FOUR-BAR LINKAGE WASHING MACHINE POWERED BY WIND ENERGY

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ABSTRACT

A washing machine that is operated by wind energy, and which uses a mechanism that produces an oscillating motion, is analyzed, designed and manufactured. Accordingly a four-bar-linkage (FBL) mechanism is developed for this purpose. All dimensions of the FBL are determined by making use of KAAU's Al-Yaseer software package. The resulting mechanism is animated by computer, and kinematics and kinetic analyses are carried out. The fabricated FBL is installed on a Savonius rotor. The resulting windmill is successfully tested in the Aeronautical Engineering Department's wind tunnel at KAAU.

1. INTRODUCTION

As a result of the 1970's energy crisis, the world woke up from a deep sleep realizing that oil, coal, and other non-renewable sources of energy would not last forever. A sincere search for renewable resources began [1]. Renewable sources of power include wave energy, biomass energy, solar energy, solid-waste energy geothermal energy, tidal energy, and wind energy. In this paper wind energy is utilized to drive a washing machine that features a four-bar linkage.

1.1 Wind Energy

Wind energy is an indirect form of solar energy. Wind is induced by the uneven heating of earth's crust by the sun, as well as by some other effects like earth's rotation. Wind energy can be classified as planetary and local. Planetary winds are caused by greater solar heating of the surface of the earth near the equator than at the northern and southern poles [2]. The local winds are caused by two mechanisms. The first is the differential heating of land and water. The presence of hills and mountain sides causes the second mechanism.

Human beings have always dreamt of converting wind power to mechanical and electric power. In ancient times, wind energy was used to power sailboats and to grind wheat [2]. The concept of windmills seems recent when compared to the mechanism used for sailing. One of the most successful kinds of the vertical axis mill is the one named after Savonius of Finland. The Savonius windmill is made of a single or multiple S-shaped sails and a vertical axis; a single S-shaped sail is used in this paper.

1.2 Total Power

The total power of a wind stream is equal to the rate of the incoming kinetic energy of the air stream [1]

$$P_{tot} = \frac{1}{2} \rho A V_i^3 \tag{1}$$

Where, P_{tot} is the total power in Watt, V_i is the incoming wind velocity in m/s, ρ is the incoming wind density in kg/m^3, and A is the cross-sectional area of stream in m^2. Therefore the total power of a wind stream is directly proportional to its density, area, and the cube of its velocity. The ideal, or maximum, theoretical efficiency η_{max} (also called the power coefficient or Betz limit) of a wind turbine is the ratio of the maximum power obtained from the wind and is equal to 60%. In other words, a wind turbine is capable of converting no more than 60 percent of the total power of a wind to useful power.

1.3 Actual Power

Because a wind-turbine wheel cannot be completely closed, and due to spillage and other effects, practical turbines achieve some 50 to 70 percent of the ideal efficiency. The real efficiency η is the product of this and η_{max}, and is the ratio of actual to total power [2]

$$P = \frac{1}{2} \eta A V_i^3 \quad (2)$$

Where η varies between 30 and 40 percent for real turbines.

2. DESIGN OF WINDMILL

The windmill that is used to operate the four-bar-linkage washing machine is a Savonius single 'S' rotor that consists of two halves of a barrel welded to a vertical shaft (see Fig.1). The shaft is supported by two bearings, where both bearings are fixed to the frame of the washing machine.

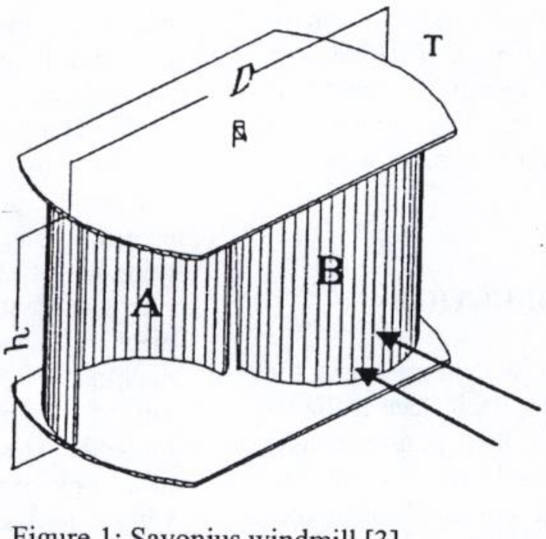

Figure 1: Savonius windmill [3].

For the shown direction of the wind in Fig.1, the drag coefficient of blade A is greater than that of blade B. This causes the rotor to rotate clockwise.

