Project-Oriented Questions

1

Basics of Turbomachines

Problem 1

It is required to make a comparative study of the turbomachines (handling air or gas), which are mentioned in the solved and exercise examples of this chapter with respect to the parameters such as pressure ratios, speed, power per unit flow rate, size, and efficiencies. Take up this activity as a small project; and evaluate/assess the performances. Also, make an audit of energy balance.

Solution: A comparative study of turbomachines handling air/gas:

Results obtained from solved examples and exercise problems:

Example or Problem	Equipment	Pressure Ratio	Inlet Temperature (K)	Outlet Temperature (K)	η_{is}	W (kJ/kg)	$\dot{m}$ (kg/s)	P (kW)
1.5	Gas turbine	6:1	900	593.5	0.85	367.7	1	367.7
1.6	Compressor	1:6	300	527.9	0.88	229.6	1	229.6
1	Compressor	1:5.8	238	451.5	0.85	216.6	5	1081.32
2	Turbine	5.8:1	1053	686	0.88	390	5	1950

In the solved Examples 1.5 and 1.6, a turbine and a compressor have been illustrated, respectively, with same pressure ratio (6:1 or 1:6). Suppose that the examples are combined to form a gas turbine power plant. The situation is explained as follows:

1. Compressor requires a specific work of 229.6 kJ/kg.
2. Turbine supplies a specific work of 367.7 kJ/kg.
3. The net work output of the power plant is 138.1 kJ/kg.
4. The input is the energy in heating the air from the compressor output (527.9 K) to the turbine input (900 K).
5. This input is $c_p \Delta T = 1.004\,(900 - 527.9) = 373.6$ kJ/kg.
6. This has to be accounted along with energy required to increase the kinetic energy at inlet to the turbine, which is equal to $\dfrac{350^2}{(2\times1000)} = 61.2$ kJ/kg.
7. Therefore, the net input is (373.6 + 61.2) = 434.8 kJ/kg.

8. The efficiency of the plant is $\left(\frac{138.1}{434.8}\right) = 0.3176$.

9. The unutilized energy is (1 − 0.3176) times the supplied energy, that is, (434.8) × 0.6824 = 296.75 kJ/kg. This is the energy that is spent in the exhaust gases in the form of its enthalpy and kinetic energy (above the inlet condition).

A similar analysis can be made in the case of the compressor and turbine of exercise Problems 1 and 2, respectively. In these equipments, the pressure ratio is 1:5.8 or 5.8:1. We have the following.

1. Energy input to the compressor (including kinetic energy component) is 216.26 kJ/kg.

2. Energy output from the turbine (including effect of kinetic energy) is 390.00 kJ/kg.

3. Therefore, the net output of the power plant is (390 – 216.26) = 173.74 kJ/kg.

4. Energy required to heat the air from outlet of compressor to the inlet of turbine is 1.004 (1053 – 451.53) = 603.87 kJ/kg.

5. Hence, the efficiency is $\frac{173.74}{603.87} = 0.2877$.

6. The unutilized energy is 603.87 − 173.74 = 430.13kJ/kg. This is the equivalent of the "exhaust losses," that is, both effects of enthalpy and kinetic energy.

7. One interesting conclusion (also in agreement with thermodynamics) is that the two efficiency values of the present power plant (0.2877) and the previous power plant (0.3176) correlate with the pressure ratios of the equipments.

Problem 2

It is required to undertake the assessment of the equipments handling water (pumps and turbines separately) mentioned in the solved and exercise examples of this chapter, with respect to the parameters such as head, flow rate, speed, specific speed, power, and efficiencies. Take up this activity as a small project. Prepare a table of the design parameters, evaluate and present your assessment. You may use the data of Table of Specific Speeds, if required, to comment.

Solution: A comparative study of pumps and turbines:

Results obtained from solved examples and exercise problems:

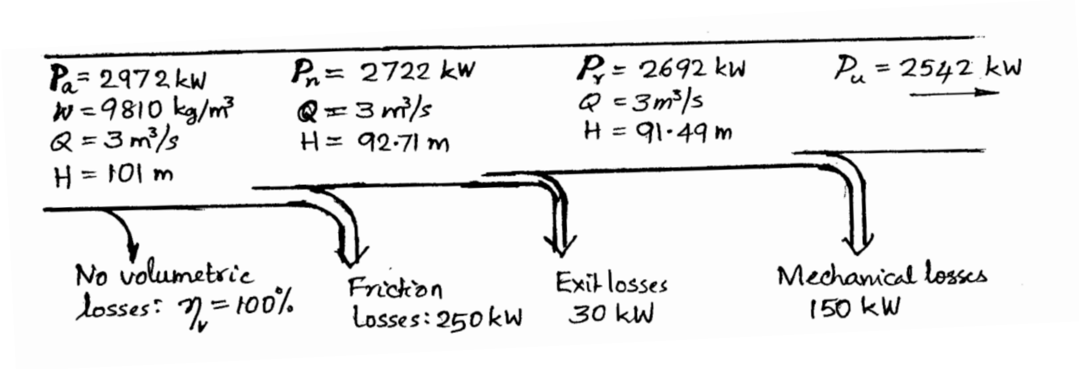
Example/ Problem	**Equipment**	**Speed (rpm)**	**Head (m)**	**Flow Rate (m^3/s)**	**Shaft Power (kW)**	**Overall Efficiency**	**Specific Speed**	**Type of Equipment**
1.8	Pump: model		4.1	0.019	0.99	0.772	54.5	Fast radial flow centrifugal pump
	Pump: prototype		42	3.89	1885	0.85	54.5	
1.9	Turbine	375	101	3	2542			

