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CHARACTERISTICS OF A RECIPROCATING PUMP FOR LOW-COST SUSTAINABLE WATER HYDRAULIC TECHNOLOGY DEMONSTRATOR

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Abstract

An investigation on water-based reciprocating triplex piston pump is being conducted, as a low cost solution in substituting traditional oil hydraulics to water hydraulics. Triplex pumps are used in applications that require continuous pumping, and generally are capable of handling a wide range of fluid types, including corrosive fluids, abrasive fluids, and slurries containing relatively large particulates. Thus, an evaluation by using simple simulation process has been conducted on the volumetric efficiency, in order to understand its ability in energy-efficient system. In this paper, the results of a simulated study on a positive displacement triplex piston pump are presented. The result concludes that the use of water is relatively efficient if the slip factor is maintained to 0.003, with system pressure from 10 to 40 bar.

Keywords: *Water Hydraulics, Triplex Piston Pump, Energy Efficient*

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CIRI PAM SALINGAN SEBAGAI PENUNJUK TEKNOLOGI HIDRAULIK AIR KOS RENDAH

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Abstrak

Siasatan ke atas pam salingan tiga omboh berasaskan air dijalankan, sebagai penyelesaian kos rendah dalam menggantikan hidraulik minyak mineral untuk hidraulik air. Pam tiga omboh digunakan dalam aplikasi yang memerlukan pam berterusan dan pada amnya adalah mampu mengendalikan pelbagai jenis cecair, termasuk cecair yang menghakis, cecair yang kasar dan buburan yang mengandungi zarah yang agak besar. Oleh itu, penilaian dengan menggunakan proses simulasi mudah telah dijalankan ke atas kecekapan dan isipadu untuk memahami keupayaan dalam sistem cekap tenaga. Dalam kertas ini, keputusan kajian simulasi pada pam anjakan tiga omboh positif dibentangkan. Hasilnya menyimpulkan bahawa penggunaan air adalah agak berkesan jika slip factor dikekalkan pada nilai 0003, dengan tekanan sistem 10-40 bar

Kata kunci: *Hidraulik Air, Pam Tiga Omboh, Cekap Tenaga*

1.0 INTRODUCTION

The use of water hydraulics promotes possibility in developing fluid power systems with sustainable, energy efficient and environmental friendly elements. In this case, water hydraulics plays a role as a technology, which is using tap water or water-based fluids as the working fluid to transmit energy and power. The aim of using water as the hydraulic medium is to transfer the energy, power and the resource sustainably, at a rate that does not compromise the natural environment. The use of non-renewable resources such as fossil fuels, natural gas and coal has to be decreased, in promoting eco-friendly technology for a greener future. This involves the use of hydraulic oil which is acquired from petroleum-based mineral oil. The use of water is vital in developing sustainable fluid power system. Simultaneously, water characteristics involving hygiene, safety and low maintenance cost provide interesting perspectives for design engineers due to concern over hydraulic fluid disposal, contamination, costly maintenance and flammability. The impressive uniqueness of energy and power transmission has also brought the technology to wider scopes of application. The challenging problems which normally occur in water hydraulic system such as low lubricity and highly corrosive properties can be lowered down by the usage of a water sprayer by the triplex piston pump. Water is significantly different from oil, which at the same time can provide advantages in one aspect while producing disadvantages in other aspects. Water hydraulics can offer a design for hygiene solution in various industries, as demonstrated by the development of water hydraulics driven burger machine, beef cutter and ice filled machine in the food processing industry, and the use of environment-friendly industrial scissor lift and waste packer lorry.

Therefore, based on the current reality, this paper investigates the effect of using a triplex piston pump on a water hydraulic technology demonstrator. The demonstrator will be use to promote the usage of water hydraulic in various area such as food processing, robotics and in education. Pump is the most important component in water hydraulics system. The triplex piston pump used in this study is a spray pump with maximum pressure up to 40 bars which is usually used for car wash. This pump has a built in pressure regulator with an electric motor as its prime mover. The size of the pump is 84 cm x 50 cm x 50 cm. A simulation study is being conducted on this triplex piston pump in order to determine the volumetric efficiency parameter of suction and discharge and the water flow characteristics, under the influence of various pump speed and dimensions.