2.1 Forces on the Rotor

There are two forces acting on the rotor: The drag force, which is desirable, and the lift force, which is undesirable, because of its tendency to lift the rotor. The lift force F_L and the drag force F_D, can be calculated as [4]

$$F_L = C_L \eta (V^2/2) A \quad (3)$$

$$F_D = C_D \eta (V^2/2) A \quad (4)$$

Where C_L and C_D are the drag and lift coefficients, respectively. The C_L and C_D constants are functions of the tip speed ratio (the speed at the tip of the rotor divided by the wind speed, TSR).

Now as a numerical example assuming a Savonius windmill with real efficiency η=15%, ρ = 1.23 kg/m^3, A=0.6 m^2, V=25m/s, and TSR=1 leads to C_D =1.3 and C_L=1.6 [4]. The total resultant force F_T due to F_L and F_D on the rotor is 575 N.

2.2 Design of the Shaft

The above forces have to be carried by the shaft connecting the two halves of the barrel. Assuming F_T is the only force acting on the shaft, the torque on the shaft is equal to 230 N-m for an 80 cm windmill diameter. For a windmill height of 0.6 m, the bending moment at the middle is maximum and it is equal to 172 N.m. The shaft diameter is found by using the ASME shaft design equation [5] to be 25mm for an allowable torsional yield strength of 95 MPa.

2.3 Selection of Bearings

The inner race of the bearing is 25 mm. It is subjected to an axial force equal to the weight of the windmill, which is approximately 370 N, and a radial force that equals to half of the resultant force (288N). For SKF 6005 bearing, the value of dynamic Co and static C rating are 6550 and 11200, respectively [6]. The life of the ball bearing is satisfied because of large Co and C.

2.4 Manufacturing of the Windmill

The windmill blades are made of steel sheet. They were formed by the rolling machine to achieve the half-barrel shape. The mill shaft is made of steel. The two barrel shaped halves are welded to the mill shaft to form an 'S' shape. Two steel plates are welded to the top and the bottom of the windmill leaving the output shaft extended at both sides. These extensions are to be supported by bearings, which are affixed to a frame made of steel angles and bars.

3. DESIGN OF THE FOUR BAR LINKAGE

3.1 The Mechanism

The agitation motion of any washing machine (or any other similar application) can be obtained by a mechanism called a Four-Bar Linkage (FBL). In the FBL a crank is connected to the output bar by coupling the bar as shown in Figure (2). The distance AoBo is the fixed member, AoA is the crank, AB is the coupler, and BBo is the output member [7]. This mechanism is used in this paper, where the crank is driven by the shaft of the windmill and the lundary fins (blades).

3.2 Design of the FBL

In designing the FBL it is necessary to determine the length of each bar so that the mechanism would not get stuck. The Al-Yaseer Mechanism Software [8] was used to study the performance of this FBL, and to ensure that the mechanism would run smoothly. Referring to Fig.2 and using the dimensions measured from a commercial washing machine, it is determined that member AoA is the crank and its length is equal to 50 mm; and AB is the coupler and its length is 175mm.

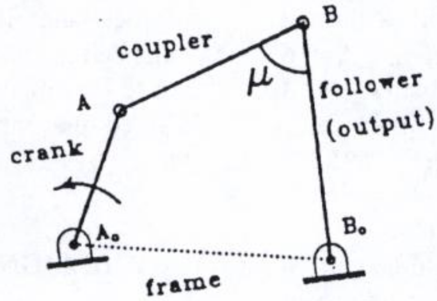

Figure 2: Four-Bar Linkage Mechanism [7].

The output member, BBo is 60mm in length. The fixed member, AoBo has a length of 180mm. The minimum transmission angles of the mechanism are 27.2 and 34.3 degrees and occur at crank angles of 180° and 0° respectively. Inertial effects are expected to ensure the smooth running of the mechanism.

The time ratio, defined as the time taken by the return motion divided by the time taken by the forward motion, is founed to be 0.98. Therefore, the average forward speed of BoB is approximately the same as its reverse speed.

3.3 Dynamic Analysis

Assuming that the agitator is run at a constant rotational speed of 50 rpm tawafwise (counterclockwise), dynamic analysis iss carried out using the Al-Yaseer Software developed at KAAU. Figure (3) shows the crank angle versus the output angle. For one revolution of the crank the output angle varies from about 200 degrees to 310 degrees. The swing angle of the output is about 110 degrees.

