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Development and Construction of a Sliding Vane Pump

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ABSTRACT

Average industries in Nigeria ranging from the oil sectors, water factory, brewery industries, etc. make use of pump especially the sliding vane pump. However, due to unavailability of pumps and cost required in importing one makes it necessary for design of pumps locally. In this research work, we developed and constructed a sliding vane pump. The machine consists of the following main parts; housing, rotor, vane, inlet and outlet, and working chamber. The volumetric flow rate was assumed to be 3.5m3/h, while the head loss, displacement, pumping house, force, and power require were all calculated for. The results obtained show that a head loss of 10.2m, displacement of 0.00243m, pumping house of 0.00456m^3, force of 462.07N, and 3hp were required for the operation of the machine. The machine was constructed and tested for efficiency and performance. The results obtained show that the machine was efficient (89.05%) and can be used for both domestic and commercial purpose.

Keywords: *Sliding vane pump, efficiency, head loss, power, volumetric flow rate*

INTRODUCTION

Man's progress from ages to his present civilisation has been accompanied by an ever-increasing use of water which many-a-times had to be lifted from a lower to a higher level. This necessitated development of pumping devices. The earliest devices for lifting water are still in operation in Nigeria. A typical example is the scoop lowered into a river by means of a balance beam or in later development by a pulley, rope and a horse or donkey. Also, some oil devices and industries that have to do with fluid are equipped with sliding vane pump, and some are equipped with rotary vane pump (such as the delivery pumps in oil pipeline).

A pump is a device that moves fluids by mechanical action. It can be classified majorly into three groups according to the method used to move the fluid: direct lift, displacement, and gravity pumps [1]. The mode of operation of pumps is either via reciprocating or rotary and energy is consume in performing the mechanical work of moving the fluid. Pumps use several energy sources such as electricity, engines, winds, etc. and it come in different sizes, from microscopic use in medical applications to large industrial use [2].

The working principles of rotating vane pump (centrifugal pump) and sliding vane pump are completely different. The former belongs to positive displacement pumps, while the latter belongs to dynamic pumps [3]. A centrifugal pump is a dynamic machine that uses impeller to increase the pressure of a fluid. They are generally used for liquid transportation in different areas. Their operation ranges from full-load down to close to the shut-off head. In order to develop a reliable machine for this extremely demanding operation, the behaviour of the flow in the entire pump has to be predicted before they are put in actual use [4-5]. In centrifugal pumps, the relative motion between the rotor and stator and the small radial gap between the impeller blades and diffuser vanes result in a highly unsteady flow [6].

In dynamic pumps, energy is continuously added to the fluid to increase its velocity within the machine to values in excess of those occurring at the discharge such that the subsequent velocity reduction within or beyond the pump produces a pressure difference [7]. A dynamic pump is a device in which energy transfer occurs between a flowing fluid and a rotating element due to dynamic action resulting in a change in pressure and momentum of the fluid. The principal components of a dynamic are a rotating element carrying vanes operating in a stream of fluid, a stationary element or elements which generally act as guide vanes or passages for the proper control of flow direction and the energy conversion process, an input and/or an output shaft, and a housing. The rotating element carrying the vanes is also known by the names rotor, runner, impeller, etc., depending upon the particular application. Energy transfer occurs only due to the exchange of momentum between the flowing fluid and the rotating elements [8-9].

Sliding vane pumps is a fixed displacement pump. The vane pump includes a ring mounted inside a cylindrical case. The ring includes a number of radial slots in which are located sliding vanes. The ring is mounted eccentric to the case and the vanes are designed to press against the inside wall of the case [10]. The vanes are forced against the wall by hydraulic pressure or spring force or due to centrifugal force resulting as the ring are rotated. The prime mover is used to rotate the ring and fluid flow into compartments between the vanes and the case inner circumference. As the ring rotates, the liquid is trapped in the compartment and is then compressed and forced out through the discharge connection [11]. Figure 1 shows the schematic diagram of sliding vane pump.