2.0 MATHEMATICAL MODELING AND ANALYSIS

Figure 1 illustrates a reciprocating pump that basically consists of a cylinder, piston, suction and delivery valve. The pump used in this study is considered as a triplex single-acting pump. Generally, a triplex piston pump exhibit typical flow variations in the delivery and suction caused by the rotary motion of the electric motor that drives the displacement elements which is piston or plungers in three cylinders. In the suction stroke event, the piston moves to create vacuum in the cylinder. This vacuum causes the suction valve to open, and thus allowing water to enter the cylinder. In the event of a delivery stroke, the piston's opposite movement increases the pressure inside the cylinder. The increment of pressure causes the suction valve to close and delivery valve to open, where the water is forced into the outlet pipe.

Figure 1 Triplex Piston Pump

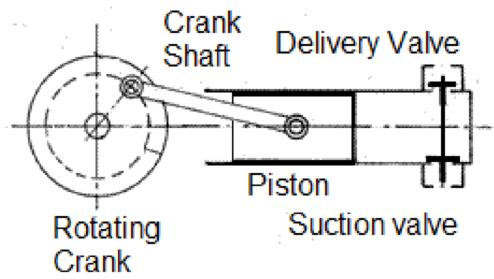

Figure 2 Reciprocating Pump Geometry

In Figure 2, the piston is connected to the rotating crank by a crank shaft. It is obvious that the piston will move, forward and backward, thus creating a simple harmonic motion. Therefore the velocity of the piston will not be uniform at all points. It will be zero at its extreme ends, whereas it will be at maximum on its centre. In addition, the piston will also have acceleration at the beginning and retardation at end of every stroke. This acceleration and retardation of piston causes a variation pressure in the cylinder and consequently in the suction and delivery pipes. The angular velocity of rotating crank, ω, can be stated as,

$$\omega = \frac{2\pi N}{60} \tag{1}$$

The angle can be described with respect to time, t, as,

$$\theta = \omega t \tag{2}$$

The displacement of piston in *t* seconds is,

$$x = r - r\cos\theta \tag{3}$$

Thus, the equation of the piston velocity can be shown as,

$$v = \omega r \sin\theta \tag{4}$$

The analysis on the velocity of the piston represents how fast the water is delivered in the system. The delivery or flow rate of a triplex piston pump can be calculated by identifying the volumetric displacement of the pump. Thus, the volumetric displacement, V_D, of triplex piston pump can be represented by,

$$V_D = \frac{\pi}{4} D^2 LC \tag{5}$$

where D,L and C refers to piston diameter, stroke length and number of piston used in the pump. Thus, the theoretical flow rate of the triplex piston pump is,

$$Q = \frac{V_D N}{60} \tag{6}$$

where N is the rotational speed of the pump in RPM. In energy efficiency, the volumetric efficiency must be achieved with minimum losses as much as possible. The slippage that influences the losses must be reduced by an optimum setting of operating conditions. Any changes in slippage and pressure have little effect on the performance, provided that it is operating at higher rotational speeds and flow rates. Because the clearances are so small, leakage flow is treated as laminar as,

$$Q \propto \Delta P \tag{7}$$

Thus for a triplex piston pump, the outlet to inlet leakage or slip flow is shown as,

$$Q_L = SF\left(P_2 - P_1\right) \tag{8}$$

where SF is the slip flow coefficient. During operation, a partial vacuum is created at the pump inlet as the piston moves. The fluid will flow into the cylinder and at this moment the liquid have chances to slip at the edge of piston and cylinder wall. By applying the principle of continuity to the inlet and outlet pipe, the expression for actual flow rate can be state as,

$$Q_2 = Q_1 - Q_L \tag{9}$$

where Q_2 is the actual flow rate, Q_1 is the ideal flow and Q_L is the slip flow rate,

$$Q_2 = V_D N - SF(P_2 - P_1) \tag{10}$$

The expression for volumetric efficiency can be stated as,

$$\eta_V = \frac{V_D N - SF(P_2 - P_1)}{V_D N} \tag{11}$$

3.0 RESULTS AND DISCUSSION

The simulation value of piston velocity with respect to rotation of the rotating crank is presented in Figure 3. The piston velocity is represented by some theoretical parameters which is, rotational speed of pump, N = 700 rpm, stroke length, L = 300 mm and radius of rotating crank, r = 150 mm. The data is also represented with three sets of degree value which is considered as the degree of rotating crank by three pistons. It is obvious that the shape of the simulated curve describes the process of the pump which is suction (negative value) and delivery (positive value). The type of pump is responsible for the curve pattern.