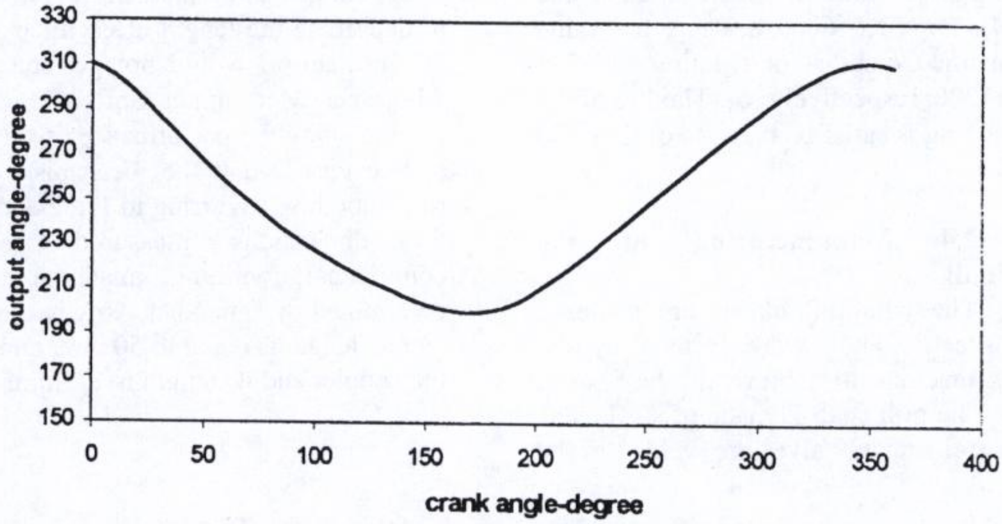

Figure 3: Output (follower) angle versus the crank angle.

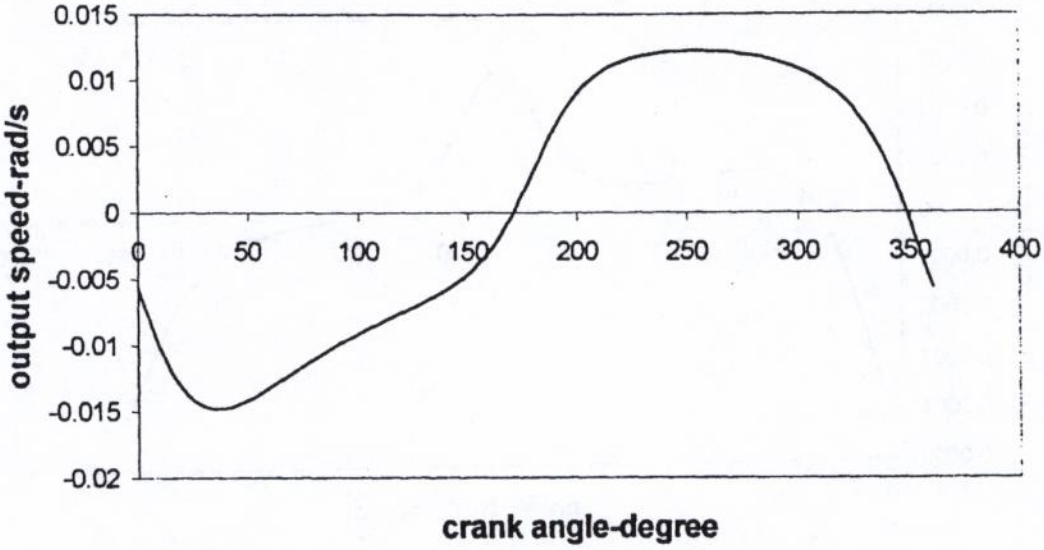

Figure 4: Output (follower) speed versus the crank angle.

Figure (4) shows the crank angle versus the output speed. For one revolution of the crank the output member goes clockwise and then counterclockwise. Forward and backward speeds of the input member are seen to be of different patterns. Figure (5) shows the crank angle versus the output acceleration. For one revolution of the crank the output acceleration increases to a positive peak of 0.00025 rad/s^2 at the minimum transmission angle, and then decreases again to a minimum of –0.0004 rad/s^2. The acceleration of the output member is nearly steady between around 50 and 150 degrees. A negative peak occurs at the second minimum transmission angle, corresponding to zero crank angle.

3.4 Selection of Bearings

The shaft diameter of the output member is taken to be 25 mm which will be the inner race diameter of the bearings. One side of this shaft is connected to the output member and the other side is coupled to the lundary blades. The selected bearing is SKF 6005. The dynamic load C and static load Co were 11200 N and 6550 N, respectively [6]. Figure 6 shows an assembly drawing of the FBL mechanism of the washing machine.

