

# Simple and Efficient Methods to Perform the Optimum Matching Between a Reciprocating Piston Pump and a Wind Machine

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**Abstract:** One of the major problems facing the use of the wind driven reciprocating lift pump is the problem of starting. The required starting torque of the pump is at least three times the average torque. This means that the pump will need a high wind velocity just to be started, after that it will continue to operate at a lower wind velocity because of the lower average torque, provided that there is enough inertia in the system. For this reason, the torque

characteristics of the wind turbine – reciprocating pump combination are very important. Thus, there is a real need to develop new methods in order to reduce this starting performance of the reciprocating pump. This paper presents a theoretical study to reduce the starting torque of a non-conventional reciprocating piston pump using new methods, for example, changing the wind machine parameters, such as the aerodynamics configuration of the rotor and blade elements, or by studying the effect of wind speed velocity on the starting torque. Also by changing the cross-section area of the piston or by changing the static head of the piston pump or by controlling the flow rate of the piston pump.

**Keywords:** Wind machine, Reciprocating piston pump, Starting torque, Optimum matching, Windmill parameters, Pump performance and characteristics.

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## 1 Introduction

The torque applied by the pump on the wind turbine axis is a fluctuating torque. The energy furnished by the wind turbine is absorbed mainly in raising the water and the piston when the piston moves upward. The piston goes downward under its own weight added to the driving force causes acceleration. This has a direct adverse effect on the starting speed.

In fact a much larger torque than the average torque and consequently a much higher wind speed is required to start the machine. In order to reduce the necessary starting wind speed and increase the yearly operating time of the machine, the maximum starting torque should be smoothed out as much as possible.

It is important to obtain an efficient water pumping system. The accomplishment of this goal requires good rotor-to-load matching. Matching is dependent mainly on the accurate knowledge of the post-stall blade section characteristics and rotor parameters. On the other hand, hydraulic characteristics of pumping load (pump) plays an

important rule in matching process, also the effect of the wind regime in the selected site must be considered [1-2].

Previous work on matching of pump and windmill has been done in [3-4]. References [3] presented some specific examples for wind pumping system to illustrate how an optimization procedure is effective in maximizing system output. Reference [4] gave a more generalized presentation that illustrates how operating points may be predicted for wind system driving speed-dependant and constant-speed load. Reference [5] used the procedure given in [3] and [4] to select the optimum pump type which will be matched optimally with a given windmill and the optimum windmill which will be matched optimally with a given pump, but neither the rotor characteristics as a function of wind speed nor the hydraulic characteristics of the pump have been studied, and consequently the starting behavior and the off-design performance have not been considered. He stated that the wind regime characteristics of the site affect the selection of the suitable water pumping

systems, and it is needed to construct a procedure to relate the wind regime characteristics, with rotor and pump characteristics.

In [6] the effect of rotor parameters on the output energy of wind energy conversion systems was studied and the results of investigation showed that the blade setting angle is the most important parameter which affects the system performance.

References [7-8] dealt also with the problem of matching between rotor and pump but all of them were carried out for a specific site and the results depend on the experimental data obtained in the site.

Positive displacement pump, as normally be used, requires an average torque independent of speed, which is not matched to the rotor output as a function of wind speed. This problem can be solved by using a variable stroke reciprocating pump [9, 10].

The main objectives of this study can be summarized in the following points:

1. To overcome the mismatch between reciprocating pump and rotor by using a simple and efficient methods.
2. To relate a wind regime characteristics with rotor and pump characteristics to obtain the optimum size of the pumping system.
3. To improve the starting performance of the wind pumping systems.
4. To match the rotor and the pump characteristics for optimum performance.

## Application

Let us evaluate the force which acts on the piston rod during the upward stroke of the piston. If  $P$  is the weight of the moving parts,  $H$  is the total static head,  $A_p$  is the cross-sectional area of the piston and  $\gamma$  is the specific weight of the water. Then the vertical force  $F$  which has to be overcome for raising the water is:

$$F = P + \gamma A_p H$$

If the radius of the crank shaft is ( $a$ ), the moment ( $T$ ) to be overcome is:

$$T = KaF = Ka(P + \gamma A_p H) = KaP + \frac{30}{N} \gamma QH$$

Where  $K$  is the gear ratio,  $N = \text{rps}$  (rotational velocity).