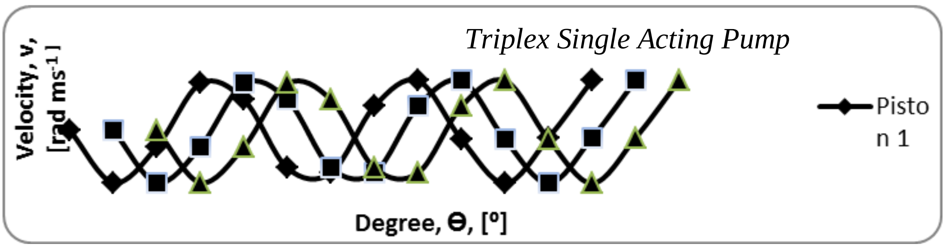

Figure 3: Velocity Curve

This shape basically depends on ratio of connecting rod length to crank radius. All the pistons movement is controlled by the crank shaft. Thus, the first piston starts to rotate a 0 degree while the second and third piston starts at 30 and 60 degree respectively. At the beginning of the stroke, the piston velocity start on 0 rad m/s and dropped to -10.86 rad m/s due to the suction process. The pistons reach the bottom dead centre at the centre of the crank rotation. On the delivery stroke, the piston moves to the right at 9.8 rad m/s. Because of the typical harmonic motion, the liquid entering and leaving each cylinder experiences a start-stop flow with velocities ranging from zero to maximum.

The simulated value of volumetric efficiency, with respect to slip flow coefficient, SF, is presented in Figure 4. The efficiency is represented with various pressures, ranging from 10 bar, 20 bar, 30 bar, and 40 bar as the maximum loading pressure for the pump. The data is also represented with various rotational speeds, ranging from 0 to 4000 RPM. All figures show the trend of the volumetric efficiency, with slip factor coefficient of 0.003, 0.015, 0.03 and 0.06. Basically, the slip factor is increased from 5, 10 and 20 times of the original SF. The simulated data is recorded for a triplex piston pump having theoretical volumetric displacement of 0.038 m^3/rev. At loading pressure, P_L = 10 bar, for slip flow coefficient, SF = 0.003. It is noted that the efficiency is around 96% to 98%, from 250 RPM up to 3500 RPM. The efficiency for the pump decreases when the slip factor is increased 5 times the original value, into SF = 0.015. At the same loading pressure, the efficiency is around 80% to 98%, ranging from 250 RPM up to 3500 RPM. At SF = 0.03, or 10 times the original value, the efficiency declines from 62% to 96%, which is recorded from 250 RPM to 3500 RPM. At 20 times the original value (SF = 0.06), the volumetric efficiency is around 24% to 82%, and also can be measured from 250 RPM to 3500 RPM.

The value of simulated volumetric efficiency slightly changes when the loading pressure increases to 20 bar. It is noted that for slip flow coefficient, SF=0.003, the efficiency is around 92% to 98%, from 250 RPM up to 3500 RPM. The efficiency for the pump decreases when the slip factor is increased to SF = 0.015. At the same loading pressure, the efficiency is around 62% to 96%, ranging from 500 RPM up to 3500 RPM. At SF = 0.03, the efficiency decreases from 24% to 90%, which is recorded from 1000 RPM to 3500 RPM. At SF = 0.06 (20 times the original value), the volumetric efficiency is around 0% to 82%, but now, it is only measurable from 400 RPM to 3500 RPM. Changes can be seen more clearly when the loading pressure increases to 30 bar. For slip flow coefficient, SF = 0.003 the efficiency is around 90% to 98% which is recorded from 250 RPM up to 3500 RPM. At SF = 0.015, the efficiency dropped to around 44% to 90%. The efficiency for the pump keep decreasing when the slip factor is increased to SF = 0.03 and SF = 0.06. At the same loading pressure, the efficiency is ranging from the efficiency is around 0% to 84%, and around 0% to 80%, while it can only be measured from 300 RPM up to 3500 RPM and from 400 RPM to 3500 RPM respectively. Lastly, at P_L = 40 bar, It is obvious that for slip flow coefficient, SF=0.003, the efficiency is around 84% to 96%, from 250 RPM up to 3500 RPM. The efficiency for the pump decreases when the slip factor is increased to SF = 0.015. At the same loading pressure, the efficiency is dropped until 24% to 88%, ranging from 250 RPM up to 3500 RPM. At SF = 0.03, the efficiency shows significant decrement from 0% to 82%, which is recorded from 350 RPM to 3500 RPM. At SF = 0.06 (20 times the original value), the volumetric efficiency is around 0% to 78%, but now, it is only measurable from 800 RPM to 3500 RPM. From this figure, it shows that at a typical rotational speed of below 800 RPM, no efficiency can be recorded with the use of pumps having slip factor of 0.06. Therefore, if the slip factor represents the use of water hydraulics in triplex piston, it would be acceptable if a higher RPM is used. And even if the highest RPM is possible, for example around 3500 RPM, it will only provide volumetric efficiency around 78%.

