. If it is decided to scale the rig up, this needs to be taken into consideration.
It should also be further investigated, if the electrical energy produced by running the rigs can be fed back into the main system, as well as how this can be done.

Filtration System

A filtration system should be installed to get the particle content down to a level where it does not damage equipment and impact results. It has to be further investigated how this can be done.

System for Calibrating Flow Rate

The design of the system for calibrating flow rate needs to be updated to accommodate for the change of plans since the calibration facility was designed. It also needs to be investigated, if the updated design causes any conflicts with the placement of the Pelton rig as suggested in this thesis.

Budget

The budget proposed in this thesis contains estimated prices. Prices of instruments and equipment should be further investigated along with transportation and installation costs.

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Appendix A

Calibration Procedures

Here, the procedures for the calibration of pressure, flow and torque are presented. At the Waterpower Laboratory, the data from calibration is obtained using a National data acquisition unit and LabView for computation and the presentation of the data. This is also the proposed solution for TTL.

The Waterpower Laboratory has established calibration procedures for the Francis rig. For the calibration of pressure and torque transducers, parts of the procedures for the Francis rig are identical to the procedures for the Pelton rig. These are used as the base for the procedures presented in this chapter [10] [12].

At the Waterpower Laboratory, the weighing method is used when calibrating flow rate. Johanne Seierstad proposed in her master thesis that TTL should calibrate the flow rate using the volumetric method. The procedure presented here is written by Johanne Seierstad for a Francis rig, and only minor changes have been made to adjust it for the Pelton model test rig [16].

Kyrre Reinertsen's master thesis specifies the procedure for the calibration of friction torque at the Waterpower Laboratory [14]. There will be only minor differences between how the friction torque is calibrated at the Waterpower Laboratory, and how it will be calibrated at TTL. The main difference will be the weights that are used, which has no influence on the overall procedures.

A.1 Calibration of Pressure Transducer

The procedure presented here is based on the manual for the deadweight manometer from GE Sensing [17] and the procedure for calibrating pressure for the Francis rig at NTNU [10].

Figure A.1 shows a hydraulic deadweight that has the same features as the one used at NTNU. It will be recommended that TTL purchases a deadweight manometer from the same producer as the manometer at NTNU. The procedure specified here is thus for a deadweight manometer using the same principles.

For pressure below 10 bar, weights are loaded onto the small piston. For pressures above 10 bar, the larger piston is used. The small piston is referred to as piston 1 and the larger piston as piston 2.

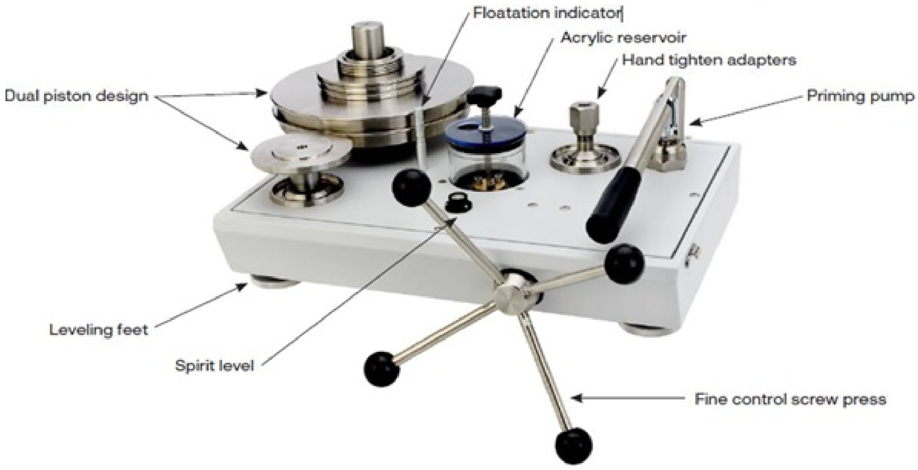


Figure A.1: P3200 manometer from GE Sensing [4]

Figure A.2a shows the assembly of nuts used to attach the pressure transducer onto the manometer at the Waterpower Laboratory and Figure A.2b shows the assembly when attached. This assembly creates a hollow column that will be filled with water. The transducer is screwed onto the horizontally protruding nut.

(a) Assembly of nuts used to attach the pressure transducer to the manometer

(b) The assembly in place

Figure A.2: Attaching the transducer to the manometer

The principle behind the manometer is to pressurize a fluid using a piston of known area. Weights of known mass are loaded onto the piston creating different pressures and a calibration curve can be created. Pressure P $[Pa]$ is defined as force F $[N]$ over an area A $[m^2]$:

$$p = \frac{F}{A} \tag{A.1}$$

Where

$$F = m \cdot A \tag{A.2}$$

The data obtained from calibration is used to correct the parameter in question to give a result independent of changes to the instrumentation. The correct parameter is calculated using the equation

$$p = a \cdot (MV) + b. \tag{A.3}$$

p stands for pressure, MV is the measured value and a and b are values retrieved from the linear calibration curve.

