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Development of a System for Analyzing Centrifugal Pump Performance

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ABSTRACT

A system for the analysis of centrifugal pump performance was developed to demonstrate overall pump characteristics across a test set of various speed, flow and head conditions. The main unit consisted of a pumping system of a pipe, motor dynamometer, inverter, rotary flow meter, measuring tank, tachometer and a centrifugal pump. Suction and discharge pressure were measured by gauges, mounted on a panel. A wheeled frame supported the main unit and a main storage water tank. The unit provided a means of evaluating the effects of several variables on pump performance. The overall performance characteristics of a centrifugal pump obtained with this method were consistent and replicable.

Key words: system for analyses, centrifugal pump performance, characteristic centrifugal pump curve

INTRODUCTION

On farms, water pumps are used mainly for farm supplies, irrigation and animal husbandry. Farmers must know about pump performance in order to select a suitable one. Two important factors that must be understood are the required output per hour or flow rate and the pressure or total head.

Many farmers have little knowledge of the variation in the total head and water flow of pumps, especially centrifugal pumps. To understand suitable applications for centrifugal pumps, an instrument is needed that can accurately and rapidly determine the total head under various flow rate conditions and the power requirement.

A centrifugal pump is a kinetic energy device, which accelerates water from a low to a high velocity and converts the velocity into pressure or head at the discharge. The principle of a centrifugal pump involves the exertion of centrifugal force by the impeller causing rotation in the liquid, resulting in a total head and flow of water. The faster the impeller rotates, the greater the water flow rate, total head and power input requirement. In theory, from pump affinity laws, the volume rate of flow is proportional to the pump speed (n), the total head is proportional to n^2 and the hydraulic power is proportional to n^3.

A pump performance test is usually conducted with the pump mounted on the floor above a large pit or sump filled with water. The pump draws water by suction from the sump, the flow passes through instrumentation that can measure the flow and pressure, and then the flow is returned back to the sump. The test loop has a throttling valve to allow variation of the flow, so that the pump can be run over its full performance

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range. Finally, the test facility has the capability to measure brake horsepower, which is the power required by the pump (Volk, 2005).

A flow meter (Smith *et al.*, 1994) may be fitted into the discharge pipe in such a position that flow disturbances produced by the pump or pipefitting will have no effect on the meter. The discharge pipe should be arranged to enable the flow to be directed into a large measuring tank of known size. The time taken to fill the tank is measured.

If the static head of suction and discharge cannot be changed by re-positioning the pump, a valve may be fitted into the suction and discharge pipes to vary the pressure (RNAM, 1983).

Education plays a major role in providing accurate and helpful information to students and farmers with the goal of increasing their knowledge of the principles of centrifugal pumps and their understanding of how to choose and use the right centrifugal pump. The objective of the current study was to develop an affordable system that could assess the performance characteristic of a centrifugal pump.

MATERIALS AND METHODS

System description

The system designed for the analysis of centrifugal pump performance (Figures 1, 2 and 3) was mounted on a table with a wheeled frame and holding the main water storage tank.

The system had the following components: 1) the piping system; 2) a centrifugal pump; 3) a motor dynamometer (2 hp) with a torque arm of 18 cm; 4) a spring balance that could measure up to 5 kg in 0.1 kg increments; 5) an inverter (4.0 KVA) using 380 V, 3 phase, 50 cycle power supply; 6) a digital stationary tachometer, capable of measuring speeds ranging from 5 to 50,000 rpm; 7) a measuring tank recalibrated and capable of holding 120 l of water; 8) a vacuum gauge capable of measuring from -10 to 0 bars, installed on the 4-inch pump inlet; and 9) a pressure gauge measuring from 1 to 10 bars, on the 4-inch pump discharge.

