Experiment Instructions

HM 450.01 Pelton Turbine

Experiment Instructions

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This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

Table of Contents

1 Introduction

The **Pelton Turbine HM 450.01** is a functional small turbine.

A transparent housing cover provides an optimum view of the running turbine. This enables the interaction of the nozzle, water flow and impeller to be clearly seen. In keeping with actual practice, power is regulated by an adjustable nozzle. The turbine can be loaded with an adjustable brake mechanism.

Speed, torque output and inlet pressure are measured electronically and displayed on the trainer **HM 450C Characteristic Variables of Hydraulic Turbomachines**. This enables typical turbine characteristic curves and power curves for different speeds to be plotted.

In conjunction with the trainer **HM 450C Characteristic Variables of Hydraulic Turbomachines**, it provides a convenient turbine test bench with closed water circuit.

The mobile trainer with autarkic water circuit means that the Pelton turbine is suitable for both demonstration experiments in the lecture theatre and for practical exercises by students.

Learning objectives are

- Determining mechanical output
- Determining efficiency
- Turbine characteristics
- Influence of nozzle opening on output.

2 Safety

2.1 Intended use

The unit is to be used only for teaching purposes.

2.2 Structure of safety instructions

The signal words DANGER, WARNING or CAUTION indicate the probability and potential severity of injury.

An additional symbol indicates the nature of the hazard or a required action.

Signal word	Explanation
⚠ DANGER	Indicates a situation which, if not avoided, **will** result in **death or serious injury**.
⚠ WARNING	Indicates a situation which, if not avoided, **may** result in **death or serious injury**.
⚠ CAUTION	Indicates a situation which, if not avoided, may result in **minor or moderately serious injury**.
NOTICE	Indicates a situation which may result in **damage to equipment**, or provides instructions on **operation of the equipment**.

Symbol	Explanation
	Notice

2.3 Safety Instructions

Also observe the safety instructions in the manual for HM 450C.

NOTICE

Improper handling of the terminal box can damage the unit.

- Before opening the terminal box: Disconnect the HM 450.01 from the HM 450C trainer.
- Work should only be performed by qualified electricians.
- Protect the terminal box against moisture.

NOTICE

Inadequate cooling of the brake causes damage to the brake.

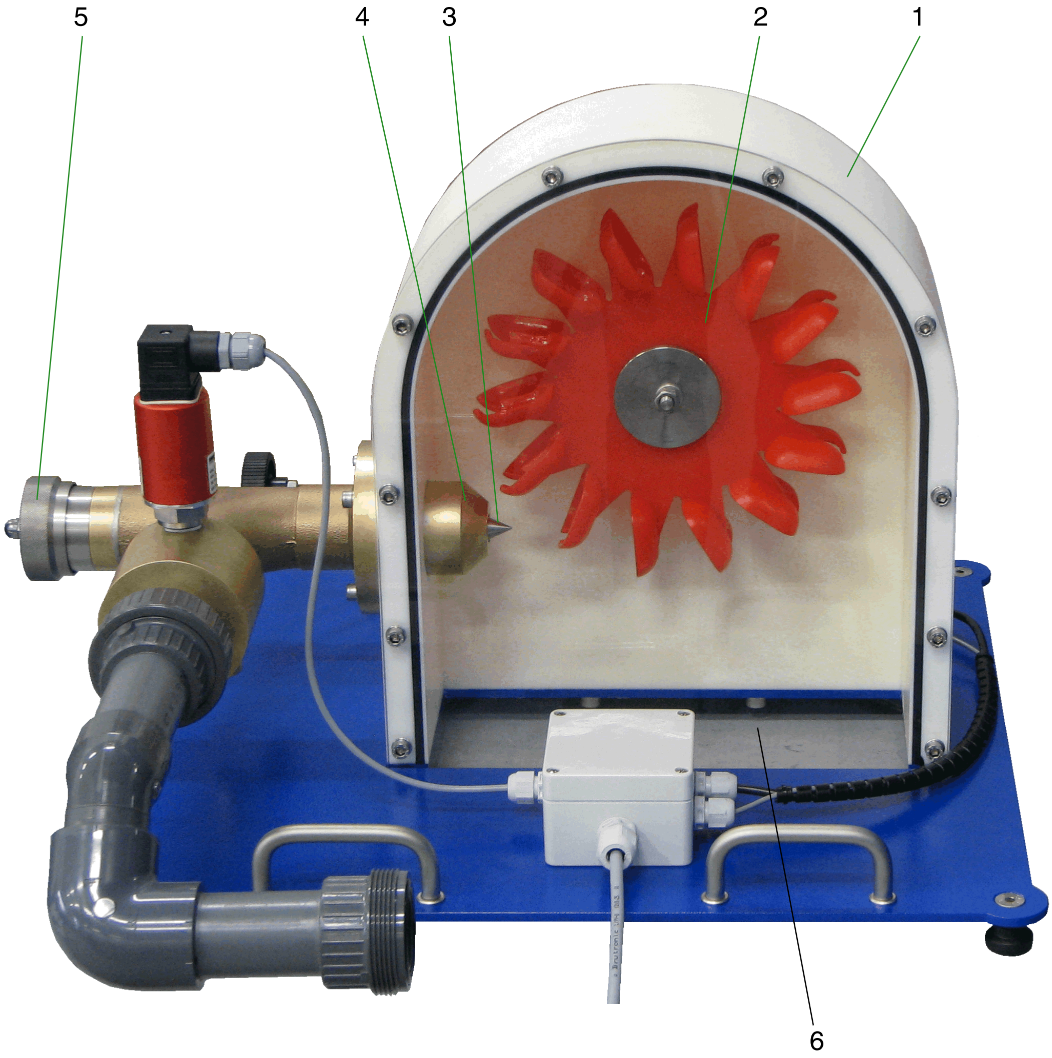
- Always operate the brake with a sufficient cooling water supply.

2.4 Ambient Conditions for Operating and Storage Location

- Enclosed room.
- Free of dirt and moisture.
- Level and secure base.
- Frost free.

