Micro-Hydro Test Machine

All hydroelectric generation is renewable and merits international support (WSSD 2002). Hydroelectric power stations convert the kinetic energy of the falling or flowing water into electricity, which can then be used anywhere from homes to businesses, depending on its grid scale (large, small, or micro). Unlike the wind and sun, this resource is available twenty-four-seven. Hydroelectricity also aids the fight against climate change by producing small amounts of greenhouse gases, and doesn't release any pollutants into the air we breathe, thus reducing acid rain and smug. In the long term, it improves our quality of life by bringing electricity, highways, industry and commerce to communities, consequently developing the economy.

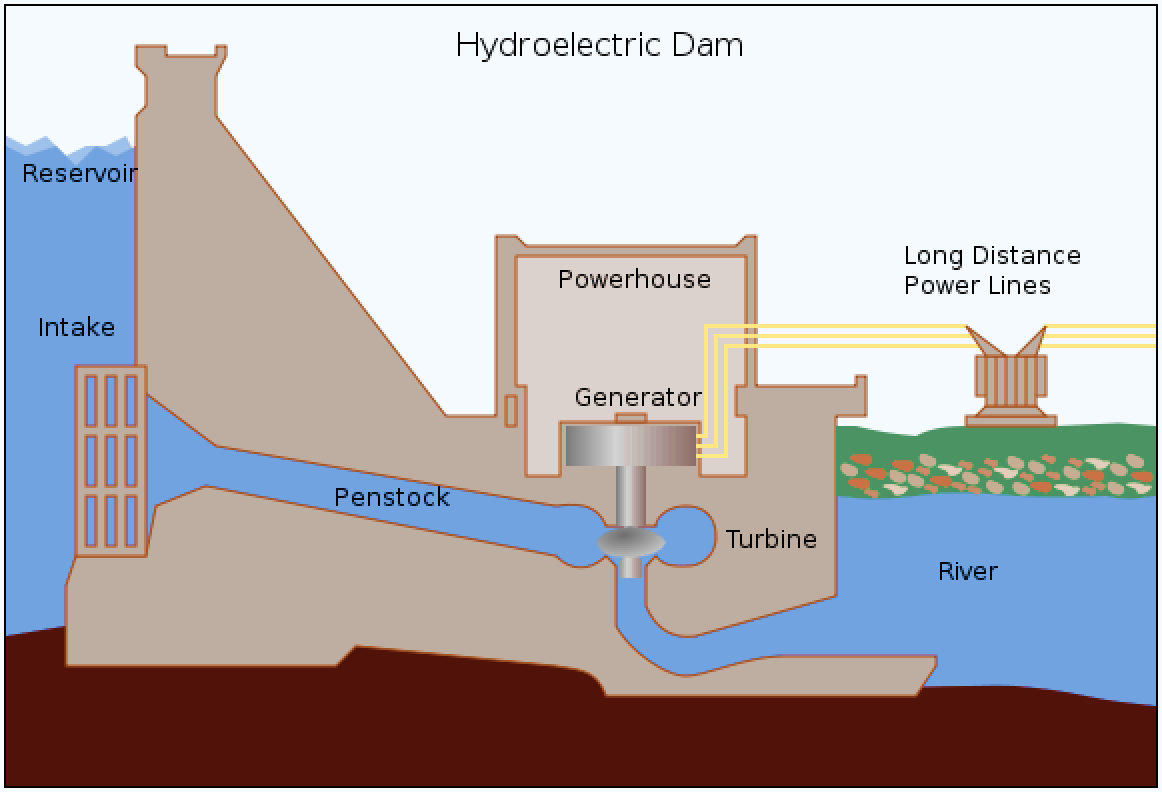
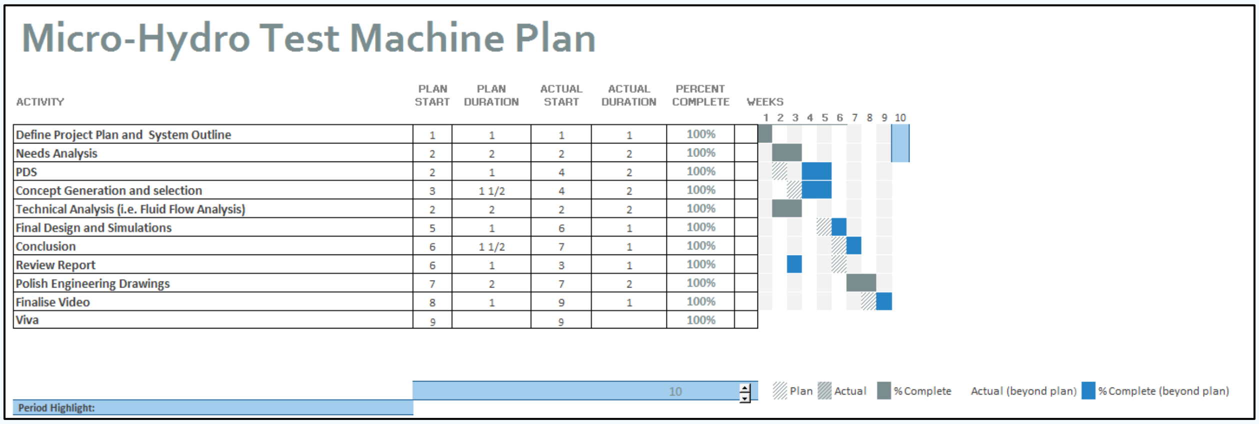


Figure 1. Hydroelectricity diagram (REEI 2010)**.**

Fundamentally, these systems are the combination of water flow and vertical drop or "head". They can vary from high head (above 3m) to low head (below 1.5m). The vertical drop creates pressure and the continuous flow of water provides the ongoing source of "pressurised liquid energy". Since this is trapped in a pipe or penstock, as shown in the figure above, and directed to a turbine which is connected to a generator, its energy becomes electricity. Hence, it is pivotal to select the turbine according to the type of system (high head, or low head), or else the system's life cycle might be shortened.

PROJECT PLAN



Micro-Hydro Test Machine Plan

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Define Project Plan and System Outline	1	1	1	1	100%
Needs Analysis	2	2	2	2	100%
PDS	2	1	4	2	100%
Concept Generation and selection	3	1 1/2	4	2	100%
Technical Analysis (i.e. Fluid Flow Analysis)	2	2	2	2	100%
Final Design and Simulations	5	1	6	1	100%
Conclusion	6	1 1/2	7	1	100%
Review Report	6	1	3	1	100%
Polish Engineering Drawings	7	2	7	2	100%
Finalise Video	8	1	9	1	100%
Viva	9		9		100%

Period Highlight: 10

Figure 2. Project Plan.

A test machine has been designed to evaluate micro-hydro devices, within a time frame of ten weeks. This was achieved by following a structured, clear project plan (seen in figure 2 above). In depth research was performed as the system's outline was defined. The needs analysis was approached with the sole purpose of producing a precise product design specifications. Although a holistic design approached was utilised, a few concepts were generated and then compared against the PDS before selecting the optimal one. A broad range of technical analysis and simulations were done to support the chosen design, as well as its supporting structure. The final design of the testing machine is a direct product of this project plan.

NEEDS ANALYSIS AND MARKET RESEARCH

The global hydropower-market demand is rising fast, especially in developing countries, due to an increase in populations and industrialization (WGR 2017). Geographically, this growth has been split into different regions; United States, China, Europe, Japan, Southeast Asia, and India (the U.S being the largest, and India the smallest producer of hydroelectricity). In the United Kingdom, opportunities to use this technology in a large scale, are now limited, mostly because the economically- attractive schemes have already been used (DBEIS & EA 2013). For this reason, it is crucial that the remaining micro-hydro resources are exploited in a sustainable manner. These regions and their respective hydropower production follow some steps that ought to be considered *before* a scheme can be built. For example, economics, environmental permits (i.e. carbon emission reduction), planning consent, connection to the local electricity network, energy security, and the opportunity to profit from feed-in tariffs.

FAB 3R	*Bharat Heavy Electricals*
ANDRITZ	*Tech. Escher Wyss Flovel*
HYDROHROM	*Jyoti*
WEG	*HPP Energy*
Voith	*International Center on Small Hydro Power*
General Electric	*Hunan Sunny Hydropower*
Canmet ENERGY	*SHZ*

Table 1. Main global hydropower players.

Its market competition has been concentrated within the top manufactures listed above. It has been found that each manufacturer specialises on different types of grid-scales as well as turbines. This is so because, there is a wide range of customers and needs in accordance to the range of capabilities in the market. Each individual company has its own competitive advantage, but not all fall within are of generating micro-hydro power. A few of these companies have been compared to see how their services, affect their overall competitive advantage.

Grid-scale variety, machine capabilities, technical expertise, and rigorous project management is what FAB 3R, the Canadian hydropower company, offers its customers in the U.S and Canada (FAB 3R 2013), where they mostly provide low-head systems for other businesses. On the other hand, ANDRITZ, an Austrian engineering group, has installed over thirty-thousand turbines *globally* (ANDRITZ 2017) as they have covered all ranges in the market. This engineering group has focused on testing and staff training for both their mechanical and electrical equipment. Then again, a Czech electro-mechanical equipment supplier, HYDROROM, is a newer company (compared to the ones just discussed) that has risen and expanded globally over the last century as it widened its range of capabilities (Hydrorom 2017). In their case, one prominent competitive advantage is their history; The Czech's hydro turbine manufacturing and production tradition started back in the nineteenth century, and they became home for the invention of the Kaplan turbine. However, with only about fifty years of experience, Jyoti, has managed to offer all the major equipment for hydro projects; Turbines, generators, monitor and control panels. (Jyoti 2012). The original Indian installations has quickly expanded globally, thus they went from executing 50KW to 48MW in a short time frame.