4. MANUFACTURING THE FBL

The input crank and the output follower were machined from aluminum disk for the sake of rigidity, ease in installation and balancing. These two solid disks were 70 mm and 60 mm in diameter and 50 mm in width. The two discs were machined on the lathe to achieve the final shape. The link between the two discs (the coupler) is a bar made of aluminum. Two holes were drilled at the ends of the link. The output shaft is connected to the follower and it is made of low carbon steel and its diameter is 30 mm. It was machined on the lathe after being cut to the required length by a saw. The output shaft then had to be surface finished at the locations of the bearings. Fine straight turning process was used to do that. Figure 7 illustrates the washing machine in its final configuration.

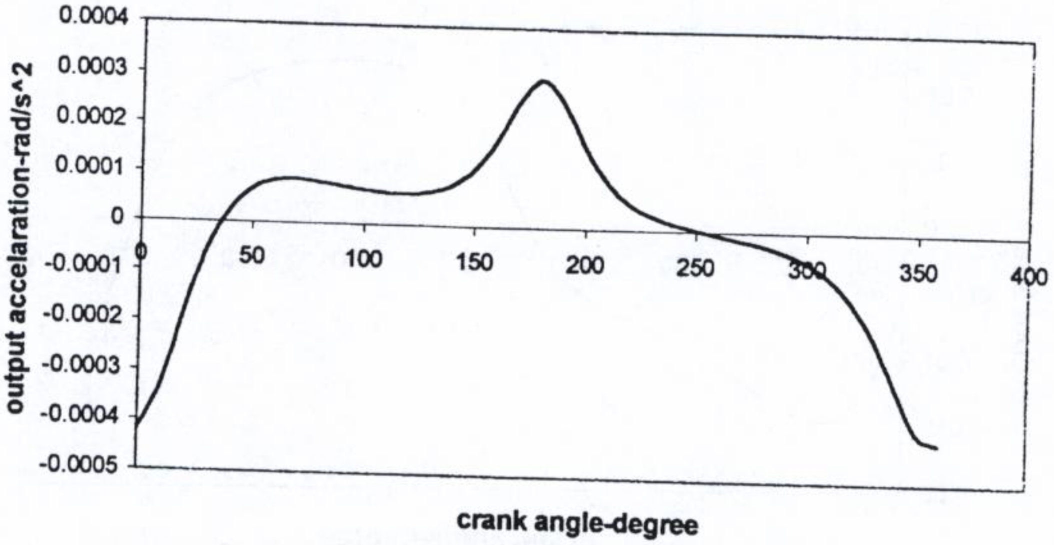

Figure 5: Output (follower) acceleration versus the crank angle.