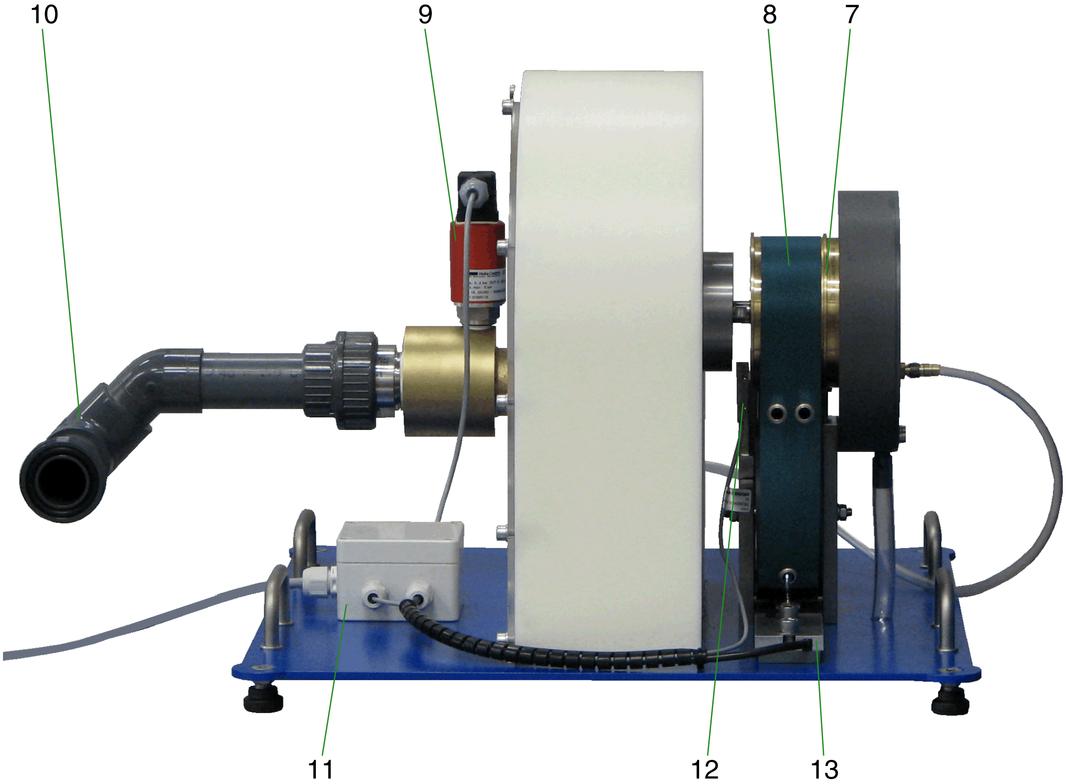
3 Unit Description

3.1 Unit Design



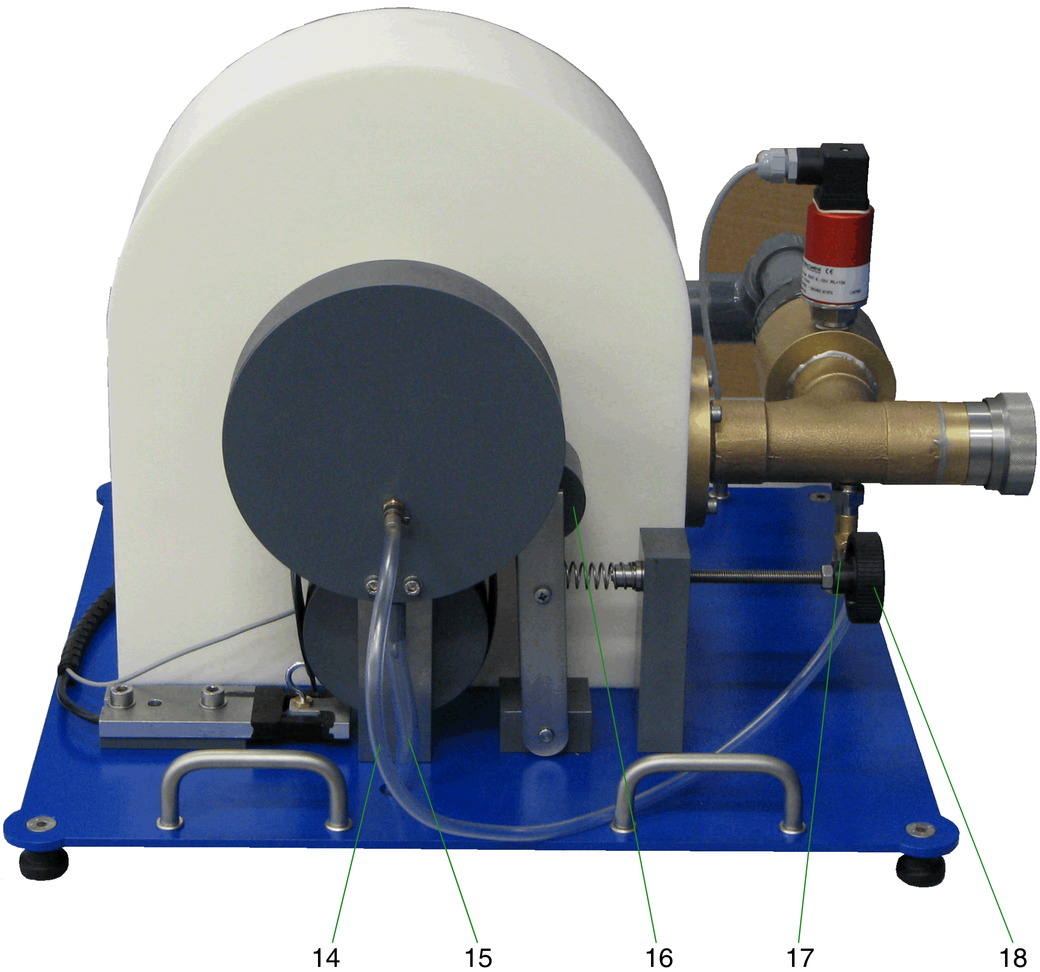
1	Housing
2	Runner with runner vanes
3	Nozzle needle
4	Nozzle
5	Hand wheel to adjust nozzle needle
6	Water outlet

Fig. 3.1 Front view



7	Brake drum
8	Belt
9	Pressure sensor
10	Water inlet from HM 450C
11	Terminal box
12	Speed sensor
13	Force sensor for determination of torque

Fig. 3.2 Side view



14	Hose for cooling water inlet
15	Hose for cooling water outlet
16	Tension pulley for belt tension
17	Needle valve to adjust cooling water flow
18	Hand wheel to adjust belt tension

Fig. 3.3 Rear view

The housing (1) contains the runner (2). The transparent front housing cover provides a view into the running turbine.