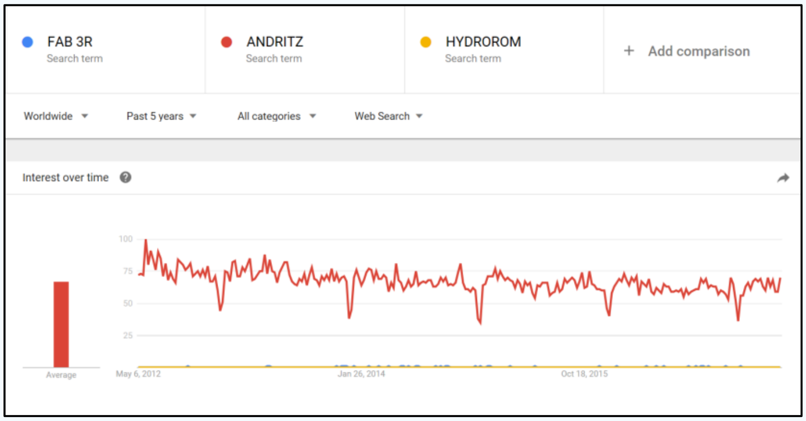


Figure 3. Google trends analysis comparison between top providers.

Although customers seek specific services, they tend to turn to the provider with the wider range of capabilities and more experience. Since hydropower generation is a global market, it is almost impossible to precisely determine who is on top of the competition. By comparing these few companies, it has been proven that despite the years of experience, if a company provides all possible services and can prove its reliability with testimonials, it will rise (as seen in Jyoti's case). These companies are able to maintain its position in the market by keeping its customers rather than seeking new ones because it is easier to stay on top in this way. As seen in figure 3 above, these few companies have constant customers to work with.

CAPABILITIES

Ergo, the test machine requested for one off production, must follow *specific* technicality and capabilities so it can fit in the market to fulfil customer's needs. The machine must be capable of testing micro-hydro devices with a rated output of 1KW, as it delivers a net head of 1-10 meters (with clear increments) for at least 1 minute, whilst the respective turbine operates at full load. A system has been designed to make sure its complexity is measured, controlled and monitored (MCM) at all times. Its entire system involves the same electro-mechanical equipment provided by existing companies in the market, but experienced engineers are needed to provide a reliable MCM system to the low-medium head customers and their projects.

COMPETITIVE PRODUCT TECHNICAL ANALYSIS

The competitive product, in this scenario, is the overall service being offered. So, the service's capabilities need to be described in more detail for it to work efficiently. A Product design specification has been created with this aim. This is relevant because, a clear and specific PDS provides additional advantage to companies in the market, because it increases the possibilities of success in the project being developed.

PDS (SI units)

System	Medium-High head.
Testing Time	60 seconds.
Water Head	1-10
Head Increments	2, 4, 6, 8, 10
Pressure Head (Pa) Increments	Dependent on water viscosity. See table 5 or 7.
Volumetric Flow (m^3/s)	0.01-0.05
Installed Power Capacity (Kw)	1-8 kW
Structure (material, max stress)	4 steel (S355J2) supports 2 per each pipe. Max stress on support 1 and 2 respectively: 280N/m, 3980N/m.
Micro-Hydro Devices	Best suitable for impulse devices; Pelton Wheels.
Turbine	Impulse. Pico Pelton Wheel hydro turbine, or other.
Generator Type	Synchronous Alternator.
Tank	Short and wide. Plastic
Tanks' capacity	≈ 15 m^3
Height monitor	Ultrasonic level sensor.
Pipes	PVC with pressure rating 40% above water's static pressure.
Pipes size and length (mm)	500 mm diameter→1500mm X 1, 1000mm X 5, 500mm X 1.
Pipe fittings	508 mm diameter→5 x 90 degree elbows curved.
Pipe fitting losses (Pa)	23.1
Pipe Losses (Pa)	Variable dependent on head or pressure allowed. See table 14.
Pipe control panel	2500mm long.
Nozzle	100-150mm.
Pump	Centrifugal, submersible. To be used as reversible.
Pressure Gauge	0 – 11 Bar.
Power Meter	Between turbine and generator to calculate efficiency.
Flow Meter	Large diameter FLOMAT electromagnetic flowmeter.
Thermostat	Surface mounted L641B Pipe Thermostat.
Efficiency	≈ 20%
Environment	Controlled inside testing facility (15-23 degrees C).
Maintenance	Periodical. Dependent on all components.
Life time	20-90
Ball Valve	1
Gate Valve	1
Control Panel Losses (Pa)	30
Cost	≈ £10,000

Table 2. Product Design Specification.

Depending on the head increment and turbine being tested, the product's constraints must be set up accordingly. The water inside the tank is pumped up through the pipe control panel (pressure gauge, flow meter, valves) to the turbine's runners, and the turbine's connection to the generator should allow the output of 1KW each time it runs a test for at least one minute. Every test needs to be MCM with the chosen products correctly set up to obtain and provide the customer with accurate results.

CONCEPT DEVELOPMENT

Concept Development

The aim is to design a product that can be manufactured easily and economically. Designing For Manufacture (DFM) aspects have been integrated into the concept development and selection process, since about 70% of a product's manufacturing cost is determined by design decisions (Chang et. al.1998). Consequently, design guidelines such as the PDS and TPS (BS8888:2017) have been followed.

The features to be MCM (i.e. volumetric flow) highly influenced the concepts creation. These have been defined and discussed in more detail in the Engineering Analysis section. Any hydro-turbine in a micro-hydro machine can be tested, if the correct vertical drop distance, or head, is selected. The turbine's runner for low-head turbines may be a Turgo or Francis type. For high head ones, the common runners are Turgos on the low end, and the most common, Pelton, for medium to high heads (OEE & RE 2017). For this reason, a head increment of 2 meters has been clearly defined with its five different set-ups, within the machine shown below.

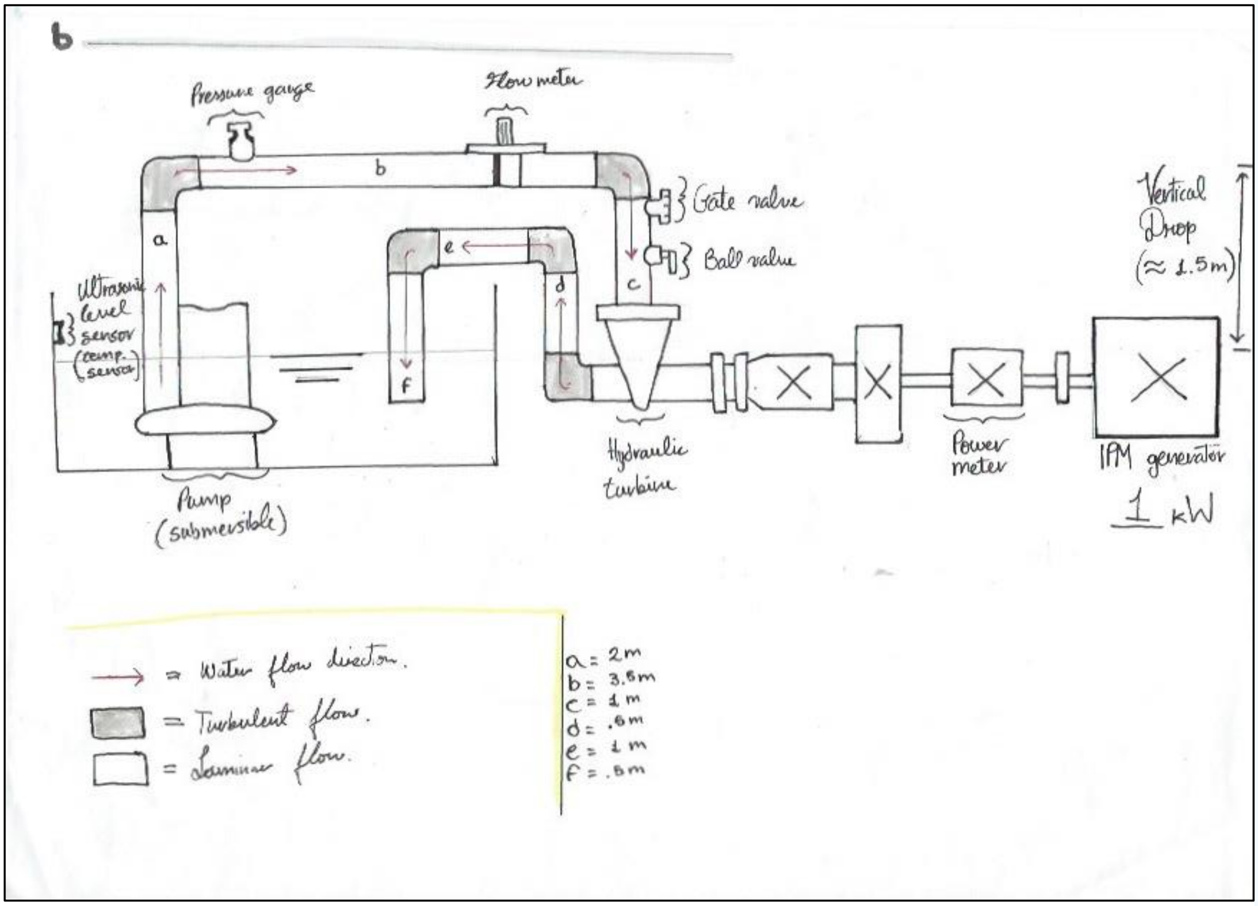


Fig 4. Test machine diagram.

