Birzeit University

Mechanical Engineering Department and Mechatronics Program

Thermal Fluid Application Lab - Part One
ENMC 411

Prepared by

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Fluid Mechanics
Experiment # 1 Flow measurements of hydraulic systems
Apparatus: Flow measurement apparatus – fluid mechanics lab.

Objectives:

1. To learn the operation principle of a hydraulic bench.
2. To measure flow rate using hydraulic bench
3. To read manometers and calculate pressure differences.
4. Measure flow rate by venture-meter
5. Measure flow rate using an orifice
6. Measure flow rate using Rota meter.
7. Measure pressure drops in fittings and devices.
8. Compare measurements from different devices.

Apparatus description:

The flow measurement apparatus is mounted on a hydraulic bench. The hydraulic bench provides a constant rate flow rate of water through the system. In addition the actual flow rate can be measured by timing and collecting fixed amount of water that flows through the system. Figure (1) shows the system.

Water enters the equipment through a Perspex Venturi-Meter, which consists of a long gradually-converging section, followed by a throat, then by a long diverging section. After a change in cross-section through a rapidly diverging section, the flow continues down a settling length, and through an Orifice plate meter. Then through a further settling length, a right angle bend and a Rota meter. Various manometers along the system gives the pressure at given locations of the system. Using this monometer readings velocity and flow rate can be calculated through the system and major and minor losses can be estimated.

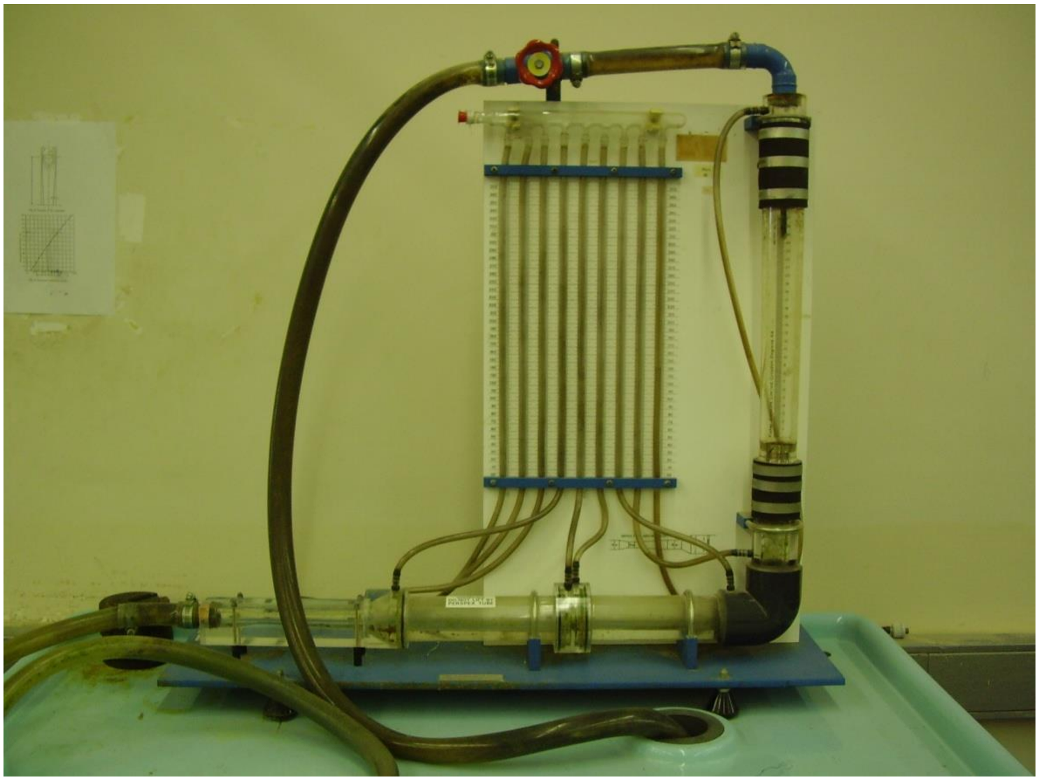


Figure (1) Flow measurement apparatus

Experimental procedure

1. The flow measuring apparatus is connected to the hydraulic bench water supply and the control valve is adjusted until the Rota meter is about mid-position in its calibrated tapered tube.
2. Air is removed from the manometer tubing by flexing it. The pressure within the manometer reservoir is now varied and the flow rate decreased, until, with no flow the manometer height in all tubes is about 280 mm.
3. Open the control valve slightly and start to measure the discharge.
4. Read the manometers and the float height of the Rota meter.
5. Repeat for eight different flow rates.

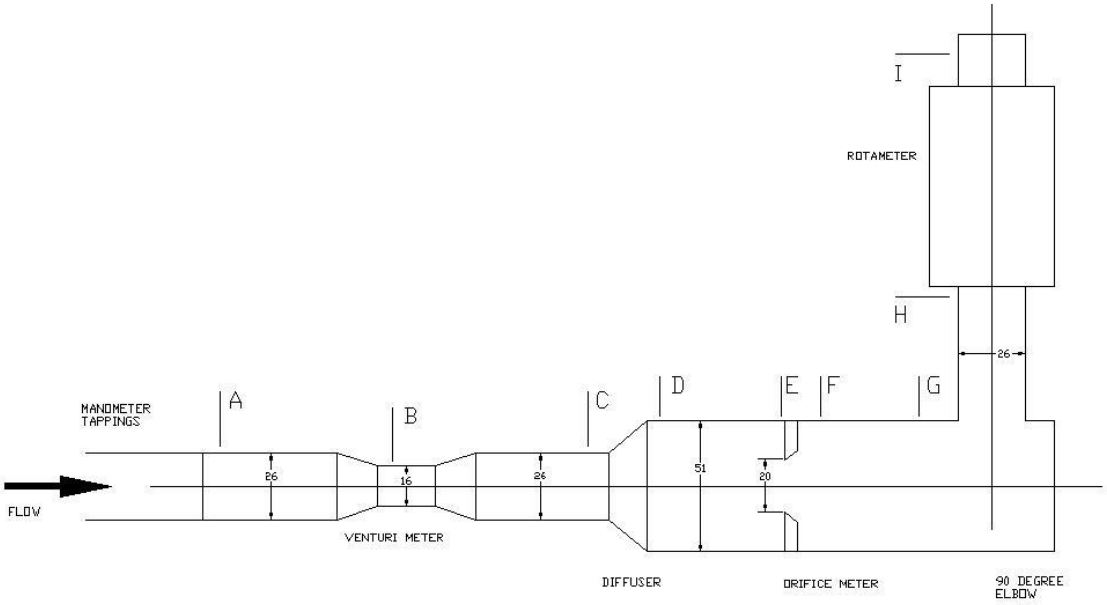


Figure 2: Obstructions and locations of manometers.