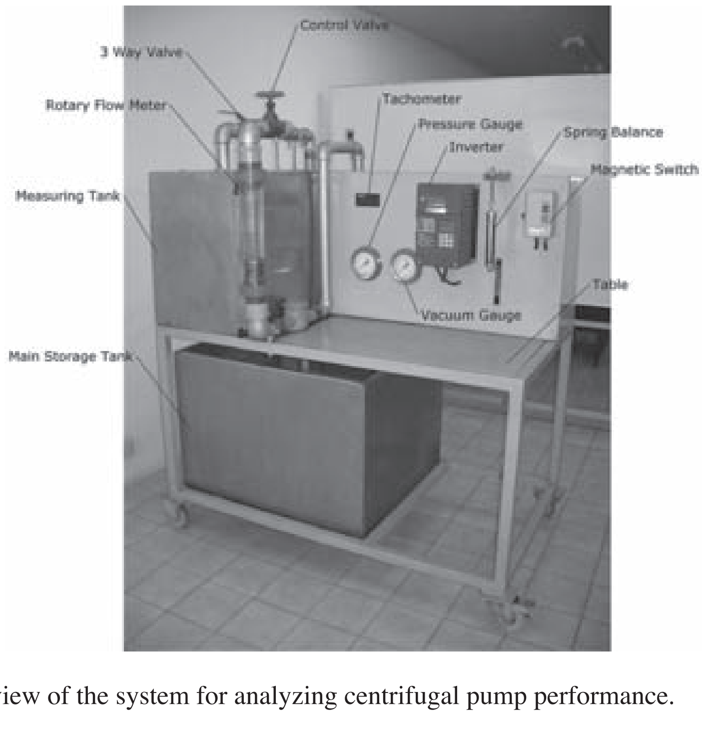

Figure 1 Front view of the system for analyzing centrifugal pump performance.

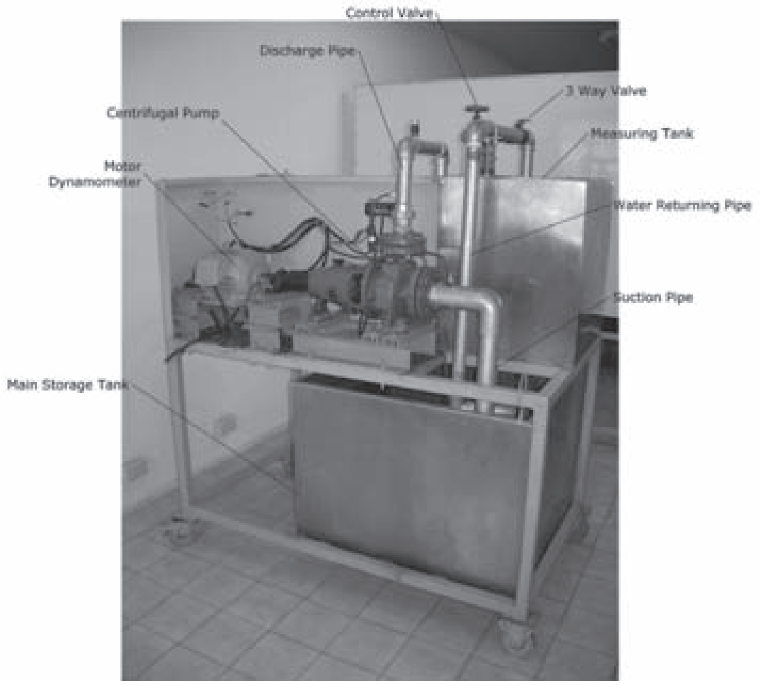

Figure 2 Back view of the system for analyzing centrifugal pump performance.