To produce a rated output of 1KW, each set-up, although similar, will logically need a different amount of water flow because it will input a different amount or water pressure or head. Within the Newtonian-fluids equations utilised to equate the power generated is the understanding that systems with low vertical drop (head) need more flow to generate the same amount of energy as those with high head. Typically, low-head systems will have high flow, and high-head systems will have lower flow.

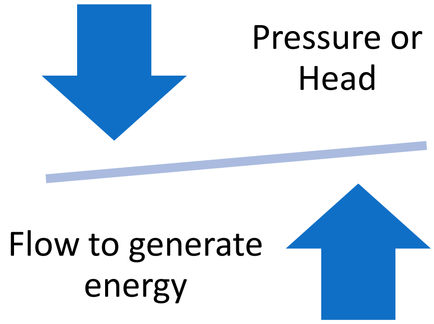


Fig 5. Head-flow relationship.

Pipe Nominal Size (mm)	Head (m)
125	10
150	8
200,250	6
300,400	4
450,600	2

Table 3. Concept 1.

Using straight-thinking, if more flow is needed, then a wider pipe must be used. But the more variety in pipe size, the costlier the final testing machine will be. Variety, in this case, isn’t justified, because the system could work as efficiently by choosing one as an intermittent variable; The pressure or the flow. As seen in figure 4, if more pressure is applied to the runners by the water, less flow is needed and vice-versa.

Pipe Nominal Size (mm)	Head (m)
125	10
125	8
200,250	6
200,250	4
450,600	2

Table 4. Concept 2.

For the pipe size to match each type of system (low, medium, high head) all volumetric flow (VF) values needed were compared to the one needed at the lowest head: 2 meters. Meaning that the VF at 2 meters was divided by the other ones separately. This provided a logical approximation for the pipe-size ratio. For example, the VF at 10 and 8 meters is four times smaller than the one at 2 meters, thus, the diameter at 2 meters should be 4 times bigger than the ones at 8 and 10 meters.

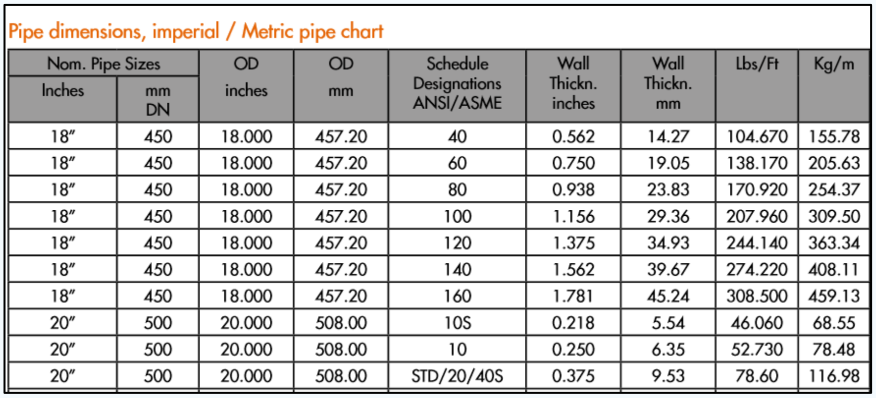
But these concepts are a lot more precise than they are cost effective, yet, they can be more DFM friendly without losing their precision in their MCM aspect. From here, the final concept:

Pipe Nominal Size (mm)	Pressure Head (Pa)	Simulated Head (m)
500	97980	10
500	78284	8
500	58487	6
500	38358	4
500	16488	2

Table 5. Concept 3.

Where a 1KW to 8KW Pico Pelton Micro Hydro Turbine Generator, with a 500-1000 mm diameter capacity, will be utilised. This was chosen because of its wide pressure or head range and big flow capacity, the bigger it is, the less space the test machine will need- since the actual physical head will be the lowest possible. For this reason, the actual head, or height, must be between 1 and 2 meters. The turbine wide range of pressure allows it to operate at full load for at least a minute, as the pump "recycles" the water.

A nominal pipe size of 500mm has been chosen after considering the height from the hose of the upper part duct to the hydraulic turbine, which equates to 1.5 meters. This design permits any micro-hydro device to function as part of the system, given that the pressure or head required for the device can be easily adjusted. Different turbines are produced to fit different systems, this system, is physically a low head of 1.5 meters, but it can simulate a high head system by changing its pressure set-up. So, if a low head must be tested, a Turgo or Francis type could be used, or a high head-the common runners are Turgos, and the most common, Pelton, for medium to high heads.



Pipe dimensions, imperial / Metric pipe chart

Nom. Pipe Sizes		OD	OD	Schedule Designations ANSI/ASME	Wall Thickn. inches	Wall Thickn. mm	Lbs/Ft	Kg/m
Inches	mm DN	inches	mm					
18"	450	18.000	457.20	40	0.562	14.27	104.670	155.78
18"	450	18.000	457.20	60	0.750	19.05	138.170	205.63
18"	450	18.000	457.20	80	0.938	23.83	170.920	254.37
18"	450	18.000	457.20	100	1.156	29.36	207.960	309.50
18"	450	18.000	457.20	120	1.375	34.93	244.140	363.34
18"	450	18.000	457.20	140	1.562	39.67	274.220	408.11
18"	450	18.000	457.20	160	1.781	45.24	308.500	459.13
20"	500	20.000	508.00	10S	0.218	5.54	46.060	68.55
20"	500	20.000	508.00	10	0.250	6.35	52.730	78.48
20"	500	20.000	508.00	STD/20/40S	0.375	9.53	78.60	116.98

Fig 6. Pipe-line sizing (Matrix Solutions Ltd.).

CONCEPT DEVELOPMENT

MCM (MEASURED, CONTROLLED, MONITORED)

Whichever input on the machine will methodically produce an output, in this case, 1KW of power. This can only occur if the machine allows for constant measure and control. MCM aspects are classified and justified below:

The temperature of the water, because this directly affects the water's viscosity. This decreases markedly with increasing temperature, as proved in the calculations. When the viscosity decreases, Reynold's number increases and the flow resistance (or coefficient of friction) decreases. So, for the same driving force (that is the pressure drop per unit length) the water flow rate will be higher. It means that, since the geometry of the pipe remain the same, the flow will be faster when the water is at higher temperatures. The dynamic viscosity decreases almost 5 times its initial value in the range of 0-80 degrees Celsius: *1.8- 0.5 Pa s*, as seen on table 10. The plastic tank will only MCM temperature in this range to stay within the safety factor.

The Pump for pressure or head. The centrifugal pump is one of the most popular pumps which can generate pressure by centrifugal force caused by the turn of the impeller. The exit of the reversible pump-turbine relates to the hose to a water tank. The increase of revolving speed of the submersible pump causes increase of water flow and pressure. This results in an increase of total head. The pressure head and volumetric flow are controlled with a pressure gauge and flow meter, respectively. The pressure gauge provides a wide range of 0-11 bar, which is safe to run the tests with about 1 bar of pressure. FLOMAT's electromagnetic flowmeter was chosen because it is used for large diameter pipes, and is specifically suitable for low and medium temperatures.

The water level. As the flow is laminar and turbulent at times, the ultrasonic level sensor is ideal to measure the change in head of water. This should ideally stay constant, as the water is being recycled back into the tank. An ultrasonic level sensor is used to track the level as well as the temperature. Because Omega's LVTX-10 sensor includes an advanced diagnostic feature that will retrieve the tank's ultrasonic waveform for analysis, and display it on any computer to aid with debugging complex installations.

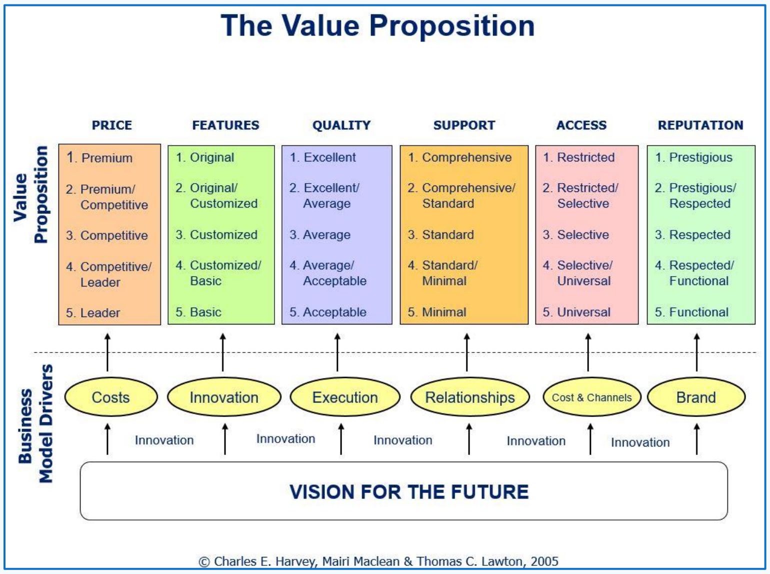
The flow, although not affected by water's viscosity, and the pressure within the pipe-control panel (made up of the pipes b and c, seen in figure 4). These will be MCM by using a pressure gauge, flow meter and a gate valve proceeded by a ball valve. The valves are positioned vertically on pipe c, right before the turbine, for more pressure and flow. A ring stem gate valve and a stainless-steel ball valve from Bundor are placed one after the other for a better control: As the pressure head is applied appropriately by the pressure gauge, these valves will provide further control on the transition from pipe to turbine's runners.