The water supply (10) for the turbine is provided by the HM 450C and the water outlet (6) is also to the HM 450C. The water enters the housing through a nozzle (4). The nozzle needle (3) is adjusted using a hand wheel (5).

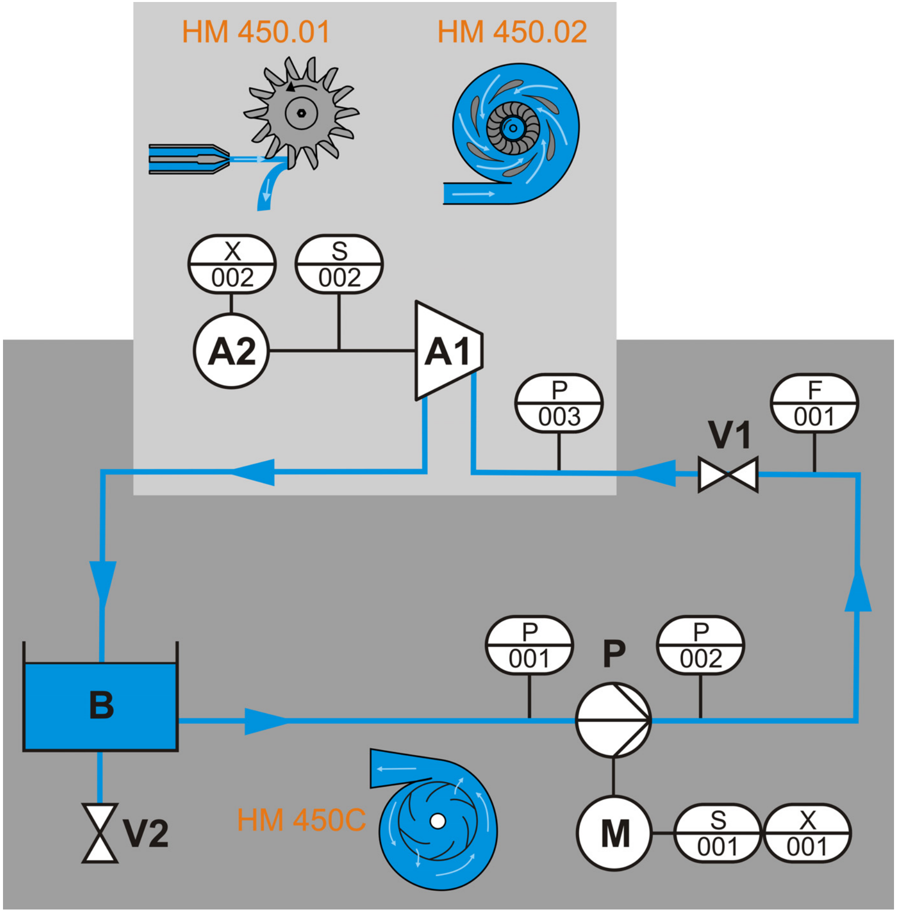
The runner is made of plastic, overhung and has 14 vanes. The runner shaft is mounted on two grooved ball bearings in the bearing housing. The water chamber is sealed off with a radial shaft seal.

The turbine brake device consists of a brake drum (7) and a belt (8) mounted on the free end of the runner shaft. The belt tension is adjusted using a hand wheel (18).

The brake drum is water-cooled (14) in order to dissipate the brake output. The cooling water flow is regulated by a needle valve (17) and drained via a hose (15).

The speed is recorded at the brake drum (12). The braking force is measured (13) to determine the torque. The inlet pressure is recorded before the turbine (9). In addition, the flow rate is measured on the HM 450C. The measured values for these parameters are displayed on the HM 450C control cabinet.

3.2 Process Schematic



Main components

A1 Turbine
A2 Brake
B Water tank
M Motor
P Pump
V1 Flow control valve
V2 Drain valve

Instrumentation and control

F001 Flow rate
P001 Pressure pump suction side
P002 Pressure pump pressure side
P003 Pressure turbine inlet side
S001 Speed pump
S002 Speed Turbine
X001 Torque pump
X002 Torque turbine

Fig. 3.4 Process schematic HM 450C with HM 450.01 / HM 450.02

3.3 Maintenance and Care

The turbine is largely maintenance free. To ensure that it functions reliably over the long term, the following work should be carried out from time to time:

- Belt tensioning device:
  Lubricate the guide bars of the tension roller and the thread of the adjusting spindle with a small amount of grease.
- Keep force sensor and terminal box dry.
- Keep the belt dry and free of oil.

4 Basic Principles

The basic principles set out in the following make no claim to completeness. For further theoretical explanations, refer to the specialist literature.

4.1 General

Water turbines are components of hydroelectric power stations. They are designed to convert the potential energy of the water contained in reservoirs, canals and rivers into mechanical energy, normally for the purpose of powering electric generators.

Depending on their method of operation, water turbines are classified as **impulse turbines** or **reaction turbines**.

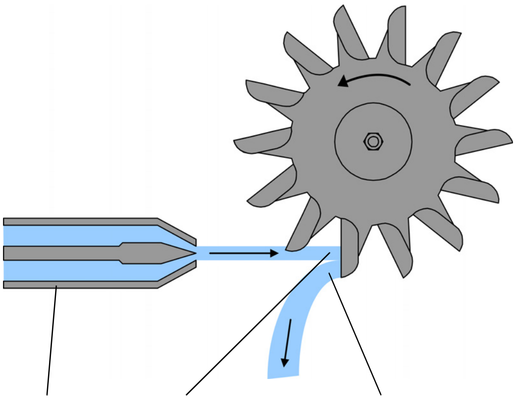


Fig. 4.1 Impulse turbine (Pelton

- Impulse turbines

  The static pressures at the runner inlet and outlet are of equal magnitude. The entire potential energy is converted into velocity in the guide apparatus. The equal pressures at the runner permit partial loading.

  The **Pelton turbine** is an example of an impulse turbine.