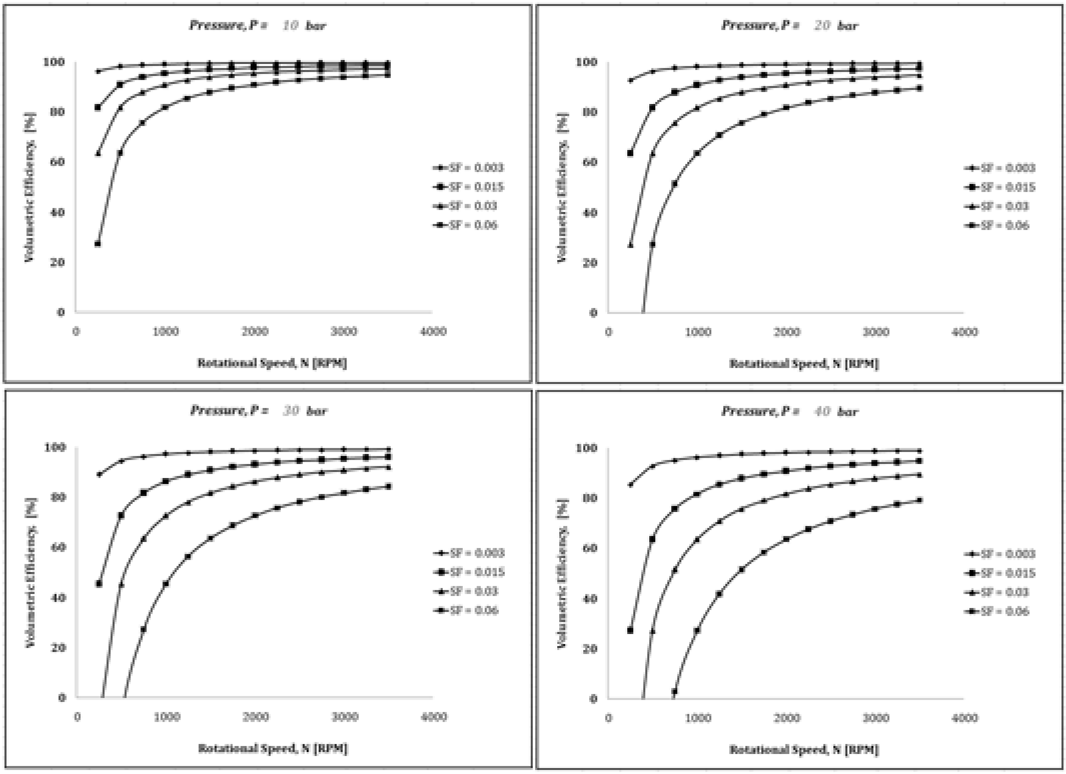

Figure 4: Volumetric Efficiency at Loading Pressure of 10, 20, 30, 40 bar

4.0 CONCLUSION

The study on reciprocating pump for water hydraulic application is being conducted at Centre of Advanced Research on Energy, Universiti Teknikal Malaysia Melaka. The objective of the study is to provide variety informationregarding to the use of low viscosity, sustainable water hydraulic in triplex piston pump. The result suggests that the use of water is efficient and practical enough, if the slip factor is maintained to 0.003, with system pressure of 10 to 40 bar. The effectiveness varies from rotational speed of 250 to 3500 RPM, and provides volumetric efficiency ranges from 6 % to 98% accordingly. The results suggest that water can be applied in using triplex piston pump to generate flow and pressure to operate a water hydraulic power system. This is true if the slip factor can be achieved with a suitable value.

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