Objectives

1. To establish a set of Turbine characteristics, at variable speeds, for the following variables: Mechanical Power, Hydraulic Power, volumetric flow rate and efficiency.
2. To find the relation between the mechanical power and the moment for different speeds.

Theory & Introduction

A turbine is a rotating device that extracts energy from a flowing fluid and convert it into useful work. This work can be used to generate electricity if the turbine is connected to an electrical generator. The turbine consists of two main components. The first component is the rotor, which is a rotating shaft, in which blades are connected to it. The other component is the stator, which is a stationary casing around the blades that contains and controls the flow of the working fluid by nozzles.

Turbines can be classified according to several criteria. For instance, it can be classified according to the type of the working fluid as follows:
1. Hydraulic turbine: the working fluid is water
2. Gas turbine: the working fluid is gas
3. Air turbine: the working fluid is air.

Moreover, turbines can be classified according to the pressure change of the working fluid as it flows through turbine into impulse and reaction turbine.
1. Impulse turbine: In the impulse turbine, all pressure energy of water is converted into the kinetic energy through a nozzle and generate a high-speed jet of water. This water jet strikes the blade of turbine and rotates it. The pressure of the working fluid remains unchanged as it is striking the blades.

2. Reaction turbine: In the reaction turbine there is pressure change of water in both the nozzle of the stator and as it passes through the rotor of turbine. So, it uses kinetic energy as well as pressure energy to rotate the turbine. The ratio of the pressure change that occurs when the working fluid passes through the rotor to the total pressure change that occurs in the turbine is called degree of reaction.

In this experiment air turbine with a degree of reaction of 100% is used. The purpose of this experiment is to investigate the characteristics of this turbine. Following are the equations that are required to study the turbine characteristics.

The mechanical power out of a working-producing rotating machine is given by

$P_{mech} = \omega . T$ [W] Eq.1

Where
ω is the angular speed [rad/sec]
T is the torque [N.m].
In the experiment, the angular speed is given in terms of revolutions per minute n, hence, ω can

be represented as follows:

$\omega = 2.\pi.n / 60$

by substituting it in Eq.1 , the equation becomes

$P_{mech} = 2.\pi.n.T/ 60 = \pi.n.T/ 30$

The hydraulic power is the theoretical power given by the working fluid to the machine is given by

$P_{hyd} = Pd.\dot{Q}$ [W]   Eq.2

Where:

P_d is the air pressure before entering the turbine (Nozzle pressure) [Pa]

$\dot{Q}$ is the volumetric flow rate of air [m3 /sec]

The efficiency of the turbine is given by $\eta = P_{mech} / P_{hyd}$ Eq.3

Apparatus

The apparatus is shown in Figure.1. The unit stands on a base frame. The turbine is supplied with compressed air through a hose located at the middle of the turbine. A regulation valve appears in the unit to control the flow rate of the air. This flow is measured using a flow meter. The output torque produced by the turbine is measured using a loading unit. A braking torque is applied on the shaft of the turbine using a belt. The belt is connected to a force transducer, which measures the tension in the belt.

Figure1. Turbine unit

Technical Data

In this experiment, the major specifications of the turbine are listed as follows:
Maximum power = 25 [W]
Outlet nozzle diameter = 1.5 [mm]
Maximum torque = 10 [N]
Maximum flow rate = 315 [L/min]
Maximum inlet pressure = 2.5 [bar]
Maximum speed = 30 000 [RPM]
Turbine wheel diameter = 50 [mm]

Experimental Procedure

1. Fully open the shut-off valve for air cooling.
2. Release the loading unit, and increase the air nozzle pressure to 2 bar by slowly revolving the regulation valve. Make sure that the nozzle pressure remains constant during the experiment.
3. Using the loading unit, the turbine is braked in steps ranging from 6500 to 27000 rpm.
4. Record the speed, torque, nozzle pressure, temperatures and volumetric flow rate.

Observed Data

Table1. Observed Data

Speed n (RPM)	Torque T (N.m)	Nozzle Pressure P_d (bar)	Inlet Temperature T_i (ºC)	Outlet Temperature T_e (ºC)	Volumetric Flow rate $\dot{Q}$ (m^3/sec)
27000	$0.17T_{max}$	2	18	17.4	50% $\dot{Q}_{max}$
23700	$0.22T_{max}$	2	18.6	17.2	50% $\dot{Q}_{max}$
17500	$0.3T_{max}$	2	18.5	16.8	50% $\dot{Q}_{max}$
15000	$0.37T_{max}$	2	18.7	16.5	50% $\dot{Q}_{max}$
12200	$0.57T_{max}$	2	19	16.7	50% $\dot{Q}_{max}$
7000	$0.65T_{max}$	2	19	16.7	50% $\dot{Q}_{max}$
6500	$0.75T_{max}$	2	19.2	17.2	50% $\dot{Q}_{max}$