Preparation and priming

1. Disconnect the pressure transducer from where it is normally attached and connect the pressure transducer to the manometer. It is important that everything is tightened properly. If not, leakages will occur and the results will be incorrect.
2. Pump up water, in the column that the pressure transducer is attached to, using the screw pump. When the water is visibly over the level of the valve, close it. There should now be no air in the system.
3. To start the priming process, open reservoir valve one turn counter-clockwise and turn screw press fully in.
4. Pump the priming pump two times.
5. Close valve and turn screw press fully out. During this operation, bubbles may appear in the reservoir. Repeat steps 3 and 4 until bubbles no longer appear.
6. With valve open, turn screw press fully out and close valve.

Procedure for pressure transducer calibration

Depending on the pressure range in which the transducer is to be used, the calibration range should cover this range and more.

A linear regression line is created using the measured points from calibration. The level of uncertainty will be higher in the beginning and at the end of the curve. The area in the middle of the calibration curve has the lowest uncertainty.

1. Measure the height difference Z between the pressure transducer and the inlet.
2. Open the reservoir valve to de-pressurize the system. Record the zero load point.
3. Close the valve. The flotation indicator has two indicated heights, where the lowest is to be used for piston 1 and the highest for piston 2. Use the priming pump to increase pressure until the bottom of the circular plate attached to the piston is leveled with the associated indicated height. Using the smallest piston, this is the mark that is the lowest on the indicator. The system is now pressurized at 1 bar.
4. The circular disc is made to spin freely to avoid frictional effects. When all movement is strictly in the horizontal plane, record the point.

5. Add desired weight and repeat the previous step. Check that the height of the piston stays correct according to the flotation indicator.

6. When reaching 10 bar, piston 2 will be raised by the induced pressure. Adjust the height of the piston according to step 3. Make the circular disc on the larger piston spin freely and record the 10 bar point.

7. Continue adding weights until reaching the desired maximum pressure.

8. Repeat the procedure back to start by off-loading weights until reaching the zero load point.

An example of a pressure calibration report is presented on the next page. The calibration was done by the author and Martine Wessel in the fall of 2013 at the Waterpower Laboratory

CALIBRATION REPORT

CALIBRATION PROPERTIES

Calibrated by: Ida Stene og Martine Wessel
Type/Producer: GE Sensing
SN: 3200 series P3223-1
Range: 0-16bar
Unit: kPa

CALIBRATION SOURCE PROPERTIES

Type/Producer: Pressurements deadweight tester P3223-1
SN: 66256
Uncertainty [%]: 0,01

POLY FIT EQUATION:

Y= -402.15994288E+0X^0 + 199.85054842E+0X^1

CALIBRATION SUMARY:

Max Uncertainty : 0.437053 [%]
Max Uncertainty : 0.626056 [kPa]
RSQ : 0.999996
Calibration points : 41

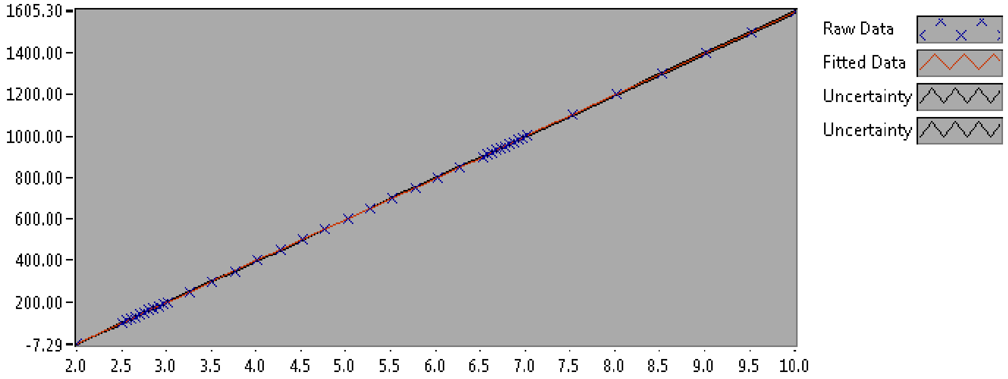


Figure 1 : Calibration chart (The uncertainty band is multiplied by 1000)

A.2 Calibration of Flow Rate Measurements

This calibration procedure and description is taken from Johanne Seierstad's master thesis where it is used for the calibration of a Francis rig [16]. Her master thesis is further described in section 2.2.3. Only minor changes have been to made to adjust the procedure for the Pelton rig.