The lower the maximum torque to be overcome, the easier will the wind start. If the necessary torque is high, a faster wind speed is required to start the windmill. The operating time of

the machine is consequently reduced. It is therefore desirable to reduce the starting torque ( $T$ ). To reduce it, and hence to make the starting easier, various actions are possible.

## Methods Used to Reduce the Starting Torque

### 1. Changing the radius of the crank shaft ( $a$ )

From the relation of the maximum torque,

$$T = KaF = Ka(P + \gamma A_p H) = KaP + \frac{30}{N} \gamma QH$$

This equation shows that, at constant delivery of water, the operating torque decreases with decreasing the crank radius ( $a$ ). Thus for reducing the starting torque of a windmill, the radius of the crank shaft ( $a$ ) should be reduced and the piston cross section area ( $A_p$ ) should be increased, as shown in figure (1).

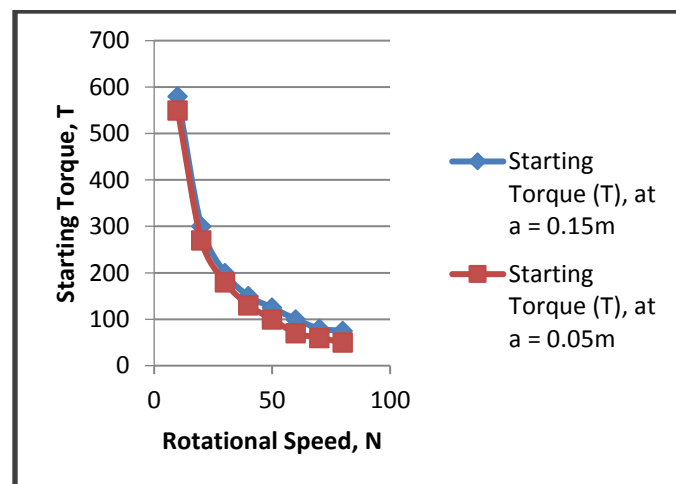


Fig. 1 Effect of changing the crank shaft radius on starting torque

As shown in Fig. 1, it is observed that the changing of the value of ( $a$ ) has a small effect in smoothing the starting torque.

### 2. Changing the speed-up ratio (gear ratio, $K$ )

From the relation of the maximum torque, the reduction in ( $K$ ) has the same effect on the starting velocity as a reduction in crank radius ( $a$ ). The weight of moving parts is thus reduced. In practice, the ratio ( $1/K$ ) is never greater than five. This effect is shown in figure 2.

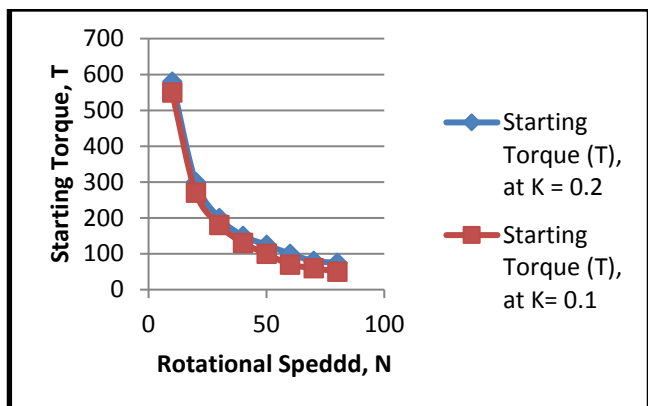


Fig. 2 Effect of changing the speed up ratio on starting torque

### 3. Changing the weight of moving parts (P)

The reduction in the weight of moving parts reduces the starting torque of a windmill. This effect is shown in figure 3.

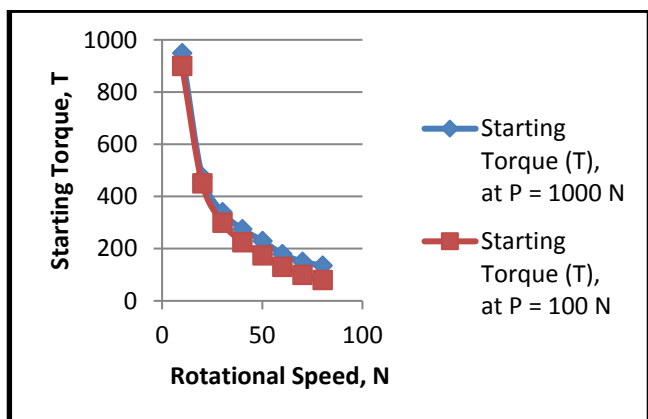


Fig. 3 Effect of changing the weight of the moving parts on starting torque

It is shown from Fig. 1, 2 and 3, the effect of reducing the value of crank shaft radius, speed up ratio and weight of moving parts has a same effect on the starting torque of a windmill.