The energy head. The whole purpose of the system is to take its potential energy, and convert it into kinetic energy, because this will produce electricity as the outcome. Thus, power: The amount of energy being produced by the system will allow for efficiency's calculation, which will help to provide the optimal bus voltage through the system.

CONCEPT DEVELOPMENT

COST

For most people, a combination of motives—environmental, independence, reliability, and cost—make hydro-electric systems attractive. The "bottom line" may end up being what the actual cost per kWh is (Home Power 2017). The local utility policies for renewable energy systems are to be known, and at what amount one will be credited or paid. One also needs to know if any incentives (utility or government) exist. Available incentives, though, may be *generous* because of hydro's 24-hour generation capability. Once these figures are obtained, one can predict how many years your system will operate and the annual maintenance costs, and then the cost per kWh can be calculated.



PRICE	FEATURES	QUALITY	SUPPORT	ACCESS	REPUTATION
1. Premium	1. Original	1. Excellent	1. Comprehensive	1. Restricted	1. Prestigious
2. Premium/ Competitive	2. Original/ Customized	2. Excellent/ Average	2. Comprehensive/ Standard	2. Restricted/ Selective	2. Prestigious/ Respected
3. Competitive	3. Customized	3. Average	3. Standard	3. Selective	3. Respected
4. Competitive/ Leader	4. Customized/ Basic	4. Average/ Acceptable	4. Standard/ Minimal	4. Selective/ Universal	4. Respected/ Functional
5. Leader	5. Basic	5. Acceptable	5. Minimal	5. Universal	5. Functional

© Charles E. Harvey, Mairi Maclean & Thomas C. Lawton, 2005

Figure 7. Product Pricing Strategy.

Using Harvey's, Maclean's, and Lawton's "Value Proposition" diagram, see above, it was decided that the final product falls within the number-one categories. Where the price is premium, the features are original, the quality is aimed to be excellent or above, there's comprehensive support, as well as restricted access to it. When using this system for value proposition, the price sets the customers' expectations, and these must, *at the very least*, be met.

The chosen £10,000 price is an approximation, since its "retail price" can only be justified by using the formula: Retail Price = [(cost of item) ÷ (100 – mark up percentage)] × 100. (Khan, 2016) after having created a Bill of Materials for the finalized- product. The final given price is a reflection of the technicality and complexity behind the final product.

Technical Analysis

ENGINEERING ANALYSIS

To test micro-hydro devices with the chosen concept, engineering analysis must be done to all areas within the system because they are in constant interaction during “running time”. The impulse Pico-Pelton turbine and its stainless-steel runners, pipes and their fittings, supporting structure, and overall efficiency have been mechanically analysed in detail. This was done using Newtonian fluids equations: Bernoulli’s, and many more, found listed in the Appendix.

Bernoulli’s equation was utilized to do a series of calculations for the turbine’s nozzle-like structure in all head increments. The step-by-step calculations can be found in the appendix in the 10 m head example.

H_t	**Q** x 10^{-3} **(m^3/s)**	**V_2 (m/s)**	**A_2** x 10^{-3} **(m^2)**	**D_2** x 10^{-3} **(m)**
2	51	6.26	8	101
4	25	8.86	3	60
6	17	10.8	1.6	45
8	12.7	12.53	1	36
10	10.2	14	0.7	30.5

Table 6. Bernoulli’s equations calculations 1.

From these volumetric flow results, the actual **Q per minute range** needed = 0.3 – 0.6 m^3/s.

Since a 500mm pipe line will be utilized:

H_t	**A_1** x 10^{-3} **(m^2)**	**D_1** x 10^{-3} **(m)**	**V_1 (m/s)**	**H_{V1} (m)**	**H_{p1} (m)**	**P_1 (Pa)**
2	196.3	500	0.25	0.319	1.68	16488
4	196.3	500	0.13	0.089	3.91	38358
6	196.3	500	0.08	0.038	5.96	58487
8	196.3	500	0.06	0.019	7.98	78284
10	196.3	500	0.05	0.012	9.98	97980

Table 7. Bernoulli’s equations calculations 2.

But, as discussed before, the change in water’s viscosity (or temperature) will most likely have an effect in the flow rate of the liquid. To prove this theory by comparison, three different values for water’s density were used at 15, 40, and 80 degrees Celsius.

Degrees Celsius	**15**	**40**	**80**
Density (kg/m^3)	1000	9922	9718

Table 8. Temperature V.S. viscosity.

The volumetric flow (Q) values stay constant, despite viscosity change. The mass flow rate, however, has a slight variance of about 5 digits through the three different viscosity values.

H_t	**Mass Flow rate Q×ρ (kg s^{-1})**		
Degrees Celsius	15	40	80
2	510	506	496
4	250	248	242
6	170	169	165
8	127	126	123
10	102	101	99

Table 9. Mass flow rate V.S. head.

Density (kg/m^3)	**1000**	**9922**	**9718**
P_1 (Pa)	97980	971401	951429
Power (Watt)	714	707	693
E (J)	42840	42420	41580

Table 10. Density V.S. pressure head, power, and energy.

Where the P_1 (pressure head) to simulate the head increments, is directly dependent on the viscosity of the water. The difference in amount of power and energy after one minute is clearly changing with the viscosity. Power and energy generated are indirectly proportional to the viscosity, and the pressure head is directly proportional to it.

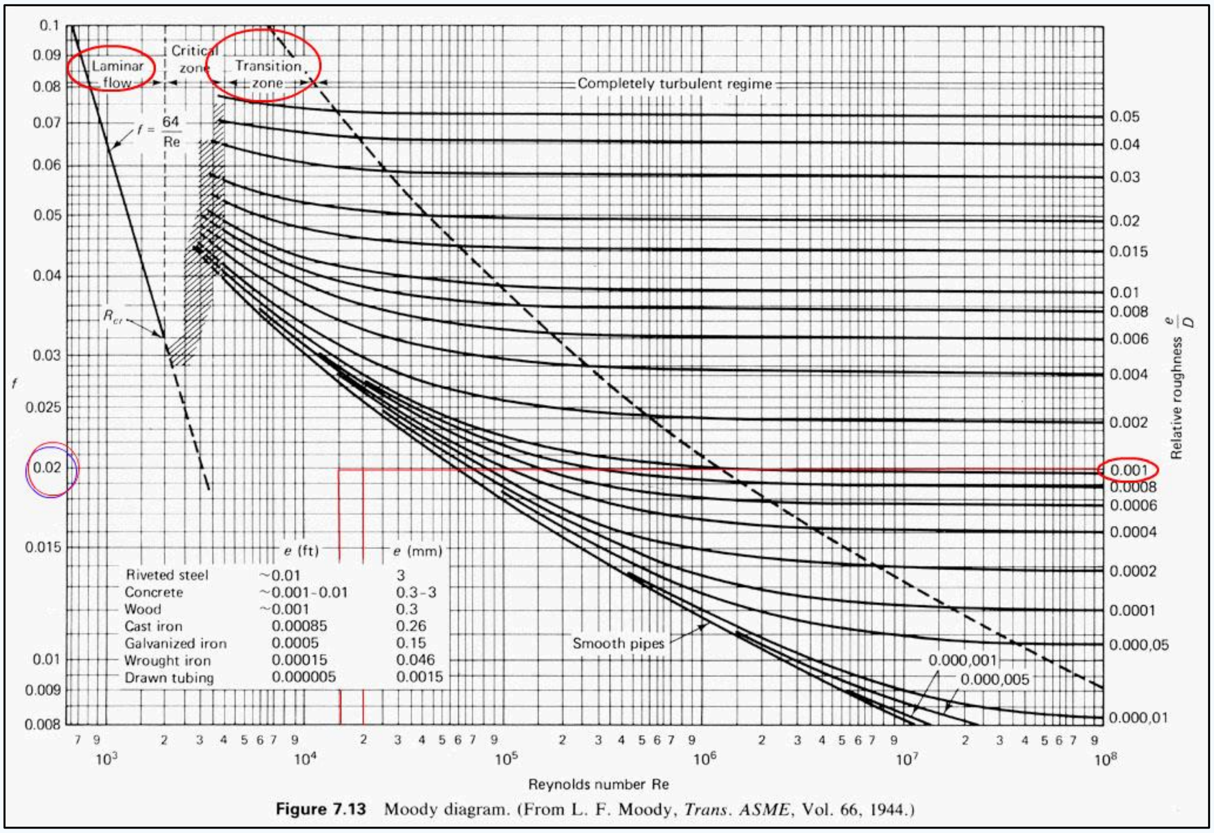


Figure 7.13 Moody diagram. (From L. F. Moody, *Trans. ASME*, Vol. 66, 1944.)

Fig 8. Moody diagram. (ETB 2017).

TECHNICAL ANALYSIS

By using a moody chart, the Darcy-Weisbach friction factor was calculated. Reynold's number for each was determined as the temperature changes, this proved that as the temperature rises and viscosity decreases, the friction factor decreases, leading to a higher flow rate.

Degrees Celsius	**15**	**40**	**80**
Dynamic Viscosity (Pa s)	1.793	0.653	0.354
Reynold's Number (Re)	4 X 10^{-3}	1 X 10^{5}.	2 X 10^{5}
Pipe Roughness (Micron)	1.5	1.5	1.5
Friction Factor (f_D)	0.016	0.02	0.02

Table 11. Temperature V.S. viscosity, Re, roughness, and friction.

Here, it can be seen that as the temperature increases, the flow becomes less laminar, more turbulent.

The Reynold's number for the dynamic viscosity at 40-80 degrees Celsius falls within the *critical zone*, meaning the flow of water will be a random mixture of turbulent and laminar flow. When at room temperature, or 15 degrees Celsius, the flow is laminar. The friction factor for the laminar flow was easily calculated using the corresponding equation, $f = \frac{64}{Re}$.

