MEC E 403
Lab 1: Centrifugal Pumps

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Abstract

This will be a summary of the lab. It will include the purpose of the lab, the methods used, and the results obtained. This will be completed after the lab is finished.

Contents

1 Nomenclature

will do this after the lab is done because I don't know what all the variables used will be yet.

asd

2 Introduction

2.1 Background

TO DO: Reword and find sources for information. Pumps, turbines, and fans are turbo machines whose function is to change the energy level of a fluid. A pump or compressor increases the total head or pressure of the fluid while a turbine decreases it and extracts energy from the flow. Analysis of turbo machines is an important piece of technology, and a knowledge of their general characteristics is essential for many branches of engineering.

The geometry of turbo machines varies appreciably for the differing types that have been developed. Broadly there are two classes. In the first class there is a pronounced change in radius from the inlet to the discharge; these may be said to be centrifugal turbo machines. This is an important type of turbo machine as there are a great number of pumps, turbines and compressors that fall into this category. The other class consists of axial machines in which the flow is largely parallel to the axis of rotation. Between these extremes are examples in which the flow may proceed along conical surfaces of revolution, and these are sometimes called mixed-flow turbo machines. In all these varying types, however, there must be a rotating member, usually called a rotor, or impeller, to do work on the fluid.

2.2 Objectives

1. To measure the performance of a centrifugal pump and compare the results with the manufacturer's specification and theoretical predictions.

2. To compare the performance of parallel and series pump system configurations.

3 Procedure

3.1 Equipment

- Pump system that can be configured as a single pump or as two pumps in series or parallel operation. This is the system being studied.

- Stopwatch to measure time to fill a container

- Strobotach to verify pump rotational speed

- Mass scale to measure 200 lbs of water
- 1.401 kg mass to measure moment arm (torque) of motor
- Pressure transducers to measure pump pressure differential

3.2 Procedure

1. The pump system will be tested individually at 1800, 2700, and 3600 RPM. The speed of the pump will be verified using the strobotach.
2. At each pump speed, the flow rates at 4 different pressures will be recorded (shutoff, full open, and two other equally spaced intermediate settings). The speed of the pump will be set to the correct value when changing the pressures before taking any other readings.
3. At each operating condition, the pump speed, pressure transducer output, the moment arm and dyno mass (to determine the torque produced by the motor), and time required to collect a known quantity of water will be recorded.
4. Items (2)-(4) will be repeated for parallel and series system configurations with both pumps set at 2700 RPM.

4 Theory

4.1 Euler's Turbomachinery Equations

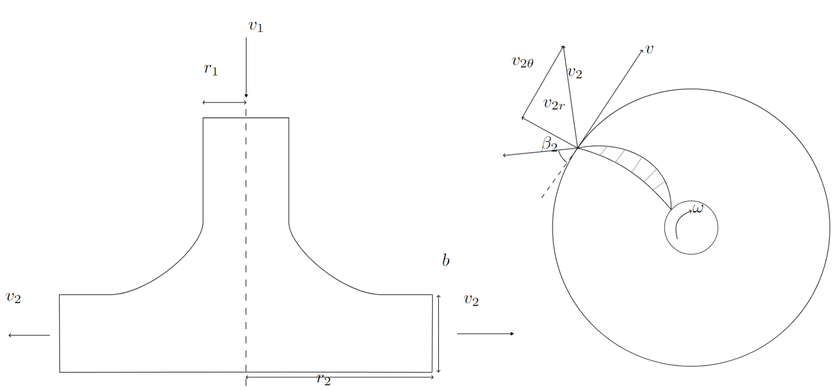

Figure 1: Impeller Diagram

Using the following assumptions:

1. Viscous effects are negligible

2. Velocity profile is uniform at the exit

3. All work done by the pump is transferred to the fluid

Then by conservation of angular momentum,

$$\mathrm{T} = \dot{\mathrm{m}}\mathrm{r}_2\mathrm{v}_{2\theta} \tag{1}$$

where T is the torque, $\dot{\mathrm{m}}$ is the mass flow rate, r_2 is the radius of the impeller, and $\mathrm{v}_{2\theta}$ is the tangential velocity at the exit. From Figure 1, we can see that

$$\mathrm{v}_{2\theta} = \mathrm{U} - \mathrm{v}_{2\mathrm{r}} \cot\beta_2 \tag{2}$$

where U is the tip speed, $\mathrm{v}_{2\mathrm{r}}$ is the radial velocity at the exit, and β_2 is the blade angle. Combining (1) and (2), we get

$$\mathrm{T} = \dot{\mathrm{m}}\mathrm{r}_2(\mathrm{U} - \mathrm{v}_{2\mathrm{r}} \cot\beta_2) \tag{3}$$

By Assumption 3, we can say that

$$\mathrm{T}\Omega = \dot{\mathrm{m}}\mathrm{g}\mathrm{H} \tag{4}$$

where Ω is the impeller angular velocity, g is the acceleration due to gravity, and H is the total head rise across the pump. By combining (3), (4), and the kinematic relationship $\mathrm{U} = \mathrm{r}_2\Omega$, we get

$$\frac{\mathrm{Hg}}{\mathrm{U}^2} = 1 - \frac{\mathrm{v}_{2\mathrm{r}}}{\mathrm{U}} \cot\beta_2 \tag{5}$$