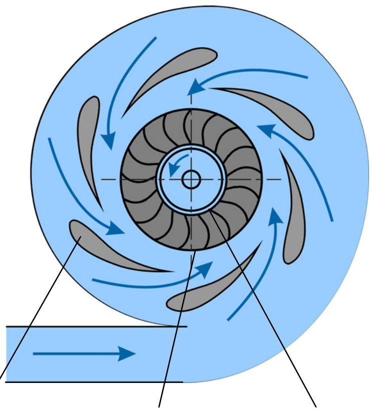


Fig. 4.2 Reaction turbine (Francis)

- Reaction turbines

  The static pressure at the runner inlet is greater than at the outlet. The conversion of potential energy into kinetic energy is distributed over guide apparatus and runner. The degree of distribution is known as the degree of reaction. On account of the differing pressures at the inlet and outlet, it is only possible to have full runner loading.

  The **Francis turbine** is an example of a reaction turbine.

4.2 Pelton Turbine

4.2.1 Principle of Function

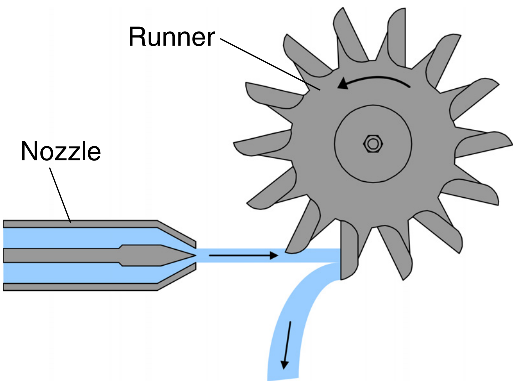


Fig. 4.3 Pelton turbine

On a Pelton turbine, the water jet is accelerated in a nozzle and emerges with atmospheric pressure. After free flight, the jet strikes the vanes of the impeller tangentially. Because of the free water jet, Pelton turbines are also known as free jet turbines.

In the vanes, the water jet is diverted by almost 180°. The impulse of the water jet is transferred to the impeller. If the jet velocity and circumferential velocity of the impeller are optimally coordinated, the absolute velocity c_2 and the outlet and thus the outlet loss is almost zero. The vanes have the shape of a double cup. Fig. 4.4 shows a section through the vane.

In practice, a Pelton turbine powers a synchronous generator, which must run at a constant speed. The speed of the impeller must therefore be kept constant, regardless of the torque absorbed. To achieve this, the flow rate is regulated by a nozzle.

In the experiment, this regulation is not used as the characteristic curves need to be plotted for a constant flow rate, i.e. the nozzle is fully open.

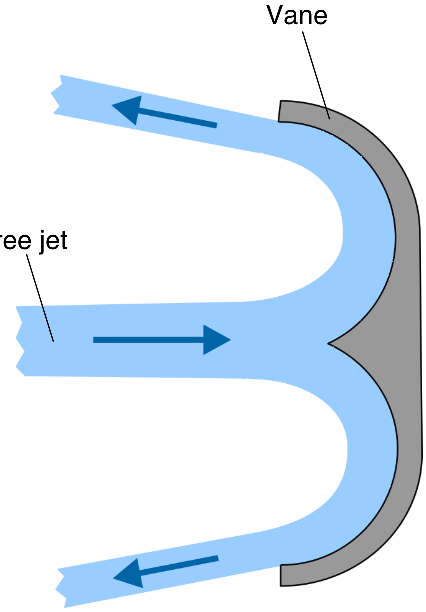


Fig. 4.4 Pelton turbine vane

4.2.2 Specific Work

The specific work Y of a turbine is generally given by:

$$Y = \frac{1}{\rho} \cdot (p_p - p_s) + \frac{1}{2} \cdot (c_p^2 - c_s^2) + g \cdot (z_p - z_s) \quad (4.1)$$

On a Pelton turbine, once it has left the vane and then drips down into the downstream water, the water does not perform any more work. The height difference $z_p - z_s$ here is therefore a pure head loss, which means that the term $g \cdot (z_p - z_s)$ has to be completely eliminated from Formula (4.1).

In addition, the speed in the intake fitting (downstream) is so low that it can be ignored, $c_s = 0$.

The intake fitting is open to the surroundings, i.e. the ambient pressure $p_s = p_0$ is present there. This simplifies Formula (1.1) for the Pelton turbine to the form:

$$Y = \frac{1}{\rho} \cdot (p_p - p_0) + \frac{1}{2} \cdot (c_p^2) \quad (4.2)$$

$$= \frac{1}{\rho} \cdot \Delta p_p + \frac{1}{2} \cdot c_p^2$$

The speed c_p can be calculated from the volumetric flow and the cross-sectional area in the pressure fitting with:

$$A_p = \frac{\pi \cdot D_p^2}{4} = 0{,}001029\text{m}^2$$

$$c_p = \frac{Q}{A_p} \quad (4.3)$$

Incorporating this into Formula (4.2) then gives:

$$Y = \frac{1}{\rho} \cdot (p_p - p_0) + \frac{1}{2} \cdot \left(\frac{Q}{A_p}\right)^2 \qquad (4.4)$$

The pressure loss from measuring point PI3 to shortly before the nozzle due to deflection, pipe friction and reduction is ignored.

4.2.3 Theoretical Specific Vane Work

The theoretical specific vane work of a Pelton turbine is given by:

$$Y_{theor} = u \cdot (c_{1u} - c_{2u}) \qquad (4.5)$$

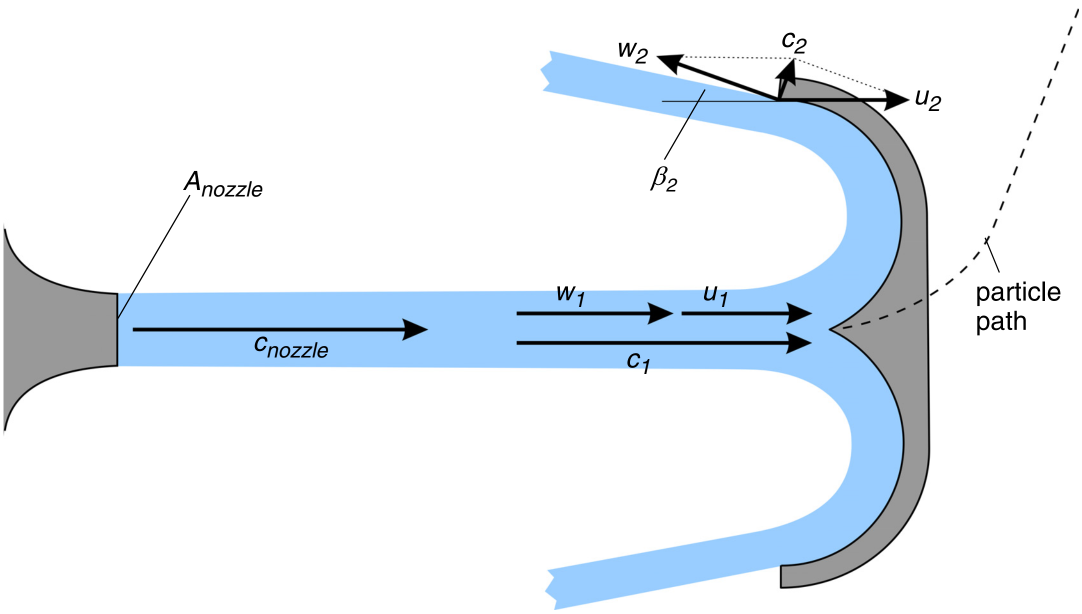


Fig. 4.5 Velocity ratios at the vane

Fig. 4.5 shows the speed relationships at the blade. This allows the following relationships to be derived:

$$c_{1u} = c_1 = c_{nozzle} \tag{4.6}$$

$$c_{2u} = u_2 - w_2 \cdot \cos\beta_2 \tag{4.7}$$

The relative speed in the blade is reduced due to friction. The following applies:

$$w_2 = \zeta_{vane} \cdot w_1 \tag{4.8}$$

For the loss coefficient ζ_{vane} a value based on experience of $\zeta_{vane} = 0{,}9$ can be used. The circumferential speeds u_1 and u_2 are equal.

$$u_2 = u = \frac{D_m}{2} \cdot \omega = D_m \cdot \pi \cdot n \tag{4.9}$$

$$w_1 = c_1 - u_1 \tag{4.10}$$

$$c_{2u} = u_1 - (c_1 - u_1) \cdot \zeta_{vane} \cdot \cos\beta_2 \tag{4.11}$$

Formula (4.11) inserted in Formula (4.5) gives

$$Y_{theor} = (1 + \zeta_{vane} \cdot \cos\beta_2) \cdot (c_1 \cdot u - u^2) \tag{4.12}$$

or

$$Y_{theor} = (1 + \zeta_{vane} \cdot \cos\beta_2) \cdot D_m \cdot \pi \cdot n \cdot (c_{nozzle} - D_m \cdot \pi \cdot n) \tag{4.13}$$

4.2.4 Outlet Speed

The outlet speed c_{nozzle} can be determined from the law of the conservation of energy, which is applied between the measuring point PI3 and the nozzle outlet. It states

$$\frac{1}{2} \cdot c_{P003}^2 + \frac{p_{P003}}{\rho} = \frac{1}{2} \cdot c_{nozzle}^2 + \frac{p_0}{\rho} + g \cdot \Delta h + \varphi_{P003,nozzle} \quad (4.14)$$

The speed at the measuring point P003 is calculated from the continuity equation using the measured volumetric flow Q.

$$c_{P003} = \frac{Q}{A_{P003}} = \frac{Q \cdot 4}{\pi \cdot D_{P003}^2} \quad (4.15)$$

At the measuring point P003, the pipe has an internal diameter $d_i = 0{,}037\,\text{m}$. The geodetic height difference between the measuring point P003 and the nozzle outlet is $\Delta h = 0{,}0\,\text{m}$. The friction losses between the measuring point P003 and the nozzle outlet are made up of the losses in the pipe elbow and the loss in the nozzle.

$$\varphi_{P003,nozzle} = \frac{1}{2} \cdot c_{P003}^2 \cdot (\zeta_{bend} + \zeta_{nozzle}) \quad (4.16)$$

The following values can be used for the loss coefficients: $\zeta_{bend} = 0{,}3$ and $\zeta_{nozzle} = 0{,}05$.

For the nozzle outlet velocity, this gives

$$\zeta_{P003,nozzle} = \frac{1}{2} \cdot c_{P003}^2 \cdot \frac{35}{100} \tag{4.17}$$
$$= \frac{35}{200} \cdot c_{P003}^2$$
$$\approx \frac{1}{6} \cdot c_{P003}^2$$

Inserted in Formula (4.14)

$$\frac{1}{2} \cdot c_{P003}^2 + \frac{p_{P003}}{\rho} = \frac{1}{6} \cdot c_{P003}^2 + \frac{1}{2} \cdot c_{nozzle}^2 + \frac{p_0}{\rho} \tag{4.18}$$

It follows

$$\frac{1}{2} \cdot c_{nozzle}^2 = \frac{1}{3} \cdot c_{P003}^2 + \frac{p_{P003} - p_0}{\rho} \tag{4.19}$$

$$c_{nozzle}^2 = \left(\frac{2}{3} \cdot c_{P003}^2\right) + \left(2 \cdot \frac{p_{P003} - p_0}{\rho}\right) \tag{4.20}$$

With Formula (4.15)

$$c_{nozzle}^2 = \frac{32}{3 \cdot \pi^2} \cdot \frac{Q^2}{D_{P003}^4} + 2 \cdot \frac{p_{P003} - p_0}{\rho} \tag{4.21}$$

$$c_{nozzle} = \sqrt{\frac{32}{3 \cdot \pi^2} \cdot \frac{Q^2}{D_{P003}^4} + 2 \cdot \frac{p_{P003} - p_0}{\rho}} \tag{4.22}$$

4.2.5 Hydraulic Efficiency

The hydraulic efficiency is defined as

$$\eta_{hydr} = \frac{Y_{theor}}{Y} = \frac{P_{theor}}{P_{hyd}} = \frac{Y_{theor} \cdot \rho \cdot Q}{Y \cdot \rho \cdot Q} \quad (4.23)$$

4.2.6 Mechanical Power on the Shaft

The power on the shaft (coupling power) is calculated as:

$$P_{mech} = M \cdot \omega = 2 \cdot \pi \cdot M \cdot n \quad (4.24)$$

The coupling power P_{mech} and the specific work Y are related as follows:

$$P_{mech} = \eta_{eff} \cdot P_{hyd} = \eta_{eff} \cdot \dot{m} \cdot Y = \eta_{eff} \cdot \rho \cdot Q \cdot Y \quad (4.25)$$

4.2.7 Overall Efficiency of the Turbine

The overall efficiency can be determined from Formula (4.24) and Formula (4.25).

$$\eta_{eff} = \frac{P_{mech}}{P_{hyd}} = \frac{2 \cdot \pi \cdot M \cdot n}{\rho \cdot Q \cdot Y} \quad (4.26)$$

5 Experiments

The selection of experiments makes no claims of completeness but is intended to be used as a stimulus for your own experiments.
The results shown are intended as a guide only. Depending on the construction of the individual components, experimental skills and environmental conditions, deviations may occur in the experiments. Nevertheless, the laws can be clearly demonstrated.