Theory

Applying the energy equation between any two locations 1 & 2:

$$\frac{P_1}{\rho g}+\frac{u_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{u_2^2}{2g}+Z_2+\Delta H_{1-2}$$

Where ΔH_{1-2} is the lost head between 1 & 2

For Venturi-Meter :

Neglecting losses and head difference between locations A & B:

$$\frac{P_A}{\rho g}+\frac{u_A^2}{2g}=\frac{P_B}{\rho g}+\frac{u_B^2}{2g}$$

Continuity equation*:*

$$\dot{m}=u_A\, a_A\, \rho = u_B\, a_B\, \rho$$

Then:

$$\dot{m}=\rho\, a_B\left(\left(\frac{2g}{1-\left(\frac{a_B}{a_A}\right)^2}\right).\left(\frac{P_A}{\rho g}-\frac{P_B}{\rho g}\right)\right)^{\frac{1}{2}}$$

This is the ideal mass flow rate.

For the Orifice-Meter*:*

Applying energy equation between sections E & F

$$\frac{u_F^2}{2g}-\frac{u_E^2}{2g}=\frac{P_E}{\rho g}-\frac{P_F}{\rho g}-\Delta H_{E-F}$$

Which can be written as:

$$\frac{u_F^2}{2g}-\frac{u_E^2}{2g}=C_d{}^2(\frac{P_E}{\rho g}-\frac{P_F}{\rho g})$$

Where Cd is the coefficient of discharge

Solving with the continuity equation:

$$\dot{m}=\rho a_F C d(\frac{2g}{1-(\frac{a_F}{a_E})^2}(h_E-h_F))^{\frac{1}{2}}$$

which can be read directly from the manometers.

For Rota meter:

The Rota meter is a device that gives directly the fluid flow rate by reading the flow rate from the calibration curves of the device, normally manometer readings versus flow rate.

Minor losses:

Minor losses for fittings can be given as $h_m = K(u^2/2g)$, on the other hand applying energy equation for a fitting as given in equation 1 above, letting z =0 , u1 =u2 then

$h_m = (P1-P1)/\rho g$,

However $P/\rho g$ is the manometer readings.

Analysis & calculations

1. Calculate the ideal mass flow rate for the Venturi meter and Orifice.
2. Compare in a graph the ideal flow rates from venture and orifice with the actual (from hydraulic bench).
3. Find the coefficient of discharge of the orifice and venturi meter (average).
4. Calibrate the Rota meter to give the actual discharge directly by plotting actual flow from bench versus the Rota meter readings.
5. Compute the minor losses h_m for the bend and the loss coefficient K, compare with theoretical values.
6. In a table summaries the flow rate measured including: actual rate, rotometer, ideal orifice, ideal venturimeter over the measured flow rate range.

Appendix:

Data sheet
Calibration rotometer curve.

Fluid Mechanics
Experiment # 2 Friction & pipe flow of compressible systems
Apparatus: Thermo –fluid tutor apparatus – thermodynamic lab.

Objectives:

- Understand Air flow system & fans
- Learn pressure measurements by manometers and pressure gauges
- Measure pressure losses in fittings
- Measure pipe friction losses
- Apply steady flow energy equation.

Apparatus description:

The ductwork is normally designed to pass fluid from point to point such that the total pressure loss in the system is overcome by some type of pump/fan system. The important parameter, from the designer point of view, is therefore the pressure loss down the ductwork for a given flow.

The majority of duct work consists of straight lengths of pipe work, bends and other items such as screen, flow measuring devices……etc. Figure 1 shows the thermo-fluid tutor set up; it contains straight sections of duct ,bends, venturimeter, orifice, heating section, and manometers and thermocouples for temperature measurements, in addition to a fan for air flow.

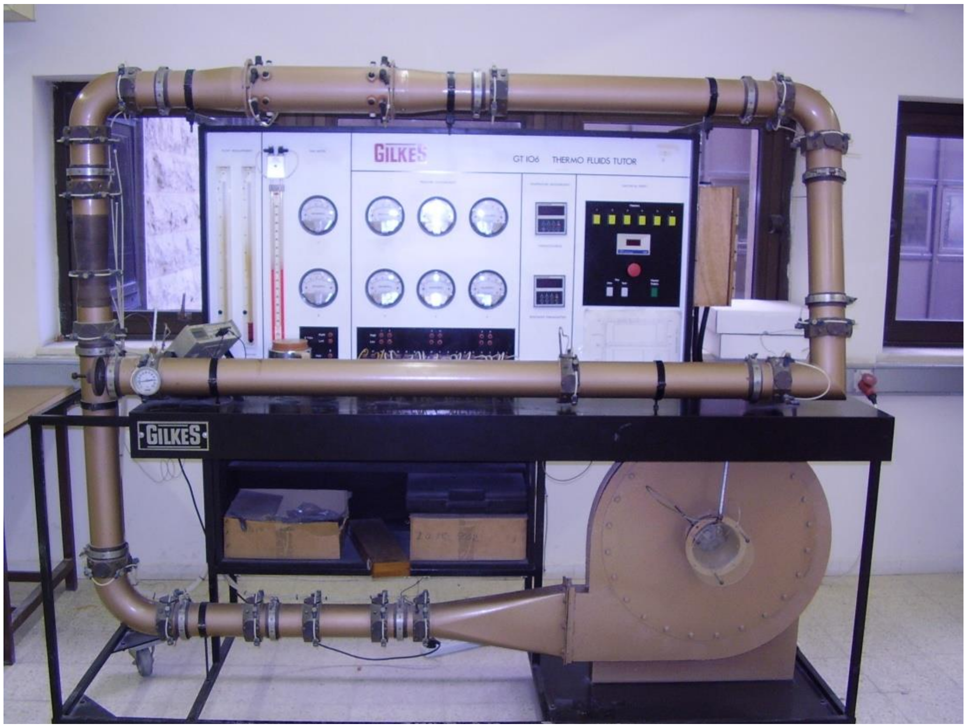


Figure 1: Thermo-fluid tutor device.

Experimental procedure

1. Run the tutor fan at the slow speed, using the differential pressure gage measurement instrument measure the static pressure loss between each pair of traverse position, and the pressure loss between the first and the last sections. From orifice and venture measuring tubes measure hv, and ho
2. Repeat the previous procedure for the fan at high speed.

Section		ΔP_{loss} (mmH_2O)	ΔP_{loss} (mmH_2O)
		Slow speed	High speed
1 – 2	Screen		
2 – 3	Straight duct		
3 – 5	Orifice meter		
5 – 6	Round elbow		
6 – 7	Straight duct		
7 – 10	Venturi meter		
10 – 11	Round elbows		
11 – 12	Heat bank		
12 – 13	Straight duct		
13 – 14	Round elbow		
14 – 15	Straight duct		
15 –16	Right angle elbow		
16 – 18	Straight duct		
1 – 18	Total ΔP_{loss}		

Theory

The total pressure loss through the system is calculated as the summation of the pressure losses of each component in the system.

