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Design and analysis of quad-acting reciprocating pump: A novel approach

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SUMMARY

Reciprocating pumps are those in which the oscillating motion of pistons, plungers or membranes causes a fluid to move. The discharge of a single-acting reciprocating pump is low compared with a double-acting one for the same input power. In this respect an attempt has been made to increase the discharge by making some modifications in the double-acting pump with the same input power. Two additional pistons have been placed vertically and adjacently to the main cylinder. The fluid flow analysis of four quad-acting reciprocating pump has been performed in ANSYS FLUENT V12. The various parameters such as mass flow rate of fluid flow, velocity of the fluid flow, volume of the fluid flow and force of the fluid flow have been considered in this paper. These parameters have been studied for each cylinder in an outlet to determine the performance of the pump. The results show that, using the same input power used for the double-acting reciprocating pump, the total discharge of fluid of the four-acting pump has been increased.

Key words: *discharge, reciprocating, velocity, force.*

1. INTRODUCTION

A pump is a device used for lifting water from depths. ‘Reciprocate’ means to move backwards and forwards. A piston in a reciprocating pump is moving inside the cylinder for suction and delivery of fluid. Reciprocating pumps are classified into single-acting and double-acting pumps. The discharge of the single acting pump is low if compared with the double-acting one. Reciprocating pumps exhibit certain typical flow variations in the discharge and suction caused by a rotary motion of the power end driving the displacement elements. Figure 1 shows a double-acting reciprocating pump.

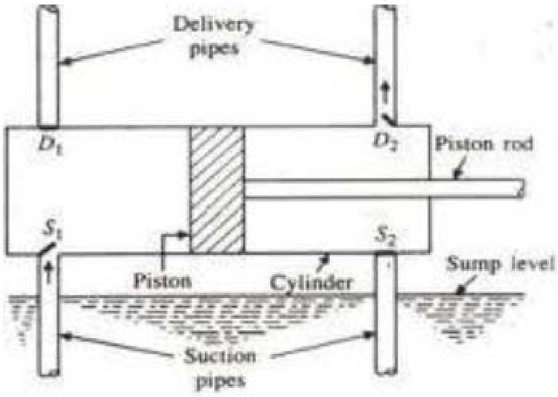

Fig. 1 Double-acting reciprocating pump

2. LITERATURE REVIEW

Libou et al. [1] discussed the principle of induced flow in a reciprocating pump and compared theoretical solutions with experimental measurements conducted in the first commercially available pump. Kilsung et al. [2] presented a proton exchange membrane fuel cell (PEMFC) integrated with an electromagnetic (EM) air pump. The EM air pump provides the PEMFC with air by reciprocating motions of the permanent magnet attached to a flexible membrane. Deliang Yu et al. [3] presented a new method for identifying the working conditions of a submersible reciprocating pumping system. Based on the analysis of the working principle of a pumping unit and the pump structure, different characteristics in loading and unloading processes of the submersible linear motor were obtained at different working conditions. Ragoth Singh and Nataraj [4] presented the use of a general purpose Computational Fluid Dynamics (CFD) to simulate the flow within the triplex-reciprocating pump and compare the results with experimental data. The effect of volume flow rate considered at various crank angles were discussed. Herbert [5] discussed the selection of components of a reciprocating pump with correct configuration for good operating and reliability of the machine. The volumetric and mechanical efficiency and net positive suction head available were discussed in the paper. Mahmoud [6] presented a theoretical study to reduce the starting torque of a non-conventional reciprocating piston pump using new methods such as the change of the wind machine parameters (aerodynamics configuration of the rotor and blade elements or the effect of wind speed velocity on the starting torque). Shuaibu [7] presented design and fabrication of a hydraulic pump capable of lifting water from a depth of 2 m without an external energy source, thereby showing that the efficiency of the pump is 57.3 %. Junfeng et al. [8] presented the FEA model of a reciprocating pump valve's collision contact and its effect on the performance of the pump through simulation and experiments. The von Misses stress in valve disc and its seat, changed by the variables such as valve closing speed, mass, diameter, and taper angle in the collision contact process, were quantitatively determined. Krishnan et al. [9] presented a computational fluid dynamics study of a dense slurry flow in a centrifugal pump casing. The various parametric analyses were then performed to determine the effect of the flow on important physical quantities viz. solid velocities, solid concentration and solid stresses near the wall with various operational geometric conditions of the pump. Pagalthivarthi and Visintainer [10] discussed the two-dimensional Eulerian (volume-averaged) continuity and momentum equations governing multi-size slurry flow through pump casings, which were solved by applying a penalty finite element formulation.

