Design and Fabrication of a Pedal Powered Washing Machine

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Abstract

Washing clothes is one of the essential parts of life. We all wash our clothes either by hands or by machine. A washing machine is a device designed to wash laundry such as clothes and sheets. In these days there exists a wide variety of washing machines in the market and there is stiff competition among the manufacturers. These washing machines cost between $350 to $750 depending upon functions and features. All of these washing machines are powered by electricity and the basic principle of operation is by creating a turbulent flow of the detergent around the dirty clothes. Almost 60 percent of our population lives in rural areas where it is impossible to use electric powered washing machines, mainly due to the unavailability of electricity or the absence of the machine itself due to high costs of purchasing a new washing machine. Washing clothes by hand is laborious, strenuous, takes a lot of time and leaves one breathless. This paper intends to directly address the problems faced by people in the rural areas when washing clothes by designing and fabrication a pedal powered washing machine. The machine can also be used in urban areas to save electricity and also to exercise. The machine does not require electricity or an engine but uses human power. The transfer of human energy through the use of a foot pedal and crank mechanism is what is known as Pedal power. This is the mechanism that has been used to propel bicycles. The paper designs and fabricates the pedal powered washing machine. Experiments are conducted in order to determine the optimum operating conditions.

Keywords
Design, Powered washing machine, Pedal, Fabrication.

1. Introduction
Washing machines are one of the most useful devices in households today. A washing machine [1] is basically a machine designed to wash or clean laundry such as towels, clothing and sheets. Generally washing machines are powered by electrical energy. This project intends to design and fabricate a washing machine which uses our energy instead. All washing machines work by using mechanical energy, chemical action and thermal energy. Mechanical energy is transmitted to the clothes load by the rotation of the agitator or by the whirling action of the drum. In this project, rotation of the drum or agitator is caused by the rotation of the pedals. The temperature of the wash bath supplies the thermal energy. The chemical energy is supplied by the detergent. Pedal power [2] involves transferring power from a human source by means of foot pedals and crank system. This form of transfer has been mainly used for transportation, for example bicycles are propelled by pedal power.

1.1 Background
Washing laundry is one of activities that many households do daily. Basically this is done either by our hands or by powered machines. Washing by hands involves scrubbing, beating, soaking and rinsing the dirty clothes. This is a laborious and time consuming task. Electric Powered washing machines were developed to eliminate the labour and time involved in washing clothes manually. In rural areas electric powered machines are not viable mainly because there is no electricity or because the machine itself is expensive. Women are mainly the ones burdened by the washing of clothes and can spend an entire day washing clothes. The project intends to solve the problem faced by so many people in their day-to-day life.

Figure 1. People washing in Zimbabwe (Source: www.newsday.co.zw)

In rural areas washing laundry is a laborious and time-consuming task. Electric powered washing machines do not work because of lack of electricity and also due to their high cost. The detergents used in washing clothes are chemically harmful to hands. The scrubbing process also strains muscles.

1.2 Justification

Thus the paper has the following merits:

- The machine does not use electricity thus suitable for places where electricity is not available or is expensive
- Saves time as compared to washing clothes manually
- The machine will be low cost and thus affordable
- One will also be exercising while washing
- It's an easy to maintain machine as the components are readily available
- Women no longer have to be in contact with soapy water which may damage hands.

It is therefore necessary to design and fabricate a pedal powered washing machine.

2. Literature review

A washing machine is a machine that is used to wash laundry, such as sheets and clothing. Usually this term is applied to machines that use water as compared to dry cleaning which uses cleaning fluids or ultrasonic cleaners.
Washing clothes manually is strenuous, laborious and time consuming. Washing machines were developed to address these challenges. The first washing machines were operated by hand and made from wood, while later machines were made of metal and made it possible to burn a fire below the washtub, keeping the water warm throughout the washing process which helps supply the required thermal energy.