### 4. Changing the rotor diameter (D<sub>T</sub>)

As shown from the equation of starting torque,

$$T = KaP + \frac{30}{N} \gamma QH$$

$$\eta_m P_m = P_{hydraulic} = \gamma QH = \rho_w g QH$$

$$P_m = \frac{1}{2} \rho_a V^3 \frac{\pi}{4} D_T^2 C_p$$

For slow wind turbine (multi-bladed) the mechanical power of a windmill is given by,

$$P_m = 0.15 D_T^2 V^3$$

Therefore the equation of the maximum torque is given by,

$$T = KaP + 4.5 \eta_m \frac{D_T^2 V^3}{N}$$

For reducing the starting torque of wind machine, the diameter of the rotor ( $D_T$ ) should be reduced but the output power of a wind machine is reduced. The effect of reducing the rotor diameter on the starting torque is shown in the Figure 4.

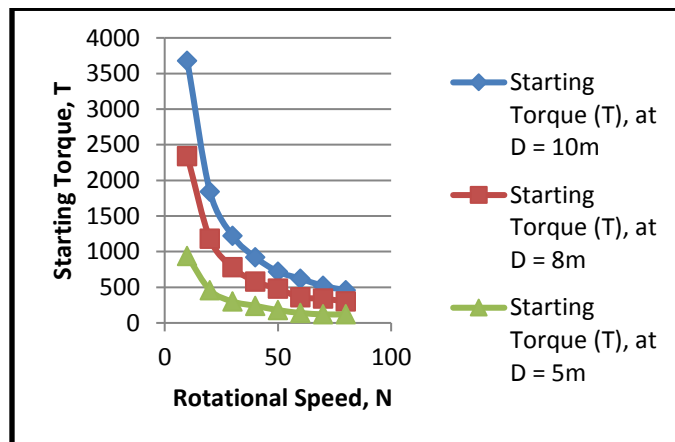


Fig.4 Effect of changing the rotor diameter on starting torque

### 5. Effect of wind speed (V) on the starting torque (T)

As shown from the equation of starting torque,

$$T = KaP + 4.5 \eta_m \frac{D_T^2 V^3}{N}$$

For reducing the starting torque of wind machine, the wind velocity ( $V$ ) should be reduced. The effect of reducing the wind velocity on the starting torque is shown in the Figure 5.