3. MATERIALS AND METHODS

The design of piston and cylinder dimensions are taken from the double-acting pump [11]. The dimensions of the cylinders are: cylinder (*C1*) diameter *=160 mm*, cylinder (*C2*) *=192 mm*, cylinder (*C3*) is similar to cylinder (*C2*), thickness of the cylinder *=20 mm*, length of the cylinder (*C1*) *=284 mm*, length of the cylinder (*C2*) *=120 mm*, cylinder (*C3*) length is similar to cylinder (*C2*). The dimensions of the pistons are: diameter of the piston (*P1*) *=150 mm*, diameter of the piston (*P2*) *=70 mm*, and piston (*P3*) diameter is the same as piston (*P2*). Length of the piston (*P1*) *=264 mm*, length of the piston (*P2*) *=172 mm*, and piston (*P3*) length is similar to piston (*P2*). The dimensions of other components: crank radios *=192 mm*, difference in valve between the centre *=0.94*, crank speed *=440 rpm*, crank angle *=360°*, input power *=0.15625 kW*, total head *=5.48 m*, pump efficiency *=88 %*, maximum percentage of slip *=39.2 %*, coefficient of discharge *=0.6427*, pressure head *=0.3* kg/cm^2, actual discharge *=0.0023* m^3/sec and theoretical discharge *=0.00030* m^3/sec.

3.1 Model of four-acting reciprocating pump

Figure 2 shows the model of four-acting pump. It consists of the main cylinder and two vertical cylinders and it is acting by a spring force and the piston of the main cylinder. The piston is linked with a connecting rod and the rod is coupled with an electric motor. The main piston is operated by an electric motor and vertical cylinder operated by the piston of the main cylinder in the forward stroke and return by the spring force.

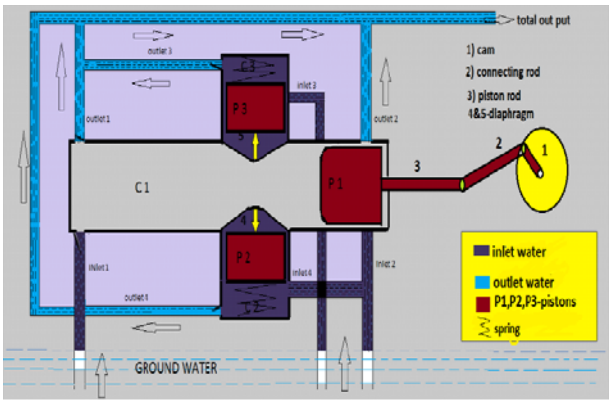

Fig. 2 Model of four-quad-acting pump

3.2 Cross-sectional model - Four-acting pump

Figure 3 shows the cross-sectional model of a four-acting reciprocating pump, with denotations for the full assembly of the working model. It has one main cylinder and piston; two vertical pistons and cylinders are arranged for increasing the discharge rate of fluid.

