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Construction and Performance Test of a Pedal Operated Double Cylinder Reciprocating Pump

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Abstract- Bangladesh is an agricultural country, so irrigation or watering of the cultivable land is a great concern for the farmers. Capable farmers use motorized centrifugal pumps for the purpose of irrigation or lifting water. On the other hand, poor farmers, particularly those have small lands, cannot afford motorized pumps. Also, electricity problem has become a big issue during the irrigation season and many areas of the country are still deprived of electricity. As most of the farmers in rural areas are below the poverty line, so the electricity bill of these motorized pumps become a burden for them. In this circumstance, a manually operated, cost effective and high efficient water pumping system is going to be a great importance. So, this project emphasizing the design and construction of a pedal operated double cylinder reciprocating pump that may be an amazing solution to this irrigation problem of poor farmers. At this moment, some farmers are using treadle pump in place of motorized centrifugal pump. But it is proven that bicycling pedaling is much more comfortable and efficient, so a pedal operated double cylinder reciprocating pump system would be more convenient than the treadle pump. A model of the proposed pump was constructed and tested. The results show that the pedal operated double cylinder reciprocating pump system is cost effective, easy maintenance and gives an average discharge of about 1250 liter/hr. So, the poor farmers of the remote areas where electricity problem is acute can be benefitted by using this pedal operated pump.

1. Introduction

Bangladesh is an agricultural country and therefore irrigation plays a vital role in production of food grains and cereals for the people of the country. The productivity of any species depends upon the fertility of land and of course on other inputs such as improved seed, fertilizer and largely on the availability of ensured water supply in the fields. With the supply of irrigation water, most of the agricultural lands can be brought under cultivation of high yielding crops. The productivity of the land, which is now producing food under natural condition, can be increased considerably by the application of supplemental irrigation. The socio-economic condition of Bangladeshi farmer does not permit large scale irrigation investment. Hence, introduction of small scale irrigation using treadle pumps or pedal pumps can play a vital role for increasing food production in Bangladesh. Capital intensive technology like deep tube-wells, shallow tube-wells are beyond the purchasing capacity of the poor farmers, while they can afford labor intensive technologies such as pedal pump, hand pumps, rower pumps, treadle pumps etc. due to their lower cost, easy maintenance and user friendly technology. In the context of Bangladesh, where labors are abundant and most of the farmers are poor, the pedal pump seems to be an appropriate irrigation technology. Such kind of irrigation technologies are operated and maintained by farmers themselves from their own capital for producing crop in the small fragmented lands. The average small farm sizes spreading over a number of scattered plots are unsuitable to irrigate with a large size of stream. But the manually operated technology with a small stream size is suitable for small and fragmented farm holding and involves less mechanical and maintenance problems. From [1], it is seen that, according to statistics of the Peoples' Republic of Bangladesh 1986; the poor farmers represent 70% of the population in the country and they own only 20% of total land. Due to their extreme poverty, they are gradually joining the landless group. In this context, manually operated pedal pump is helpful for poor farmers to reduce poverty. The current success of manually operated pump can be explained in terms of factors like appropriate design, low cost, effective marketing, and high cash returns [1].

Some researchers had focused their endeavor on the development of low lift labor-intensive devices and had succeeded to develop some devices of such characters like treadle pump, rower pump, wheel pump, diaphragm pump, blower pump, etc. But these pumps still are not popular in the country due to their low efficiencies and discharges, short service lives, high friction losses and many other mechanical troubles. Operation of the devices is very laborious and operators often complain about their suffering from various health hazards [2].

Nobody can work at much over $^1/_5$th of a horse power for very long period. As mentioned before [2], many users of these devices complained about their health troubles and desired to get a better technology requiring less manual power and mechanical troubles. High initial maintenance cost, non-availability of spare parts, requirements of large irrigable land and similar other restrictions make the poor illiterate farmers reluctant to

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use even the shallow tube-wells. But the components of pedal pumps can be locally produced with low-cost and all spare parts are available in the country. Hence, a study is needed to design and develop the pedal pump to make it simple to ensure automatic participation of farmers [3].