The flow rate Q $[\frac{m^3}{s}]$ is calculated as a change in volume V $[m^3]$ for a given time t $[s]$

$$Q = \frac{\Delta V}{\Delta t} \tag{A.4}$$

The data obtained from calibration is used to correct the parameter in question to give a result independent of changes to the instrumentation. The correct parameter is calculated using the equation

$$Q = a \cdot (MV) + b. \tag{A.5}$$

Here, Q stands for flow rate, MV is the measured value and a and b are values retrieved from the linear calibration curve.

Procedure for Flow Calibration

During the calibration, it is recommended to have two operators available in the lab. Operator 1 is available on the lab floor, and operator 2 is in the control room.

Preparatory Work

1. Start to set the pipe loop in calibration mode by opening the pump valve and opening and closing the relevant valves connected to calibration of the Pelton flow meter.
2. Check that the level in the volumetric tank is within the critical level, z c .
3. Check that the drain valve at the volumetric tank is closed.
4. Start up the pump.
5. Find flow rate 1 by varying the rpm on the pump.
6. Clarify the calibration program and software.
7. Operator 2 sets the filling time on the control computer
8. Prepare to start the calibration.

Main calibration

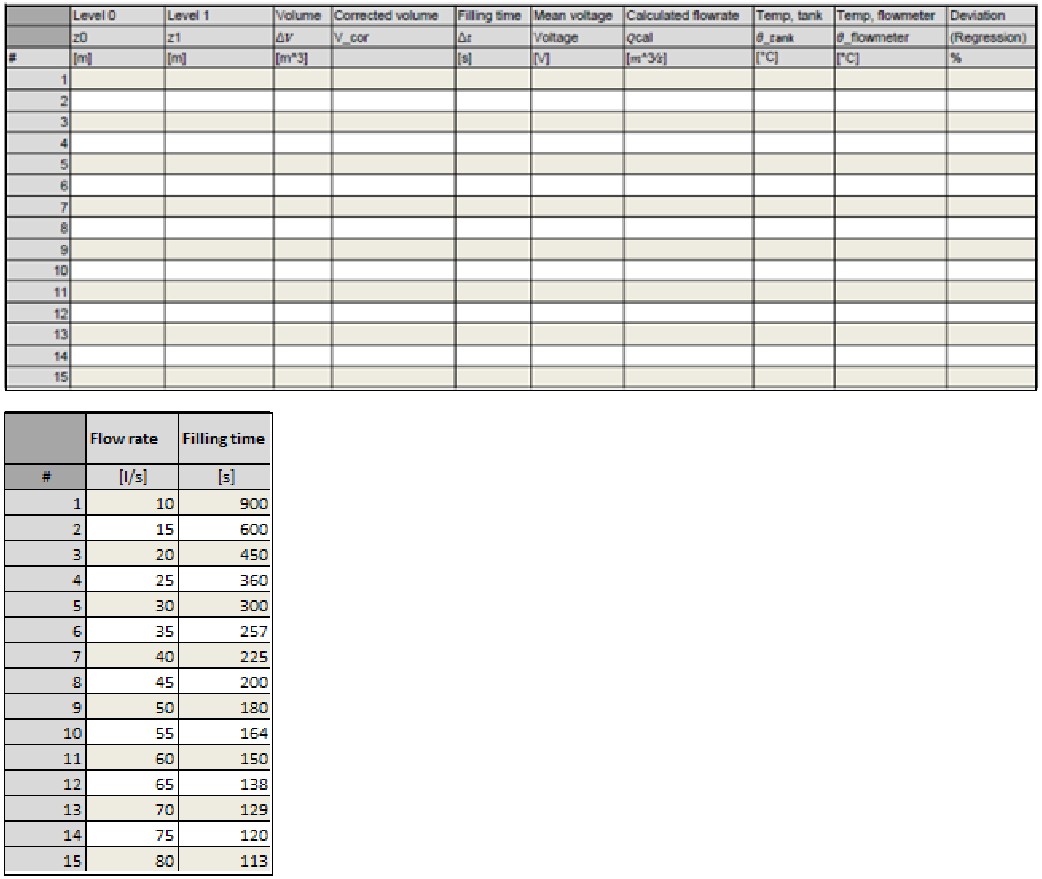
9. Operator 1 conducts and reports level measurement 1, Z0.
10. Operator 2 registers z0 in the calibration sheet, and prepares for the logging of voltage values from the flow meter.
11. Operator 1 releases the deflector mechanism and reports to operator 2.
12. Operator 2 starts the logging of the voltage signal immediately after the deflector mechanism is released.
13. Operator 1 reports to operator 2 ten seconds before the filling time ends.
14. Operator 2 stops the logging and saves the data.
15. The deflector mechanism goes to initial position and operator 1 reports actual filling time.
16. Decrease the pump speed, and prepare to shut down the pumps.
17. When the system comes to rest, operator 1 executes the level measurement Z1 immediately and reports the result.