Calculated Data

Table2. Calculated Data

Speed n (RPM)	Torque T (N.m)	Mechanical Power P_{mech} (W)	Hydraulic Power P_{hyd} (W)	Volumetric Flow rate $\dot{Q}$ (m^3/sec)	Efficiency η %
27000	0.0425	120.166	531.825	0.002625	0.2260
23700	0.055	136.502	531.825	0.002625	0.2567
17500	0.075	137.445	531.825	0.002625	0.2584
15000	0.0925	145.299	531.825	0.002625	0.2732
12200	0.1425	182.055	531.825	0.002625	0.3423
7000	0.1625	119.119	531.825	0.002625	0.2240
6500	0.1875	127.627	531.825	0.002625	0.2400

Sample of calculations:

For first trail:

1)The maximum torque given by the turbine is T_{max}=$F_{max} * \frac{d}{2}$= 10*0.025 =0.25 N.m

2) The torque measured by the loading unit is T= 0.17*T_{max} =0.17*0.25=0.0425 N.m

3) The mechanical power produced b the turbine is $P_{mech} = \frac{\pi.n.T}{30}$=$\frac{\pi*27000*0.0425}{30}$ = 120.166 W

4) The maximum volumetric flow rate is $\dot{V}_{max}$=315 $\frac{l}{min}$,P_d =2 bar

5) The actual measured volumetric flow rate $\dot{V}$=50%$\dot{V}_{max}$=0.5*315=157.5 $\frac{l}{min}$ = 2.625*10^{-3} $\frac{m^3}{s}$

6) The hydraulic power given by the working fluid is $P_{hyd} = P_d * \dot{V}$ = 2*101.3*2.625*10^{-3}

=531.825 W

7)The efficiency of the turbine is given by : $\eta = \frac{P_{mech}}{P_{hyd}}$ = $\frac{120.166}{531.825}$ =0.2260

Results

The following curves are the performance curves of the turbine. The speed is on the x-axis, while the mechanical power, hydraulic power and the torque are on the y-axis.

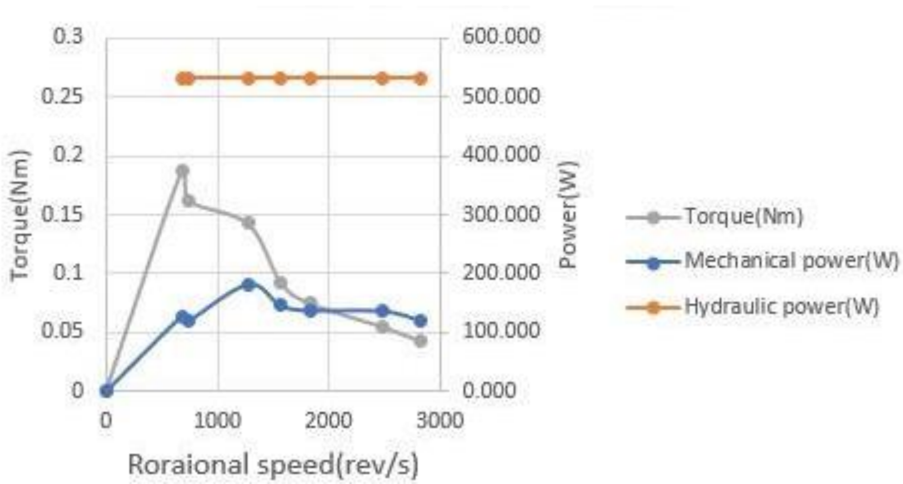

Figure2 . Plot of the relationship between Torque, mechanical power, hydraulic power and rotational speed

Discussion & Conclusions

A turbine is a rotating device that extracts energy from a flowing fluid and convert it into useful work. Several conclusions can be drawn after performing this experiment. First, as found in the calculated data, the mechanical power delivered by the turbine is higher than the maximum power given in the machine specifications. The reason beyond that is …………………
In addition, referring to table 2, we can see the hydraulic power is const because both the volumetric flow rate and the nozzle pressure are kept constant. Moreover, we can notice that the hydraulic power is higher than the mechanical power. Which is predictable as the efficiency of the turbine isn't 100%. It is noticeable that the efficiency increases to a certain value, then it drops again. This means, there is an optimum efficiency for the turbine. Air turbines are used to convert air flow's kinetic energy to provide the mechanical power to turn electric generators to generate electricity.

References

[1] Engineering Fluid Mechanics, Elger, D. F., Williams, B. C, Crowe, C. T., and Roberson, J. A., John Wiley and Sons., 10th edition,(SI units)

[2] Fluid Mechanics Lab. manual: The University of Jordan.