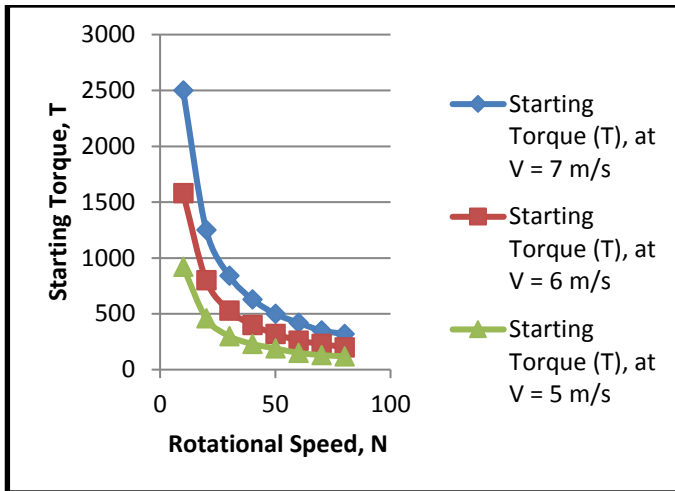


Fig.5 Effect of changing wind speed on starting torque

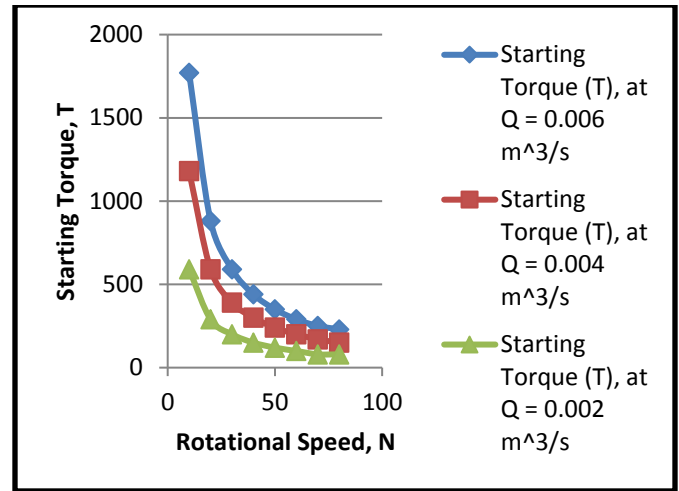


Fig.6 Effect of reducing the flow rate on starting torque

### 6. Effect of reducing the flow rate (Q)

As shown from the equation of starting torque,

$$T = KaP + \frac{30}{N} \gamma QH$$

From this equation we notice that, as the value of flow rate of the pump reduced, we can smooth the starting torque. This effect can be made by making a small hole in the piston which is useful at starting by making some leakage in water at low speed which reduces the force acting on the piston and smoothing the starting torque. This effect is the same of the idea of a leakhole pump which will be discussed later. The effect of reducing the flow rate on the starting torque will be shown in Figure 6.

### 7. Effect of static head (H)

As shown in the above equation of starting torque, the static head is directly proportional to the starting torque, i.e. as the static head decrease the starting torque decrease. By this way we can smooth the starting torque. The changing of static head depends up on change the suction head ( $H_s$ ) where,

$$H = H_s + H_d$$

Where,  $H_d = \text{delivery head}$

The effect of this static head is shown in figure 7.

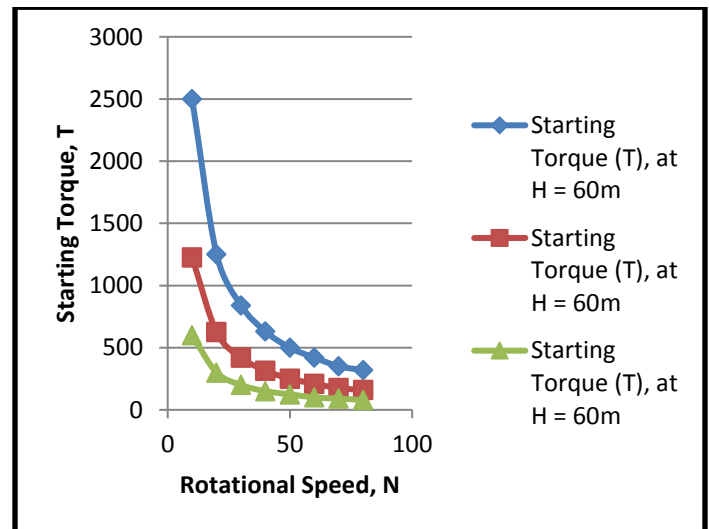


Fig.7 Effect of static head on starting torque

## 8. Changing the piston cross section area ( $A_p$ )

As shown from the equation of starting torque

$$T = Ka(P + \gamma A_p H)$$

From this equation we notice that, we can smooth the starting torque by reducing the cross-sectional area of the piston by any ways:

### A) Drill a very small hole in the piston.

The effect of this leakhole is that at very low speeds (at starting), all water that could be pumped is leaked through the hole. This implies that the pressure on the piston is very low and as a result the starting torque required is low. If the speed is high, then the quantity of water leaking through the hole is small compared to the normal output of the pump and the pump behaves as a normal pump.

### B) Use the spring valve in the piston.

The effect of this spring valve is that, at low speeds and during the upward stroke of the pump, the spring will keep the piston valve open for a certain time, thus the water which is above the piston will flow through the piston valve gap, being not delivered during the upward stroke. This means that less force is required to leave the piston up. After that and due to the increase of the gained inertia, the pump rod force will force the spring to be compressed and causes the piston valve to be shut to perform the pumping procedure. The whole idea of this system is to delay the closing of the piston at starting then the valve will be shut at a late point during the upward stroke.

The last two methods are aimed to reduce the cross-section area of the piston to smooth the starting torque. This effect of changing the piston cross-section area is shown in Fig. 8.