1.12	Turbine: model	600	12	0.05	5.1	0.87	60.67	Slow Francis
	Turbine: prototype	300	60	6.6	1144.7		60.68	
5	Pump	1440	20	0.05	9.81		106.6	Mixed flow centrifugal pump
	(Same pump)	1200	13.89	0.042	5.678		106.6	
6	Pump: prototype	960	15	2.1	363.55		182.5	Mixed flow centrifugal pump
	Pump: model	1440	2.11	0.049	1.24		183.1	
7	Test rig: pump	2880	60	0.015	8.83		16.36	Slow centrifugal pump
	Turbine	600	52.64	0.015	7.35		11.47	Single jet Pelton turbine
9	Turbine: prototype	600	80	1.8	1158.3	0.82	85.35	Slow Francis
	Model	759	8	0.036	2.289		85.35	
10	Pump: model	980	10	0.02			24.65	Medium radial flow
	Pump: prototype	1440	101.67	0.3			24.63	
11	Pump: model	307	3.4	0.015	0.5		15.00	Slow, radial flow
	Pump: prototype	1440	150	0.2			15.02	
12	Turbine: prototype	375	35	15	5150		316	Axial flow, Kaplan
	Model	250	2	0.461	9.045		316	

The solved examples and exercise problems cover a wide range of specific speeds. In some cases, the specific speeds have been calculated using the data or results. Because the specific speed is the main indicator of the type of pump or turbine, the range of the values of specific speeds suggest that different types of machines are covered in the problems. The type of the pump or turbine, in each case, is mentioned in the above table.

The solved Examples 1.4 (a turbine), 1.7 (a pump) and the Exercise Problem 7 (a test-rig in laboratory) present an opportunity to further analyze the energy flow, in the form explained in Figs. 1.9 and 1.10. With the available numerical values, these diagrams are drawn for each of these three problems.

Example 1.4 Energy flow (power flow) diagram for the turbine.