Consider the schematic ductwork shown in figure (1), the pressure loss in each section in the system can be calculated as:

$$\Delta P_{loss} = K\left(\frac{1}{2}\rho V^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9.1)}$$

Where:

$\frac{1}{2}\rho V^2 = \text{Dynamic Pressure}$

ρ = Fluid (air) density	Kg/m^3
V = Fluid velocity	(m/s)
K = Friction loss factor = $f\,\frac{L}{D}$	
$\Delta P_{loss} = \text{Static Pressure Loss}$	(Pa)

Minor losses calculated as

$$\Delta P_{loss} = K\left(\frac{1}{2}\rho V^2\right)$$

The loss coefficient, K can be found in fluid mechanics text book or in catalogues.

Fluid velocity can be calculated either using the orifice plate or the venture meter.

$$V = \frac{Q_v}{A} \quad \text{m/s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9.2)}$$

$$V = \frac{Q_o}{A} \quad \text{m/s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9.3)}$$

Where:

Q_v = flow rate using venture meter.

$= 163.3\sqrt{h_v}$ m^3/hr

Q_o = Flow rate using orifice meter.

$=123.7\sqrt{h_o}$ m^3/hr

$A = \dfrac{\pi D^2}{4} \qquad m^2$

D = 0.0984 m

Reynolds number = Re = VD/υ

Where υ is the kinematic viscosity of air.

Equivalent length for fittings can be calculated using the formula,

Le = KD/f

Analysis & calculations

1. Calculate air flow rate from both venturi and orifice meters.
2. Calculate fluid main velocity.
3. Calculate the pressure loss (drop) for each section in the system, compare with theoretical values for both fittings and major losses.
4. For each section calculate velocity, h_{minor}, K coefficient for fittings, or h_f and f for straight duct sections. In a table list both experimental and theoretical values.
5. Specify the elements which caused the maximum and minimum pressure losses.
6. Which of the flow measuring devices cause more pressure loss?
7. Discuss the results you obtain.
8. Calculate Reynolds number and friction coefficient f using Moody’s chart (for steel pipes) and calculate theoretically expected pressure drops, and compare with experimental values.
9. Calculate the equivalent length of the system depending on the total pressure loss.
10. If you know that the total tutor length is L = 7.42 m, comment on your results.

Appendix

Data sheet

Fluid Mechanics
Experiment # 3 Pumps
Apparatus: Radial pump system– Fluid mechanics lab.

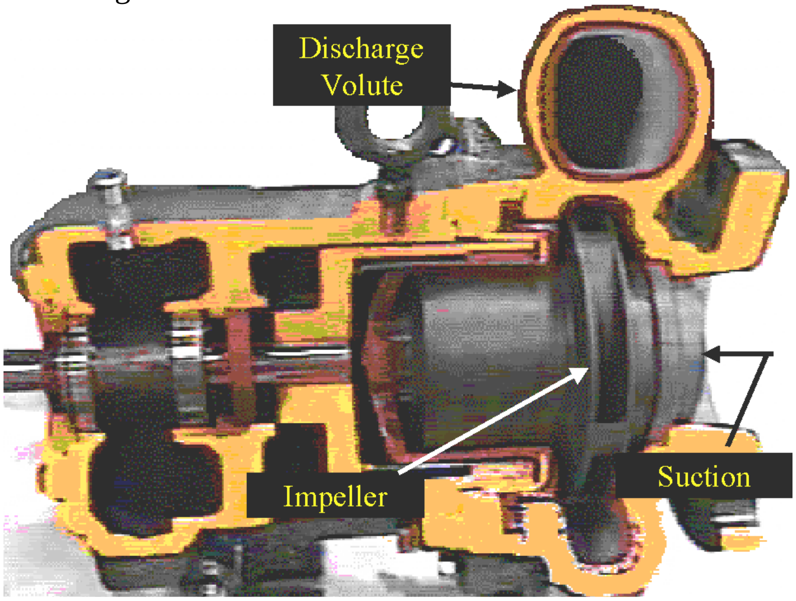
Objectives:

- See and understand operation of radial pump
- Measure mechanical and electrical power of a pump
- Measure flow rate and head of a pump
- Calculate efficiency of a pump
- Establish the pump performance curves.
- Investigate the effect of pump speed rpm on head and flow rate
- Learn how to connect pumps in parallel and series
- Investigate performance of pumps in parallel and in series.

Apparatus description:

A centrifugal pump consists basically of three components : an inlet duct, a set of rotating vanes called impellers, enclosed within a stationary housing called casing.

Water is forced through the center of the impeller by atmospheric or other pressure and set into rotation by impeller vanes. The resulting force accelerates the fluid outward between the vanes until its thrown from the periphery of the impeller into the casing. The casing collects the fluid, converts part of its velocity head into pressure head by increasing the cross sectional area of flow and directs the flow to the pump outlet.



Experimental procedure

The system consists of Pump(1)(The large pump), Pump(2) (The small pump), Piping and a system of valves to control the path of flow : i.e To operate a single pump or two pumps in parallel or in series according to the following table:

Valve No.

Operation	1	2	3	4	5	6	7
Pump (1) only	o	o*	●	●	●	●	●
Pump (2) only	●	●	o	o*	●	●	●
Parallel operation	o	o*	o	●	●	●	o
Series operation	o	●	●	o*	o	●	●

o = valve open
● = valve closed
o* = controlling valve

Pressures:

P_1	Pump (1) Inlet Pressure	m H_2O
P_2	Pump (1) Outlet Pressure	m H_2O
P_3	Combined Outlet Pressure	m H_2O(Parallel)
P_4	Pump (2) Inlet Pressure	m H_2O
P_5	Pump (2) Outlet Pressure	m H_2O
P_6	Combined Outlet Pressure	m H_2O(Series)

Speeds:

N_1	Pump (1) speed rpm
N_2	Pump (2) speed rpm

Torque arm force:

F_1	Pump (1) N.
F_2	Pump (2) N.

Heads:

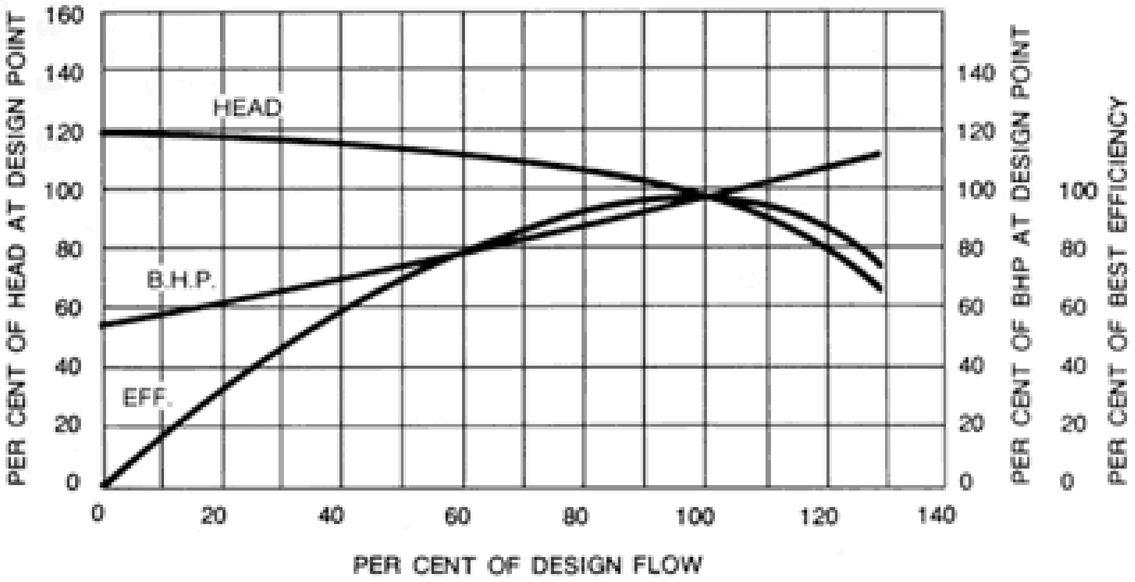
$H_1 = P_2 - P_1$ m H_2O (Pump (1))
$H_2 = P_5 - P_4$ m H_2O (Pump (2))
H parallel = P_3 m H_2O
H series = P_6 m H_2O
1 bar = 10.194 m H_2O