Due to globalization, competition for the market has increased. This has resulted in many times of washing machines being invented. Recent designs have been getting noiseless, more and more effective, economical, less weight and their designs adapt to where you want to use them. At first, clothes were washed using hot water and soap, and the fine fabrics were kept soft. Technology began to appear in 1780 with the invention of the washing machine by Robinson Lancashire. The machine also dripped clothes. In 1855 another washing machine to wash and dry clothes was invented in Crimea's hospitals. 1880 saw the first washing machines being built. They were steam-driven. They water was heated with coal and gas. In 1888 Incola Tesla joined electronics with washing by creating a compact electric engine. In 1901, Alva Fisher invented the first washing machine by adding an electric engine which impelled a cylinder to the already existing machines. An automatic mechanism inverted the spinning sense from time to time so that the clothes did not compress, which frequently used to happen. Rollers were then added to drip clothes. This is the date when the first washing machine was born. Washing machines started selling highly in Western countries after the Second World War, in 1945. Prices for washing machines were now much cheaper than before.

2.1 Types of Washing Machines

Basically washing machines are available in two main configurations. The classification depends on the way the clothes are introduced and the axis of rotation. The two main configurations are top loaded and front-loaded.

2.1.1 Top Loaded

This design is more common in America, Canada and some African states. Clothes are placed in a vertically mounted basket which has perforations. This basket is contained within a tub which retains water. At the center of the clothes basket is a finned vertical axis agitator. Clothes are loaded at the top of the machine through a hinged door. During washing the water in the tub has to fully immerse and suspend the clothes in the inner basket. As the agitator moves, water is pushed outwards between the fins towards the edges. The water then moves outward, up the sides of the basket, towards the center, and then down towards the agitator to repeat the process, in a circular pattern. The agitator direction is reversed periodically as continuous motion in one direction would lead to the water spinning around the inner basket with the agitator rather than the water being pumped in the torus-shaped motion.

Figure 2. Top Loaded Washing machine (www.google.co.zw)

2.1.2 Front Loaded

This type of design is more popular in Europe. The front loaded design instead mounts the inner basket horizontally. The clothes are loaded through a glass door at the front of the machine. The back-and-forth rotation of the cylinder and gravity supplies the agitation. The paddles in the drum lift up the clothes and then let them drop. This motion loosens the weave of the fabric and thus forces water and detergent solution through the clothes load. Clothes are not required to be fully immersed into the water so only enough water is needed to moisten the fabric. Since front-loaders require less water, they use a lesser amount of detergent and the repeated lifting and dropping action of the folding action of whirling results in large amounts of foam.

Figure 3. Front Loaded Washing machine (www.google.co.zw)

3. Materials and Methods

Mechanical design is the design of objects and systems that are mechanical in nature. Examples include machines, structures, engines and engine parts and tools. In most cases mechanical design uses material science, mathematics, and mechanical science applied to engineering. Mechanical design requires one to know various engineering disciplines that include thermal and fluid sciences. For this paper, material science, mechanical science and the finite element method will be used in the design and fabrication of the components. The design of any machine should start with the identification of a need and the definition of the problem. The design process is then decided. After the process, the design should then be tested for evaluation and presentation.

3.1 Design Specifications

The most important aspect in the design of the washing machine is its ability to make the washing of clothes easier and faster. The quality of clothes washed by the pedal powered washing machine should match those that have been washed by hands without adding too much overheads for example in terms of water usage, wear and tear of clothes and the effort required to wash the clothes. In order to make the machine successful and more useful, a number of goals with varying degrees of importance were identified. Since chain drives have certain safety risks, a number of safety features should be included in order to extenuate the inherent safety issues. The size and weight of the machine should be such that it is portable so that it is possible to share among families and also so that it can be transported close to a nearby water source for operation, or so that it fits in households where space is limited. Load sizing, pricing and water usage depend on the targeted community. Since the quantity of laundry varies between families, an initial size was selected based on existing washing machines, and designs allowing for easy re-sizing were preferred.

The specifications are summarized below:

- Clothes washed by the machine must be as clean as those hand-washed for 10 minutes
- Must wear clothes at slower rate than hand-washing.
- It must have a capacity of about 5kg of clothes/load and should be easy to re-size.
- The machine must be as economical as possible, it must use at most 15L water / 1kg clothes.
- A maximum of 15 minutes each for wash and rinse cycles.
- The total time should not exceed 1 hour inclusive of fetching the water, washing, draining, and cleaning the machine
- The machine must not require a lot of energy. Maximum 125W (comfortable level of human-power output).
- The machine must cost at most $100 so the components must be chosen wisely.
- It must be as durable as a bicycle, expected durability is 5 years assuming daily use.
- All components must be available locally. This will make maintenance easier and cheaper.
- The overall size must be less than combined size of a bicycle and commercial washing machine.
- Maximum 30kg so that it can be carried in doors once washing is done so that it will not be stolen or damaged.