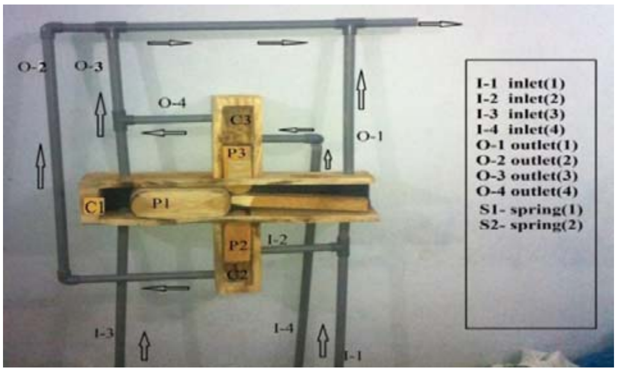

Fig. 3 Cross-sectional model - Four-acting pump

3.3 CAD modelling

Figure 4 shows a three-dimensional view of a piston and cylinder assembly model in Pro/Engineer (Pro-E) Wildfire 5. In this type of pump (pistons and cylinders), vertical piston moves perpendicularly to the movement of the main cylinder piston.

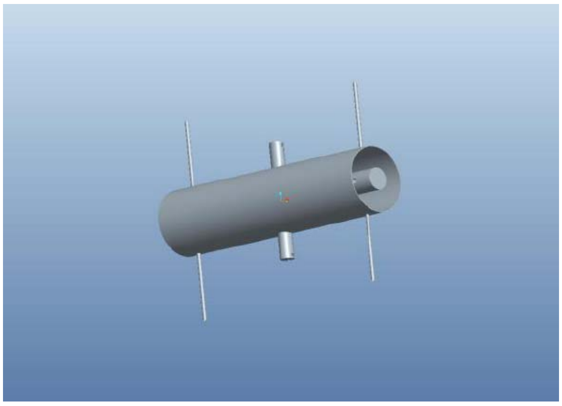

Fig. 4 CAD model of a piston and a cylinder

3.4 Analysis of four-acting cylinder

The following are the conditions used for a static analysis of cylinder and piston in the contact area between piston and cylinder:

a) cylinder and piston are assembled at maximum force acting on a surface,
b) the force acting through the piston over the cylinder,
c) outlet volume, velocity, and mass flow of water are analyzed in a particular area of cylinder.

These conditions are considered for analyzing the two vertical piston and cylinder output result. The four-acting pump model has been created in the Pro-E modelling software and all three pistons have been assembled in the main cylinder. The inlet and outlet ports have been given in the assembled model. The flow analysis of the fluid has been performed in ANSYS FLUENT V12. The various parameters like velocity of fluid, mass flow rate and volume of fluid delivered are considered for the performance of the four-acting pump.

3.4.1 Input parameter - flow analysis

The following are the parameters given as input for analysis of the fluid flow in the ANSYS FLUENT V12. The input parameters are shown in Table 1. These are: velocity of fluid, density of water, water flow iteration and density of material of the cylinder and piston.

Table 1. Outlet mass flow rate of each cylinder

S. No.	Parameters	Unit	Values
1	Input velocity	m/s	2
2	Density of water	Mg/m^3	1000
3	Given water flow iteration	-	500
4	Stainless steel density	Mg/m^3	7.85

3.4.2 Mesh model – FLUENT

Figure 5 shows the optimal surface mesh for cylinder and piston for obtaining the best possible results of fluid flow analysis. The number of statical nodes is *132111* and the number of elements is *3180*.

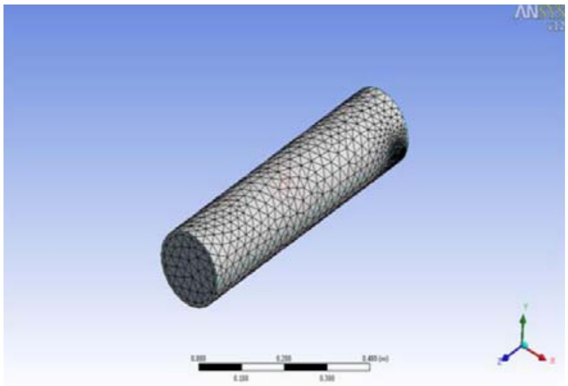

Fig. 5 Mesh model - FLUENT

3.4.3 Analysis of velocity of flow fluid

The fluid flow analysis has been carried out in the four-acting cylinder model. The velocity of fluid flow has been analyzed in the main cylinder (*C1*) and the vertical cylinders (*C2* and *C3*), as shown in the cross-section view of the pump in section 4.2. It has been observed that the sizes of cylinders *C2* and *C3* are identical. Therefore, the analysis has been done for *C1* and *C2* cylinders only.