18. Empty the volumetric tank, and prepare for a new calibration session.
19. Be aware of remaining water droplets at the tank wall, and ensure the tank is totally empty before the next calibration point.
20. Register the tank- and flow meter temperature.

Data processing

21. Register all calibration data in calibration sheet 1.
22. Calculate the mean voltage values for the flow meter voltage output.
23. Determine the calibration curve and values through a linear regression.

An example form of the kind that is filled out during testing and a filling schedule for Pelton flow meter are presented in Figure A.3 on the next page. The form is taken from Johanne Seierstad's master thesis [16].



	Level 0	Level 1	Volume	Corrected volume	Filling time	Mean voltage	Calculated flowrate	Temp, tank	Temp, flowmeter	Deviation
	z0	z1	ΔV	V_cor	Δt	Voltage	Qcal	θ_tank	θ_flowmeter	(Regression)
#	[m]	[m]	[m^3]		[s]	[V]	[m^3/s]	[°C]	[°C]	%
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

	Flow rate	Filling time
#	[l/s]	[s]
1	10	900
2	15	600
3	20	450
4	25	360
5	30	300
6	35	257
7	40	225
8	45	200
9	50	180
10	55	164
11	60	150
12	65	138
13	70	129
14	75	120
15	80	113

Figure A.3: Form for testing and filling schedule

A.3 Procedure for Calibrating Torque

The steps for calibrating torque are taken from the procedure for calibrating generator torque on the Francis rig at NTNU [12]. The procedure has been adjusted to fit the Pelton rig. In Figure 5.4, the set-up for torque calibration can be seen.

Torque is the product of mass m $[kg]$, gravity g (m/s^2) and length L $[m]$.

$$T = m \cdot g \cdot L \tag{A.6}$$

The data obtained from calibration is used to correct the parameter in question in order to give a result independent of changes to the instrumentation. The correct parameter is calculated using the equation

$$T = a \cdot (MV) + b, \tag{A.7}$$

where T stands for torque, MV is the measured value and a and b are values retrieved from the linear calibration curve.

Procedure for generator torque calibration

The shaft must be kept from rotating on the generator side. The torque is only added on the turbine side.

1. Record the voltage without any weights added.
2. Attach the weight holding fixture onto the torque arm. Record the voltage.
3. Place the weights onto the holding fixture until the desired start weight is reached. The weight-holding fixture and the weights in use must have a known weight. Record the voltage. Make sure the weights have no pendulum motion and no rotation when the recording is made.
4. Repeat the previous step until the highest desired weight has been recorded.
5. With all the weights in place, add force by slightly pressing down on the weights for a few seconds. After releasing, record the reading again.
6. Remove the weights in the same fashion as when adding weights and record each point. This will generate two recorded points for each set weight.
7. Continue until all the weights are taken off. Record the voltage.
8. Remove the fixture and record the voltage.

Appendix B

Testing

Testing is done to determine different performance parameters for the model turbine. Efficiency testing is performed to determine the best operating point and region for the model turbine. Runaway speed is determined to gain knowledge of how the turbine would behave if it is disconnected from the grid.

In this chapter procedures for testing the efficiency and runaway speed are presented along with procedures for start and stop of the Pelton rig.

B.1 Start and Stop Procedures

In this section, the procedures for start and stop of the Pelton model test rig are presented.

Start-up Procedure for the Pelton Rig

1. Open and close the relevant valves connected to the Pelton rig.
2. Switch on the frequency transformer connected to the pump.
3. From the control room, start the pump and the generator. These should start at 100 rpm.
4. Increase the pump's rotational speed by stages of 100 rpm until the pump is running at 500 rpm.[1]
5. Increase generator's rotational speed by 100 rpm.
6. Continue increasing the head while keeping the turbine running close to design load.
7. When there is no air bubbles in the flow, ventilate the pressure measurement system.

---

[1] Depending on local conditions, water should at this stage start to exit the nozzle

8. Continue increasing head until the desired head is reached.

Shut-down Procedure for the Pelton Rig

1. Decrease the rotational speed of the pump and generator while keeping the turbine running close to design load.
2. Stop the generator and the pump when both have a rotational speed of 100 rpm.
3. If there is an emergency, a red stop button must be located in the control room.

B.2 Efficiency testing

Efficiency testing is done by keeping the head constant while the rotational speed of the runner and the nozzle opening are varied. This way the efficiency is determined for a wide range operating conditions.

The data from testing can be visualized by using a Hill chart which shows how the efficiency changes at different flow rates and rotational speeds. Figure B.1 shows an example of a testing matrix where the efficiency is determined for each point in the matrix.