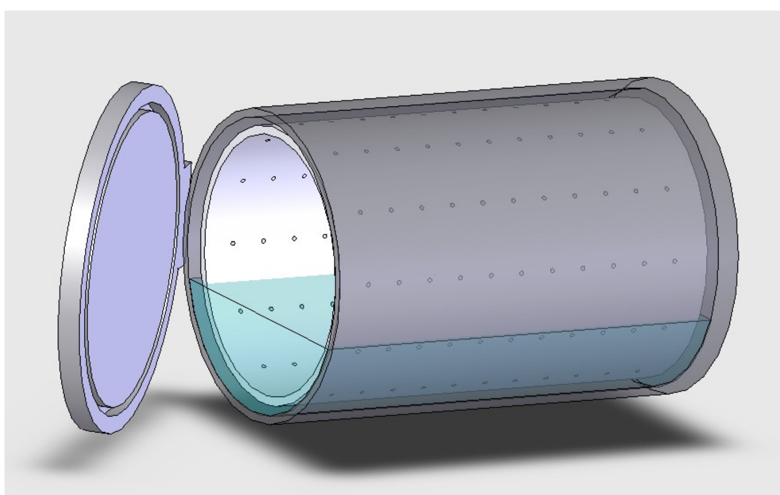

Figure 4. Chosen washing machine.

4. Results and Discussions

Throughout history, human has applied energy through the use of arms, hands and back. With the invention of bicycle and pedalling, legs then began to be considered as a means to transfer power from human muscles. A person can generate four times more power by pedalling than by hand cranking. At the rate of 1/4hp, continuous pedalling can be done for only short periods, about 10 minutes. However, pedalling at half this power (1/8hp) can be sustained for around 60 minutes. The same rate of power achieved by hand cranking can be achieved by pedal power but with far less effort and fatigue. Pedal power allows one to drive devices at faster rates or to operate devices that require too much power and hand cranking cannot provide the power. Over the centuries, the treadle has been one of the most popular method of using legs to produce power. Treadles are still found in low-power range machines such as sewing machines. Treadles have a very small maximum power output which can range from only 0-15 percent of what can be produced by an individual using pedal operated cranks under optimum conditions. Power levels that can be produced by a human through pedalling are dependent on how strong the person is and also on how long the person needs to pedal. The graph in Figure 9 shows various record limits for pedalling under optimum conditions. Any point on the curves has a corresponding maximum time that the indicated class of person can maintain the given power level.

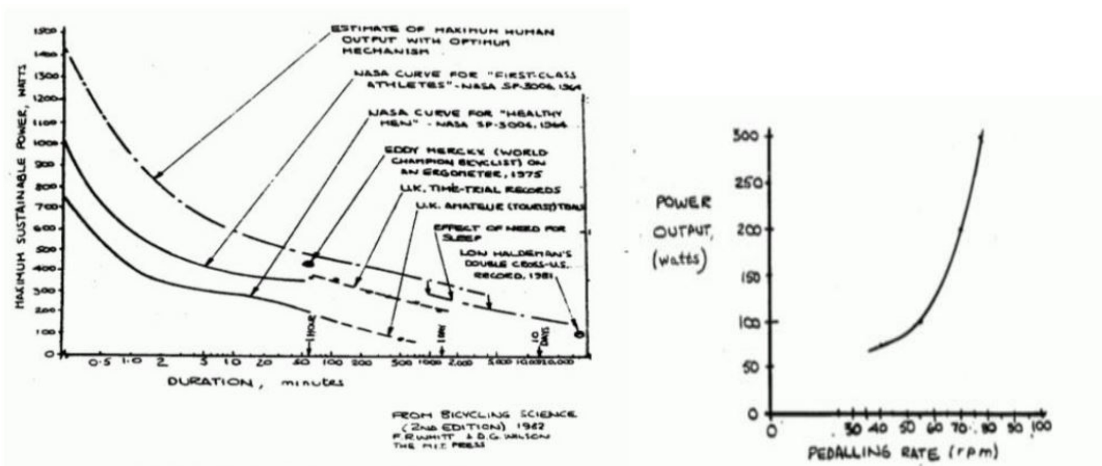

Figure 5. a.) Human power available as depending on the time of the exercise b.) How Optimum Pedaling Rate Varies with Desired Power Output