1. Operate pump 1 only at speed $N_1 =$ 2500 rpm. Record the Torque arm Force F_1, of the spring after balancing it with the motor Torque, P_1, P_2, Q_1, Voltage and current.
2. Change the flow rate by the control valve, and by using the speed controller keeping the same N_1 rpm. Repeat this several times by changing Q and maintaining the same N_1
3. Connect the two pumps in series and operate at 2500 rpm change flow rate 5 times, recording all pressures, flow rate, forces, current and voltage.
4. Connect pumps in parallel run at 2500 rpm, record all data as before and change flow rate five times.

Theory

Pumps are mechanical devices that impart energy to fluid . Pumps lift water from one elevation to a highest level, overcome friction and minor losses during the conveyance and add pressure head to the outlet..

Figure shows a typical centrifugal pump performance curves. It includes head versus flow rate, power versus flow rate and efficiency versus flow rate.



The power added to the fluid flow by the pump (P_o), is defined using SI units by:

$P_o = \rho g \Delta H Q$

where:

P_O is the output power of the pump (W)
ρ is the fluid density (kg/m^3)
g is the gravitational constant (9.81 m/s^2)
ΔH is the energy Head added to the flow (m)
Q is the flow rate (m^3/s)

Torque to run the pump
Torque = F × L (Nm).
L , being the force arm = 0.165 m.

Mechanical power
P= Torque x angular velocity= Tω
ω , the angular velocity = $2\pi N / 60$ (rad/s).

Efficiency
Efficiency η is defined as power delivered to the liquid divided by power supplied to pump driver.

$$\eta_1 = \frac{\rho g Q_1 \Delta H}{T_1 \omega} \qquad \Delta H = (P_2 - P_1)$$

Electrical power is calculated as current times the voltage
Electrical power = V.A

Analysis & calculations

1. For each run calculate the torque, mechanical and electrical power, efficiency.
2. Summarize your results in table that includes the rpm N, head, flow rate, torque, mechanical power, electrical power, and efficiency.
3. On a single figure plot head, power and efficiency versus flow rate, comment on the characteristic curves of the single pump.
4. Plot on one figure head versus flow rate for single pump for two pumps in series and two pumps in parallel, comment on the figures.
5. How does flow rate and head change if two identical pumps are connected in series, and in parallel?

Appendix

Data sheet

Fluid Mechanics:
Experiment # 4 Fans
Apparatus: Air fan/ Thermodynamic lab

Objectives:

- Distinguish different types of fans
- To see the different components of a centrifugal fan system
- Measure fan head, flow rate, mechanical and electrical power
- Establish the fan performance curves: head versus flow rate, power versus flow rate, efficiency versus flow rate.
- Test the effect of fan speed on fan performance.
- Test the effect of the fan impeller on the fan performance.

Apparatus description:

Figure 1shows the fan test set up, the system consists of AC motor that drives a centrifugal fan. Impeller mounted on the fan can be radial, forward or backward curved. Air flow throw the fan can be adjusted by varying the opening on the fan exhaust (10 – 100% opening). Manometers record the pressure at nozzle inlet, before and after the fan. Mechanical power is measured by measuring the force on the balancing belt. Speed of motor can be adjusted to give different speeds rpms.

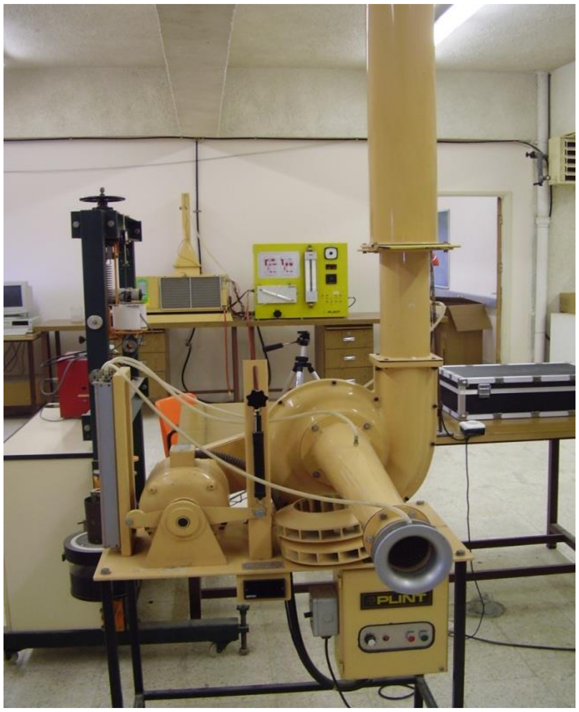


Figure 1: Fan test system.