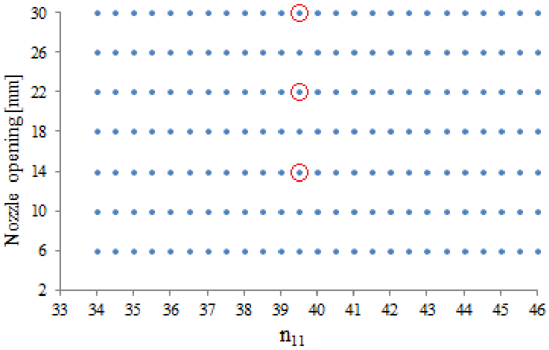


Figure B.1: Example of a set of measuring and control points used to create a Hill chart [18]

Efficiency Test Procedure

1. Adjust the nozzle to the lowest opening it is desired to test at. Keep the head constant during testing.

2. Adjust the modified rotational speed n_{11} to the chosen start point. Record the point.
3. Repeat the process for all the points in the testing matrix.
4. To ensure the validity of the results, controls must be taken to see if the condition of the rig has changed during testing. This is done by moving back to a previous test point and by checking if the same result is obtained [2].

Post processing

Process the results from testing using a mathematical software, in this case MATLAB. Example MATLAB code that is used to process test results can be found in Appendix C.

1. Sort the raw data into one file for each nozzle opening. These files need to be in a format supported by MATLAB.
2. Run the MATLAB code.
3. The results from running the MATLAB code should look similar to the illustration in figure 5.6.

---

[2] For the example of a test matrix illustrated in figure B.1, the control points are marked red.

B.3 Runaway speed

Testing the runaway speed is done to determine the behavior of the turbine if it is disconnected from the grid. This effect can be simulated by either having the generator switched off, or by adjusting the total torque to be zero. Having the generator running increases control. The following procedure therefore uses a running generator.

Without load, the turbine will spin until it reaches its maximum level of revolutions per minute for that specific head, n_{max}. n_{max} can also be calculated theoretically. First, the speed of the water exiting the turbine, c_2, is found using Bernoulli's equation without losses:

$$\frac{p_1}{\rho \cdot g} + \frac{c_1^2}{2g} + z_1 = \frac{p_2}{\rho \cdot g} + \frac{c_2^2}{2g} + z_2 \tag{B.1}$$

Assuming that the pressure is atmospheric for both cases, that the original velocity of the water is zero, that z_1 equals H_e and z_2 is zero, c_2 can be derived from Equation B.1:

$$c_2 = \sqrt{2g \cdot H_e} \tag{B.2}$$

After first finding the angular velocity ω, the maximal rotational speed can be calculated:

$$c = \omega \frac{D}{2} \tag{B.3}$$

$$n = \frac{60}{2\pi}\omega \tag{B.4}$$

Runaway speed test procedure

1. Increase to the maximum head desired to test at[3].
2. Adjust the rotational speed of the generator so the total torque approximates 0 Nm.
3. Record a point when the torque is positive close to zero and a point where the torque is negative close to zero. Interpolate to get a result for zero torque.
4. Decrease head and repeat the process until the lowest head desired to test at is reached.

---

[3] Air bubbles can be present at low heads. If first increasing to a high head and then decreasing the head, the problem of the air bubbles is no longer present.