4.1 Pedalling Rate

Human beings are very adaptable and can produce power over a wide range of pedalling speeds. However, people can produce more power for a much longer time if they pedal at a certain rate. This rate varies from person to person and depends on their physical condition, but for every person there is a pedalling speed in between straining and fatigue that is the most comfortable, and that has the most efficient power production. Generally most people engaged in delivering power continuously for 1 hour or more will be most efficient when pedalling in the range of 50 to 70 rpm. For simplicity's sake, 60 rpm is used, as an easy reference value for estimates of the gear ratios required to drive a given load. The washing machine has 3 different processes which require different pedalling rates. The processes are: washing, rinsing and drying.

Table 1. Operating Specifications of a Conventional Washing Machine

Process	**Time Taken**	**RPM Required**
1. Washing	30min	20 rpm
2. Rinsing	5min	500 rpm
3. Drying	15min	1000 rpm

It can be seen from table 1 that the total time required for the entire process is 50 minutes. For a more comfortable and efficient power production through pedalling the pedalling rate is taken as 60 rpm. From Figure 5, it can be seen that under optimal conditions, when pedalling at 60 rpm a healthy person produces 125 Watts of power. The total cycle time from table 1 is 50 minutes and it can be seen from Figure 9 that maximum sustainable power developed by a healthy man is around 200 Watts. Thus, pedalling at 60 rpm and developing a power of 125 Watts provides considerable factor of safety for the person pedalling. Now, keeping the input power constant at 125 W and using different speeds as required for different processes, we can calculate torque for the three different processes.

Power, **P**=$\frac{2\pi NT}{60}$, Torque available at the tub for **washing, T**=$\frac{60x125}{2\pi x20} = 59.68Nm$

Now calculating the actual power available for **washing, P**=$\frac{2\pi x20x59.68}{60} = 2.5W$

Torque available at the tub for **rinsing, T**=$\frac{60x125}{2\pi x500} = 2.38Nm$

Now calculating the actual power available for **rinsing, P**=$\frac{2\pi x20x59.68}{60} = 62.5W$

Torque available at the tub for **drying, T**=$\frac{60x125}{2\pi x1000} = 1.19Nm$

Now calculating the actual power available for **drying, P**=$\frac{2\pi x20x59.68}{60} = 125W$

The minimum torque is the deciding factor for determining the capacity of washing machine as the same load of clothes remains during all the three processes. Therefore the capacity of the washing machine is calculated to be around 1.2 kg.

Table 3. Required power and torque for each of the three processes

Process	RPM Required	Torque Available	Power Required
1. Washing	20 rpm	59.68Nm	2.5W
2. Rinsing	500 rpm	2.38Nm	62.5W
3. Drying	1000 rpm	1.19Nm	125W

4.2 Designed washing machine.

Figure 6.1 a.) Solidworks model b.) Manufactured (physical) model c.) Schematic diagram

The model is shown simplified in the schematic diagram in Figure 6c and has the following

1. Gear
2. Pedal
3. Chain
4. Rear Sprocket/ Flywheel
5. Shaft
6. Outer Drum
7. Inner Drum

At 1 we have the gear which drive power to the sprocket by means of a chain drive. The shaft is attached to the inner dram by means of rivets. When the shaft rotates, the inner drum also rotates. The inner drum is the one which holds the clothes. It has rectangular bars fitted on its walls, these help in lifting the clothes during the wash cycle. It has a door at the top. The outer drum is the one which contains the water. The sprocket is a standard 18 teeth back flywheel of a bicycle. The components are further described below.

4.3 Fabrication

A working model of pedal powered washing machine was fabricated using the selected components as mentioned in the design. The machine was fabricated to study the design feasibility and the efficiency of the working model. It was found that pedal powered washing machine can be easily manufactured in a workshop using scrap components and conventional manufacturing processes. Manual Metal Arc Welding (MMAW) was key manufacturing process used. Other operations such as lathe works, press fitting, cutting and grinding of scrap metals etc. were also done. The fabrication of the model provided the cost estimate for the machine.