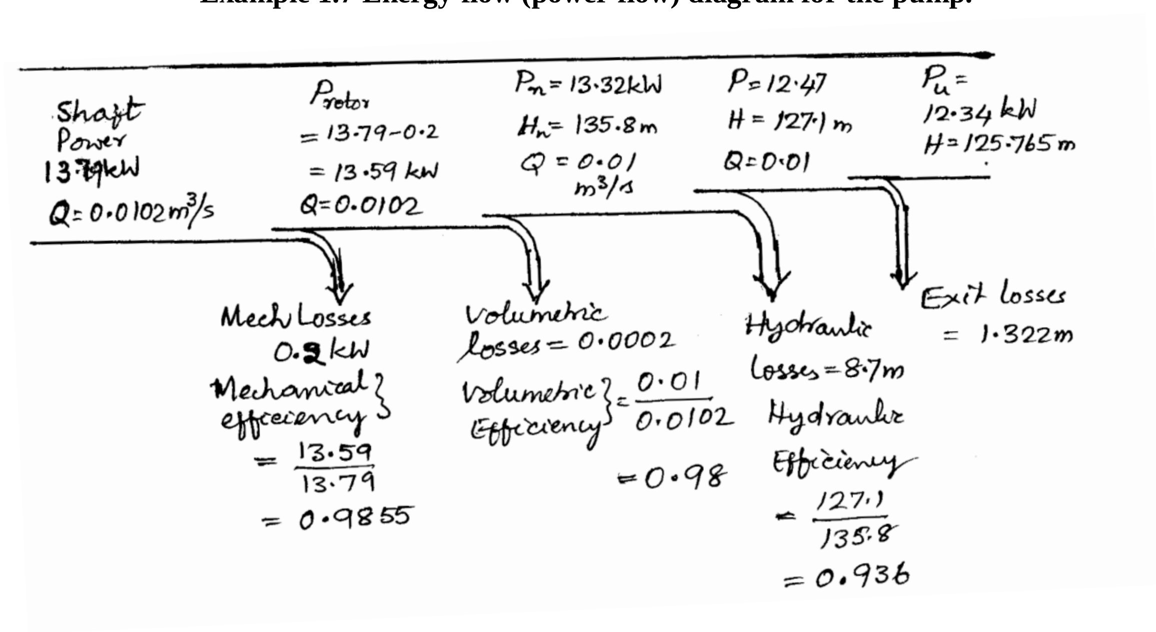


$$\text{Hydraulic efficiency} = \frac{2692}{2972} = 90.5\%$$

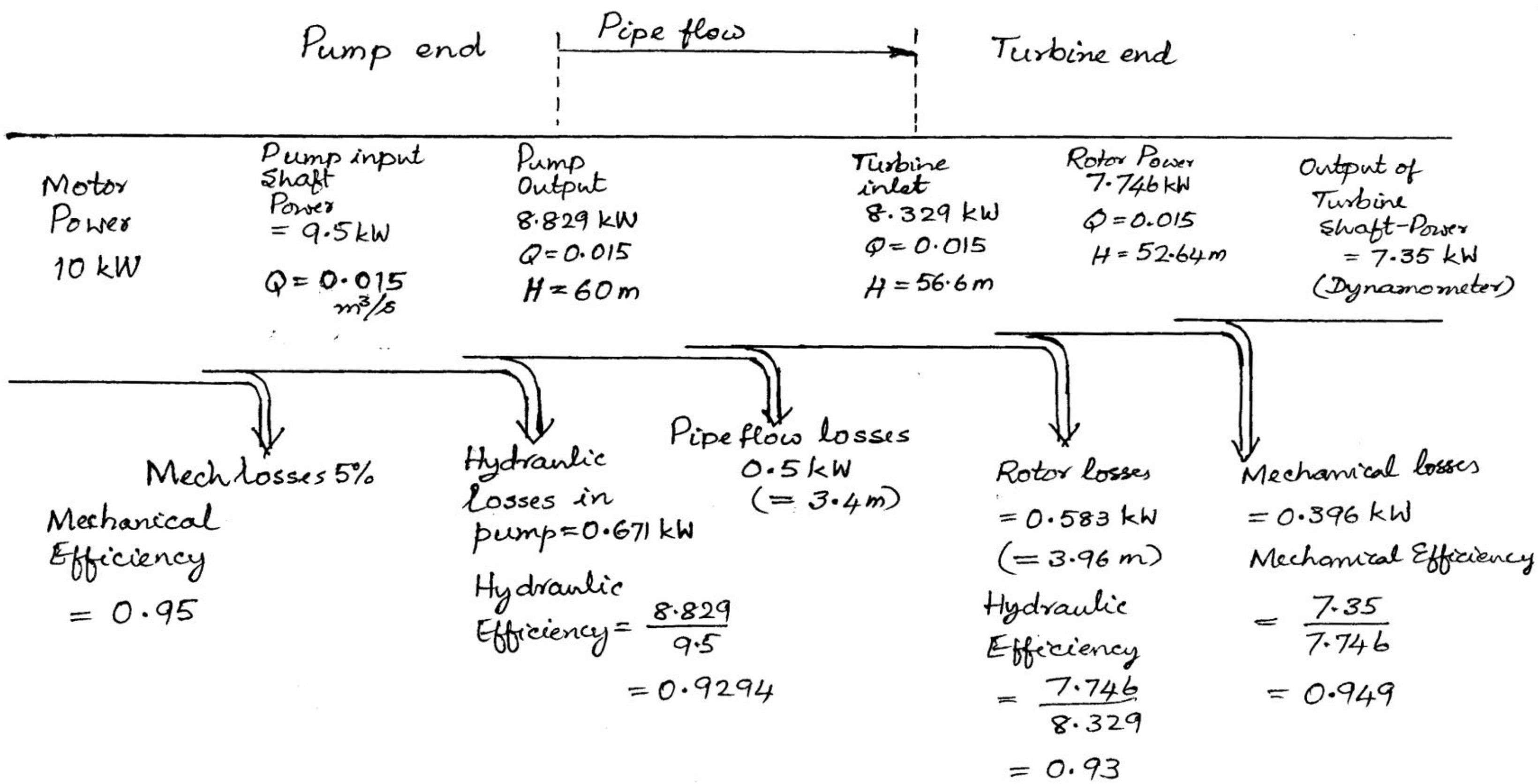
$$\text{Mechanical efficiency} = \frac{2542}{2692} = 94.4\%$$

$$\text{Overall efficiency} = \frac{2542}{2972} = 85.52\%$$

Example 1.7 Energy flow (power flow) diagram for the pump.



Exercise Problem 7: Energy flow (power flow) diagram for the test rig in lab.



Pump end
Pipe flow
Turbine end
Motor Power 10 kW
Pump input Shaft Power = 9.5 kW
Q = 0.015 m³/s
Pump Output 8.829 kW
Q = 0.015
H = 60 m
Turbine inlet 8.329 kW
Q = 0.015
H = 56.6 m
Rotor Power 7.746 kW
Q = 0.015
H = 52.64 m
Output of Turbine Shaft-Power = 7.35 kW (Dynamometer)
Mech losses 5%
Mechanical Efficiency = 0.95
Hydraulic Losses in pump = 0.671 kW
Hydraulic Efficiency = 8.829 / 9.5 = 0.9294
Pipe flow losses 0.5 kW (= 3.4 m)
Rotor losses = 0.583 kW (= 3.96 m)
Hydraulic Efficiency = 7.746 / 8.329 = 0.93
Mechanical losses = 0.396 kW
Mechanical Efficiency = 7.35 / 7.746 = 0.949