Appendix C

Matlab script

This code was written by Lorentz Fjellanger Brastad and altered by Bjørn Winther Solemslie.

```
%-------------- IMPORT PELTON RAW DATA -------------------------------------
--------%
%
%   This function import rawdata from .txt files with the layout:

%    ------- ------- ------- ------- -------
%   |   A   |   B   |   C   |   D   |   E   |
%    ------- ------- ------- ------- -------
%   |  a_1  |  b_1  |  c_1  |   .   |   .   |
%   |  a_2  |  b_2  |   .   |   .   |   .   |
%   |   .   |   .   |   .   |   .   |   .   |
%   |  a_n  |  b_n  |  c_n  |   .   |   .   |
%    ------- ------- ------- ------- -------
%   |   A   |   B   |   C   |   D   |   E   |
%    ------- ------- ------- ------- -------
%   |  a_1  |  b_1  |  c_1  |   .   |   .   |
%   |   .   |   .   |   .   |   .   |   .   |
%   |  a_n  |  b_n  |  c_n  |   .   |   .   |
%    ------- ------- ------- ------- -------
%
%   and return a matrix


function [rawdata] = rawdata_import()

    %Open file import dialog
    [files,path] = uigetfile('*.txt','Import file(s) - (.txt) only',...
        'MultiSelect', 'on');

    %Find number of files selected
    if ischar(files) == 1
        fileNum = 1;
    else
        fileNum = length(files);
    end
    %Loop through source files

    for j = 1:fileNum

        if fileNum == 1
            file = files;
        else
            file = char(files(j));
        end

        filepath = [path,'',file];
        file = dir(filepath);
        fid = fopen(filepath);

        pos = 1; %Byte number to start import
        i = 2;
        while pos < file.bytes

            [rawdata(i,j),pos] = textscan(fid, '%f %f %f %f %f
%f','HeaderLines',2,...
                'CollectOutput', 1);
            i = i+1;
        end
```

```
        rawdata{1,j} = file; %Set file info as column header
        fclose(fid);

    end
end
```

```
 %------- CALCULATE MEAN DATA FROM RAW DATA (meandata_create.m) -----------
---------%
%
%   Creates a new matrix 'meandata' from a source MxN:

%           1       .       .       .       N
%        ------- ------- ------- ------- -------
%     1 |   A   |   B   |   C   |   D   |   E   |
%     .  ------- ------- ------- ------- -------
%       |  a_1  |  b_1  |  c_1  |   .   |   .   |
%     . |  a_2  |  b_2  |   .   |   .   |   .   |
%       |   .   |   .   |   .   |   .   |   .   |
%     . |   .   |   .   |   .   |   .   |   .   |
%       |   .   |   .   |   .   |   .   |   .   |
%     M |  a_M  |  b_M  |       |   .   |   .   |
%        ------- ------- ------- ------- -------

%   Where A-E indicates different nozzles (headers), and (a,b,c,..)_m is
%   measurements at
%   different constant rotational speeds.
%
%   OUTPUT      meandata        Nx1 struct table
%               meandata_spl    Nx1 struct table
%               nan_map         (M-1)xN table of '0' and '1' where '1'
indicates
%                               that the source containes NaN values


%   source      rawdata matrix (from rawdata_import.m)

% function [meandata meandata_spl nan_map] = meandata_create(source)
function [meandata nan_map] = meandata_create(source)


    %----------------------------------------------------------------

    D = 0.478674;             %Diameter of runner [m]
    g = 9.82146514;         %Gravity in the NTNU laboratory
    p_error = 0.207;        %Pressure transducer correction [m]
    t = 1.960;              %Degrees of freedom (random uncertainty)

    n11_a = 34;             %Reduced rot. speed (n_11) start
    n11_b = 46;             %n_11 end
    n11_step = 0.5;         %n_11 increment

    %----------------------------------------------------------------


    s = size(source);
    nan_map = zeros(s(1),s(2));

    %Create 'meandata'

    for j = 1:s(2)

        for i = 1:s(1)-1

            if isempty(source{i+1,j})
```

```
            p_temp(i,1) = NaN;
            q_temp(i,1) = NaN;
            T_temp(i,1) = NaN;
            M_temp(i,1) = NaN;
            Mlm_temp(i,1) = NaN;
            Mtot_temp(i,1) = NaN;
            n_temp(i,1) = NaN;
            q11_temp(i,1) = NaN;
            qed_temp(i,1) = NaN;
            n11_temp(i,1) = NaN;
            ned_temp(i,1) = NaN;
            Ph_temp(i,1) = NaN;
            Pm_temp(i,1) = NaN;
            rho_temp(i,1) = NaN;
            etah_temp(i,1) = NaN;
            head_temp(i,1) = NaN;
            Eh_temp(i,1) = NaN;

            nan_map(i,j) = 1;

        else


            p = source{i+1,j}(:,1);
            q = source{i+1,j}(:,2);
            T = source{i+1,j}(:,3);     %temperature
            M = source{i+1,j}(:,4);     %torque
            Mlm = source{i+1,j}(:,5);  %torque friction
            n = source{i+1,j}(:,6);

            %Mean values of raw data
            p_temp(i,1) = mean(p);
            q_temp(i,1) = mean(q);
            T_temp(i,1) = mean(T);
            M_temp(i,1) = mean(M);
            Mlm_temp(i,1) = mean(Mlm);
            Mtot_temp(i,1) = mean(M) + mean(Mlm);   %total torque
            n_temp(i,1) = mean(n);

            %Calculate error and standard deviation of raw data