5.1 Aim of the Experiment

- Determination of mechanical output
- Determination of efficiency
- Recording of characteristic curves
- Investigation of the influence of the nozzle cross-section on the power output

5.2 Preparing the Experiment

1. Turn off the main switch on the HM 450C trainer.
2. Disconnect the HM 450C trainer from the power supply.
3. Close the drain valve V2 on the water tank.
4. Fill the water tank with 150...200 L clear tap water. The water level in the tank should be 20...28 cm.

Connecting tube

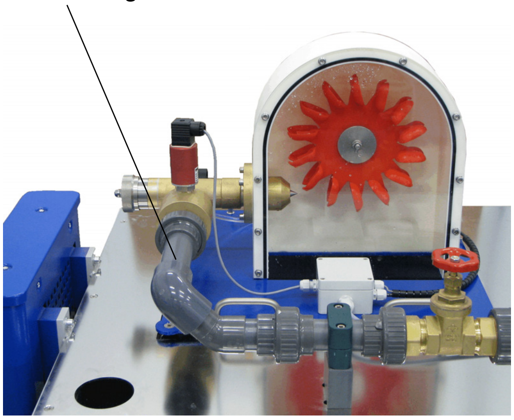


Fig. 5.1 Connecting tube

Fig. 5.2 Reset the torque display

5. With 2 people:
   Place the HM 450.01 pelton turbine onto the water tank.
6. Screw and fasten the connecting tube between the HM 450C and HM 450.01.
7. Connect the HM 450C trainer to the power supply.
8. Turn on the main switch.
   - All displays light up.
   - The displayed pressure values are 0,95...1,05 bar.
   - The displayed flow rate and speed values are approx. 0.
9. For the displays "Torque Pump" and "Torque Turbine": press the "RST" button. The displays are reset to 0.

5.3 Performing the Experiment

1. To adjust the nozzle needle, turn the hand wheel to position 7. The nozzle is now open.
2. Ensure that the belt is linked to the brake.
3. Loosen the hand wheel to adjust the belt tension so that the turbine is not braked and that the torque is 0 Nm.
4. Close the flow control valve V1.
5. Turn on the pump switch.

6. Turn the potentiometer until the pump speed is 2.900 min^{-1}.
7. Open the flow control valve V1 slowly and set a flow rate of 175 L/min.
8. Turn the needle valve to adjust the cooling water flow. A low cooling water flow is generally sufficient. The flow through the cooling water feed hose need not be the maximum.
9. Read the values for the following parameters at the control cabinet or record the values with the help of the data acquisition program:
   - n_1 Speed pump
   - Q Flow rate
   - M_2 Torque turbine
   - n_2 Speed turbine
   - p_3 Inlet pressure turbine

   The data acquisition program additionally calculates:
   - P_{mech2} Mechanical power of the turbine
   - P_{hyd2} Hydraulic power of the turbine
   - η_2 Efficiency of the turbine

10. Increase the turbine torque incrementally by turning the hand wheel to adjust the belt tension.

    Record the parameter values.

5.4 Measured Values

n_1 Speed pump in min^{-1}	Q Flow rate in L/min	Nozzle needle position	M_2 Torque turbine in Nm	n_2 Speed turbine in min^{-1}	p_3 Inlet pressure turbine in bar
2.900	175	7	0,0	1.620	2,95
2.900	176	7	0,7	1.490	2,95
2.900	176	7	1,3	1.380	2,95
2.900	176	7	2,0	1.240	2,95
2.900	176	7	2,6	1.100	2,95
2.900	176	7	3,3	960	2,95
2.900	176	7	4,0	840	2,95
2.900	176	7	4,6	700	2,95
2.900	176	7	5,3	500	2,95
2.900	176	7	6,0	330	2,95
2.900	176	7	6,3	0	2,95

Tab. 5.1 Measured values turbine characteristic curve (example)

5.5 Evaluation of the Experiment

The measured data is used to calculated the following variables:

- Velocity in pipe at PI3

$$c_{P003} = \frac{Q \cdot \pi \cdot 4}{d^2} = \frac{Q \cdot \pi \cdot 4}{D_{P003}^2}$$

- Velocity after the nozzle

$$c_{nozzle} = c_1 = \sqrt{\frac{32}{3 \cdot \pi^2} \cdot \frac{Q^2}{D_{P003}^4} + 2 \cdot \frac{p_{P003} - p_0}{\rho}}$$

- Circumferential velocity

$$u = D_m \cdot \pi \cdot n$$

- Specific work

$$Y = \frac{1}{\rho} \cdot (p_p - p_0) + \frac{1}{2} \cdot \left(\frac{Q}{A_P}\right)^2$$

- Theoretical specific vane work

$$Y_{theor} = (1 + \zeta_{vane} \cdot cos\beta_2) \cdot D_m \cdot \pi \cdot n \cdot (c_{nozzle} - (D_m \cdot \pi \cdot n))$$