Figure 7.2 Fabrication pictures

To operate the machine one has to follow the following steps:

- Open the outer and inner drum doors.
- Put the clothes in the inner drum and close the inner door.
- Pour about 5 to 10 litres of water and add a detergent.
- Close the outer door and sit on a comfortable chair.
- Begin to cycle starting slowly and increasing pace. Pedal for about 15-20 minutes.
- Remove the soapy water by opening drainage screw at the bottom of the outer drum. You can add rinsing water and pedal for a short time. Remove the water. Drying will require a faster pedaling rate. The heat in the drum will also help dry the clothes.
- Now remove the clothes from the machine. The machine has to be maintained at regular intervals. A preventative type of maintenance every 5 years is more suitable. The components that require replacement are the sprocket, gears and the chain. Chain has to be greased regularly.

4.4 Finite Element Analysis of the machine

Von Mises equivalent stress will be used to estimate the scalar value of an element's stress tensor. Von Mises is one of the best methods to predict the failure for ductile materials due to the fact that it uses the distortion energy as a criterion. This means that the value of one of the principal components can reach the yielding strength and the material is no plasticizing. The inner drum is the part that has the highest stress and is likely to fail. Solidworks will be used to simulate the Von Mises stress. The load can be treated as static despite the fact that the cylinder is rotating because the loads are assumed not to vary with time neither in value nor in direction.

The simulation considers the following loads:

1. The load that is caused by the centrifugal force due to rotation of the cylinder

2. The load due to the weight of the clothes and the water.

From calculations above, the capacity of the clothes has been estimated to be 1.2kg and the mass of the water is 40% of 15kg which is 6kg. In simulation, only a percentage of the total mass is considered. For example when a single region is loaded, only 30 %(2.16kg) is considered. The area of the inner cylinder is **0.34m²**. The results of the simulation are shown in Figure 8

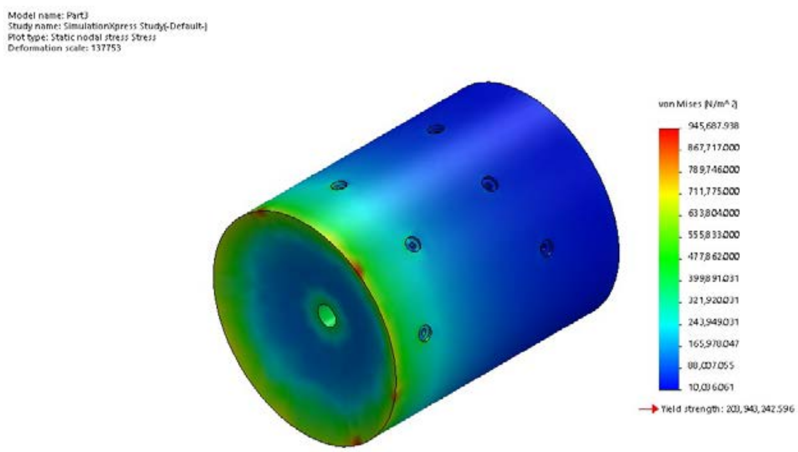

Figure 8. von Mises stress in inner drum with 1 loaded region

With the chosen scale, the stresses are almost the same for the various loading scenarios. Chances of the drum failing due to these loads are very low.

4.5 Vibrations

Pedalling will likely cause vibrations especially during the drying cycle where centripetal force would be at it's highest. Heavier material was used for the frame. The design is such that weights can be attached in order to make it heavier.

4.6 Cost Analysis

Cost benefit analysis is done to determine how well, or how poorly, a planned design project will turn out. This chapter will be devoted on capital project appraisal which will be used to deduce whether it is helpful or worth to implement the project.

Table 2. Bill of the materials

Name of Component	**Amount**
Chain	$1
Sprocket	$2
Gear	$4
Shaft	$2
Frames	$15
Inner Drum	$8
Outer Drum	$12
Welding	$10
Other	$5
Total	**$59**

A cheap new electric washing machine on average costs **$350**. The pedal powered machine costs only **$59.** It can be concluded that the pedal powered washing machine is an economical solution to the washing problems faced by people in the rural areas as it is affordable and easier to implement. Pedal powered washing machine is an environmentally friendly solution. It is the best solution for the environment since some parts use recycled material and since it also saves water. The solution does not require electric power or power from internal combustion engines thus saving energy. The design has great benefits to the social live hoods of many people in the rural areas. Villagers no longer need to waste time scrubbing clothes and thus can utilize that time for other business like working in fields. The machine helps protects people's hands which were being damaged by washing detergents when scrubbing by hands. The machine doesn't need one to get into contact with the detergent thus no danger is posed to one's skin.