Figure 6 shows a velocity plot of fluid flow in the main cylinder (*C1*) at a horizontal position. The maximum velocity of fluid is *5.67 m/s*. It has been observed that the maximum velocity of fluid takes place at the outlet of the cylinder.

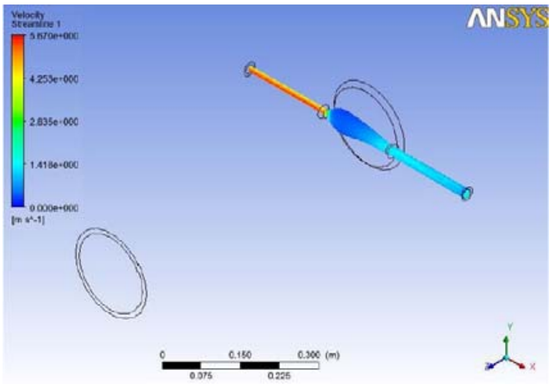

Fig. 6 Velocity of fluid flow - Cylinder 1 (C1)

Figure 7 shows a velocity plot of fluid flow in cylinder (*C2*) at a vertical position. The maximum velocity of fluid is *7.935 m/s*. It has been observed that the maximum velocity of fluid occurs at the outlet of the cylinder. Additionall, the velocity of fluid is higher than the velocity of fluid in the horizontal cylinder (*C1*).

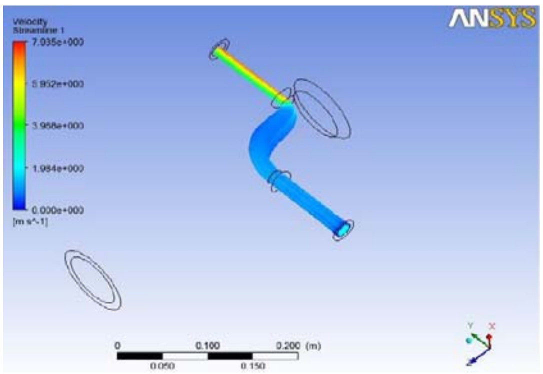

Fig. 7 Velocity of fluid flow - Cylinder 2 (C2)

3.4.4 Analysis of mass of fluid flow

The analysis of the mass flow rate at the outlet of the cylinders has been performed in ANSYS FLUENT V12 and its estimations are given in Table 2. The outlet mass flow rate of the each cylinder has been estimated in the simulation software.

Table 2. Outlet mass flow rate of each cylinder

S. No.	*Name of the cylinder*	*Mass flow rate (kg/s)*
1	*Main cylinder (C1)*	*1.09506*
2	*Vertical cylinder (C2)*	*1.57722*
3	*Vertical cylinder (C3)*	*1.57722*

3.4.5 Analysis of volume of fluid flow

In ANSYS FLUENT V12, the volume of fluid flow at the outlet of the cylinders has been estimated for each cylinder and given in Table 3. The outlet volume of fluid flow at each cylinder has been estimated in the simulation software.

Table 3. Volume of fluid flow at outlet of each cylinder

S. No.	*Cylinder*	*Volume of fluid flow (m^3)*
1	*Main cylinder (C1)*	*0.0155941*
2	*Vertical cylinder (C2)*	*0.00136034*
3	*Vertical cylinder (C3)*	*0.00136034*

3.4.6 Analysis of force of fluid flow

In ANSYS FLUENT V12 the force of fluid flow at the outlet of the cylinders has been estimated and given in Table 4. The force of fluid at the outlet of each cylinder has been estimated in the simulation software.