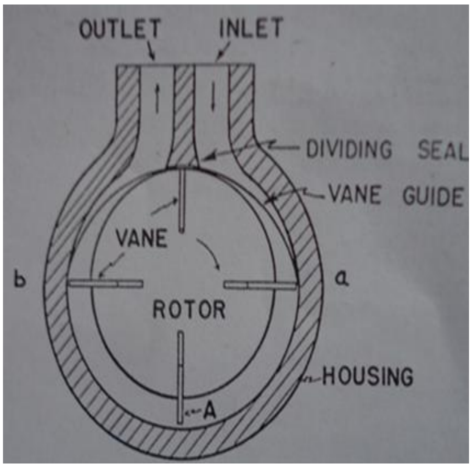

Fig1. *Schematic Diagram of Sliding Vane Pump*

Sliding vane pumps are of various sizes and designs and are constructed of metal. It has the following parts [12].

The Stator

The word 'stator' which came into existence in the late 19th century has its origin from the Latin word 'stat' that means 'somebody or something that stands' [13]. From the above definition, it is clear that the stator of any machine refers to the motionless part of that machine. In pumps, the stator refers to the part that houses the rotor. It also acts as the passageway of fluid that is being pumped.

The Rotor

The word 'rotor' came into existence in the late 19th century as a contraction of the word rotator. The rotor of any machine refers to the part that spins. For a pump, the rotor usually spins within an enclosed volume known as a stator. The rotor has slots where vanes are housed [14].

Vanes

Vanes are objects cut out of a suitable material to the shape of the slots created in the rotor. The vanes push fluid out by sweeping along the stators interior. They usually project out as rotor rotates, by centrifugal action, spring action or electromagnetic force [14].

End plate

End plate, as the name implies, is a metal piece attached to the end of the stator. In other words, it is the stator cover. It is usually made of the same material of the pump stator.

Majority of failures in rotary vane pumps can be attributed to poor oil maintenance. However, 95% of all mechanical pump problems can be resolved by flushing the pump and changing the oil. Because of the close tolerances between the rotor vanes and the stator, solid particulate matter entering the pump is likely to cause scoring of the vacuum sealing surfaces, resulting in decrease in pump performance. For this reason, precautions should be taken to minimize intake of particulates. Several manufacturers produce small screens and filters that fit on the inlet of a pump to accomplish this effect. In recent years, the concern over mechanical pump fluids (from both safety and vacuum system contamination standpoints) has become a great concern. Vacuum pump manufacturers have responded by developing and marketing oil-free mechanical roughing pumps. These pumps have, for some applications, very appealing characteristics, but there are a few drawbacks of which to be aware. Thus, it became necessary for researchers across the world to developed a better design sliding vane pump that can is efficient and can perform very well.

Generally, the advantages of dry pumps (usually of the sliding vane design) are that they eliminate the possibility of back streaming pump oil into your vacuum vessel. In addition, dry pumps may be used to safely pump large percentages of oxygen without fear of explosion. Dry pumps are also well suited for pumping of certain corrosive vapours and gases. For the ideal sliding vane pump, the following assumptions were made:

- Zero clearances and hence no slip
- Mechanical or viscous friction is zero
- Fluid handled is considered incompressible

MATERIALS AND METHOD

The sliding vane pump consists of a rotor, shaft, sliding vanes, bearings, and inlet and outlet passages.

First, there must be a surface of fixed dimensions moving through a sealed channel also of fixed dimensions. The vane of area moving in the stator fulfils these requirements. In moving through a sealed channel and forcing liquid ahead of it during this motion, it performs the positive-displacement function.

Secondly, there must be a means of admitting liquid to the unit and of discharging it from theunit. The inlet and outlet passages fulfil these requirements.Thirdly, there must be a means of sealing off the inlet from the outlet passage which is provided by the dividing seal.Finally, an arrangement for the removal of the positive-displacement element from that function must be provided. A vane guide serves this function.