A minor revolution is taking place in the field of manual irrigation in Bangladesh. Low-cost bamboo and PVC tube-wells introduced in the late 1970s have brought irrigation within the reach of millions of small and marginal farmers for the first time.

The history of positive displacement reciprocating pumps goes back as far as 275 BC in Ancient Rome. In the sixteenth century, great lift and force pumps, driven by water wheels became the effective method for pumping water to be piped in Europe [4]. As late as 1987, the World Bank estimated that, throughout the world, 1.8 billion people would need improved water supplies, and that wells equipped with hand pumps would be an appropriate choice to meet the needs of this number of people. Most of the reciprocating hand pumps commonly used in developing countries have their origins in designs developed during the late 19th and early 20th centuries in the United States and in Europe [5].

What is needed in a developing country is a manually operated pump which can be easily operated by a person for relatively longer period of time and which lifts significant volumes of water with as little effort as possible. Because of the high usage requirements and because the pump must operate as a practical device far from cities having maintenance facilities and personnel, the pump must be both reliable and easily repaired. So this project has some specific objectives. These are:

- To design and construct a cost effective reciprocating pump for irrigation and water lifting.
- To add pedaling system instead of conventional manual water pumping arrangement.
- To test the performance of the proposed pedal operated double cylinder reciprocating pump.

2. Theoretical Aspects

Various motorized water pumping system for irrigation and household purposes is introduced in the urban areas of Bangladesh, but in the rural areas of the country where electricity is hardly available hand powered tube-wells are used for lifting water and irrigation purposes. In recent years treadle pump is also introduced in Bangladesh instead of motorized water pumping. There are also various types of centrifugal pump, submersible pump available for water lifting or sewage purposes.

Hand Pump

Hand pumps are manually operated, where mechanical advantage of lever action is used to move fluids from one place to another. They are widely used in every country in the world for a variety of industrial, marine, irrigation and leisure activities. There are many different types of hand pump available, mainly operating on a piston, diaphragm or rotary vane principle with a check valve in opposing directions. Most hand pumps have plungers or valve on the entry and exit ports to the chamber operating reciprocating pistons, and are positive displacement type.

Centrifugal Pump

Centrifugal pumps are used to induce flow or raise pressure of a liquid. At the heart of the system lies impeller which is a series of curved vanes fitted inside the shroud plates. The impeller is always immersed in the water. When the impeller is made to rotate, it makes the fluid surrounding it to rotate [5]. This imparts centrifugal force to the water particles and water moves radially out. Since the rotational mechanical energy is transferred to the fluid, at the discharge side of the impeller, both the pressure and kinetic energy of water will rise. At the suction side, water is getting displaced, so a negative pressure will be induced at the eye. A low pressure in it helps to suck fresh water stream into the system again and the process continues.

Treadle Pump

A treadle pump is a human-powered suction pump that sits on top of a well and is used for irrigation. It is designed to lift water from a depth of 7 meters or less. The pumping is activated by stepping up and down on a treadle, which is nothing but a lever that drives piston, creating cylinder suction that draws ground water to the surface. Treadle pumps free farmers from dependence on rain-fed irrigation and helps farmers maximize return on their small plots of land. The treadle pump can do most of the work of a motorized pump, but costs considerably less. Pump prices including installation range between $20 and $100 [6]. Because it needs no fossil fuel, it can also cost less (50%) to operate than a motorized pump.

2.1 Limitations of Conventional Water Pump

A hand pump connected with a typical well is driven by pressing the end of a lever and by either pulling it upward or permitting it to return upward due to the weight of the well. The work of lifting the water occurs as the lever is pushed down. This requires large amount of human effort and the quantity of water lifted through this process in unsatisfactory. Again in case of centrifugal pump due to cavitation and insufficient NPSH, people face some acute problem in the irrigation period [7]. Moreover, they can hardly bear the expense of these pumps utilities. On the other hand, where electricity is unavailable motorized water pumps

whether it is centrifugal or reciprocating is of no use. So, there are various types of barrier or limitations existed in the conventional water pumping system.

2.2 Development of Pedal Operated Pump

Due to some limitations of conventional water pumps and in capacitance of the poor farmers to buy a conventional pump there is a need of developing a reciprocating pump which could be run without electricity and also cost effectively. In this respect a pedal powered reciprocating pump is the best suitable solution.