Table 4. Force of fluid flow at outlet of each cylinder

S. No.	*Cylinder*	*Force of fluid flow (N)*
1	*Main cylinder (C1)*	*4.50831*
2	*Vertical cylinder (C2)*	*0.0286877*
3	*Vertical cylinder (C3)*	*0.0286877*

4. RESULTS AND DISCUSSION

The fluid flow analysis of one horizontal cylinder (*C1*) and two vertical cylinders (*C2* and *C3*) in four-acting reciprocating pump has been conducted. The various parameters like velocity of fluid flow, mass flow rate of water, velocity of outlet fluid and volume of outlet water have been analyzed. The results obtained are discussed further on.

4.1 Results of flow analysis

Table 5 shows the output results of flow analysis of the piston and cylinder obtained by analysis in ANSYS FLUENT V12. These parameters are estimated at the outlet of each cylinder in flow conditions.

Table 5. Output results in fluid flow analysis

S No	*Parameters*	*Units*	*Values*		
			C1	*C2*	*C3*
1	*Volume of fluid flow*	*m^3*	*0.0155941*	*0.001360*	*0.001360*
2	*Mass flow rate of fluid*	*kg/s*	*1.09506*	*1.57722*	*1.57722*
3	*Velocity of fluid flow*	*m/s*	*5.689*	*7.935*	*7.935*
4	*Force of fluid flow*	*N*	*4.50831*	*0.02869*	*0.02869*

4.1.1 Volume of fluid flow

Figure 8 shows the volume of fluid flow in each cylinder in the quad-acting reciprocating pump. It has been observed that the volume of fluid flow for the vertical cylinders (*C2* and *C3*) was smaller than in the horizontal one (*C1*).

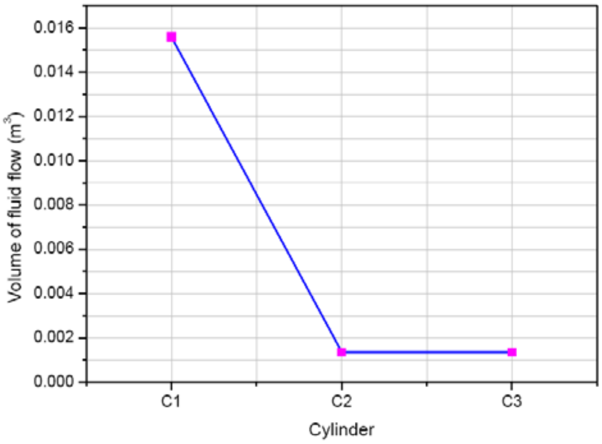

Fig. 8 Volume of fluid flow in each cylinder

4.1.2 Mass flow rate of fluid

Figure 9 shows the mass flow rate of fluid in each cylinder in the quad-acting reciprocating pump. In comparison with the horizontal cylinder (*C1*), a high mass flow rate of fluid at the outlets of both vertical cylinders (*C2* and *C3*) has been observed.

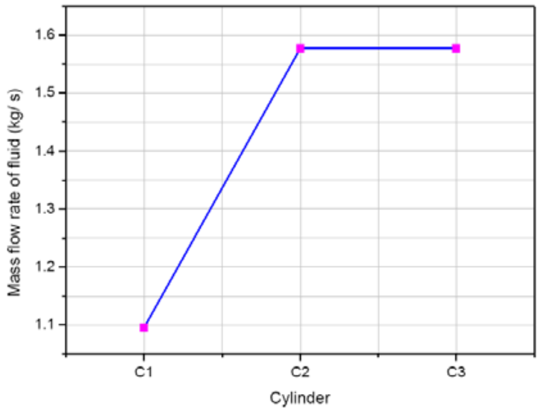

Fig. 9 Mass flow rate of fluid in each cylinder

4.1.3 Velocity of fluid flow

Figure 10 shows the velocity of fluid flow in each cylinder in the quad-acting reciprocating pump. Unlike for the horizontal cylinder (*C1*), a high velocity of fluid flow has been observed at the outlets of the vertical cylinders (*C2* and *C3*).