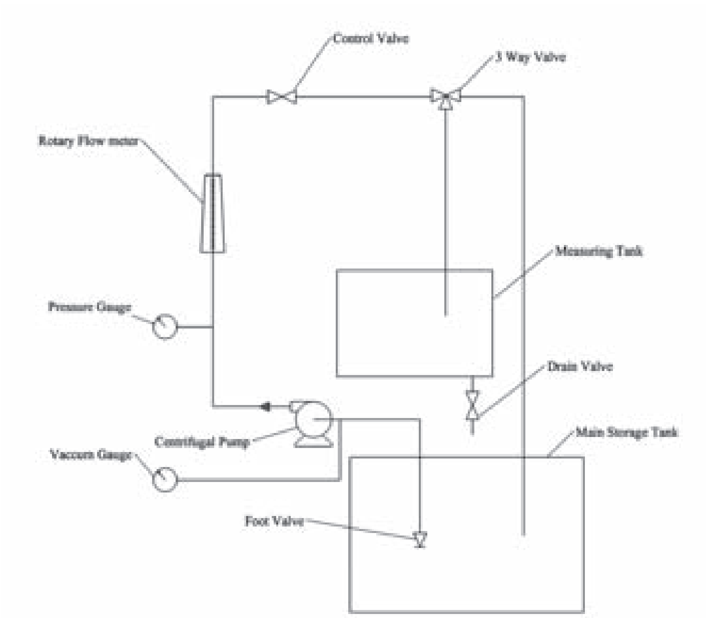

Figure 3 Schematic view of the system for analyzing centrifugal pump performance.

Centrifugal pump

Figure 4 shows a simplified diagram of a typical centrifugal pump that indicates the relative locations of the pump suction, impeller, volute and discharge. The centrifugal pump casing guides the liquid from the suction connection to the center of the impeller. The vanes of the rotating impeller impart a radial and rotary motion to the liquid, forcing it to the outer periphery of the pump casing where it is collected in the outer part of the pump casing, called the volute. The volute is a region that expands in cross-sectional area as it wraps around the pump casing. The purpose of the volute is to collect the liquid discharged from the periphery of the impeller at high velocity and gradually cause a reduction in fluid velocity by increasing the flow area. This converts the velocity head to static pressure. The fluid is then discharged from the centrifugal pump through the discharge connection (Engineers Edge, 2009).

Pump performance

To evaluate the performance of a pump, there are several pump heads factors to consider.

The pressure head is the height of water that exerts pressure on the supporting surface (Equation 1):

$$H_p = \frac{P}{\gamma} \quad (1)$$

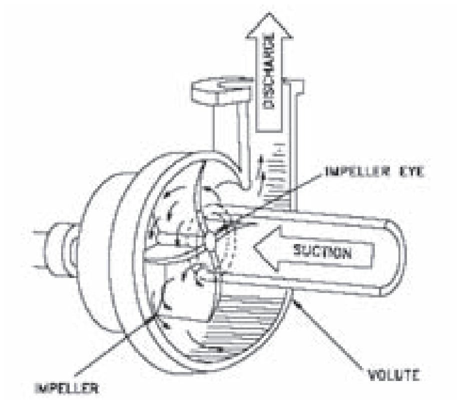

Figure 4 Simple schematic diagram of a centrifugal pump.

where, H_p = Pressure head (m)

P = Pressure (m)

γ = Specific weight of the liquid

The velocity head is the head created by the water's kinetic energy. This is equivalent to the height of water, which falls due to gravity until it gains a velocity equal to that of the flow (Equation 2):

$$H_v = \frac{V^2}{2g} \quad (2)$$

where, H_v = Velocity head (m)

V = Velocity (m/s)

g = Acceleration due to gravity (m/s^2)

The static head is the height of the liquid relative to the pump. The height of the liquid on the discharge side of the pump is called the static discharge head. The height of the liquid on the suction side of the pump is called the static suction head. The total of the two heads is called the total static head.

The total head is the sum of the pressure head, velocity head and total static head that is exerted on the liquid in a flow from one point to another. The total head is obtained from Equation 3 (Smith *et al.*, 1994):

$$H = \frac{P_d - P_s}{\gamma} + \frac{V_d^2 - V_s^2}{2g} + (h_d - h_s) \quad (3)$$

where, H = Total head (m)

P_d = Discharge gauge pressure (Pa)

P_s = Suction gauge pressure (Pa)

V_d = Velocity of water at discharge (m/s)

V_s = Velocity of water at suction (m/s)

h_d = Vertical distance between the reference plane and point where the delivered pressure is measured (m)

h_s = Vertical distance between the reference plane and point where the suction pressure is measured (m)

At constant speed, H depends on the flow rate.