When considering the pipe losses, different sections of the machine are considered; The regular pipelines (including the designed-from-scratch pipe-control system), the 90 degrees elbow fittings, gate valve, and ball valve.

The K factor of the pipe lines was found by multiplying the friction factor by the equivalent length of 9.5 meters. The equation for the change in pressure provided the pipe lines' loss value. This was first calculated for 10 meters of head, where V is 14 m/s.

$$\Delta p = k \frac{\rho V{\hat{}}2}{2}$$

F_D	0.016	0.02
K (m)	0.152	0.19
Δp (Pa)	14896	18620

Table 12. Change in pressure.

So, the less friction- the less losses.

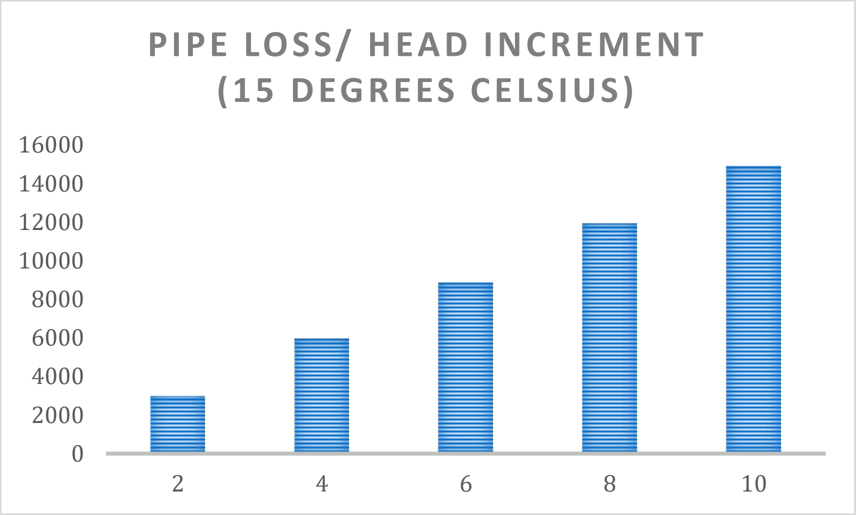


Fig 9. Pipe losses in 15 degrees Celsius.

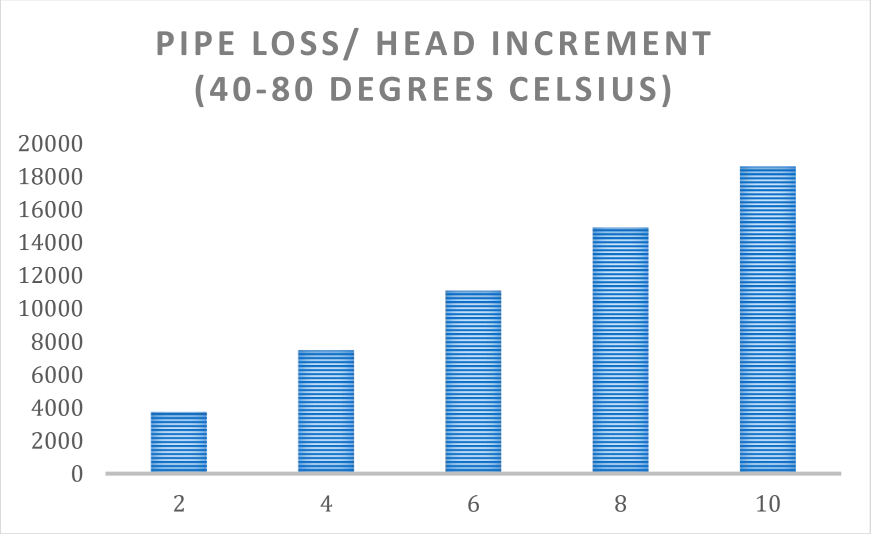


Fig 10. Pipe losses in 40-80 degrees Celsius.

The total head and loss were found to be directly proportional, and once again, the viscosity is found to affect the values by also being directly proportional to the amount of losses. The higher the temperature or/and total head, the higher the loss will be.

The losses through fittings were calculated using K = f_T (L/D)

Fitting	**L/D**	**Quantity**
Elbow-90	30	5
Gate Valve	8	1
Ball Valve	6	1

Table 13. Fittings.

Where the pipe friction for the nominal size of around 500mm is 0,011.

	Elbow-90	Gate Valve	Ball Valve
K (m)	1.65	1.22	0.91
Loss (Pa)	23.1	17.02	12.77

Table 14. Fittings' k factors and losses.

The losses (change in pressure times the velocity head) obtained, have been compared to the *actual* pipe diameter, half a meter, and for this reason the calculated losses are categorized as neglectable.

STRUCTURAL DESIGN

The current Micro-Hydro device's design, as seen in the schematic drawings, will need to be supported in a single area; The two levelled pipes. For this reason, the steel structure should not be excessive. Four steel (S355J2) I-beams, along with a strong base in compression, will support the system.

A series of calculations were done for an efficient structure-selection process by considering the limiting factors such as the stress. Firstly, the PVC pipes were analyzed- neglecting the weight of the pressure gauge and flow meter on pipe 2:

Pipe1 length (m)	1
Pipe2 length (m)	3.5
Weight (kg/m)	20
Weight when filled with water (kg/m)	124

Table 15. Pipes details a.

Pipe1 mass (kg)	124
Pipe2 mass (kg)	434
Pipe1 weight (KN)	1.2
Pipe2 weight (KN)	4.2

Table 16. Pipes details b.

After these calculations were done, the I-beam steel structure was analyzed:

Serial size (mm)	254 x 102
D (mm)	260.4
B (mm)	102.1
Mass/ m	28
Safety factor	0.6

Table 17. I-beam specifications.

Ys (MPa)	355
BM1 (Nm)	423
BM2 (Nm)	5838
Wel (cm^3)	1.5 x 10^{-6}
I (cm^4)	1.5 x 10^8
E (MPa)	210
Max Stress1 (N/m)	280
Max Stress2 (N/m)	3890
Section Modulus1 (cm^3)	1.5
Section Modulus2 (cm^3)	1.5

Table 18. I-beam calculations.

Now the deflection:

Deflection1 (cm^4)	0.008 x 10^4
Deflection2 (cm^4)	0.03 x 10^4

Table 19. Deflection values.

Then, the second moment of area from the deflection and load:

I1 (cm^4)	4.2 x 10^4
I2 (cm^4)	239 x 10^4

Table 20. Effective length.

Since it is known that the beam is held in position at both ends but isn't restrained in position, the effective length was found, in BS EN 10210-2:2006, to be = 1.0 L. The radius of gyration was found to be = 10,3 cm.

In terms of the compressive load:

Effective length1 (m)	1.41
Effective length2 (m)	5.56
Max force1 (KN)	4.2
Max force2 (KN)	8.8

Table 21. Maximum force.

S1	0.14
S2	0.54
S$_o$	15.3

Table 22. Slenderness ratio.

From these results, it can be seen the slenderness ratio is greater than s, so the failure load (Fcrip) is equal to Ys- meaning that the failure *will be* crippling. The Robertson constant was identified to be 2, and the Fcrip is 355, these were obtained by looking at table 11 and 12 from BS 2573-1 respectively.

Fcrip failure stress (MPa)	49.8
Force (KN)	76

Table 23. Failure load.

The original Fcrip value was 83 MPa, but after taking into consideration the safety factor, this became 49.8 MPa.

EFFICIENCY

Power (KW)	Voltage (AC)	Speed (rpm)	Frequency (Hz)	Rated Torque (Nm)	Current (A)	Efficiency (%)
1	220	327.6	60	73	6.7	93.8

Table 24. Generator details.

For the turbine's efficiency, the output power range of 5-100Kw, and input power range of 1-8Kw allows for an efficiency of approximately 15-20%. Since this is the case, then Q must be the equivalent of 5Kw (100% ÷ 20%), because the rated output must be 1Kw.

$\text{Efficiency}_{\text{turbine and generator}}$= (useful energy transferred ÷ energy supplied) × 100.

The generator input power = (hydraulic turbine output power Pt), the output power Pg and efficiency ηg. So, using the turbine's and generator's details, Pg/Pt. → $\frac{1}{5}= 0.2 \times 100 = \text{Efficiency}_{\text{overall system}}= 20\%$.

Since, generator efficiency increases as the head increases, and this provides a fixed frequency of 10, 20, 30, 40, 50HZ, the higher the head becomes, the higher the *optimum frequency* is. The optimum generator frequencies (*fg)* to get maximum hydraulic turbine efficiency become 15Hz, 20Hz, 27 Hz, 42Hz, and 50Hz for the heads of 2m, 4m, 6m, 8m, and 10m respectively. A relationship between turbine/ generator efficiency and head has been found: Both efficiencies are expected to be directly proportional to the total head. The more frequency the generator inputs, the more efficient the turbine will be, and the higher the head, the higher the turbine efficiency.

TECHNICAL ANALYSIS

SIMULATION

Engineering simulation (finite element analysis) was applied to the analysis of the structures as well as pipes, using SolidWorks' motion study. The results obtained provided more validation to the numerical analysis previously done.

