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The reliability analyses of gear and centrifugal pumps at different rotational speeds

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Abstract. This paper concentrates the reliability analyses of gear and centrifugal pumps at different rotational speeds and flow rates. The gear and centrifugal pumps are often controlled by adjusting their rotational speed, which affects the resulting flow rate and output pressure of the pumped fluid. Initially, focused to analyze the behavior of individual characteristic curves of the pump, to find how can be applied for the determination of the most efficient frequency of rotation a pump, then the determination of energy efficiency– and reliability–based limits for the recommendable operating region of a variable speed–driven (VSD) centrifugal and gear pumps are discussed.

Introduction

The study use of reliability based criteria in the determination by characteristics of centrifugal and gear pumps, to measure the basic representative functional curves, to evaluate the behavior of reliability, the head, and flow rate of fluid transported at different frequencies of rotation. From a reliability point of view gear and centrifugal pumps have received considerable attention in recent years [1]. The centrifugal pumps are one of the most important components in any industry which have to deal with fluids. The reliability and maintainability of centrifugal pump systems have in the overall device availability plays a very important role of a suitable maintenance strategy [2]. The type of gear pump is used for transferring and metering high viscosity fluids and power transfer in industrial processes usually at high pressure rates [3]. The gear pumps are simple and robust devices that can work at a wide range of pressures and rotational speeds, providing at the same time a high reliability. Their main applications can be found as hydraulic pumps in machine tools, also as oil pumps in engines or in fluid power transfer units [4]. The centrifugal and gear pumps operate on completely different principals [5]. The basic difference between gear and centrifugal pumps are evident in the pump's response to a system's head-flow rate curves. Several pump applications are presented to illustrate the selection process needed to insure pumps reliability. The performance overlap region, where both pump types should be considered [6]. Many authors were completed their research in the area of reliability analysis of centrifugal pump. Ferman [7], provided independent, objective engineering consulting services on new and existing pumping equipment reliability and systems. Frith and Scott studied comparison of an external gear pump wear model with test data. This research was about measuring the actual material lost due to wear is impossible in a practical sense [8].

Material and Apparatus

Following experiments is proceeded in Edibon equipment. Equipment have a four pumps. This equipment designed to determine the operating physical appearance of several types of pumps, such as centrifugal pump, axial flow pump, gear pump and Peripheral pump. The scheme of four pumps is illustrated in Fig. 1 [9]. Users are generally much more familiar with one type than the other [5].

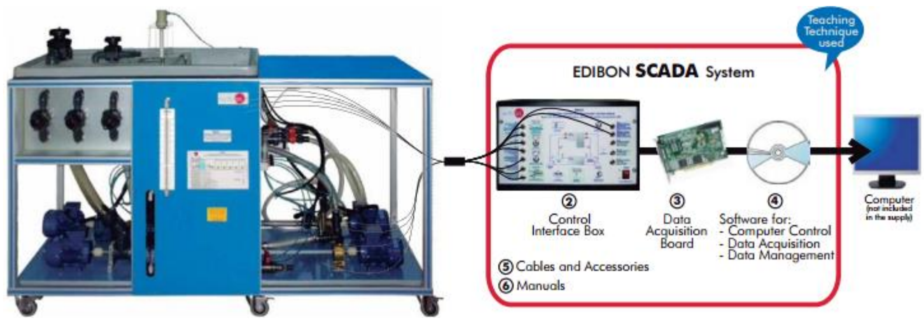

Fig. 1 Structure of a pumping system [9]

Pumping system equipped with measurement sensors that are used for control and monitoring purposes. The volumetric tank has been designed to accommodate low or high flows and it includes a level sensor (capacitive, length: 300 [mm]) to determine the water flow and the water level in the volumetric tank, an indicating transparent tube, and a graduated scale. Admission pressure sensor and discharge pressure sensor for each pump. Reading of speed (rpm) and torque [Nm] of the pump. Sensors connectors in the interface have different pines numbers (from 2–16), to avoid connection errors.

Theoretical overview and applied formulas for calculation of pumps characteristics

The same equations applied to calculate gear and centrifugal pumps characteristics.

Net head H is the height of the fluid column in the open pipe after the pump [10].

$$H = \frac{P_2 - P_1}{\rho g} \tag{1}$$

Where P_1, P_2 shows the pressure drop of the pump system. Or specific work ϵ_w done by the pump is:

$$\varepsilon_w = Hg = \frac{P_2 - P_1}{\rho} \tag{2}$$

The power given to the fluid P_w is denominated hydraulic power or output power and calculated [11]:

$$P_w = \rho g Q H \tag{3}$$

The mechanical power P_f given to the pump by the activator motor is denominated control power or input power and can be calculated as [12]:

$$P_f = \omega\, T = \frac{2\pi}{60}\, nT \tag{4}$$

$$P_\text{f} = \frac{2\pi}{60} n\text{T} \tag{5}$$

The ω is the angular axis speed in [rad sec^{-1}], n frequency of rotation in (rpm. revolutions per minute) and T the torque in the axis in [Nm], to obtain the power in [W] [13].