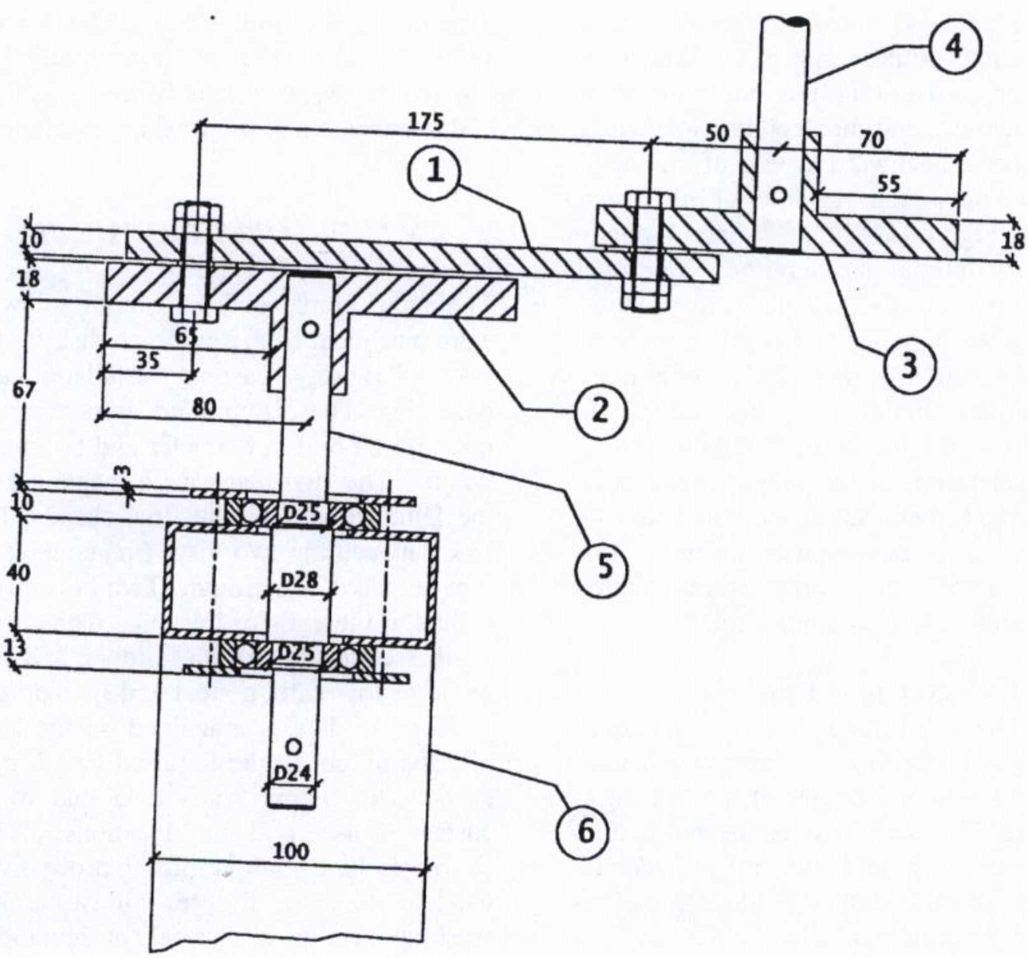

Figure 6: Assembly drawing of the Four-Bar Linkage in the washing machine.

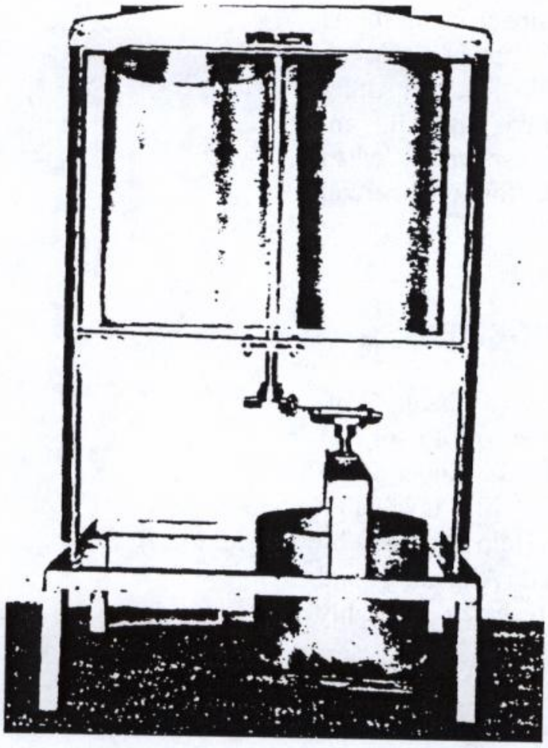

Figure 7. The washing machine in its final configuration.

5. TESTING

The washing machine is tested at the Wind Tunnel of the Aeronautic Engineering Department of King Abdulaziz University. The wind tunnel can provide different wind speeds up to 40 m/s and it has an outlet opening of 0.5 x 0.7 m. The machine began operating at a speed around 5 m/s without any load. When the washing machine is loaded with water and clothes, it worked smoothly at a wind speed of 8 m/s. It is found that, at a wind speed of 12 m/s, the washing machine needs ground supports to avoid overturning. Such a problem can be solved using heavy steel base for the machine or by fixing the frame to the ground using cables.

During the test it is determined that the FBL mechanism is operating satisfactory and smoothly. However, at a wind speed of 12 m/s, dynamic unbalanced forces start causing noise and vibration. This might be due to the small transmission angles.

6. CONCLUSIONS

The main objective of this study is to find an alternative source of energy for our daily life activities. Wind energy is the source, and washing clothes is the chosen activity. It is well known in the community of renewable energy that the the best way to get use of alternating energy is to use it as direct as possible, i.e. with minimal or no transmission or transformation. Hence this paper uses wind energy directly to powerd a washing machine with minimum losses, as frctional losses at the bearings. Windmill and washing machine elements were designed and manufactured. The resulting machine was tested at the wind tunnel. It worked successfully. As a recommendation to this project, this washing machine can be converted into a high speed spin-dryer by using a single-stage gear box instead of the FBL. Also, an indexing mechanism to the basket can be made and powered by the motion of the windmill shaft. Other accessories, like a brake system, are recommended to have especially when considering this project for commercial applications.

7. ACKNOWLEDGEMENT

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