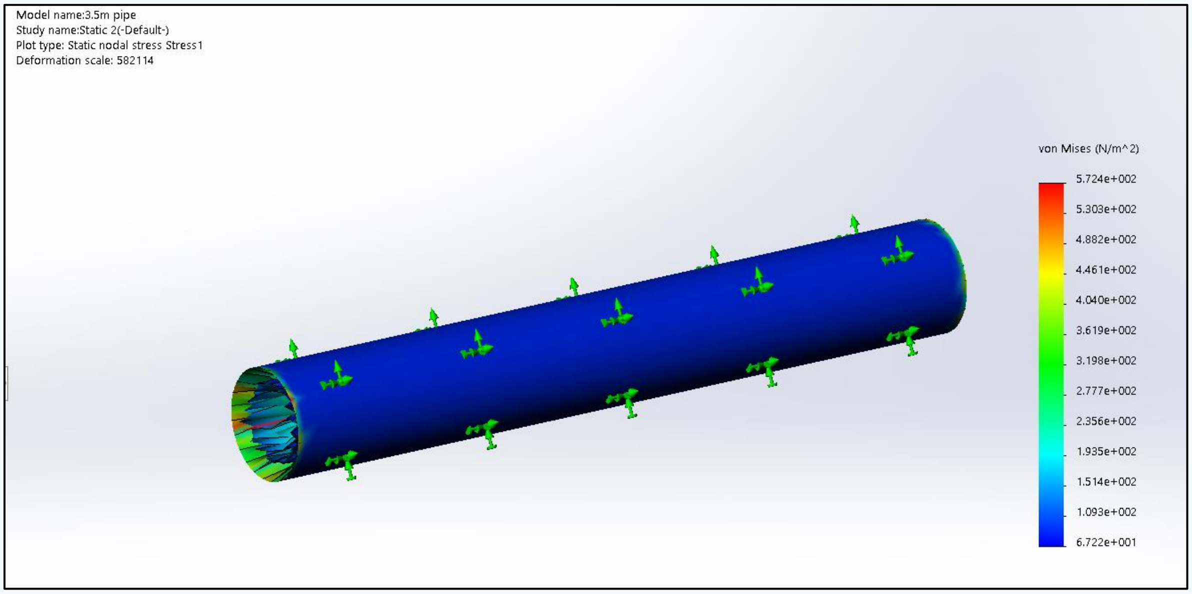


Fig 11. Pipe 1.

Stress on 3.5m pipe being supported by the steel structures when 4.2KW of force is applied.

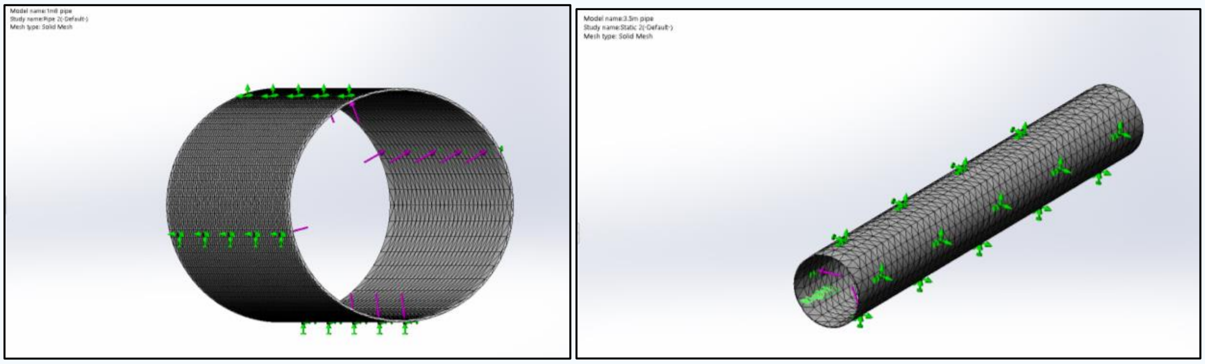


Fig 12. Pipes' fixtures around simulating supporting structures.

Where the fixture is all around the pipe, and the force of the water is applied inside it.

TECHNICAL ANALYSIS

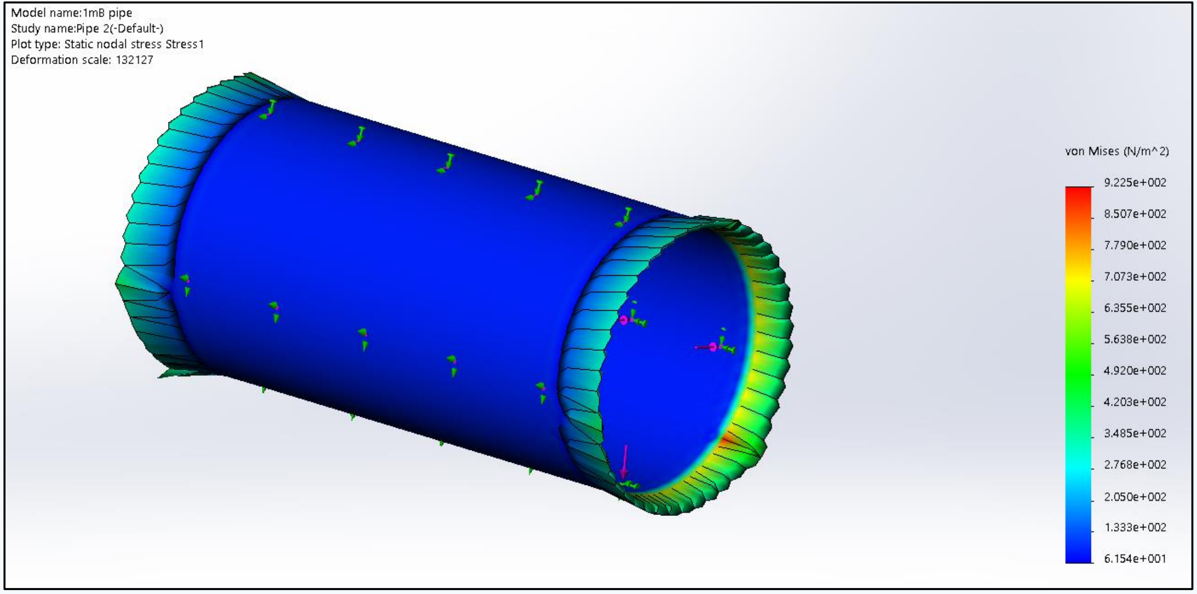


Fig 13. Pipe 2.

Stress on 1m pipe being supported by the steel structures when 1.2KW of force is applied.

Both during laminar and turbulent flow, the PVC pipes will work efficiently when the load is applied, as they stay within the safety factor of 0.6.

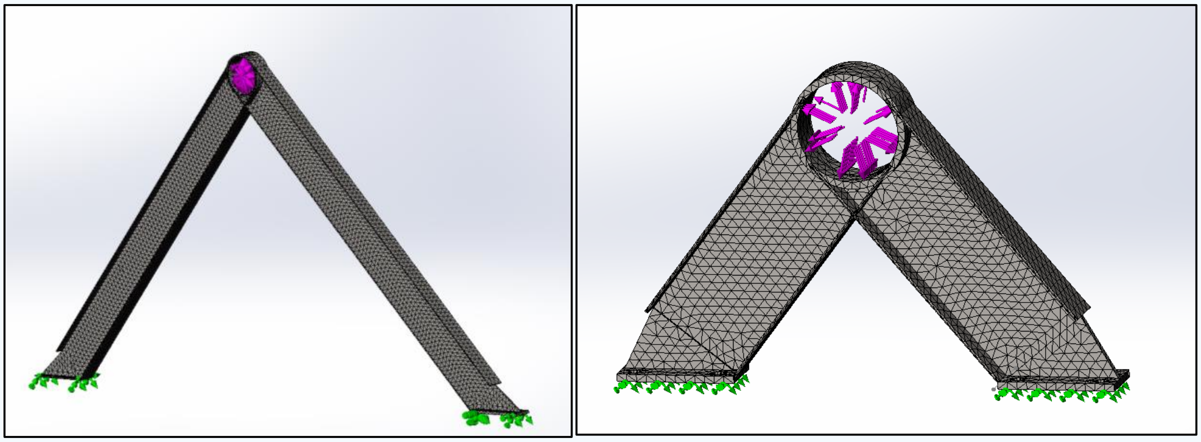


Fig 14. Supporting structures.

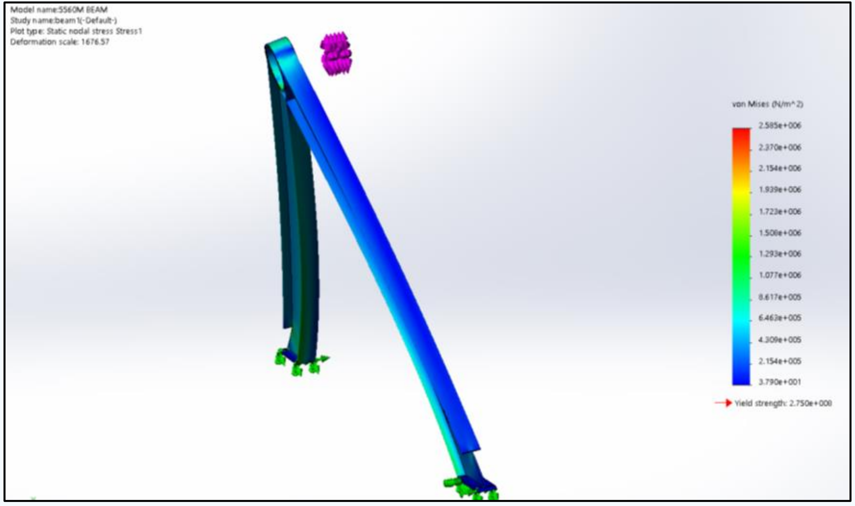


Fig 15. Support for pipe 2.

Steel beam couple structure, 5.6m long each, supporting the load of the 3.5m pipe (4.2KN).