The principal element is the rotor from which the sliding vanes, actuated by centrifugal and hydraulic means, and where it project to make contact with the housing. The rotor slots are at an angle rather than the more common radial design to create a larger area contact between vanes and stator interior, which is known to help reduce the probability of slip. The fluid flows in through the intake, filling the space behind the rotating vanes. The fluid is confined when the vane gets to the required position. The confined liquid is transported from intake to discharge side of the unit. When a vane reaches that position, the confined fluid is released and forced out of the discharge passage.

MODE OF OPERATION

The rotor and vanes helps in dividing the working chamber into two separate spaces having variable volumes. When the power is turn on, from the electric motor, the rotor turns thereby helping in the enlargement of suction chamber until it is sealed off by the second vane. The enclosed fluid is compressed waiting when the outlet valve opens against atmospheric pressure

MATERIALS SELECTION

Stator and End Plates (Pump housing)

Cast iron was used for stator because of its good fluidity, workability, strength, and excellent machinability, resistance to deformation and wear resistance. Cast irons have become an engineering material with a wide range of applications and are used in pipes, machines and automotive industry parts such as cylinder blocks and gearbox cases. It is resistant to destruction and weakening by oxidation.

Fig2. *Pictorial view of Pump housing*

Rotor

Stainless steel was used for the rotor due to ease of machinability since vane slots would be cut and also drilling operation would be carried out for shaft passage. It does not readily corrode, rust or stain as ordinary steel does. It is capable of resisting wear that can occur due to rolling friction between rotor and stator. To accomplish this however smooth machining was done, since friction is inversely proportional to smoothness.

Fig3. *Pictorial view of Sliding vane rotors and a transmission shaft*

Vanes

Carbon graphite is a standard vane material. Since, graphite is a solid lubricant; the pump will be able to run dry for a reasonable period without visible wear of the vanes. It was chosen to serve this purpose because it has the highest wear resistance when compared to other possible vane materials. Carbon-graphite materials combine the strength, hardness and wear resistance of carbon with the corrosion resistance and self-lubricating properties of graphite. Chemically aggressive applications represent another application niche for carbon-graphite. Carbon graphite materials are inherently stable and chemically resistant, making them ideally suitable for these types of application. They are temperature resistant and impermeable to fluids.

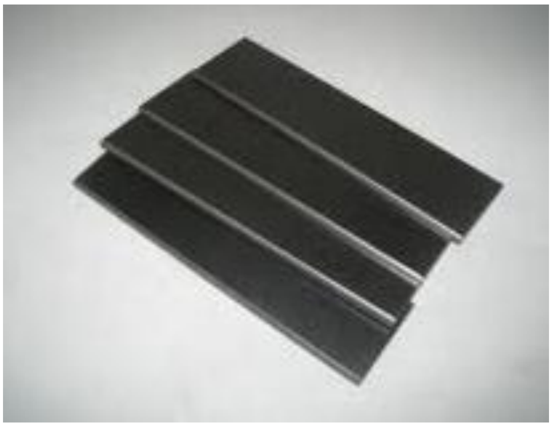

Fig4. *Pictorial view of carbon graphite vane*

Bearings

To ensure smooth rotation of shaft and also reduce heat of the member, friction between shaft and end plate need to be avoided hence, the use of bearing. It reduces rotational friction and supports axial and radial loads. For this purpose ball bearing was used considering cost and maintenance.

Fig5. *Pictorial view of ball bearing*

Seals

Gasket servethe purpose of seal in this research work as fluid sealant to prevent leakage of fluid from stator to the surrounding. A gasket generally is a mechanical seal which fills the space between two or more mating surfaces, generally to prevent leakage from or into the joined objects while under compression. Gaskets are usually produced by cutting from sheet materials, such as gasket paper, rubber, silicone, metal, cork, felt, neoprene, etc.