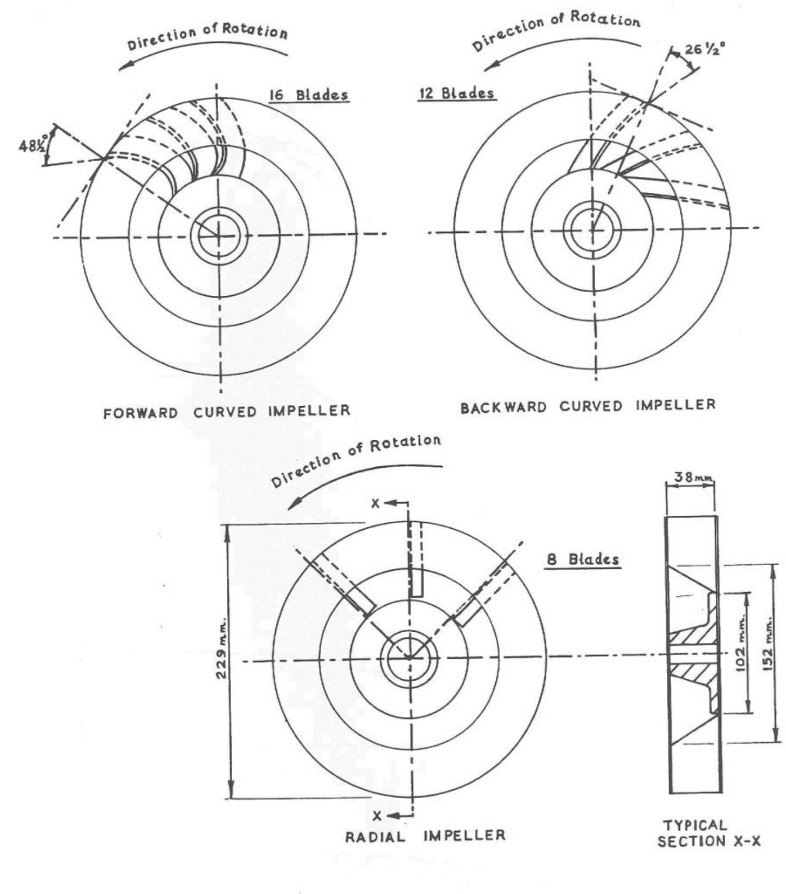


Figure 2: Schematic of impellers.

Experimental procedure

1. Switch on power.
2. Adjust the throttle opening at 100%.
3. Adjust the fan speed to a value of 2400 RPM.
4. Balance the motor case.
5. Read and record the following: Throttle opening (%), the pressure at the throat of the nozzle (h_1), the fan inlet pressure (h_2), the fan outlet pressure (h_3), Load (F).
6. Repeat the above at the same speed but at different openings 10% increments.
7. Install the second impeller blade on the fan (radial, forward or backward). The instructor will show you the proper procedure.
8. Repeat the above test at the same rpm and different openings.
9. Install the third impeller blade on the fan (radial, forward or backward).
10. Repeat the above test at the same rpm and different openings.
11. Make sure that NO impeller is installed on the fan.
12. Measure the force without the impeller at the used speed rpm.
13. For the backward impeller carry out the test at two different speeds 2400, 1200 rpms.

Theory

The fan is belt driven by a 1 horsepower AC motor. The fan is provided with three interchangeable impellers having respectively radial, forward curved and backward-curved blades. By using the inlet nozzle as a flow meter the characteristics of the different impellers may be explored.

The fan test set up, shown in Fig. 1, is supplied with three single column manometers for measuring the pressure at the throat of the measuring nozzle (h_1), the pressure before the fan (h_2), and the pressure after the fan (h_3).

Using the inlet nozzle in the present set-up as a flow meter, the volumetric flow rate, Q, and the mass flow rate, $\dot{m}$, can be obtained :

Volumetric flow rate:

$$Q = 1.006\sqrt{\frac{\Delta P T}{P_a}} \quad , m^3/s$$

Mass flow rate :

$$\dot{m} = 0.00351\sqrt{\frac{P_a \Delta P}{T}} \quad , kg/s$$

where : ΔP is in cm H_2O

$\Delta P = h_o - h_1$

h_o = atmospheric gage pressure, cm H_2O

h_1 = gage pressure at the throat of the nozzle, cm H_2O

T = absolute temp. of the air, K

P_a = atmospheric pressure, N/m^2

The Fan Total Pressure, P_{fan}, is defined as the difference between the total pressures at the fan outlet, and the fan inlet. In the present apparatus the cross sectional areas at the fan inlet and outlet, at which inlet and outlet pressures are measured, are equal. Therefore, the velocity pressures at inlet and outlet are equal to the difference between the corresponding static pressures, h_3 at the outlet and h_2 at the inlet:

$$P_{fan} = h_3 - h_2 \quad , \text{cm } H_2O$$

$$P_{fan} = \gamma_{H2O}(h_3 - h_2) \quad , N/m^2$$

The Total Air Power of the fan, TAP_{fan}, or the useful work done, is equal to the product of the Fan Total Pressure, P_{fan}, and the volumetric flow rate; Q :

$$TAP_{fan} = P_{fan}\, Q \quad , J/s \equiv Watt$$

The power input from the dynamometer to the shaft, SP, is given by:

$$\text{Shaft Power,} \quad SP = \frac{2\pi r.F.N}{60} \quad , Watt$$

where: r = torque arm radius (m)

F = force (N)

N = speed (RPM)

The impeller Power, IP, is equal to the shaft power, SP, minus the losses in the driving belt and the bearings. These losses can be measured by driving the fan with the impeller removed.

The net fan total efficiency, η_{fan}, is defined as the ratio of the total air power of the fan, TAP_{fan}, to the impeller power, IP:

$$\eta_{fan} = \frac{TAP_{fan}}{IP}$$

Analysis & calculations

The performance curves of the tested fan are to be established, including power, versus flow rate, pressure rise (head) versus flow rate and efficiency versus flow rate at certain speed.

1. Calculate the losses in the driving belt and the fan bearings at the tested speed.
2. For the three types of impellers calculate and summaries in a table:
    a. The volumetric flow rate, Q, in m^3/s.
    b. The mass flow rate, $\dot{m}$, in kg/s.
    c. The fan total pressure, P_{fan}, in N/m^2
    d. The total air power of the fan, TAP_{fan}, in Watts.
    e. The shaft power, SP, in Watts.
    f. The impeller power, IP, in Watts.
    g. The net fan total efficiency, η_{fan}.
3. For the three types of impellers at the tested fan speed RPM (plot for the three impeller on the same figure);
    a. Plot the fan total pressure, P_{fan}, vs. the volumetric flow rate, Q
    b. Plot the impeller power, IP, vs. the mass flow rate, $\dot{m}$
    c. Plot the fan efficiency, η_{fan}, vs. the volumetric flow rate, Q
4. For the backward curved impeller blades;
    a. Show the total fan pressure, P_{fan}, vs. the volumetric flow rate, Q, for the two different speeds.
    b. Show the fan efficiency, η_{fan}, vs. the volumetric flow rate, Q, for the two different speeds.
5. Discuss the effect of impeller type on the above performance curves.

Fluid Mechanics:
Experiment # 5 Reciprocating Compressor
Apparatus: Two stage reciprocating compressor/ Thermodynamic lab

Objectives:

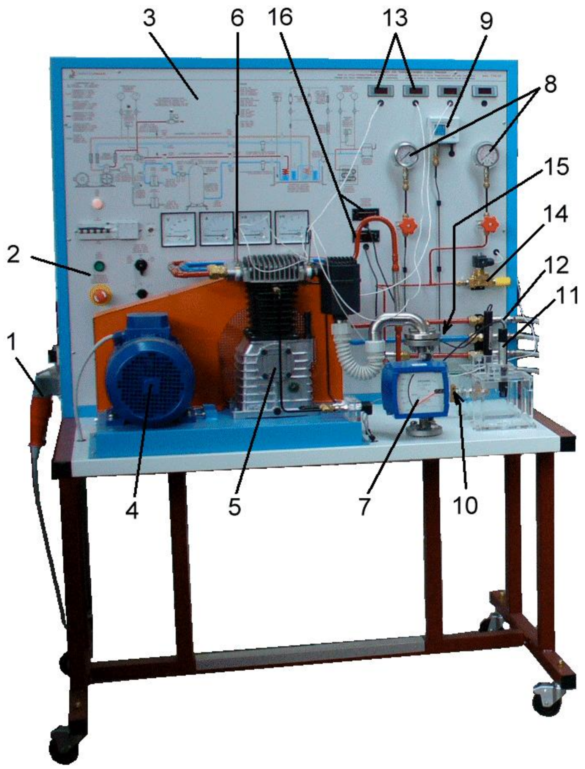
- Distinguish different types of compressors
- Examine parts of a reciprocating compressor.
- To measure air flow rate, pressure rise, power of a compressor
- Analyze p-v diagram of a single and a two stage compressor
- Measure volumetric, mechanical and isentropic efficiency of compressor
- Study the effect of compression ratio on performance
- First law analysis of compressor
- Operate a two stage compressor
- Study the effect of inter cooling on compressor performance
- Thermodynamic analysis of stored air (ideal gas and real gas).
- Study the effect of rpm on compressor performance.

Apparatus description:

The experimental set up includes a reciprocating two stage compressor with optional intercooler and a compressed air storage tank.

The system used to acquire the parameters of the compressed air as shown in figure 1 consists of a series of sensors that transmit the operation data to an electronic interface. The PC and the software take these data and process them. The measured parameters include:

- The air humidity at the circuit inlet and outlet (atmospheric pressure)
- The pressure in the cylinder of the 1st and 2nd stage
- The air temperature at inlet and outlet of 1st and 2nd stage
- The compressor rpm
- An ammeter and a voltmeter to measure the power of the compressor.



1. Power supply: 3-phase with neutral and ground
2. Electrical panel
3. Synoptic diagram in silk-screen aluminum
4. Electrical motor
5. 2-stage compressor
6. Temperature sensors
7. Flow sensor
8. Pressure gauges for high and medium pressure
9. Safety pressostat
10. Pressure regulator
11. Humidity sensors
12. Quick couplings for connection to opt. cooler
13. Digital thermometers
14. Electric safety valve
15. Mechanical safety valve
16. Hygrometers

Figure 1: Two stage reciprocating compressor set up.

The control panel includes switches and read outs as shown in figure 2.

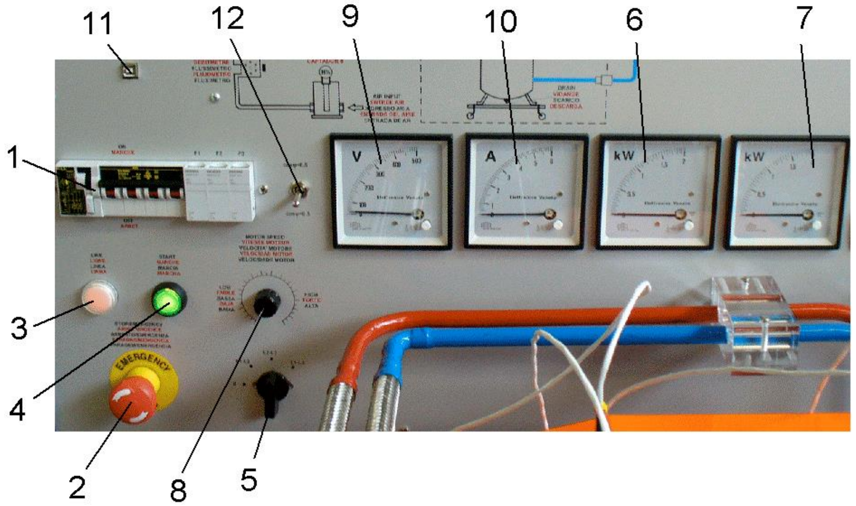


Figure 2: Control panel of system

1. Magneto-thermal switch, differential switch, fuses
2. Emergency push button
3. Line lamp
4. March button
5. Voltmetric selector
6. Wattmeter1
7. Wattmeter 2
8. Electric motor speed regulating potentiometer
9. Voltmeter
10. Ammeter
11. USB port
12. Voltmetric inverter of wattmeter no. 2

Dimensions of each stage

1st. stage diameter = 90 mm
1st. stage stroke = 65 mm
2st. stage diameter = 50 mm
2nd stage stroke = 65 mm

Heat exchanger

For each exchanger
Pipe diameter 12 mm
Pipe length 6.72 m
Surface area =0.255 m^2.

Experimental procedure

The experiments that can be done with this equipment include;

- Study of a compressor.
- Measurement of the cycle pressure and temperature values.
- Determination of the aspired air mass.
- Determination of the specific heat absorbed by the air during the compression in the 1st and 2nd stage.
- Determination of the work done on the air mass.
- Determination of the exchanged heat.
- Calculation of the compressor volumetric efficiency.

- Calculation of the rated power of the 1st and 2nd stage.

Compressor speed, rpm

Through the electric motor speed regulating potentiometer you can modify at your best the motor rotation speed from zero value (when the potentiometer is completely rotated clockwise) to the maximum value (when the potentiometer is completely rotated counter-clockwise). Starting from the configuration corresponding to electric motor still, to increase the rotations of the motor you must rotate the control potentiometer clockwise.

Pressure regulation

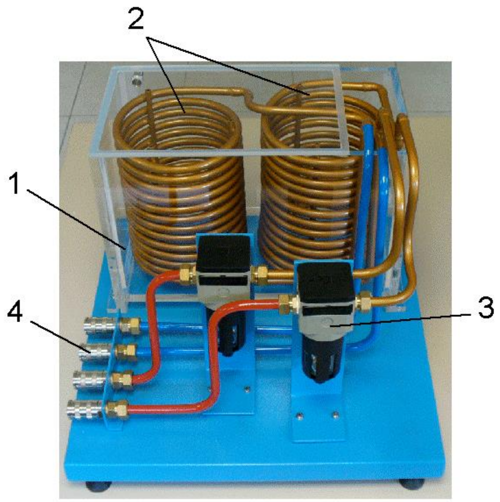
The regulation of the system operating pressure is done using the pressure regulator set at the air outlet.

Operation with air tank

The compressor operation is controlled by the pressure switch which interrupts the motor supply when the air pressure in the tank reaches the maximum established value. When the pressure drops under the differential, it is necessary to press run button to start again.

Operation with cooler

If you connect the water tank to an external cooling circuit (shown in figure 3) you can cool the compressed air both at the 1st and 2nd compression stage. The gas cooling is accomplished by heat lost to the water tank from the copper tubing.