One problem with most reciprocating pumps is caused by the fact that the lever is used to operate the pump, while providing an exceedingly simple mechanism, does not make particularly good use of the ability of the human body. Another problem with most reciprocating pump arises from the fact that the work of lifting water and the pump mechanism occurs only as the lever is pushed down. For example, a conventional reciprocating pump requires a force of about 20 kg as the lever is pushed down, while a force of only about 4 kg is required to move the lever. Thus, uneven demands are placed on the user to supply energy to the pumping process. But in case of pedal powered reciprocating pump, such kind of problems will not arise. As treadle pump is making a great impact in the rural areas where electricity is unavailable, so it can be said that the manual pumps which are powered by the legs are much more convenient. But in the type of pump where legs are not moved in circular direction, makes the user uncomfortable and tedious. So, efficiency is decreased when it works for a longer duration. So, a pedaling system containing a seat to sit down on it, in order to operate the pump, makes the user more comfortable. On the other hand, if two cylinders are used for the suction of the water from the sump while rotating the crank, the two pumps might be adjacent so that each one will work for 180^0 of the crank rotation. Thus, the power required could be reduced at the same time balancing of load will be minimized. But the resulting system would deliver almost double water with same input effort.

A schematic view of the proposed pedal operated double cylindered reciprocating pump is shown in Fig. 1.

3.1 Design Consideration

There are several requirements for a pedal operated reciprocating pump. The area which is beyond electricity is badly in need of a pump for irrigation and other purposes. Some assumptions are considered during designing the pedal operated reciprocating pump. This kind of reciprocating pump is suitable in the remote areas where there is an acute problem of electricity and the farmers who cannot afford the expenses of the motorized pump. The double cylinder reciprocating pump will be connected with the crank as shown in Fig. 4. These cranks are slightly different from conventional cranks. They also work as flywheel. The cranks are supported on a common shaft to which power is transferred through chain and sprocket. The sprocket is fixed at the middle of the shaft and is connected with the pedal through a chain. When the force is applied on the pedal, the sprocket will start rotating and the valves of the cylinders move forward and backward at the same time. The connecting rod is connected with the crank is such a way that when one pushes up one valve, the other one pushes down the other valve. The cylinders are supported on a frame. The suction pipes to the cylinders should be separate. There should be a sitting arrangement to operate the pump. Considering these facts, the design is made. The design considerations are based on general and mechanical view points. The two types of considerations are briefly described below-

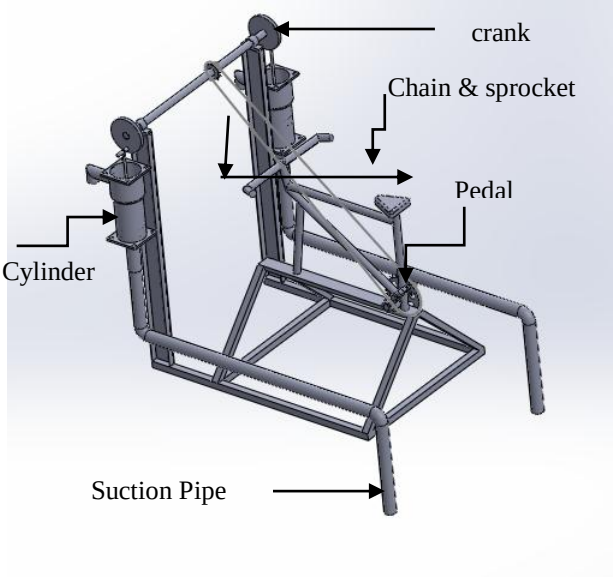

Fig. 1: Schematic of the proposed Pedal Operated Reciprocating Pump

General Consideration

The general considerations include:

- The design and construction should be as simple as possible.
- The assembly and disassembly of components should be easy and convenient
- The construction materials should have local availability as much as possible.
- Maintenance process should be simple.
- The cost of the construction should be as low as possible.

Mechanical Consideration

The mechanical considerations are:

- The main structure should be light weighted but rigid and should withstand the forces while in action.
- The parts should be easily assembled and replaceable.