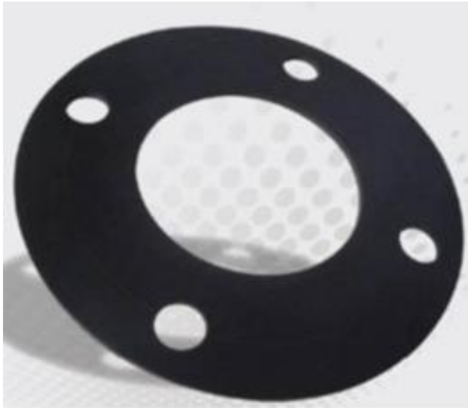

Fig6. *Pictorial view of rubber seal*

DESIGN CALCULATION

The design calculation helped to determine all the possible design parameter values. The following parameters were designed for:

- Volumetric flow rate was assumed to be $3.5m^3/h$
- Head loss
- Determination of required displacement
- Determination of housing dimensions
- Diameter of the stator
- Vane length required
- Required power

Head Loss

$$H = \frac{10.2P}{SG} \quad (1)$$

where,

H = Head loss (m)

P = Pressure = 1atm = 101.325kPa

SG = Specific gravity of water = 1

$$H = \frac{10.2P}{SG} = \frac{10.2 \times 1}{1} = 10.2\text{m}$$

Determination of Required Displacement

$$D = \frac{Q}{N} \quad (2)$$

where,

D = Displacement

N = 1440rpm (Speed rate of the pump)

$D = \frac{3.5}{1440} = 0.00243m$

Determination of Pump Housing

$A_S = \pi r_s^2$ (3)

$A_r = \pi r_r^2$ (4)

$A_v = lb$ (5)

$d_s = 4(r_s - r_r) + d_r$ (6)

$A = A_s + A_r + A_v$ (7)

$V = Ah$ (8)

All dimensions were measured and the values obtained were used for the determination of required parameters.

where,

ds = Diameter of stator = 0.075m

dr = Diameter of rotor = 0.065m

r_r = Radius of rotor = 0.0325m

r_s = Radius of stator = 0.0375m

L = Length of vane = 0.0655m

B = Width of vane = 0.0365m

A_s =Area of stator

A_r =Area of rotor

A_v =Area occupied by vane

h = Height of pump housing =0.45m

A= Area of pump housing

V = Volume of pump housing

Therefore,

$A_s = 3.142 \times 0.0375^2 = 0.00442m^2$

$A_r = 3.142 \times 0.0325^2 = 0.00332m^2$

$A_v = 0.0655 \times 0.0365 = 0.00239m^2$

$A = 0.00442 + 0.00332 + 0.00239 = 0.01013m^2$

$V = 0.01013 \times 0.45 = 0.00456m^3$

Power Required

$P = 2\pi rANP_s$

where,

PS = Suction pressur (9)

$P = 2 \times 3.142 \times 0.0325 \times 0.01013 \times 1440 \times 760 = 2264.15$wattsBut,

1hp = 750

2264.15 = 3hp

Thus, 3hp is required for this design

Force required

$F = \frac{P}{V}$ (10)

$V = \frac{\pi DN}{60}$ (11)

$H_V = \frac{V^2}{2g}$ (12)

where,

P= Power

V= Velocity

H_V= Velocity head

$V = \frac{3.142 \times 0.065 \times 1440}{60} = 4.90m/s$

Thus,

$F = \frac{2264.15}{4.90} = 462.07N$

$H_V = \frac{4.90^2}{2 \times 9.8} = 1.225$

RESULTS AND DISCUSSION

Figure 7 shows the fabricated sliding vane pump.