Pump efficiency η is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump [10].

$$\eta = \frac{P_w}{P_f} = \frac{\rho g Q H}{\frac{2\pi}{60} nT} \tag{6}$$

NPSH has two parts: NPSH required (NPSH_R) and NPSH available (NPSH_A). (NPSH_R) is a function of the pump and it is defined as:

$$\text{NPSH}_R = \left(\frac{P_1}{\rho g} + \frac{w_1^2}{2g} - \frac{P^*}{\rho g}\right) \tag{7}$$

Where P_1 and w_1 are the pressure and velocity at the inlet of the pump and P^* is the transported liquid's steam pressure [14]. Velocity is calculated as:

$$w = \frac{Q}{A} \tag{8}$$

Where A [m^2] is the circular surface area of the impeller which is calculated as:

$$A = \frac{\pi}{4} D^2 \tag{9}$$

Where D [m] is impeller diameter [15].

Calculation of gear and centrifugal pumps characteristics

The centrifugal and gear pumps were driven at ten different relative flow rates and at a rotational speed ranging 3000 and 450 rpm individually. To calculate the experimentation data at the begging of measuring new data we found t_{av}, for obtaining of average temperature, we measured water temperature t_1 = 21 [°C] at the beginning and t_2 = 23 [°C] at the end of the experiment, then t_{av} = 22 [°C]. According to average temperature acceleration of gravity and density of water are chosen from physical properties' table of water 9,81 [m s^{-1}] 997,9 [kg m^{-3}] respectively. Experiments recorded values with different frequency for centrifugal pump set in Table 1.

Table. 1 Calculated characteristics values of centrifugal pump at 3000 rpm

Number	Q [l min^{-1}]	H [m]	P_w [W]	P_f [W]	η [%]
1	18,12	8,88	26,2	355	9,4
2	17,7	8,99	25,9	311,0	8,3
3	16,38	9,09	24,2	301,5	8,0
4	15,34	9,40	23,5	292,1	8,0
5	13,61	9,29	20,6	282,7	7,3
6	12,16	9,29	18,4	273,3	6,7
7	10,94	9,29	16,5	263,8	6,2
8	8,71	9,50	13,5	254,4	5,3
9	6,77	9,80	10,8	241,9	4,4
10	4,55	9,70	7,20	226,1	3,1

Intersection curves of efficiency with pump curve Fig. 2 the efficiency is always below 100 % since the supplied power is always larger than the hydraulic power due to losses in controller, motor, and pump components.

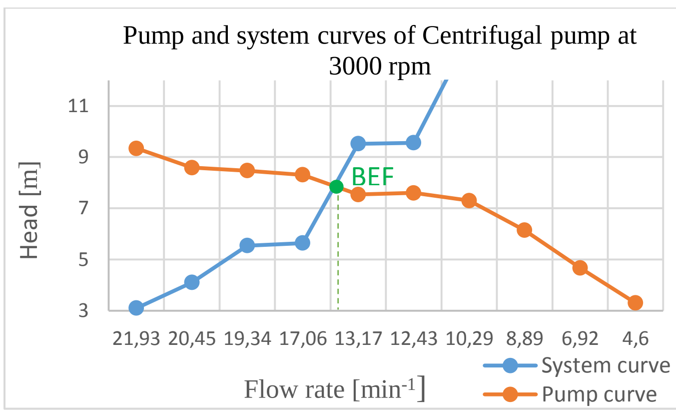

Fig. 2 Pump and system curves of centrifugal pump

Laboratory measurements were carried out for a gear laboratory pump too, the pump was driven at ten different relative flow rates and at a rotational speed ranging 450 rpm by adjusting its operation with the frequency converter and control valves. The measurement data was stored which has shown in Table 2.

System curve with pump curve see Fig. 3 which indicate the intersection point of pump curve and system curve of pump, at constant speed 450 rpm revolutions are plotted. The intersection of pump curve with system curve shows operating point [12].