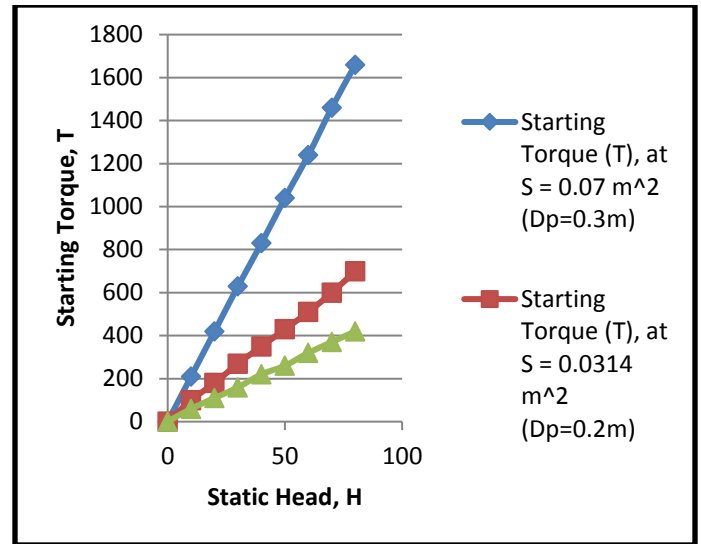


Fig.8 Effect of changing piston cross-sectional area on starting torque

As shown from Fig. 8 the best method to smooth the starting torque is reduced the cross-section area of the piston, by making a small hole of a diameter ( $d$ ) in the piston, this method known as a leakhole piston pump. The effect of the diameter of a leakhole on the starting torque will be discussed below.

## 9 Effect of the Diameter of a Leakhole on the Starting Torque

The equation of the starting torque is given by:

$$T = Ka(P + \gamma A_p H)$$

$$A_p = \frac{\pi}{4} D_p^2$$

In the case of a leakhole piston pump,

$$A_p = \frac{\pi}{4} (D_p - d)^2$$

Where,  $d$  = diameter of a leakhole made in the piston.

The starting torque of a leakhole piston pump is:

$$T = Ka(P + \gamma H \frac{\pi}{4} (D_p - d)^2)$$

The effect of the diameter of a leakhole on the starting torque is shown in figure 9.

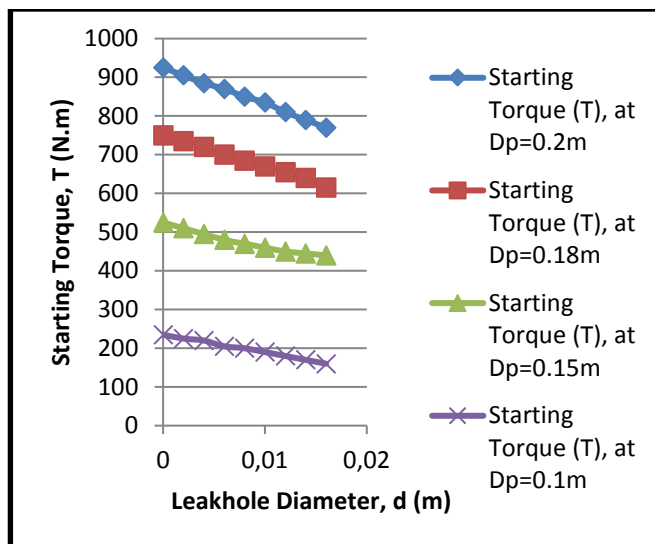


Fig.9 Effect of a leakhole diameter on the starting torque

As shown from figure 9, for reducing the starting torque of wind machine, the diameter of a leakhole (d) should be increased, but in the same time the output discharge from a leakhole piston pump is reduced due to the quantity of water leaking through the hole at very low speeds (at starting). But at high wind speeds, the quantity of water leaking through the hole is small compared to the normal output of the pump.

## 10 Conclusion

In this paper, the effects of wind machine parameters, aerodynamics configuration of the rotor, wind speed velocity, stroke volume of the pump and a leakhole in the piston of a reciprocating piston pump on reducing the starting torque were investigated theoretically. Results showed that a

leakhole method is the easier method to perform the optimum matching between a reciprocating piston pump and a wind machine and to improve the starting behavior of the pump.

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