- The sprocket should be sharp edged for transmitting power effectively.
- The force should be uniformly distributed to the double cylinder pump.
- The two cranks should be positioned in an accurate distance so that the upward and downward movement of the piston in the cylinder remains uniform.

3.2 Selection of Components

The components are selected according to the assumptions and design considerations. The components are designed in such a way to make the pedal operated reciprocating pump simpler and easy to handle.

Piston with Connecting Rod

Piston is used as pressure creating component. It is made of steel. It reciprocates within the cylinder. It is attached with a connecting rod and very close tolerance is maintained with the cylinder. A rubber bucket surrounds the piston while the pump is in operation. The piston develops the maximum pressure inside the cylinder.

Cylinder

A hand-tube well, having 304.8 mm outer diameter and 284.8 mm inner diameter, is used as a cylinder and is set up at the front-side of the main structure. The hand-tube will work as a reciprocating pump. It is connected with the structure, which is made of GI pipe. It is two in number as the whole system is acting as a double cylinder reciprocating pump. Fig. 2 shows the CAD model of the cylinder of this pedal operated reciprocating pump which is available in the market. The suction pipe is fixed at the lower portion of the cylinder. Again the discharge pipe is fixed at the front side of the cylinder.

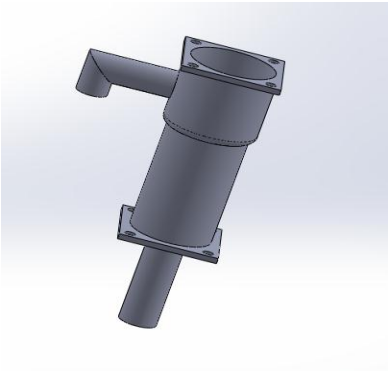

Fig. 2: Cylinder

Pedal link

A pedal is used to connect the piston rod and foot step mechanism. A chain is connecting the sprocket and the pedal. When force is applied on pedal, the power transmitted through this chain and sprocket to rotate the shaft of the circular crank. The pedal is so sturdy that it could withstand cyclic load.

Crank

A crankshaft which is connected to cranks is a mechanical part able to perform a conversion between reciprocating motion and rotational motion. In a reciprocating engine, it translates reciprocating motion of the piston into rotational motion; whereas in a reciprocating compressor, it converts the rotational motion into reciprocating motion. In order to do the conversion between two motions, the crankshaft has "crank throws" or "crankpins". This kind of crank has the special feature of working as a flywheel. Fig. 3 exposes the CAD model of the crank.

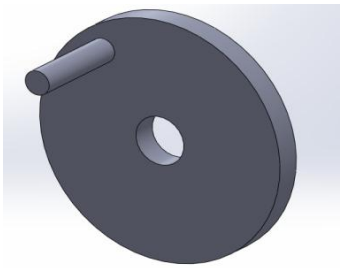

Fig. 3: Crank (designed)

Connecting Rod

It is used for connecting the piston and foot pedal. It is also used to push the piston according to the foot pedal action. The maximum pressure is achieved due to pumping lift height. It will convert angular motion to linear motion.

4.1 Construction and Performance Test

The pedal operated double cylinder reciprocating pump was constructed and tested in the laboratory of Mechanical Engineering department of KUET. The barrels of two small hand tube wells were used as cylinders. The crank was constructed with mild steel plate. MS rod was used as the shaft. An old bicycle frame was used as part of the frame. The frame was constructed so that it can be installed over a sump. Two foot valves were used in the suction lines. The delivery line was united to a single point, so that discharge can be collected in a single reservoir. Finally all the components and parts of the project have been assembled and mounted on the frame.

4.2 Performance Test:

The performance test of the constructed pedal operated double cylinder reciprocating pump was carried out in a small size of sump. Because of fund limitation the test was not carried out with underground water. For underground water lifting, both the suction line should be in the same water reservoir. It was possible to conduct the performance test with a considerable period of time. A water drum of 150 liter capacity was used to measure the discharge of water. The discharge time was

estimated with a stop watch. Finally the discharge rate was calculated.