Table. 2 Measured characteristics values of gear pump at 450 rpm

Number	Q [l min^{-1}]	T [Nm]	H [m]	P_W [W]	P_f [W]	μ [%]
1	12.67	3.99	1.67	3.46	183.02	1.84
2	12.48	4.31	1.64	3.34	202.95	1.65
3	12.69	3.93	1.96	4.06	185.26	2.19
4	11.48	5.61	3.81	16.53	264.60	6.25
5	10.83	5.74	3.74	15.55	270.77	5.74
6	9.39	6.35	12.14	18.64	299.20	6.23
7	9.24	6.41	12.12	18.31	302.13	6.06
3	7.99	9.00	22.19	23.99	424.23	6.83
9	6.18	10.21	23.20	23.52	481.22	6.93
10	5.26	11.72	33.43	28.75	552.37	7.20

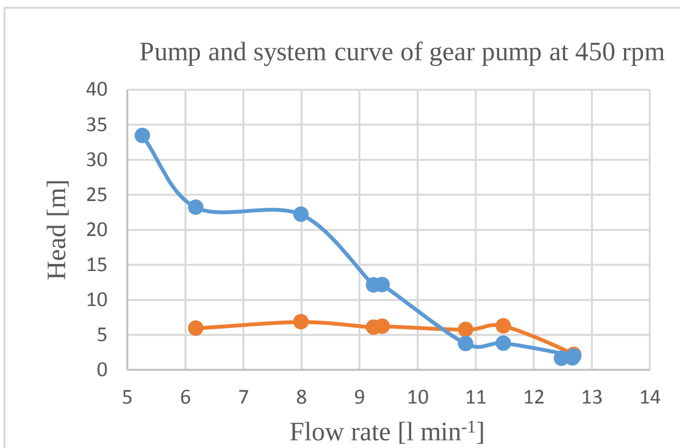

Fig. 3 Pump and system curve of gear pump

Results

The experimental data from comparison of centrifugal and gear pumps showed that these pumps can operate at different rotational speeds, various heads, and flow rates without any mechanical problem [16]. Pumping system equipped with measurement sensors that are used for control and monitoring purposes. The results are shown in (Table 1) and (Table 2) the flow rate, Head, Powers, efficiency and torque are measured in different speeds of rotation from (3000, 450 rpm) for centrifugal and gear pump respectively, and the result are calculated from equations (1-3-5 and 6). The H, P_w, P_f and η for centrifugal pump at 3000 rpm are calculated in ten steps of different flow rate see (Table 1). According to these data the Fig. 2 is plotted that shows the pump runs reliable at its operation region, the figure shows the pump curve at 3000 rpm represented that in the value of H, is 9,7 [m] the flow rate Q is 4,55 [l min^{-1}], decreasing of H to 8,8 [m] cased to increase the flow rate to 18,12 [l min^{-1}]. For gear pump the head, hydraulic power, mechanical power, efficiency, and net position suction head at 450 rpm are measures too in ten different flow rate see (Table 2). Based on these data the Fig. 3 is shows that the gear pump runs reliable at its operation region too, the figure shows the pump curve at 450 rpm represented that in the value of H, is 33,43 [m] the flow rate Q is 5,26 [l min^{-1}], decreasing of H to 1,67 [m] cased to increase the flow rate to 12,67 [l min^{-1}]. The $NPSH_R$, velocity, and surface area for centrifugal pump, by using equation (7, 8 and 9) are calculated 11 [m], 0,47 [m s^{-1}] and 0,0007 [m^2] respectively. The measured data results of gear and centrifugal pumps indicated that often gear pump is used for producing high pressure then centrifugal pump.

Conclusion

From a reliability point of view centrifugal and gear pumps have received considerable attention in recent years. Therefore it is necessary to determine the effective of reliability. The reliability and maintainability of centrifugal and gear pumps systems have in the overall device availability plays a very important role of a suitable maintenance strategy [17].

Gear pump constructions have been used and developed for over 400 years. Johannes Kepler created the first gear unit in 1604. The primary application of the patented solution at that time was to pump water in dehydrated mines [19].

This article relates to the problem of reliability analyses of gear and centrifugal pumps at different rotational speeds and flow rates [18].

The gear pumps are capable of moving a wide range of fluids. Entrained gasses, solids, low viscosity to high viscosity, and low net positive inlet pressure available can all be designed. The high mechanical efficiency offers energy savings. Peripheral pump can be used for pressure increasing, fluid transfer and distribution. They are suitable for flooded suction applications. In Table 2 from characteristic calculation of gear pump achieved that in 450 rpm in the low flow rate 5,26 [l min^{-1}] can produced a high head 33,43 [m]. However from characteristics calculation of the centrifugal pump which is run in 3000 rpm see Table 1, in low flow rate 4,55 [l min^{-1}], produced the head of 9,7 [m]. Furthermore in Table 1 and Table 2 the consumption of hydraulic power and mechanical power in gear or positive displacement pump is from low flow rate to high gradually increasing too much, but in centrifugal pump from low flow rate to high flow rate the consumption of hydraulic power and mechanical power gradually increasing is not reached to higher values of consumption as gear pump.

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