- Power on the shaft

$$P_{mech} = 2 \cdot \pi \cdot M \cdot n$$

- Hydraulic efficiency

$$\eta_{hyd} = \frac{Y_{theor}}{Y}$$

- Overall efficiency

$$\eta_{eff} = \frac{P_{mech}}{P_{hyd}} = \frac{P_{mech}}{Y \cdot \rho \cdot Q}$$

n Speed in min^{-1}	c_{P003} Velocity in the pipe at P003 in m/s	$c_1 = c_{nozzle}$ Absolute velocity in m/s	u Circum-ferential velocity in m/s	Y Specific work in m^2/s^2	Y_{theor} Theoreti-cal specific vane work in m^2/s^2	P_{mech} Power on the shaft in W	η_{hydr} Hydraulic efficiency in %	η_{eff} Overall efficiency in %
1.620	2,71	19,81	14,00	197,4	154,3	0	78	0
1.490	2,73	19,81	12,87	197,4	169,4	109	86	19
1.380	2,73	19,81	11,92	197,4	178,4	188	90	32
1.240	2,73	19,81	10,71	197,4	184,8	260	94	45
1100	2,73	19,81	9,50	197,4	185,8	299	94	52
960	2,73	19,81	8,29	197,4	181,1	332	92	57
840	2,73	19,81	7,26	197,4	172,8	352	88	61
700	2,73	19,81	6,05	197,4	157,9	337	80	58
500	2,73	19,81	4,32	197,4	126,9	278	64	48
330	2,73	19,81	2,85	197,4	91,7	207	46	36
0	2,73	19,81	0	197,4	0	0	0	0

Tab. 5.2 Evaluation of measured data for turbine characteristic curve (example)
Needle valve position: 8 (fully open)
p_0 = 1,013bar

The measured values are shown graphically in the following diagrams. For comparison, the second measuring series is shown with reduced power and a needle valve position of 3.

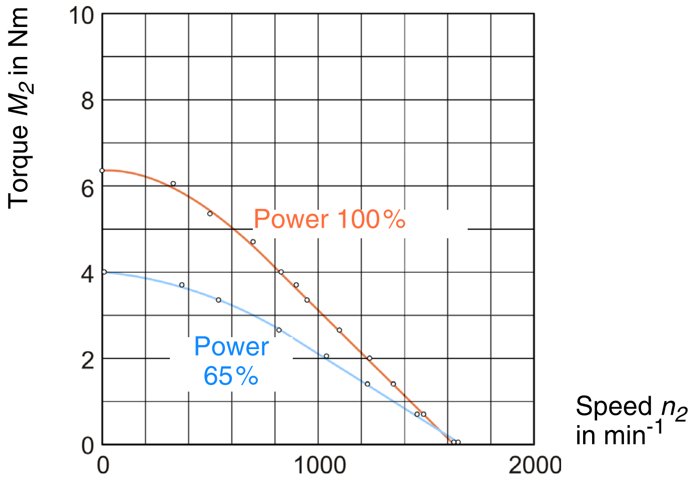


Fig. 5.3 Torque curve

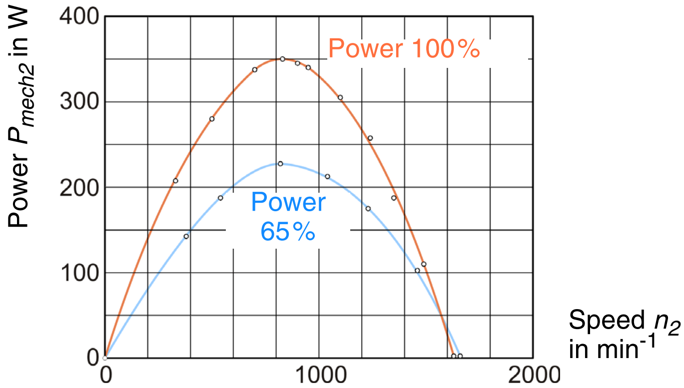


Fig. 5.4 Power curve

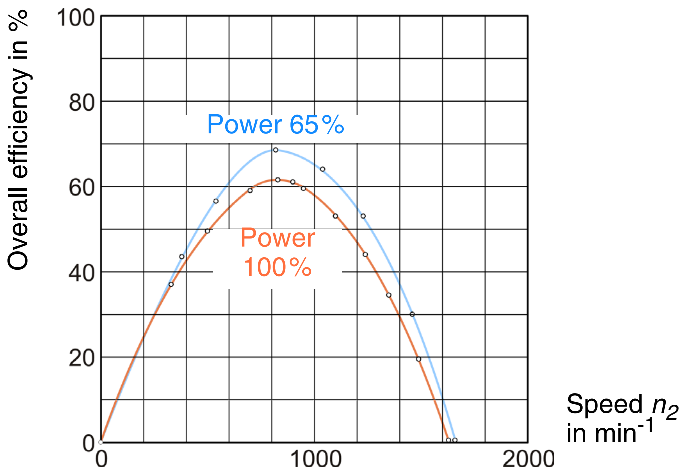


Fig. 5.5 Overall efficiency

The experimental results correspond closely to the theoretical predictions.

It is astonishing that the efficiency is slightly higher with reduced power than at full load. This is due to the slightly disturbed water feed in the blades at full jet diameter.

In addition, it is interesting that the flow rate and therefore the inlet pressure are independent of the power and speed. This is typical for impulse turbines, as the conversion of the pressure energy into kinetic energy occurs solely in the fixed control device.

6 Appendix

6.1 Technical Data

Dimensions

Length x Width x Height	660 mm x 570 mm x 400 mm
Weight	27 kg

Design data

Flow rate	2,5 kg/s
Fall height	20 m
Speed	max. 1500 min^{-1}
Power	350 W / 1000 min^{-1}

Runner

Medium runner diameter D_m	165 mm
Vanes	
Number	14
Inlet angle φ	17 °
Outlet angle β_2	5 °

Outlet nozzle fully open

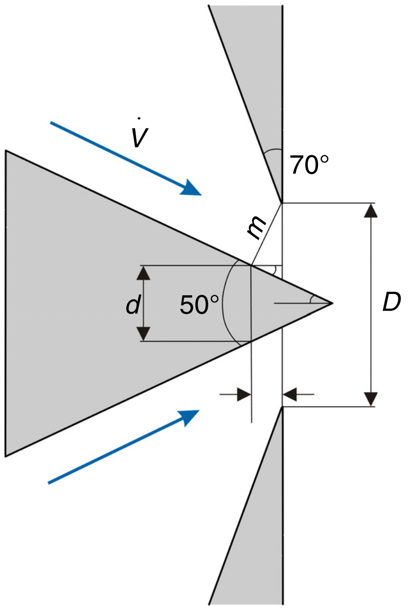
Outer diameter nozzle D	16,5 mm
Needle diameter (position 7) d	7,00 mm
Casing length m	5,24 mm

Casing area A_m

$$A_m = \frac{\pi}{2} \cdot m \cdot (D + d)$$

Casing length m

$$m = \frac{D - d}{2 \cdot \sin 65°}$$



Internal diameter of the tubes

Turbine pressure line	37,0 mm
Measuring point of turbine pressure sensor (P003)	37,0 mm

Measurement technology

Torque measurement	
Using belt brake and force sensor	
Measuring range	0...10 Nm
Speed measurement	
Measuring range	0...9999 min^{-1}
Pressure measurement	
Measurement range	0...4 bar abs.
Tolerable overload	8 bar abs.
Rupture pressure	12 bar abs.