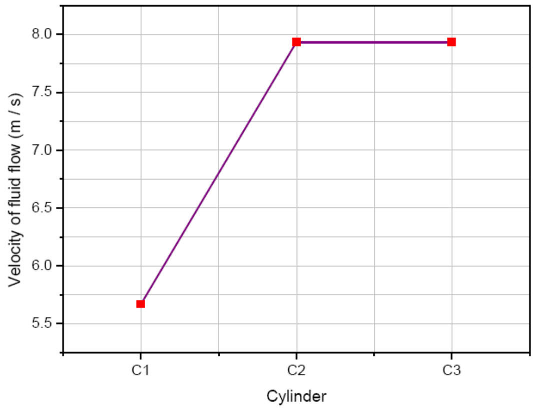

Fig. 10 Velocity of fluid flow in each cylinder

4.1.4 Force of fluid flow

Figure 11 shows the force of fluid flow in each cylinder in the quad-acting reciprocating pump. In comparison with the horizontal cylinder (*C1*), less force of the fluid flow has been observed at the outlet of the vertical cylinders (*C2* and *C3*).

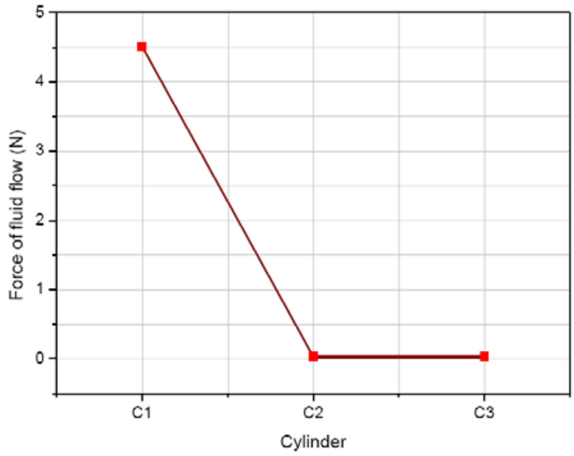

Fig. 11 Force of fluid flow in each cylinder

The quad-acting reciprocating pump has been studid in the fluid flow analysis in ANSYS FLUENT V12. The various parameters like volume of the fluid flow, mass flow rate, velocity and force of the fluid flow have been studied. It has been noticed that the force and volume of the fluid flow in the vertical cylinders (*C2* and *C3*) were low in comparison with those in the main cylinder (*C1*).

5. CONCLUSION

The four-acting-quad reciprocating pump has been designed and its working model has been developed in the cross-sectional view of the wooden pieces. The four-acting pump has been modeled in Pro-E and the assembled model imported to ANSYS FLUENT V12 for analysis. The fluent flow analysis has been done for the three various cylinders: horizontal cylinder (*C1*) and two vertical cylinders (*C2* and *C3*). Mass flow rate, velocity of the fluid flow, volume of the fluid flow and force of the fluid flow at the outlet of the cylinders were parameters observed in this study. It is concluded that the total discharge of the fluid in the four-acting pump has been increased applying the same input power which is used for a double-acting reciprocating pump.

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DIZAJN I ANALIZA RADA ČETVERORADNE KLIPNE PUMPE: NOVI PRISTUP

SAŽETAK

Klipne pumpe su pumpe u kojima oscilirajući pokreti stapova, klipova ili membrana pokreću fluid. Pražnjenje jednoradne klipne pumpe je niže u odnosu na dvoradnu pumpu za istu količinu uložene energije. Stoga, pomoću određenih modifikacija pokušano je povećanje pražnjenja na dvoradnoj pumpi za istu uloženu energiju. Dva dodatna stapa su postavljena vertikalno i odmah uz glavni cilindar. Analiza protoka fluida četveroradne klipne pumpe je provedena u programu ANSYS FLUENT V12. U ovome su radu razmotrene različite varijable kao što su protok mase, brzina protoka mase, volumni protok te sila protoka fluida. Ove varijable su promatrane na jednom ispustu za svaki cilindar kako bi se odredila učinkovitost rada pumpe. Rezultati pokazuju da je ukupna količina pražnjenja fluida četveroradne pumpe povećana uz korištenje iste energije uložene za dvoradnu pumpu.

Ključne riječi: *pražnjenje, klipna pumpa, brzina, sila.*