The brake power is the power that the motor exerts on the pump. This is the power input to the pump (Equation 4):

$$B_p = \frac{T \times N}{9549} \quad (4)$$

where, B_p= Brake power (kW)
T = Torque (N-m)
N = Revolutions per minute (rpm)

The water power or hydraulic horsepower is the power required for the water to flow in the system. This is the power output of the pump (Equation 5):

$$W_p = \frac{Q \times H}{367} \quad (5)$$

where, W_p = Water power (kW)
Q = Rate of flow (m^3/hr)
H = Total head (m)

The efficiency of the pump is the ratio of the power gained by the liquid to the power input to the pump (Equation 6):

$$\text{Pump efficiency} = \frac{\text{Water power}}{\text{Break power}} \quad (6)$$

Testing procedure

Calibration of rotary flow meter

In order to measure the flow of water correctly, the rotary flow meter should be calibrated for different flow rates by recording the time required to fill the measuring tank.

Performance of a centrifugal pump

Before starting the test, the main storage tank was filled and the pump cavity was filled with water through a plug at the top of the pump (a foot valve was installed at the end of the suction pipe). The control valve on the discharge side of pump was closed. The inverter was adjusted to its lowest level (0 Hz). The pump was started and the inverter frequency slowly increased until the pump speed reached about 1,200 rpm based on the tachometer reading. The control valve at the pump discharge was opened slowly to obtain the desired flow rate as shown by the rotary flow meter. The water was allowed to flow for 2-3 min until steady conditions were observed. The 3-way valve was adjusted to let the water flow from the discharge pipe and the drain valve of the measuring tank was opened to drain the water into the main storage tank until the water was at the lowest level in the measuring glass tube. The drain valve was closed and the highest level of water in the glass tube was recorded.

The experiment was started by recording simultaneously the time and the inlet and outlet pressures of the pump. The 3-way valve was adjusted to let the water flow from the discharge pipe into the measuring tank. The pump was allowed to run for about 1 min or until the measuring tank water level was near its maximum and the spring load reading was recorded. The load reading multiplied by the torque arm length was used to calculate the torque.

The experiment was halted by simultaneously recording the time, adjusting the 3-way valve to let the water flow to the main storage tank and recording the flow from the rotary flow meter and the water level in the metering tank. The flow control valve was adjusted to obtain the next flow rate. The pump speed was adjusted to the desired level (2,000 rpm and 3,000 rpm) using the inverter and the pump allowed to run for a few minutes to ensure steady state flow.

RESULTS AND DISCUSSION

Calibration of rotary flow meter

The flow meter reading and discharge into the measuring tank are plotted in Figure 5. The line of best fit was computed. The least squares regression line had an R^2 value of 0.9999, showing that the correlation between the two variables was nearly perfect and a straight line was the best fit. Either the flow meter or the measuring tank discharge can used to measure the flow rate accurately.

Performance of a centrifugal pump

The objective was to develop a system for rapidly measuring and analyzing the flow and discharge components of a centrifugal pump.

Several experiments were performed with various operating conditions to verify the accuracy of the system. The flow rate for each set of test conditions was calculated. A comparison of the flow rates using a measuring tank and by rotary flow meter showed a good correlation indicating that either could be used to plot a pump performance curve (Figure 5). The power input to the pump was calculated from the torque and speed. The pump performance curve based on various control valve settings could be plotted using various parameters, including: total head versus flow, power input versus flow and efficiency versus flow.

To check that the measurements could be reproduced, each test was replicated three times (Rep.1, Rep.2 and Rep.3, respectively). Figure 6 shows a sample plot of the head, power input and efficiency as a function of the water discharge rate for the three replications, with pumping at a speed of 2900 rpm; the figure indicates that the function was replicable.