6.2 List of Symbols and Units

Formula symbol	Mathematical / physical quantity	Unit
A_{nozzle}	Cross-section area at nozzle inlet	m^2
A_p	Cross-section area on pressure side	m^2
A_{P003}	Cross-section area at measuring point P003	m^2
c_1	Absolute velocity when striking the vane	m/s
c_{1u}	Circumferential velocity at vane inlet	m/s
c_2	Absolute velocity when leaving the vane	m/s
c_{2u}	Circumferential velocity at vane outlet	m/s
c_{nozzle}	Velocity at nozzle inlet	m/s
c_p	Velocity on pressure side	m/s
c_{P003}	Velocity at measuring point P003	m/s
c_s	Velocity on suction side	m/s
d_i	Inner diameter of the pipe	m
D_m	Medium runner diameter	m
D_p	Inner diameter on pressure side	m
g	Acceleration due to gravity	m/s^2
H	Fall height	m
$\dot{m}$	Mass flow	kg/s
M_D	Torque brake	Nm
n	Speed	min^{-1}
p	Pressure	bar, Pa
p_0	Ambient pressure	bar, Pa
p_p	Pressure on the pressure side	bar, Pa
$p_{P003} = p_3$	Pressure at measuring point P003	bar, Pa
p_s	Pressure on the suction side	bar, Pa
P_{hyd}	Hydraulic power	W, kW
P_{mech}	Mechanical power	W, kW
P_{theor}	Theoretical power	W, kW

Formula symbol	Mathematical / physical quantity		Unit
Q	Flow rate		m^3/s, L/min
u	Circumferential velocity		m/s
u_1	Circumferential velocity at vane inlet		m/s
u_2	Circumferential velocity at vane outlet		m/s
w	Relative velocity		m/s
w_1	Relative velocity at vane inlet		m/s
w_2	Relative velocity at vane outlet		m/s
Y	Specific work		m^2/s^2
w_1	Relative velocity at vane inlet		m/s
w_2	Relative velocity at vane outlet		m/s
Y_{theor}	Theoretical specific vane work		m^2/s^2
z_p	Height on the pressure side		m
z_s	Height on the suction side		m
$\beta = \beta_2$	Outlet angle		°
Δh	Height difference		m
Δp_p	Pressure difference		bar, Pa
ζ_{vane}	Loss coefficient vane	0,90	–
ζ_{bend}	Loss coefficient bend	0,30	–
ζ_{nozzle}	Loss coefficient nozzle	0,05	–
η_{hydr}	Hydraulic efficiency		%
η_{eff}	Overall efficiency		%
ρ	Density Water: 1000 kg/m^3		kg/m^3
$\varphi = \varphi_{P003,nozzle}$	Specific loss energy		m^2/s^2
ω	Angle velocity		s^{-1}

Index	Explanation
bend	bend
eff	effective
hydr	hydraulic
mech	mechanical
nozzle	nozzle
theor	theoretical
vane	vane

6.3 Conversion Tables

Unit	mm^3	cm^3	L	m^3
1 mm^3	1	0,001	0,000001	0,000000001
1 cm^3	1.000	1	0,001	0,000001
1 L	1.000.000	1.000	1	0,001
1 m^3	1.000.000.000	1.000.000	1.000	1

Tab. 6.1 Conversion table for volume units

Unit	L/s	L/min	L/h	m^3/min	m^3/h
1 L/s	1	60	3600	0,06	3,6
1 L/min	0,01667	1	60	0,001	0,06
1 L/h	0,000278	0,01667	1	0,00001667	0,001
1 m^3/min	16,667	1000	0,0006	1	60
1 m^3/h	0,278	16,667	1000	0,01667	1

Tab. 6.2 Conversion table for volume flow units

Unit	bar	mbar	Pa	hPa	kPa	mm water column*
1 bar	1	1.000	100.000	1.000	100	10.000
1 mbar	0,001	1	100	1	0,1	10
1 Pa	0,00001	0,01	1	0,01	0,001	0,1
1 hPa	0,001	1	100	1	0,1	10
1 kPa	0,01	10	1.000	10	1	100
1 mm water column*	0,0001	0,1	10	0,1	0,01	1

Tab. 6.3 Conversion table for pressure units
* Rounded values

6.4 Work Sheets

6.4.1 Measured Values

Experiment No. ____________					
Date ____________					
n_1 Speed pump in min^{-1}	Q Flow rate in L/min	Nozzle needle position	M_2 Torque Turbine in Nm	n_2 Speed Turbine in min^{-1}	$p3$ Inlet pressure turbine in bar

6.4.2 Evaluation

Experiment No. ____________								
Date ____________								
n_1 **Speed Pump** in min^{-1}	Q **Flow rate** in L/min	**Nozzle needle position**	M_2 **Torque turbine** in Nm	n_2 **Speed turbine** in min^{-1}	p_3 **Inlet pressure turbine** in bar	P_{mech2} **Mechanical power** in W	P_{hyd2} **Hydraulic power** in W	η_2 **Efficiency** in %

6.4.3 Calculation

Experiment No. ____________	Nozzle needle position: ____________
Date: ____________	

Speed n in min^{-1}	Velocity in the pipe at P003 c_{P003} in m/s	Absolute velocity $c_1 = c_{nozzle}$ in m/s	Circum-ferential velocity u in m/s	Specific work Y in m^2/s^2	Theoreti-cal specific vane work Y_{theor} in m^2/s^2	Power on the shaft P_{mech} in W	Hydraulic efficiency η_{hydr} in %	Overall efficiency η_{eff} in %