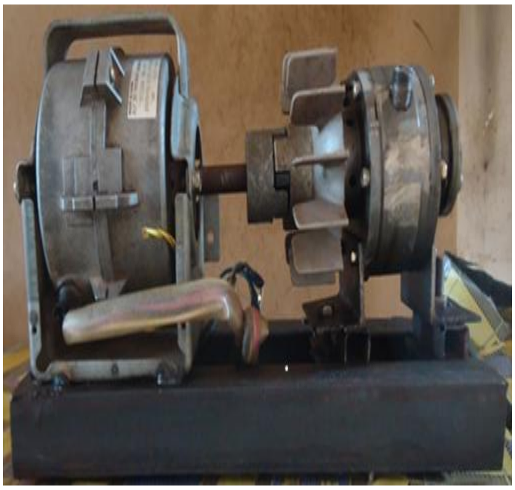

Fig7. *Fabricated Sliding Vane Pump*

The fabricated rotary vane pump was tested for performance evaluation and efficiency. Seven consecutive tests were carried out with different volume of water. Both the fabricated pump and a control pump (imported pump) where used for pumping of water. The time required to pump specified quantity of water with both pumps were recorded.

The results obtained with the locally fabricated pump were compared to the imported rotary vane pump. Both pumps (locally fabricated and existing/imported) have the same power rating (3hp). The results obtained (Table 2) were used to determine the efficiency of the locally fabricated sliding vane pump.

Table1. *Performance Test Evaluation Results*

S/N	Volume of pump water	Locally fabricated pump		Existing pump (Imported)		Pump Efficiency (%)
		Time (min)	Q (Litre/min)	Time(min)	Q(Litre/min)	
1	500	9.20	54.35	7.85	63.69	85.34
2	1000	17.00	58.82	15.00	66.67	88.22
3	750	12.55	59.76	11.05	67.87	88.05
4	1500	25.65	58.48	22.05	68.03	85.96
5	2000	34.45	58.06	31.20	64.10	90.57
6	3000	50.00	60.00	43.50	65.93	91.00
7	2500	38.35	65.19	36.12	69.21	94.19
∑						623.33
A						89.05

Figure 8 shows the plot of pumping time against volume of water. From the graph, pumping time is directly proportional to volume of pump water. Moreover, the higher the volume of pump water, the higher the pumping time. As a means of assessing the performance of the locally design and fabricated pump, similar plot with imported pump show the same results. Thus,the designed and fabricated pump was good enough and can do the same job just as the imported pump. The minimum efficiency recorded was 85.34%, maximum efficiency is 94.19% and the average efficiency obtained for consecutives test of seven times was 89.05% (Figure 6). This simply means the rotary vane pump is efficient enough.

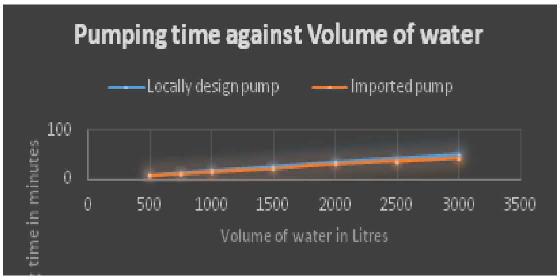

Fig8. *Fabricated Sl*

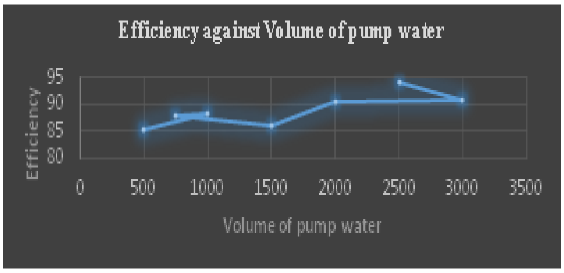

Fig9. *Fabricate*

CONCLUSION

In this research work, we successfully designed and fabricated a sliding vane pump from locally source available materials in Nigeria. The pump was tested for performance. The results obtained show that the rotary vane pump was efficient (89.05%) and work perfectly well like imported pumps. Thus, the pump can be used for both domestic and industrial purpose, and this will help to save cost and promote local content.

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