All data of each three replicates were averaged and plotted (Figure 7). The best results were obtained with a polynomial fitting of degree 2 for the head with respect to discharge (R^2 = 0.998), a polynomial fitting of degree 3 for the

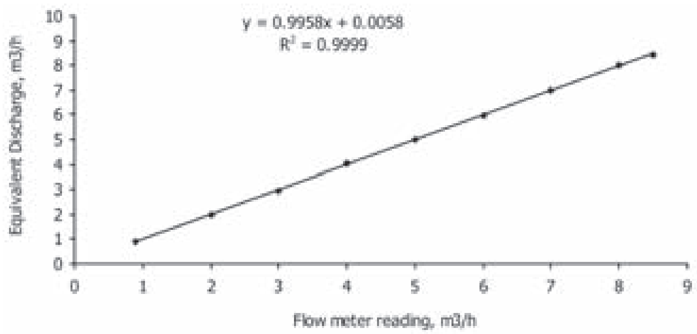

Figure 5 Rotary flow meter calibrations.

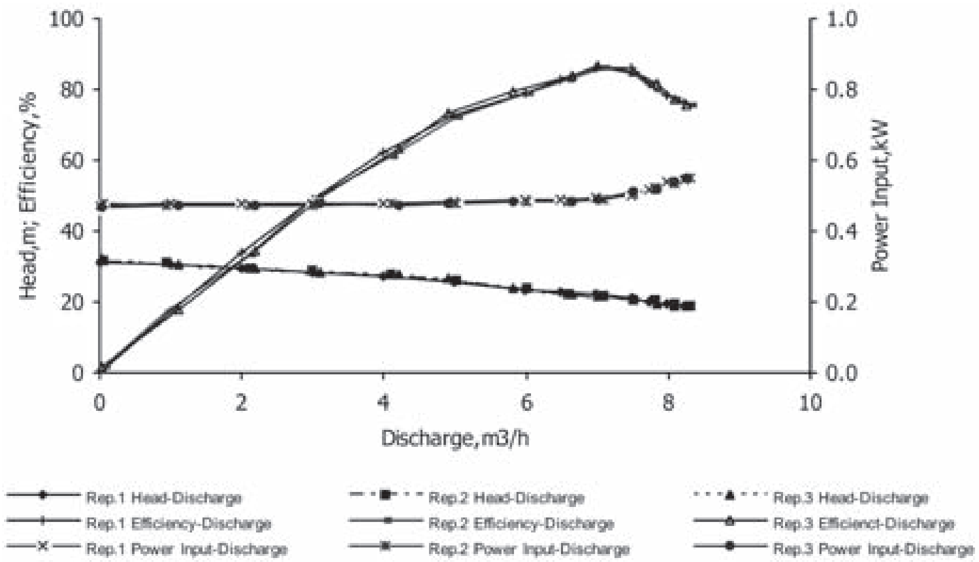

Figure 6 Results of three replications of the head-discharge, power input-discharge and efficiency-discharge pumping at 2900 rpm.

efficiency with respect to discharge ($R^2 = 0.9973$) and a polynomial fitting of degree 4 for the power input with respect to discharge ($R^2 = 0.9882$). Figure 7 represents typical performance characteristics of a centrifugal pump, and indicates that the total head reaches a maximum value called "the shut-off head" (Chaurette, 2009), when the valve is closed. The pump is noisy and vibrates excessively at this point. As the valve is gradually opened, the discharge flow increases and the pump head decreases, but the power input gradually increases. The pump cannot operate past this point, which represents the maximum flow rate. The pump consumes the maximum amount of power, is also noisy and vibrates excessively.

Figure 7 shows the pump efficiency increased with an increase in discharge flow, until it reached an optimum value and started to decrease.

Figure 8 shows the performance characteristics of a centrifugal pump operating at 2900 rpm and 1900 rpm. It can be seen that for any fixed speed of operation, the efficiency varies as the flow is adjusted. For adjustable speed operations, the head versus discharge curve and power input versus discharge curve will move downwards with reduced speed, and the efficiency curve will move to the left in such a way that the efficiency will remain constant relative to points on the curve for reduced flows.