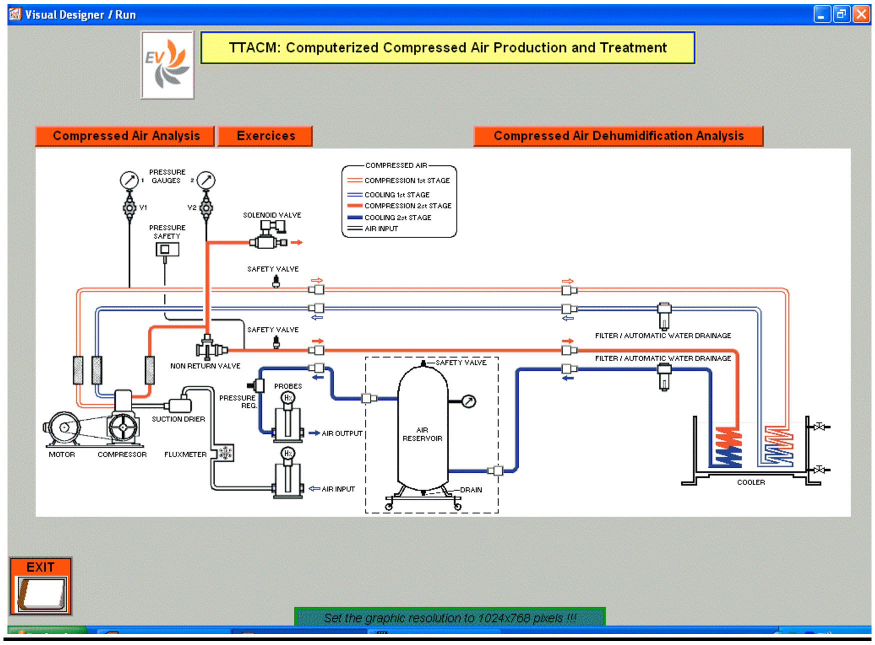
1. Tank , 2. Heat exchangers, 3. Automatic water drainage,4. Quick pipe couplings for connection to TTACM/EV

Figure 3: inter-cooling heat exchanger.

TTACM Software

The bench TTACM/EV application software is given from which the compressor system can be analyzed.

1. Running the program, the trainer’s supervision window appears on the display. As shown in figure 4



Set the graphic resolution to 1024x768 pixels !!!

Figure 4: Supervision window.

2. Pressing button “**Compressed Air Analysis**” you enter the following display see figure 5, where you find the main components of the equipment, the temperature values, the pressures, the air relative humidity at the bench inlet and outlet, the value of the suction air flow, the number of turns of the compressor.

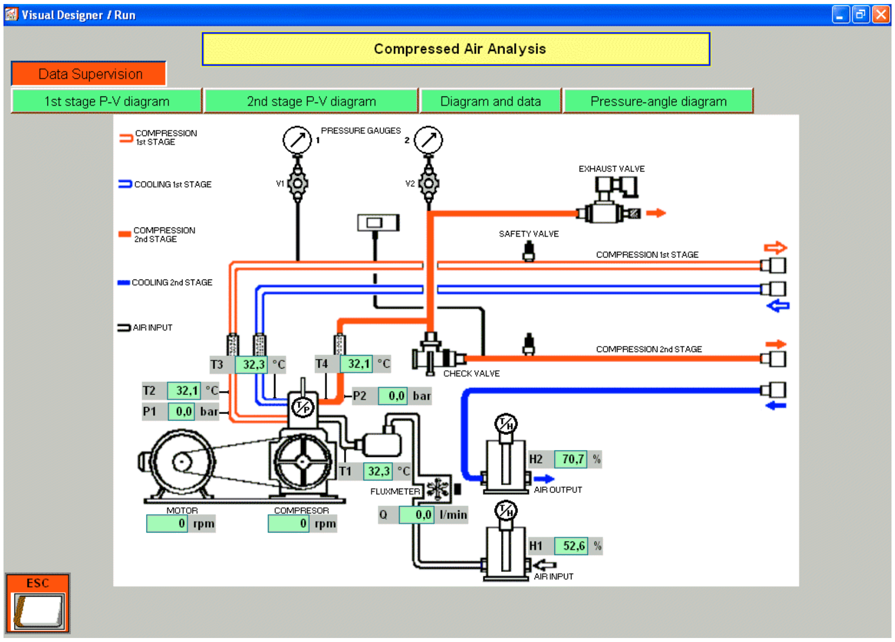


Figure 5: Compressor air analysis window.

On the top of the syn-optical diagram as shown in figure 5, there are four buttons which, when pressed with the mouse, allow to enter the thermodynamics elaborations, based on the values acquired by the probes.

Pressing the key “**1st stage P-V Diagram**”, the pressure data corresponding to each position the first stage piston assumes during its run appear on the P-V diagram, figure 6.

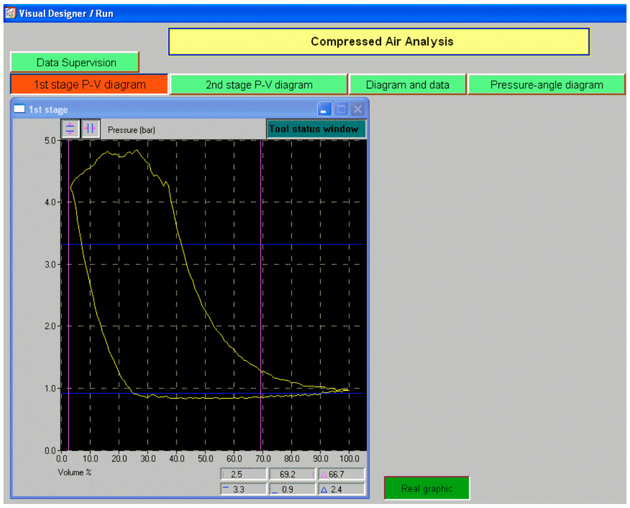


Figure 6: P-V diagram of 1st. Stage.

Pressing the key “**2nd stage P-V Diagram**”, the pressure data corresponding to each position of the second stage piston assumes during its run is drawn in the Pressure – Volume diagram, generating the real compression cycle. The same considerations developed for the first one are valid for this diagram.

Pressing the key “**Diagram and Data**” the two overlapped diagrams are represented, as shown in figure 6, whose forms, amplitudes and reciprocal position, are to be considered for evaluating the correct operation and the construction quality of the machine.

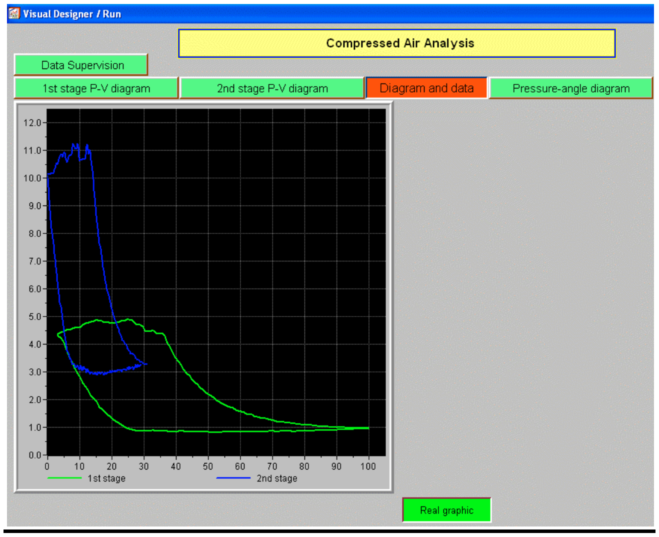


Figure 6: P-V diagram of two stages.