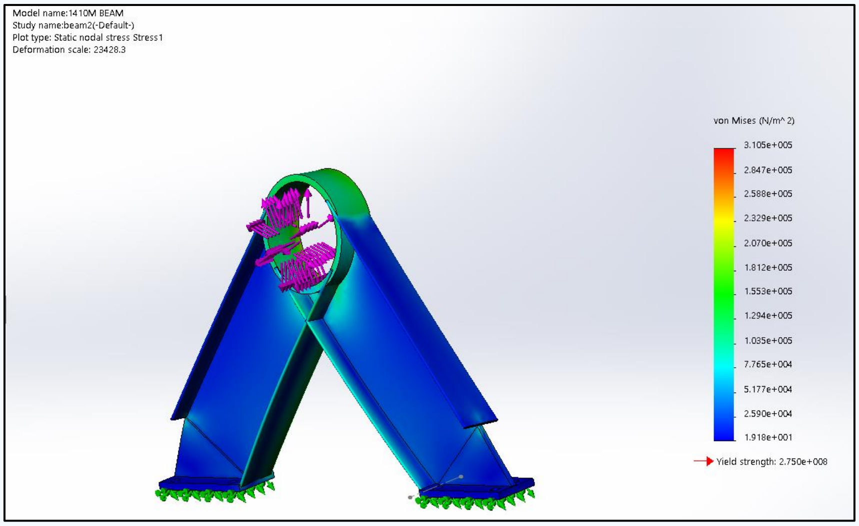


Fig 16. Support for pipe 1.

Steel beam couple structure, 1.4m long each, supporting the load of the 1m pipe (1.2KN).

As proven before with the calculations, the simulation has also certified that these hollow beam structures will work efficiently when supporting the calculated amount of load produced by the body of water when the pipes are filled as well as empty. For the pipe analysis, a more specific simulation software could have been used, such as the one Intergraph Process, Power & Marine has recently released, CAESAR II 2017, which specifically evaluates structural responses and stresses in piping systems to international codes and standards.

TECHNICAL ANALYSIS

Since Pressure is equal to Force over area, the force being applied onto the turbine's stainless steel runners, for each of the head increment, was calculated and then simulated using SolidWorks.

By referring to the table, Concept 3, F = PA.
The values obtained are:

Pressure Head (Pa)	Pipe Nominal Size (m)	Simulated Force (KN)	Head (m)
97980	0.5	49	10
78284	0.5	39	8
58487	0.5	29	6
38358	0.5	19	4
16488	0.5	9	2

Table 25. Simulated values.

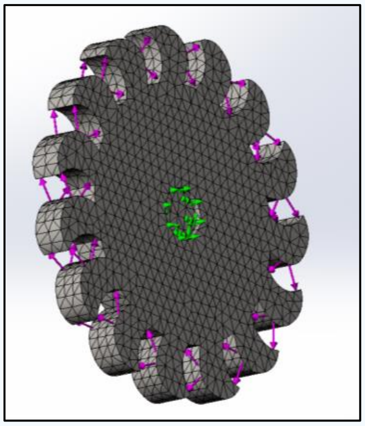


Fig 17. The force driven by the generator applied on the runners.

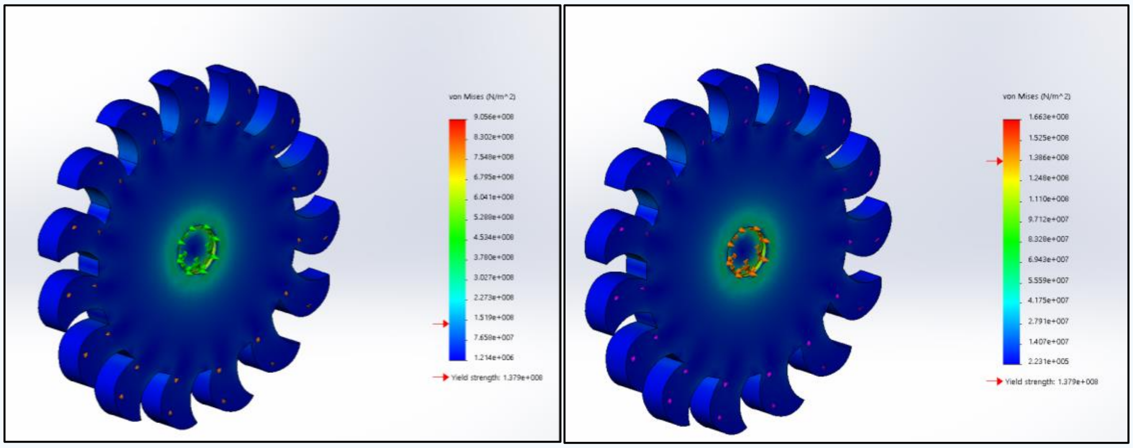


Fig 18. Stress comparison. 49KN V.S. 9KN

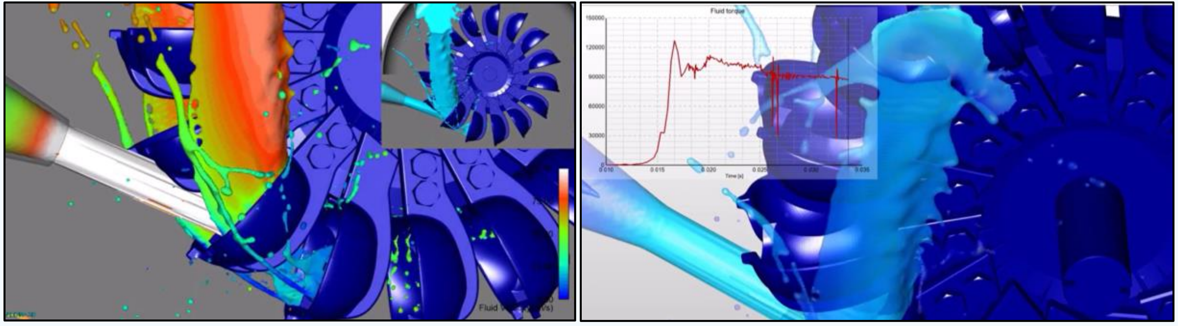


Fig 19. FlowSight simulation of pelton turbine (Flow Science Inc. 2016).

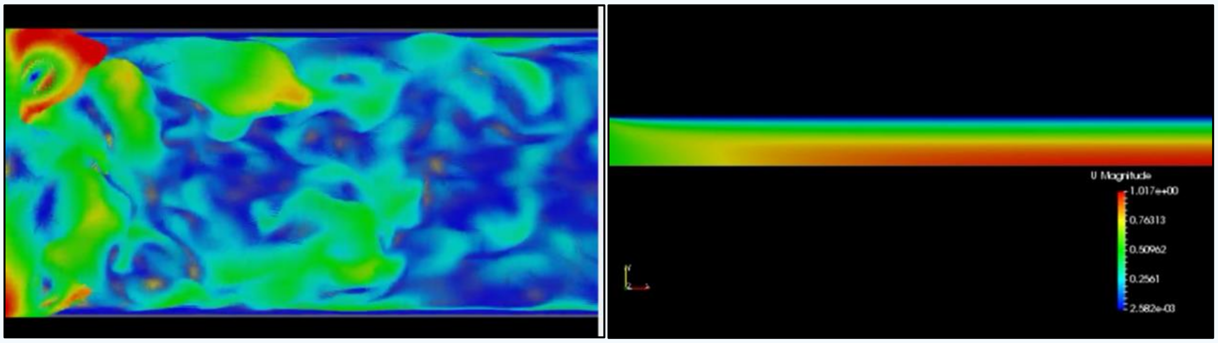


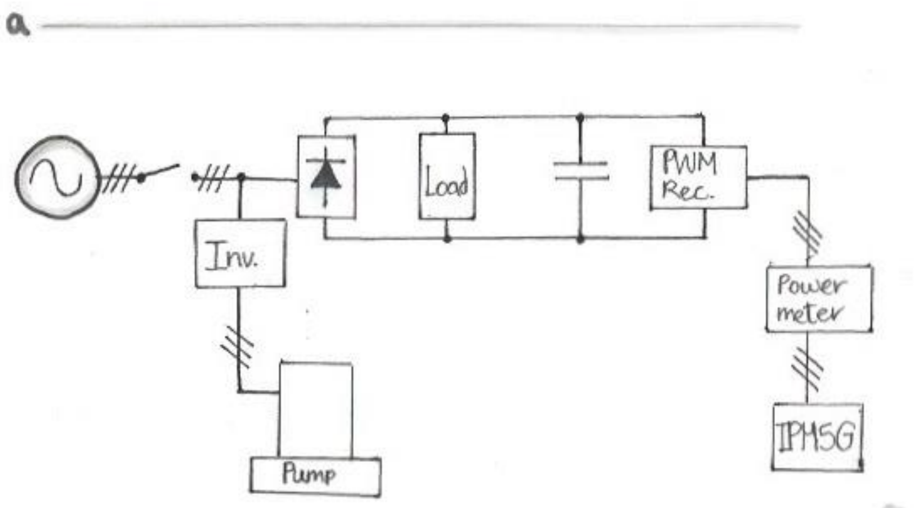
Fig 20. Turbulent V.S. Laminar flow inside pipe. (SimulationIABWeimar 2014).

Using the Large Eddy Simulation approach. The simulation is resolving the exact turbulent behaviour, where the background color (blue to yellow) visualizes the turbulence energy. These are expected to be found within the system during real-life testing with the final product.

FINAL DESIGN

Final Design

CONFIGURATIION



Note: Power meter is actually wireless, and ultrasonic level sensor to measure and control both level and temperature is done seperately. (Also using PLC).

