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Design and Fabrication of Rope Pump

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***Abstract*:- The modern rope pump is based on the principle of the ancient chain pump. By making use of new materials, it has been redesigned to provide a low-cost pump for water supply in rural areas in developing countries. Its straightforward working principle and easy construction turn it into a very effective pumping device, also in comparison with the piston pump and the centrifugal pump. It can handle a range of pumping heights and volumes and is not sensitive to silt and corrosion. Up to 1,00,000 of these pumps are in use worldwide, driven by human or animal power, by an electric motor or fuel engine, and by wind power. The rope pump is now recognized as one of the most promising solutions for rural water supply and sanitation. This paper presents a model of its hydrodynamic behaviour, which is in qualitative agreement with available empirical data and can explain the typical, light-weight construction of the pump. For a quantitative validation however, more and better empirical data under controlled conditions are needed. This paper aims to provide a basis for further research on several design aspects of the rope pump. This electronic document is a "live" template and already defines the components of your paper [title, text, heads, etc.] in its style sheet.**

Keywords—CAD Rendering, Rope, Pistons, Guide box, Pulley wheel.

I. INTRODUCTION

This Access to clean sanitary water is one of the largest issues facing our planet. Poor water quality increases poverty, impacts education and food security. Due to recent droughts and desertification of the country, world has been experiencing increasing water shortage in recent years. Women and children, the main gathers of water, must often travel many miles on foot just to collect the unsanitary water that is available. The trek is long and dangerous, and water is often unsanitary and unsafe. Some studies have shown that by 2025 more than half the world's population will be experiencing severe water deficiency in some form. Innovative ideas aimed at improving water gathering methods could greatly improve the quality of life for those in such a hardship.

Due to recent droughts and desertification of the all over the world, many countries have been experiencing increasing water shortage in recent years. Women and children, the main gathers of water, must often travel many miles on foot just to collect the unsanitary water that is available. This is extremely time consuming and exhausting. Even if a family is lucky enough to have a nearby water source, such as a borehole, the current methods of water retrieval are strenuous and often dangerous. Innovative ideas aimed at improving such methods could greatly improve the quality of life for those in such a hardship.

Attempting to make such improvements, we developed a human powered device which is capable of extracting water from boreholes. While this pump was developed with dry nations in mind, it can be implemented anywhere that water shortage is a problem. In India, boreholes typically range from 30 to 100 feet in depth and are generally less than 4 feet in diameter. Currently, the most common method of water retrieval from these boreholes is with a simple rope and bucket system. Using this method is not only time consuming, but puts major strain on the shoulders, arms, and lower back of the gatherer.

The extreme depth and narrow opening of the boreholes immediately imposed some harsh constraints for our design. Due to the extra atmospheric pressure at depths below 30 feet, all designs which "pulled" water out of the hole had to be thrown out. Only positive displacement (pushing up the water) methods could be implemented successfully. Once this was determined, our next issue was how to reduce the strain our pump would have on the operator. Designing the pump to be bicycle powered effectively satisfied this requirement. Using the largest muscle group in the body, displacing the water by peddling a bicycle at an efficient rate would reduce the amount of time and energy required to gather water from these boreholes.

Material selection was also heavily considered. For this pump to make any kind of change it had to be constructed out of material which was readily available in the country as well as be cost effective enough for families living on less than 2 dollars a day to be able to contribute to the cost of fabrication. This also holds true for the manufacturing processes used for construction. It was also determined for our design to be a success it must be able to retrieve a minimum of 200 liters of water daily. Keeping all these factors in mind, our team designed and fabricated a working prototype of a rope pump. This design was ideal because it satisfied all the design parameters associated with the project. It can be manufactured solely out of material readily available in country, and is constructed and assembled using basic techniques.

The Rope pump is an ancient technology that, with new materials and designs, now is a very effective and low cost pump option for water supply and irrigation that is used by families and small communities. It can be produced with locally available materials in local metal workshops. Compared to other low cost hand pumps, the Rope pump has a high pump capacity and can pump from wells of 1 to 35 meters deep. It can be produced in any country and is very simple to install (no black box). If properly produced, installed and maintained, over 90% of the pumps remain functional, even many years after installation. Because of these features, the Rope pump has a high potential for Self-supply. An

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example is Nicaragua, where over 70,000 Rope pumps were installed. Two reasons for its success in this country were (a) technical improvements that made the pump more effective and attractive and (b) the private sector that took interest in production and sales. The pump became a commercial product so there was "profit based sustainability". In Nicaragua the shift from imported piston pumps to locally produced Rope pumps decreased the cost for rural water points by 60%. Close to 20% of the pumps are used for communal wells and 80% for Self supply (domestic use, cattle watering, small scale irrigation). Due to these pumps, the total accumulated income at family level in the last twelve years was 100 Million US$. This is explained by the fact that families with a Rope pump earn an average 220 US$ more per year than families using a rope and a bucket. Using a Rope pump saves time, results in less health related cost (water is cleaner since it is not re-contaminated by the bucket) and can provide water for income generating activities such as livestock or garden irrigation.