Fig.4: Photographic view of Proposed Pump

The following observations were made during the performance test. The results of the test, when both the cylinders were acting, are presented in Table 1, Table 2 and Table 3. The result with single cylinder is also shown in Table 4.

Table 1: Data for Performance Test at day-1

No. of Obs.	Water discharged (liter)	Time Required (min)	Discharge rate (liter/min)
01	143.90	6.43	22.43
02	142.55	6.63	21.48
03	144.70	7.07	20.47
04	143.64	6.87	20.91
05	142.80	6.58	21.69
06	144.30	7.43	19.98
07	143.70	6.50	22.10
Average discharge rate			**21.28**

Table 2: Data for Performance Test at day-2

No. of Obs.	Water discharged (liter)	Time Required (min)	Discharge rate (liter/min)
01	144.90	6.54	22.15
02	143.75	6.80	21.48
03	144.70	7.07	20.32
04	141.64	6.23	21.52
05	143.88	6.70	21.47
06	142.35	6.43	22.14
07	143.38	7.03	20.39
Average discharge rate			**21.35**

Table No.3: Data for Performance Test at day-3

No. of Obs.	Water discharged (liter)	Time Required (min)	Discharge rate (liter/min)
01	141.50	6.26	22.60
02	143.39	6.50	22.06
03	142.78	6.87	20.78
04	144.54	6.80	21.25
05	142.54	6.23	22.87
06	143.60	7.07	20.31
07	142.32	6.53	21.79
Average discharge rate			**21.66**

Table No.4: Data for Performance Test at day-4

No. of Obs.	Water discharged (liter)	Time Required (min)	Discharge rate (liter/min)
01	143.72	10.93	13.15
02	141.78	11.28	12.57
04	142.38	11.67	12.20
05	145.90	11.39	12.82
06	142.40	12.53	11.28
07	144.2	11.05	13.05
Average discharge rate			**12.45**

The results of the performance test showed that the average discharge of pedal operated double cylinder reciprocating pump at day 1 was 21.28 liter/min, at day-2 was 21.35 liter/min and at day-3 was 21.66 liter/min. The result of the test with single cylinder at day-4 was 21.54 liter/min. So, the 4 (four) days average discharge was 21.45 liter/min. On the other hand, the average discharge of pedal operated single cylinder reciprocating pump is 12.45 liter/min. It is to be mentioned that this test was carried out by closing one of the cylinders of the main setup.

5. Result and Discussion

5.1 Results

Analyzing the data from Table 1, 2, 3 & 4, it is seen that the discharge varies with the quantity of water that means for different observation it shows different discharge. It is because of the human effort that produces power by pedaling is not remain same all the time. Again from the calculation of the average discharge it is seen that there is a difference between the discharge of double cylinder and single cylinder. In comparison the difference of average discharge between them is almost 1.70 liter/minute. That means a double acting pedal operated reciprocating pump is 1.70 times more efficient than the pedal operated single acting reciprocating pump.

5.2 Discussion

The pedal operated double acting reciprocating pump is designed to reduce the human effort in the daily purposes of water. It discharges more water than the hand powered pump. On the other hand the double cylinder pump is more efficient than the single acting

pump. In the remote area of Bangladesh where electricity is unavailable or where supply is not consistent, people who are facing problem during irrigation & agricultural purposes, this kind of pedal operated water pumping system would be of great importance. It does not require electricity for operation like the conventional motorized water pump. Again this kind of manual but efficient water pumping system helps to reduce the expense for the irrigation, as any kind of fuel isn't required; any kind of electricity bill isn't required. The maintenance cost of this pedal operated water pump is very small. The easy design of the pedal operated water pump system makes it comfortable; people can easily sit on the seat of the bicycle and can pedal as much as they can.

4. Conclusion

The Pedal operated double acting reciprocating pump, which is environmental friendly and less power consuming, is designed, constructed and tested in the laboratory. The following conclusions could be made:

- It is simple, user-friendly design, easy to carry and easy to assemble and disassemble.
- It reduces human effort, so cost of lifting water and energy consumption is less.
- Could be used in all seasons specially in winter for watering in the vegetable fields.
- Could be used to irrigate at different land at the same time with special attachment.

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