Fig 21. System's schematic diagram.

As seen in figure 21, the general-purpose inverter drives the pump. The voltage is stablished by connecting the diode rectifier to the dc bus. A PWM rectifier is connected to IPM signal generator, to simulate/apply the head equivalent of the pressure being applied. The PWM rectifier allows variable speed on the IPM signal generator, ideal for the range in head being tested. The diode rectifier is placed in parallel to the resistive load, to supply the difference between the generated power and the load power. So, if no power is generated, the diode rectifier will make sure the system is provided with the needed input power. Generated power is measured by using a digital wireless power meter, placed between the IPM signal generator and the PWM rectifier. The entire system is programmed and controlled by using a FPGA (field programmable gate array), this includes the ultrasonic level and temperature sensor, located on the internal face of the tank.

FINAL DESIGN

SOLIDWORKS MODEL

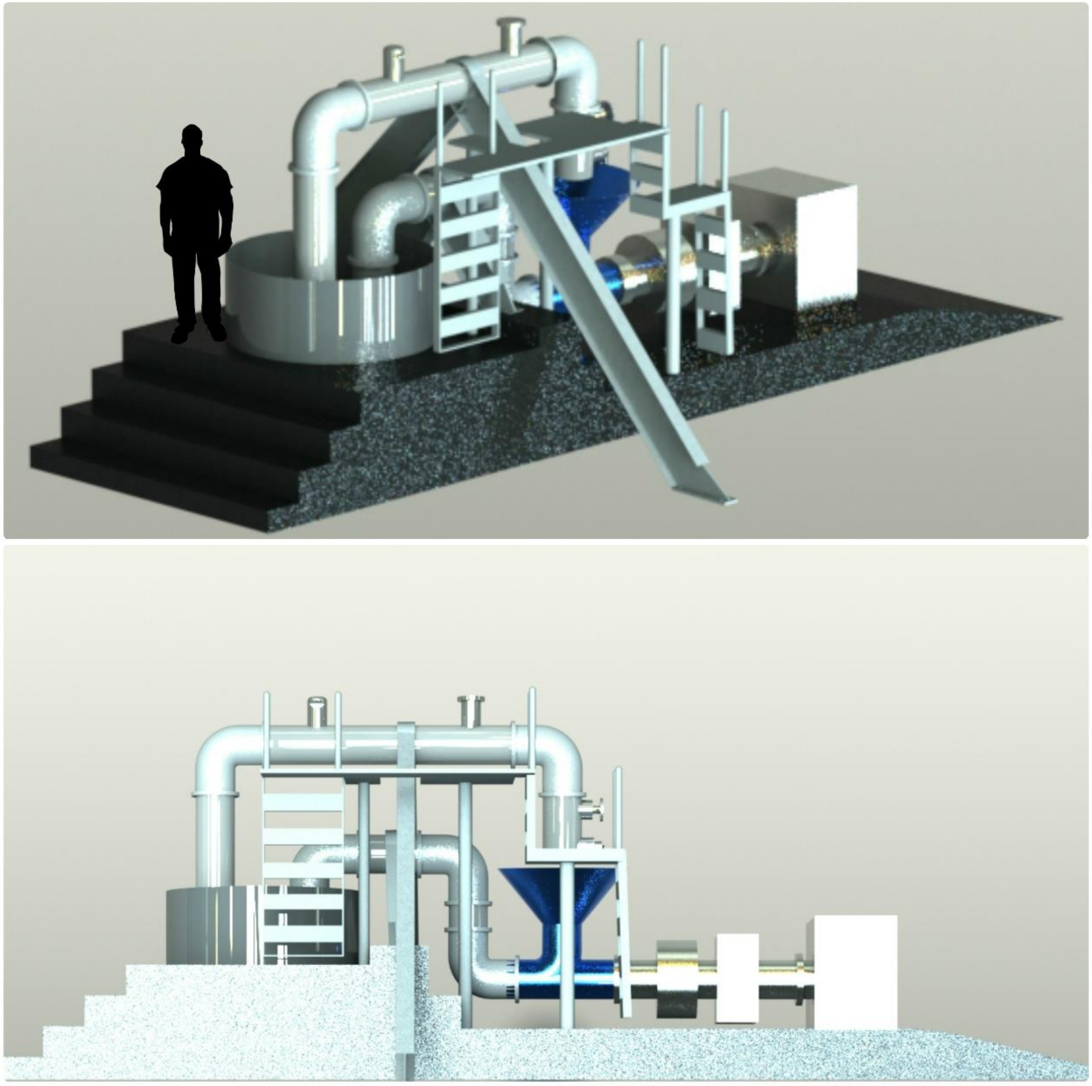


Fig 22. Final design in perspective.

The translation to the completion of the final design is shown in the developed and rendered SolidWorks model put into perspective. Each individual component was modelled and then put into an assembly. Final design optimisation aspects were added in then, i.e. the ramp to aid the process of putting it together.

FINAL DESIGN

Fig 23. Valves.

Seen in figure 23 above, the gate valve is being adjusted before the ball valve (below it). This process would take place before the testing initialisation as part of the set-up process.

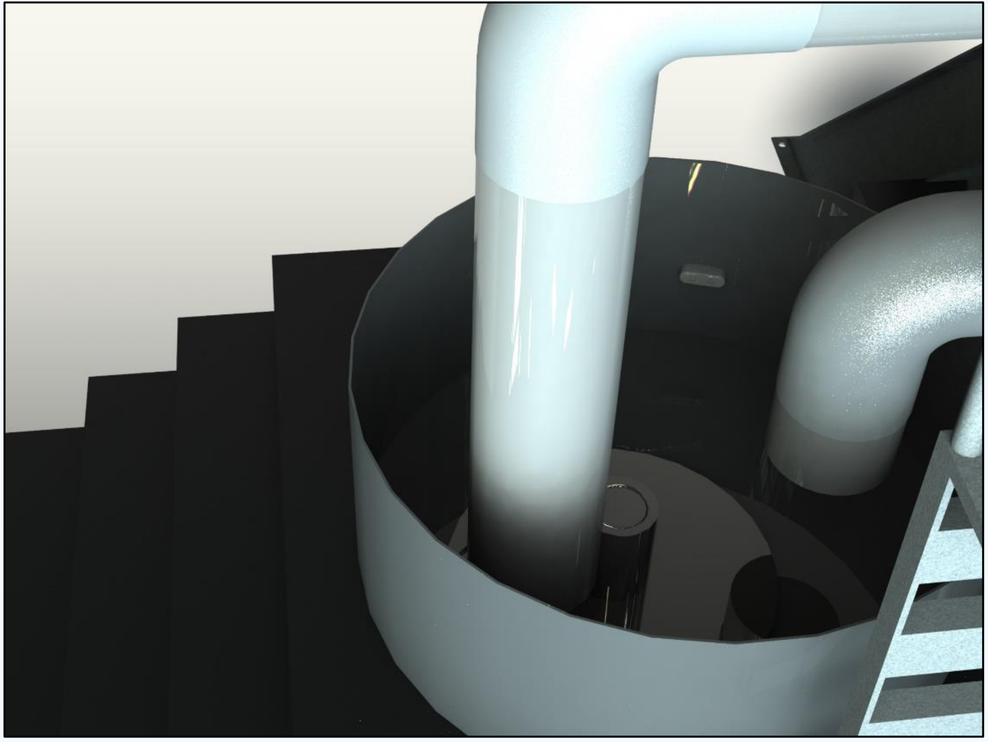


Fig 24. Tank, level sensor, and pump.

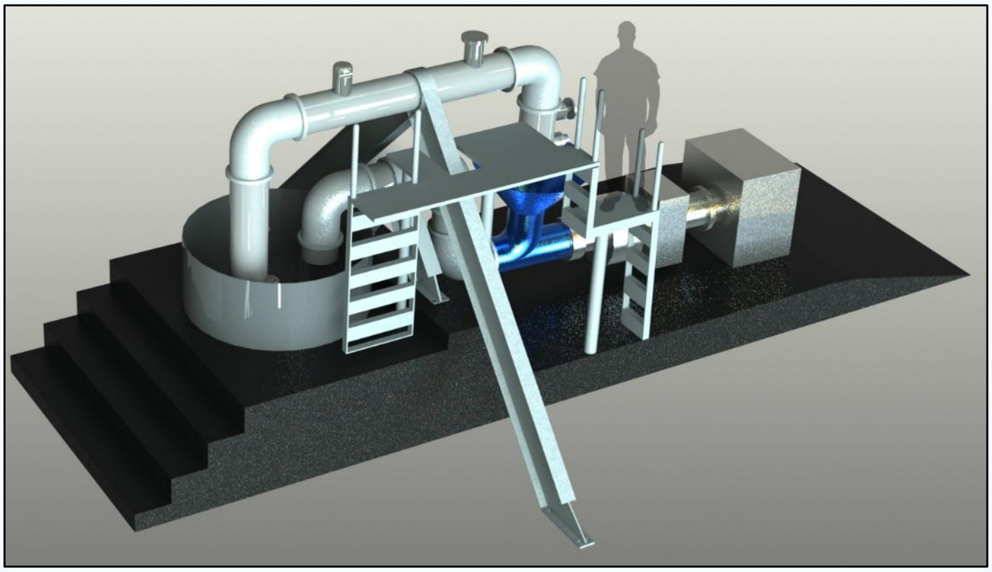


Fig 25. Test-machine with ramp.

The ultrasonic level sensor has been carefully placed on the inner face of the tank, seen in figure 24, for a precise data reading. The stairs allow easier and safer access to the component to be MCM.