II. LITERATURE REVIEW

2.1. Rope Pump

The Rope Pump features a unique design in which small plastic pistons are lined up on a rope. The distance between the pistons is approximately 1 m. The drive wheel is crank operated and pulls the rope through a plastic rising pipe. The drive wheel consists of cut old tires. A concrete guide box with a glass bottle at the well ground leads the rope with the pistons into the rising main pipe.

RWSN work has particularly focused on rope pumps in Nicaragua, Madagascar and Mozambique and public domain standards and guidelines have been produced.

Rope pumps are installed on hand dug wells and on drilled wells or boreholes. There is no need for the pumping pipe to be installed vertically which means that rope pumps can be installed as well at riversides for irrigation or at the side of e.g. scope holes.

Maximum depth reached by the rope pump.

- 40 meters standard
- 60 meters with adjustments and double crank
- 80 meters in experimental phase

2.2. *The mode of operation of rope pump*

This pump type works with a loop of rope, which is pulled through a plastic riser pipe. Regularly spaced washers are fixed on the rope (approx. 1 m spacing), which are guided into the riser pipe at the bottom of the well and are carrying water to the spout. At the pump stand, the rope is moved by a rubber lined pulley, mostly made of cuttings from worn car tires. The pulley is operated with a crank handle in a steady speed, so that sufficient water is flowing from the spout. Because of the required clearance between the washers and the riser pipe, the movement of the rope needs a certain speed, so that the velocity of the drawn water is continuous. As soon as the operation stops, the water in the rising main will drain slowly. This type of pump is usually placed on a dug-well and it's mostly used as family pump. However, there are different models existing that are suitable for larger communities and also to be installed on boreholes. The rope and washer pump has the advantage of a simple design and fairly easy maintenance.

2.3. Components of Rope Pump

- Pulley wheel
- Frame support
- Crank
- Rope
- Pistons
- PVC pipes
- Guide box

2.3.1. The Wheel

In order for the rope & washer pump to function well it is important to have a good and solid wheel around which the rope turns. The wheel must be able to pull the rope with the washers which push water up from the well through the pipe. To prevent the rope from slipping there must be rubber on the wheel.

Fig 2.1- CAD rendering of a wheel

To prevent this rubber from getting off the wheel, the wheel is made of rims made of 1" pipe, which is cut to make two "U" formed parts. Six such half pipes function as rims and are welded at the end of the spokes made of 12 mm round iron. Two circular pieces of rubber from 13" car tyre sides are clamped together with strong wire or nails and placed over the rims. When the wheel corresponds in size to the rubber circles, so that the rubber parts have to be forced over the "rim" of the angle, the rubber parts will stay in place. The wheels above are made of spokes of 12 mm round iron and pieces of 1" pipe, which are cut in half and welded at the end of the spoke. The center of the wheel is made of a 1" pipe, with a nut and bolt welded on to fasten it to the handle.

The pulley wheel is made out of the two internal rings cut out of truck tires and joined by clamps and spokes, which must be strong for intensive use. The 20" inch truck tires are used, but for wells deeper than 29 meters 16 "inch tires are used.

The rims from these specific-sized tires are used for the following reasons:

1. A large wheel implies more contact between the wheel and the rope than a smaller one (i.e. 16" hubcap) and therefore less sliding. The limits of 11,

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19 and 29 meters are also based on sliding problems, which appear over time.
2. Using rims from smaller tires implies that the force to be applied to the crank will be smaller and at the same time less water will be pumped. To compensate for this, the crank must be turned more rapidly, which is less comfortable.
3. Rims with smaller diameters (20") have less consistency, are more flexible and require more clamps and support when used in a rope pump.

Using a tire for a 20" hubcap leads to an optimum use with regard to:

- The ergonomic functioning of the body with respect to the maximum force to be applied, the radius of the turn of the crank, and speed.
- Stops sliding that occur when using smaller tires.

2.3.2. Frame Structure

A basic A-Frame structure was chosen to hold our rope pump. An A-Frame can be simply constructed, while maintaining a strong structure for the critical joints in the rope pump. This design uses less material but is more durable than other frame structures. Very few materials are needed for this design and include mild steel tubing, quarter inch thick steel plates and angle iron. The function of the rope pump structure is to support the efforts of the axle, wheel, and crank, as well as fix the pumping pipe, both entry and exit sections. It is the esthetic part (Visible) of the pump and is installed on the well cover. The types of materials and their diameters depend on the use given to the equipment.