CONCLUSION

The apparatus, instrumentation and procedure developed by the research fulfilled the objective to develop a system, which rapidly and accurately measured and analyzed centrifugal pump performance. The results obtained from several experiments using the system were consistent and replicable.

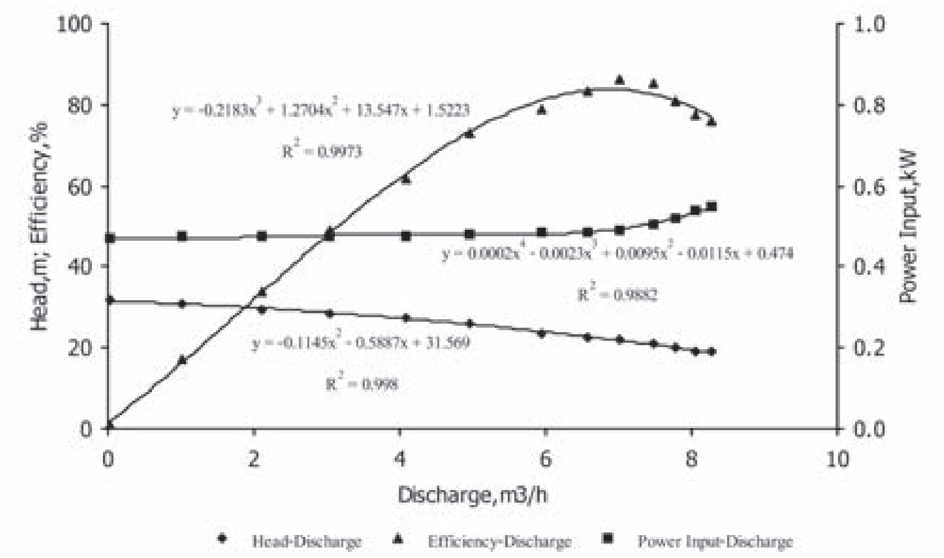

Figure 7 Performance characteristics (average of three measurements) for a centrifugal pump at 2900 rpm.

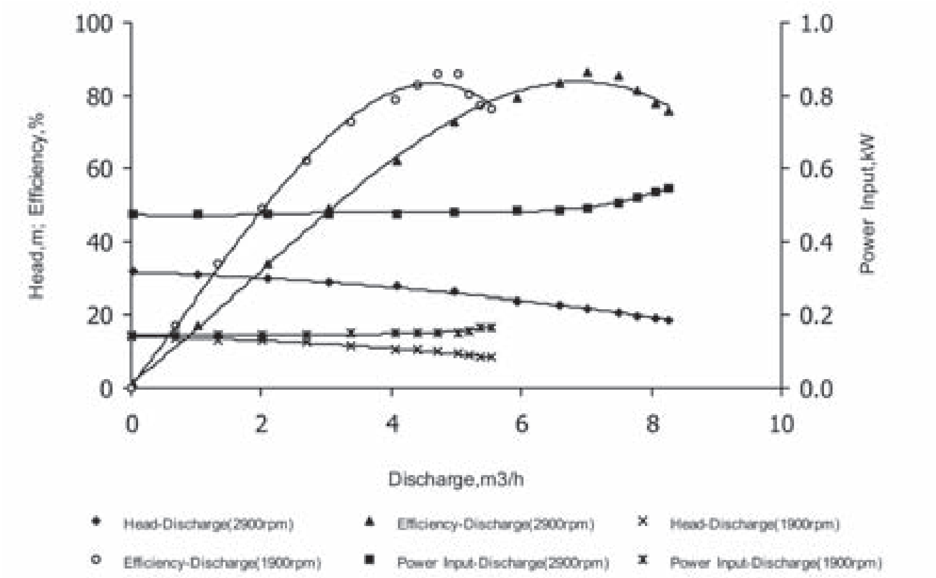

Figure 8 Performance characteristics of centrifugal pump at 2900 rpm and 1900 rpm.

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