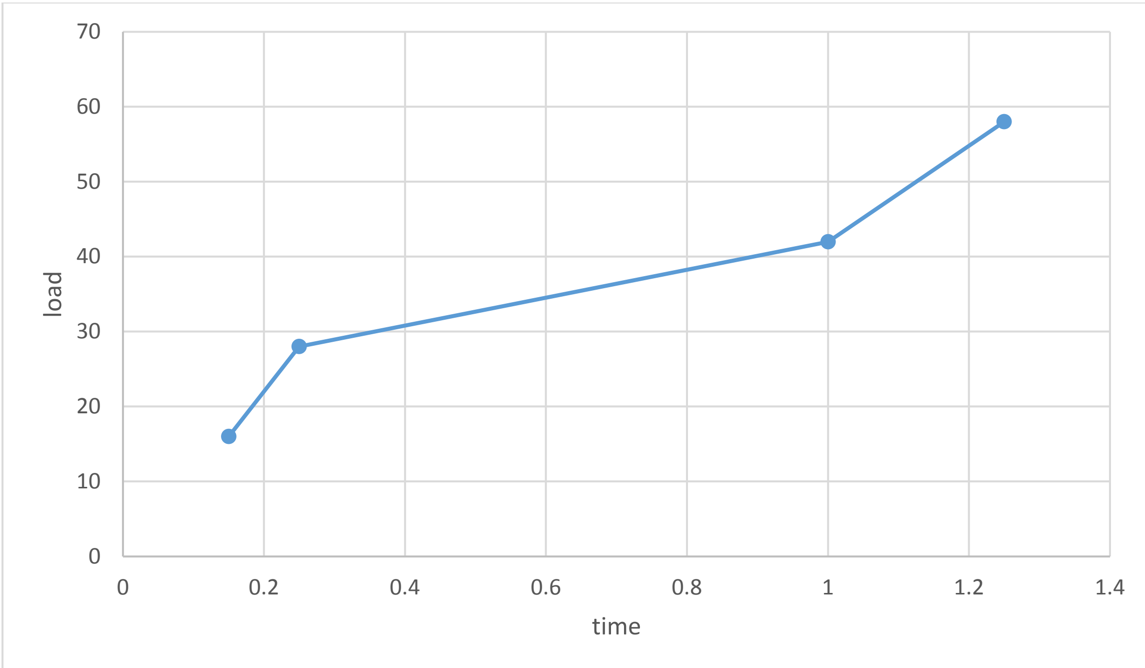

Figure 9.3 Graph of load vs time for an 80kg person pedaling at 150rpm

From the above experiment the optimal speeds for the different loads are:

1. For a person weighing 50 kg, the optimal speed is 60 rpm and clothes should weigh 1.25 kg.
2. For a person weighing 65 kg, the optimal speed is 90 rpm and clothes should weigh 1.25 kg.
3. For a person weighing 80 kg, the optimal speed is 150 rpm and clothes should weigh 1kg.

5. Conclusion and Recommendations

When any detailed design has been done, it is easily understood that no product/design get at its best or 100% efficient in its operation. There should always be opportunities for continual development and improvement. As shown, despite the fact that the selected concept proved to obtain satisfactory results, it could be still be improved to obtain a higher effectiveness of efficiency in the discharge of the intended duty. Although the working model of the pedal powered washing machine was fabricated and implemented, there is a scope of further work in the project which has not been undertaken. There are a number of ideas where the loss of power can be reutilized and the design can be modified for better performance. The energy wasted during washing can be utilized in most fruitful way by using it in another household machine which would work simultaneously as the washing goes on. The capacity of washing can be increased so that more clothes can be washed, thus utilizing the wasted energy. It would be more efficient to store energy using a flywheel and use the energy when needed. Future pedal powered washing machine should have a flywheel.

5.1 Conclusion

In order for the machine to be accepted in the community, it must be inexpensive and easy to build. I recognized this need and designed the machine from the start with low cost in mind. The machine cost $59 which was less than the $100 I had expected. The machine was built using parts which are readily available in rural areas. Therefore there is no need to import components should they wear out. We feel that the washing machine project was "successful". A functional prototype of a human-powered washing machine was built.

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