Fig 2.2 - Finalized A-Frame Support Structure

2.3.3. The Crank

The function of the crank is to turn the wheel by means of power applied by the user. It consists of an axle with two 60-degree bends. The crank or axle is made of ¾” pipe, which is black pipe for the family and extra strong pumps and galvanized pipe for the community pump. The diameter of this pipe is 27 millimeters, while the thickness of the material is 2.0 millimeters.

The radius or distance between the axle and the handle of the crank is 33.5 cm. This radius is large for children doing the pumping but is necessary in order to exert the maximum force related to the weight of the water column, which has a maximum of 10 kilograms. The radius can be a little smaller for adults because of their strength or larger because of the length of their arms. This maximum strength also depends on the depth of the well in which the pump is being used.

An important detail is the first bend at the axle. Care must be taken to ensure that the bend begins past the bushing. Beginning the bend right at the bushing will wear the axle causing it to break.

The roller and the handle are 15 centimeters in length, long enough for two children’s hands or one adult hand. The spacers on the handle are made of the same pipe as the handle without any space between them so as to avoid the hand getting caught between the handle and spacers. Experience has shown that despite their short life span, PVC can be used and replaced by opening the pipe lengthwise. There may be a need to seek alternatives for the bushings and handle should the pipe not be available on the market. These should fit snuggly around the axle pipe. Bushings can also be made of iron strip.

2.3.4. Pistons

The pistons are one of the most sensitive parts of the pump. Together with the rope they form an endless chain. When the rope rotates it leads the piston through the pumping pipe, pushing the water inside upwards. The piston is a cone shaped part with a hole on its top and must meet the following norms:

- Exact dimensions.
- Cone shape to reduce friction.
- Strong and water-resistant material.

The piston diameters vary with depth as do the pumping pipe. Piston diameter is determined by the type of pipe to be used and the well’s depth. The rope’s length, diameter and amount of pistons are determined by the well’s depth. Two-inch (0 - 3.5 meters depth) and 1 ½” inch (3.5 - 5 meters depth) pistons are used in wells which are not too deep or when motor driven rope pumps are used.

Fig 2.3 - Rubber Seal Design

A perfect fit is required between the pistons and the pumping pipe. The space between piston and inner wall of the pipe is only 0.15 mm for the 1/2 inch pipe and up to 0.40 mm for the 1 inch pipe.

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2.3.5. PVC Pipe

The system is that the rope comes into the guide box through the short PVC (Polyvinyl Chlorid) pipe with the largest diameter. The pipe has been heated in both ends to make it funnel shaped to better guide the rope and the washers into the pipe (the top end), and to better hold in the concrete (at the bottom end). This piece of PVC is 50 cm long and is at least 50 mm in diameter. The other pipe is the one where the water is pushed up from the well as the rope and the washers are moved upwards by the turning of the wheel. The bottom part of this pipe is also made funnel shaped so that it holds better in the concrete. Only a short piece of 50 cm is moulded in the concrete. Later - at the actual pump site - the rest of the pipes are glued on. The diameter of the pipe, which carry the water to the top, depends on the depth of the well.

Depth of well in meters	Diameter of pipe in mm
0 to 4 m	50 mm
4 to 10 m	40 mm
10 to 20 m	30 mm
20 to 35m	24mm

Table 2.1. - Depth of the well and diameter of the pipe

2.3.6. The guide

The guide is installed at the bottom of the well and is where the pumping process is initiated. Its function consists of guiding the rope with pistons attached so that it enters into the pumping pipe from below, as well as maintaining the pipes taught (plumbed) with the appropriate tension. Therefore, the guide has various functions integrated into one piece. It serves as well as a counterweight to tauten the rope in order to avoid sliding on the wheel.

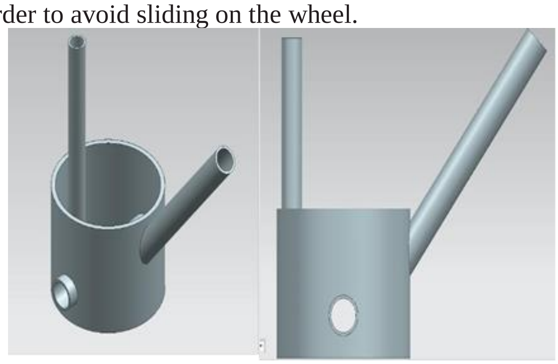

Fig 2.6 - CAD rendering of Guide Box

A guide box allows the rope to be directed into the main riser pipe which is what brings the water to the surface. The guide box shown below is the final guide box prototype and is constructed entirely out of PVC pipe. This allows the user to construct their rope pump using fewer materials and resources and at the same time retaining the same lifespan as the rest of the pump parts.