            std_p = std(p);
            std_q = std(q);
            std_T = std(T);
            std_M = std(M);
            std_Mlm = std(Mlm);
            std_n = std(n);

            err_p = (t*std_p)/sqrt(length(p));
            err_q = (t*std_q)/sqrt(length(q));
            err_T = (t*std_T)/sqrt(length(T));
            err_M = (t*std_M)/sqrt(length(M));
            err_Mlm = (t*std_Mlm)/sqrt(length(Mlm));
            err_n = (t*std_n)/sqrt(length(n)/1000);

            p_temp(i,2) = err_p;
            q_temp(i,2) = err_q;
            T_temp(i,2) = err_T;
            M_temp(i,2) = err_M;
            Mlm_temp(i,2) = err_Mlm;
```

```
                Mtot_temp(i,2) = sqrt(err_M^2 + err_Mlm^2);
                n_temp(i,2) = err_n;

                p_temp(i,3) = 100*err_p/p_temp(i,1);
                q_temp(i,3) = 100*err_q/q_temp(i,1);
                T_temp(i,3) = 100*err_T/T_temp(i,1);
                M_temp(i,3) = 100*err_M/M_temp(i,1);
                Mlm_temp(i,3) = 100*err_Mlm/Mlm_temp(i,1);
                Mtot_temp(i,3) = 100*Mtot_temp(i,2)/Mtot_temp(i,1);
                n_temp(i,3) = 100*err_n/n_temp(i,1);

%                 etah_temp(i,2) = sqrt(p_temp(i,3)^2 + q_temp(i,3)^2 + ...
%                     T_temp(i,3)^2 + M_temp(i,3)^2 + n_temp(i,3)^2);

                etah_temp(i,2) = sqrt(p_temp(i,3)^2 + q_temp(i,3)^2 + ...
                    T_temp(i,3)^2 + Mtot_temp(i,3)^2 + n_temp(i,3)^2);

                %Calc density (dens), E, H, omega, q11_temp, Ph, Pm, eta,
head_temp
                dens = 1000/ ( (1 - (4.6699e-10)*p_temp(i,1)*1000) + ...
                    (8e-6)*(T_temp(i,1) - 4 + (2.1318913e-
7)*p_temp(i,1)*1000)^2 - ...
                    (6e-8)*(T_temp(i,1) - 4 + (2.1318913e-
7)*p_temp(i,1)*1000)^3 );

                %E = ((Pstat*1000)/rhow) + g*p_error + 0.5*(q_temp(i,1)...
                        %/(0.25*pi*0.1^2))^2;
                  E = ((p_temp(i,1)*1000)/dens) + g*p_error +
0.5*(q_temp(i,1)...
                        /(0.25*pi*0.1^2))^2;

                H = E/g;
                omega = ((2*pi)/60)*n_temp(i,1);
                q11 = q_temp(i,1)/((D^2)*sqrt(H));
                n11 = (n_temp(i,1)*D)/sqrt(H);
                Ph = dens*q_temp(i,1)*E;
                Pm = Mtot_temp(i,1)*omega;

                q11_temp(i,1) = q11;
                qed_temp(i,1) = q11/sqrt(g);
                n11_temp(i,1) = n11;
                ned_temp(i,1) = n11/sqrt(g);
                Ph_temp(i,1) = Ph;
                Pm_temp(i,1) = Pm;
                rho_temp(i,1) = dens;
                etah_temp(i,1) = Pm/Ph;
                head_temp(i,1) = H;
                Eh_temp(i,1) = E;

            end

        end

        %Insert calculated data into new table 'meandata'

        noz = source{1,j};
        b = length(noz)-7;
        %From raw
        meandata{j,1}.nozzle = noz; %noz(1:b)
```

```
        meandata{j,1}.p = p_temp;
        meandata{j,1}.q = q_temp;
        meandata{j,1}.temp = T_temp;
        meandata{j,1}.torque = M_temp;
        meandata{j,1}.torque_lm = Mlm_temp;
        meandata{j,1}.torque_tot = Mtot_temp;
        meandata{j,1}.n = n_temp;
        %Calculated
        meandata{j,1}.q11 = q11_temp;
        meandata{j,1}.qed = qed_temp;
        meandata{j,1}.n11 = n11_temp;
        meandata{j,1}.ned = ned_temp;
        meandata{j,1}.power_h = Ph_temp;
        meandata{j,1}.power_m = Pm_temp;
        meandata{j,1}.density = rho_temp;
        meandata{j,1}.etah = etah_temp;
        meandata{j,1}.head = head_temp;
        meandata{j,1}.energy = Eh_temp;


        clear q11_temp qed_temp n11_temp ned_temp Ph_temp Pm_temp rho_temp
...
            etah_temp head_temp Eh_temp p_temp q_temp T_temp n_temp
    end
```

```
%------- PLOT EFFICIENCY HILL CHART (meandata_hillplot.m) -----------------
--------%

function [q11 n11 eta] = meandata_hillplot(source)

    %----------- CHANGE --------------------------------------

    n11_a = 34;             %Reduced rot. speed (n_11) start
    n11_b = 46;             %n_11 end
    n11_step = 0.5;         %n_11 increment
    xval = 34:1:46;     %Chart x-values (n_11)

    %---------------------------------------------------------

    rows1 = length(source);
    rows2 = length(source{1,1}.etah);

    g = 9.82146514;
    q11 = zeros(1,rows1);
    n11 = (n11_a:n11_step:n11_b);
    eta = zeros(rows2,rows1);

    k = 1;
    for i = 1:rows1

        q11(i) = mean(source{i,1}.q11);

        for ii = 1:rows2

            eta(ii,i) = source{i,1}.etah(ii,1);
            k = k + 1;
        end

    end

    %Create Hill chart of (n11,q11,eta) = (x,y,z)
    figure

    set(gcf,'paperOrientation','landscape','paperUnits','normalized',...
        'paperType','A4')

    [c,h] = contour(source{1,1}.n11(:,1),q11',eta',...
    [0.80:0.01:0.84 0.84:0.005:0.87 0.87:0.002:0.878 0.878:0.0015:0.8795]);

    clabel(c);
    %clabel(c,h)
    xlabel('n_{11}','fontsize',12);
    ylabel('Q_{11}','fontsize',12);
    %set(gca,'xtickmode','manual','xtick',xval,'fontsize',12);
    set(gcf,'color','w');
    grid off


end
```