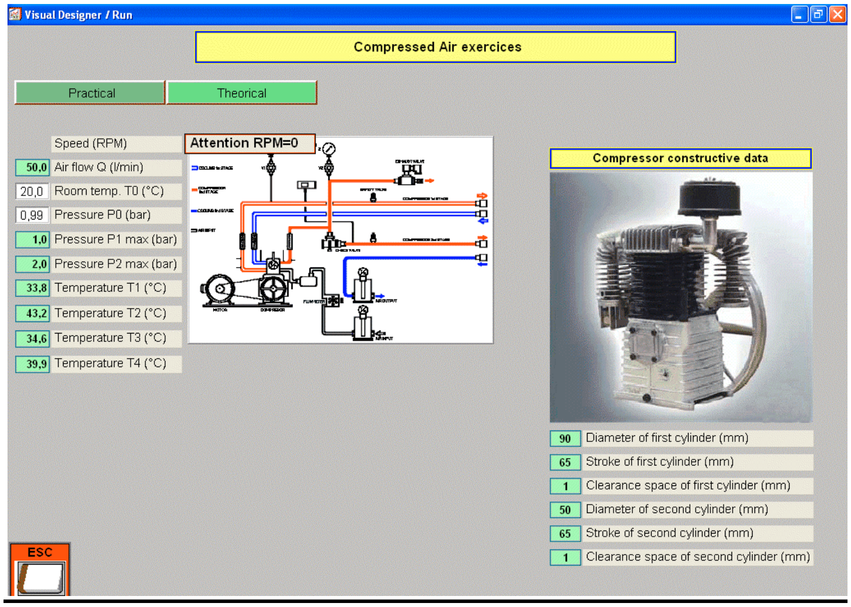
Pressing the key “**Pressure-Angle Diagram**” the pressure diagrams of the first and second states are represented, with reference to the lever.

3. Exercises

From the main screen (figure 4), pressing the button “**Exercises**” you enter the exercises session (figure 7).

Selecting the option “**Practical**” you charge the real data detected by PC for doing the exercises. Note that you must enter via keyboard the room temperature and the atmospheric pressure.

Selecting the option “**Theatrical**” you can develop theoretical exercises based on the data written via keyboard.



	Speed (RPM)
50,0	Air flow Q (l/min)
20,0	Room temp. T0 (°C)
0,99	Pressure P0 (bar)
1,0	Pressure P1 max (bar)
2,0	Pressure P2 max (bar)
33,8	Temperature T1 (°C)
43,2	Temperature T2 (°C)
34,6	Temperature T3 (°C)
39,9	Temperature T4 (°C)

90	Diameter of first cylinder (mm)
65	Stroke of first cylinder (mm)
1	Clearance space of first cylinder (mm)
50	Diameter of second cylinder (mm)
65	Stroke of second cylinder (mm)
1	Clearance space of second cylinder (mm)

Figure 7: Exercises window.

Theory

The air in the compressor will be treated as ideal gas. Thermodynamic properties of air from thermodynamic tables can be used in the calculations. Figure 8 is a schematic of the two stage compressor with intercooler.

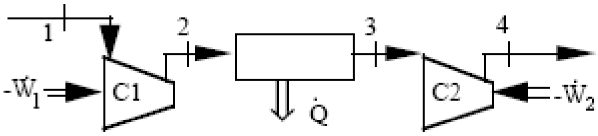


Figure 8 Schematic of the compressors with inter-cooling.

SSSF air compressor, for ideal isentropic compressor, specific work kJ/kg is given as
$w_{c,s}$ = h2,s - h1
also from second law
s2 = s1
then at s2 and P2 look up h2,s (if ideal gas is assumed h2,s is found at T2,s) where T2,s found from isentropic relation;
$T2s = T1(P2/P1)^{k-1/k}$
for air k =1.4
Also isentropic compressor efficiency is given as,
□c = $w_{c,s} / w_{c,ac}$
Where $w_{c,ac}$ is the actual work and $w_{c,s}$ is the isentropic work.

For actual compressor use the poly-tropic compression relations

$T2s = T1(P2/P1)^{(n-1)/n}$

For the inter-cooling heat lost from compressed air is calculated as
Q = mCp(T3-T2)

Ideal P-V diagram for a reciprocating compressor is shown in figure 9 and the processes include:
1-2 polytropic compression
2-3 air exhaust at constant pressure
3-4 polytropic of remained air in the clearance volume
4-1 Air intake at constant pressure.

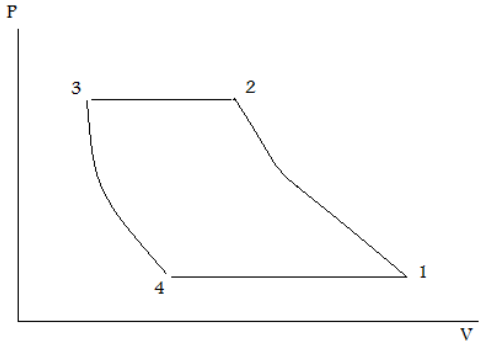


Figure 9: P-V diagram for reciprocating compressor.

Volumetric efficiency, η_v = Air volume drawn in / displaced volume
Displaced volume = (stroke) X (cross –sectional area)
Theoretically volumetric efficiency is given interims of clearance ratio **c**, the pressure ratio P2/P1 as follows;

$$\eta_v = 1 + c - c\left(\frac{\mathrm{P2}}{\mathrm{P1}}\right)^{1/k}$$

<u>Analysis & calculations</u>

1. Operate the trainer unit without connection to the storage tank (exhausting compressed air to ambient) exhaust valve is fully open and with/without inter-cooling as connected by your instructor.
2. Set rpm of motor at 1500 (or maximum speed) by adjusting knob 8 in control panel (figure 2) for the compressor unit.
3. On a table record the readings of all parameters that appear on the main diagram by selecting data supervision (see figure 5). In addition record electrical power (current and voltage). See the attached data sheet.
4. Examine the P-V diagram for each stage. Record the intake and exhaust pressure for each stage. Also record the volume % for both stages and for each process

including intake, compression, expansion, exhaust (4 values) in addition to the (clearance volume. Compare values with that given in the data supervision.

5. Calculate for each stage compression ratio, intake and exhaust volumes.
6. Calculate air mass flow rate.
7. Assuming ideal gas and constant specific heats calculate polytropic index, specific work for each stage. Compare with values computed by the software-exercises (variable specific heats).
8. Calculate the specific indicated work for each stage from P-V diagrams using software - exercises. Then calculate the power for each stage.
9. Calculate the volumetric efficiency of the first stage, and compare with theoretical value.
10. Repeat experiment at the same rpm but at three different air flow rates. Change air flow by turning the air exhaust valve.
11. Check the effect of the speed on the performance by carrying out analysis for another rpm (half speed).