Fig 2.7 - PVC Guide Box

III. DESIGN OF ROPE PUMP

3.1. Design Parameters

After much consideration, we decided to create a rope pump. A rope pump is a pump that has plugs or pistons tied on the rope, creating notches in the rope, a diagram is shown in Figure 1. As these notches move up a pipe, they carry the water up and out the pipe. At the top of the pump, there is a bike; allowing the pump to be human-pedal powered, which means, as the user pedals the bike, the rope is rotated through. At the bottom of the pump, there is an inlet system. The purpose of the inlet system is to: make sure the rope does not get tangled; serves as a pulley system for the bottom; and ensures that the notches do not get caught as they enter the pipe.

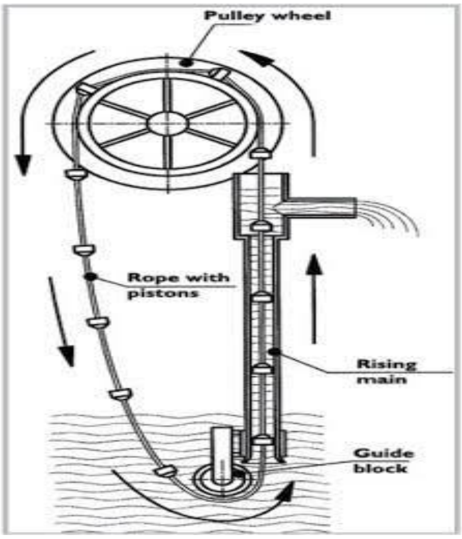

Fig 3.1 - Rope pump

3.2. Design Calculation

3.2.1. DISCHARGE OF ROPE PUMP:

Q= A_i x V

WHERE, A_i= AREA OF INNER PIPE

V= VELOCITY

V= r x w

=0.28 x 6.28

=1.7584 m/s

WHERE, r= RADIUS OF THE WHEEL

w= ANGULAR VELOCITY

A_i= π/4 x (di^2)

$=0.785 \times (2.5 \times 10^{-2})$
$=4.906 \times 10^{-4} m^2$
WHERE, di= DIAMETER OF THE INNER TUBE
$Q= 4.906 \times 10^{-4} \times 1.7584$
$= 8.627 \times 10^{-4} m^3/s$

3.2.2.MASS OF THE WATER(M):
$M= P_{water} X V_{total}$
WHERE, P_{water}= DENSITY OF WATER
V_{total}= TOTAL VOLUME
$V_{total}= A_i \times L$
$=4.906 \times 10^{-4} \times 1.565$
$=7.67 \times 10^{-4} m^3$
WHERE, L= STROKE LENGTH
$M= 1000 \times 7.67 \times 10^{-4}$
=7677kg
W= M x G
=0.7677 x 9.81
=7.532N

3.2.3.DESIGN OF ROPE:
MATERIAL SELECTION: NYLON

IV. CONCLUSION

The operating principle of the rope pump enables a light-weight, cost-effective device for small pumping applications, as witnessed by its extensive use specifically in rural areas in a number of countries (in total up to 100,000 units are in use world-wide) and as confirmed by the results of the model presented in this paper. Unlike its main competitor the piston pump, the rope pump produces a smooth, continuous flow without any dynamic loading of the rope and the pump pipe. Since the weight of the water column is equally distributed over the pistons, the static pressures in the pump pipe are very small and the radial loads minimal. Longitudinal loading of the tube is only caused by its own weight and particularly compressional loading is absent. A properly designed rope pump should have total efficiencies of around 60-70% within a reasonably wide range of operating speeds. The rope pump is also little sensitive to silt and corrosion. Based on these characteristics, one can conclude that the rope pump is a high-quality pumping device, also in comparison with the piston pump and the centrifugal pump.

The output of the pump is determined by the rope speed (in fact the relation is linear), the cross-sectional area of the pump pipe and the critical pump speed at which it just starts pumping. A larger gap shifts the critical speed to higher values. The required pump torque is constant above the critical speed and zero below it. The available measurements confirm this behavior. Important issues for further research are:
1) reliable experimental verification on how the critical pump speed depends on parameters such as pumping height, number of pistons and gap size; 2) the effect of non-alignment in the pipe; 3) the stability of the piston in the pipe and its implication on the design.

The characteristics of the rope pump suggest it is an effective device to be driven by wind of solar power. A wind driven rope pump was developed in Nicaragua, where a few hundred up to now have been installed. As far as the authors are aware of, a solar driven rope pump does not exist yet. The analysis of the performance of such systems merits investigation.

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