Appendix D

Budget proposal

Here a list of the the needed instruments, equipment, components and related expenses is presented with price estimates.

List of instruments for the Pelton model test rig at TTL

Amount	*Item*	*Model*	*Producer*	*Price estimate [NOK]*	*Francis rig*
1	Flow meter	Optiflux 2000	Krohne	50 000	
1	Pressure transducer	-	Tecsis	10000	
1	Load cell	Beam load force cell	HBM	5000	
1	Torque meter	T10F	HBM	140 000	
1	Speed sensor	-	Waterpower lab. design	10000	
1	Oxygen sensor	DIQ/S 182	WTW	25000	x
1	Temperature sensor	PT 100	-	2000	
1	Deadweight manometer	P3200 series	GE (Sensing)	120 000	x
			SUM Pelton	362 000	
			SUM Pelton - Francis instr.	217 000	

List of components , electrical equipment and another expenses relevant to the Pelton rig

Amount	*Item*	*Model*	*Producer*	*Price estimate*
1	AC asynchronous Generator			120 000
1	Frequency transformer			250 000
-	Connections Frequency transformers			-
-	Electrical installation			-
-	Wireing sensors to control room			-
1	Labview software and lincenses			20 000
1	Lab computer			30000
1	Nozzle			70000
1	Shaft			5000
-	Bearings and misc. related			15000
-	Steel turbine housing, frame and other			30 000
3m3	Plexi-glass			5000
10 m	Steel pipe inlet (AISI 304 DN100mm)			7000
			SUM Pelton	552 000

Appendix E

Field card

Field card for the visit to Kathmandu University and the Turbine Testing Laboratory together with Inger Johanne Rasmussen.

FELTKORT FOR LEDER AV FELTARBEID

Navn: Ida Bordi Stene Mob. nr.: 99464603

Bostedsadresse: Norneveien 11 b, 7033 Trondheim Forsikringsselskap: Gouda

Aktuelt sambandsutstyr på feltarbeidet: Mobiltelefon

Hvilket utstyr er tatt med på feltarbeidet, hvilke frekvenser tenkes evt. brukt på sambandsutstyret, o.l.

Nærmeste pårørende (navn, adresse og telefonnummer):

Ken Bordi, Frøsethøgda 20, 7290 Støren, 99727965

OPPLYSNINGER OM FELTARBEIDET*

Feltarbeidets navn/type, innhold/aktiviteter:

Besøke Turbine Testing Laboratory ved Kathmandu University

Feltområde/arbeidssted: Kathmandu University, Dhulikel, Nepal

Det er spesielt viktig å beskrive dette nøye dersom feltområdet/arbeidsstedet er vanskelig tilgjengelig.

Antall deltakere (inkl. leder): 2

Varighet Fra: 19.03.2014 Til: 05.04.2014

Når har evt. deltakerne fritid under feltarbeidet? Etter kl 16 og på søndager

Reiserute: (SK355, SK336) Trondheim-(QR176, QR177) Oslo -(QR652, QR651)Doha-Kathmandu

Inkluder flightnummer, flyavganger og avtalte bedriftsbesøk, etc. dersom dette er aktuelt.

Overnattingssteder: Dhulikel Lodge tlf 977-11490114, Norwegian House tlf 977-1-5538746

Navn, adresse, telefonnummer til hotell/pensjonat o.l. Opplys hvis det overnattes i telt/campingvogn o.l. på feltområdet.

Transportmidler: Lokal buss

Reg.nr. ved bruk av egen eller statens bil.

Medbrakt sikkerhetsutstyr: Ingen

KONTAKTPERSONER*

Kontaktperson ved egen enhet: Wenche Johansen Tlf: 73593857

Annen kontaktperson: Magni Fjørtoft Svartstad Tlf: 41641665

Fylles ut ved feltarbeid uten spesielle risikomomenter (se Feltarbeid – for deg som leder). Ved mer omfattende feltarbeid utarbeides egen reiseplan.

Jeg bekrefter at jeg har lest NTNUs retningslinje; Feltarbeid – for deg som leder.

Jeg bekrefter at jeg vil rette meg etter de sikkerhetsrutiner som gjelder for feltarbeidet, og at jeg vil opptre slik at min og andres sikkerhet ivaretas under feltarbeidet.

Sted/dato: 12.03.2014 **Signatur:** Ida Bordi Stene

Utfylt feltkort oppbevares ved egen enhet.