Defining the head coefficient Ψ and the flow coefficient Φ as

$$\Psi = \frac{\mathrm{Hg}}{\mathrm{U}^2} \quad \Phi = \frac{\mathrm{v}_{2\mathrm{r}}}{\mathrm{U}} \tag{6}$$

then (5) becomes

$$\Psi = 1 - \Phi \cot\beta_2 \tag{7}$$

also, $\mathrm{v}_{2\mathrm{r}}$ can be expressed by the continuity equation as

$$\mathrm{v}_{2\mathrm{r}} = \frac{\mathrm{Q}}{\mathrm{A}_2} = \frac{\mathrm{Q}}{\mathrm{b}(2\pi\mathrm{r}_2 - \mathrm{Nw})} \tag{8}$$

where Q is the flow rate, A_2 is the area of the exit, b is the blade height at the exit, N is the number of blades, and w is the width of the blade.

4.2 Shutoff Head

The ideal shutoff head can be obtained as

$$H'_{ideal} = \frac{U^2}{g}$$

by setting $\Phi = 0$ in (7). If it is assumed that all kinetic energy is lost due to friction, then

$$\frac{KE}{\text{unit weight}} = \frac{U^2}{2g}$$

where KE is the kinetic energy. Therefore, the rule of thumb for the shutoff head is

$$\begin{aligned} H'_{thumb} &= \frac{U^2}{g} - \frac{U^2}{2g} \\ H'_{thumb} &= \frac{U^2}{2g} = \frac{1}{2}H'_{ideal} \end{aligned} \tag{9}$$

4.3 Affinity Laws

For large Reynolds numbers, the flow is dynamically similar in geometrically similar machines when the flow and head coefficients are the same. For geometrically similar machines operating at different conditions (i) and (ii) such that the head and flow coefficients are the same, the following relationships hold:

$$\begin{aligned} \Psi_i &= \Psi_{ii} \\ \frac{H_i}{U_i^2} &= \frac{H_{ii}}{U_{ii}^2} \end{aligned}$$

so,

$$\frac{H_i}{H_{ii}} = \left(\frac{U_i}{U_{ii}}\right)^2 \approx \left(\frac{D_i\Omega_i}{D_{ii}\Omega_{ii}}\right)^2 \tag{10}$$

where D is the diameter of the impeller. Also,

$$\begin{aligned}\Phi_i &= \Phi_{ii}\\ \frac{v_{2ri}}{U_i} &= \frac{v_{2rii}}{U_{ii}}\end{aligned} \tag{11}$$

Assuming the blade width is negligible, from (8), we get

$$v_{2r} = \frac{Q}{\pi D b} \tag{12}$$

so (11) becomes

$$\begin{aligned}\frac{Q_i D_{ii} b_{ii}}{Q_{ii} D_i b_i} &= \frac{U_i}{U_{ii}}\\ \frac{Q_i}{Q_{ii}} &= \frac{\Omega_i b_i}{\Omega_{ii} b_{ii}} \left(\frac{D_i}{D_{ii}}\right)^2\end{aligned} \tag{13}$$

For geometrically similar machines, the ratios of b/D are the same, so (13) becomes

$$\frac{Q_i}{Q_{ii}} = \frac{\Omega_i}{\Omega_{ii}} \left(\frac{D_i}{D_{ii}}\right)^3 \tag{14}$$

4.4 Transducer Head Adjustment

In this experiment, since the inlet and outlet pipe diameters are different, the transducer head, H_t, must be corrected for flow kinetic energy to give the pump stagnation head, H, as

$$\begin{aligned}H &= H_t + \frac{v_2^2}{2g} - \frac{v_1^2}{2g}\\ H &= H_t + \frac{v_2^2}{2g}\left(1 - \left(\frac{v_1}{v_2}\right)^2\right)\end{aligned} \tag{15}$$

The volume flowrate through the system can be written as

$$Q = \frac{v_2 \pi D_2^2}{4} \tag{16}$$

and with the pipe diameters D_1 at the inlet and D_2 at the outlet, mass conservation requires that

$$v_2 \pi D_2^2 = v_1 \pi D_1^2 \tag{17}$$

With (16) and (17), (15) becomes

$$H = H_t + \frac{8Q^2}{\pi^2 D_2^4 g}\left(1 - \left(\frac{D_2}{D_1}\right)^4\right) \tag{18}$$

5 Results and Discussion

5.1 Single Pump Performance

- analyze data prolly put in appendix
- make plots
- do error analysis and propogation

5.2 Parallel Pump Performance

- analyze data prolly put in appendix
- make plots
- do error analysis and propogation

5.3 Series Pump Performance

- analyze data prolly put in appendix
- make plots
- do error analysis and propogation

5.4 Comparison of Pump Configurations

5.5 Manufacturer's Specifications

6 Conclusion

- Summarize the results of the lab
- Discuss the significance of the results
- Discuss the sources of error
- Discuss the limitations of the experiment
- Discuss the implications of the results
- Discuss the future work

6.1 Technical Recommendations

7 References

The references section will be auto populated with Bibtex.