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PROCEEDINGS

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VARIABLE STROKE PUMPING FOR MECHANICAL WINDMILLS

R. Nolan Clark
Agricultural Engineer
USDA-Agricultural Research Service
Bushland, Texas
and
J. W. McCarty
Research Associate
WTSU-Alternative Energy Institute
Canyon, Texas

ABSTRACT

Single-acting piston pumps which are used with mechanical windmills have a fixed stroke length and require constant operating torque from the windmill rotor. When available rotor torque exceeds that of the pump, the windmill rotor overspeeds almost in proportion to windspeed thus not taking full advantage of the extra power available at higher windspeeds. The pumping load can be varied by varying the stroke length of the piston pump in proportion to windspeed, thus improving the wind to water pumped conversion efficiency. Two variable stroke mechanisms were field tested on a 2.44-m multibladed windmill erected at the USDA-ARS, Conservation and Production Research Laboratory, Bushland, TX. A second windmill with a standard pump was used to compare the volumes of water pumped under the same windspeed and pumping conditions. The cut-in windspeed was not affected by the variable stroke, but smaller volumes of water were pumped at low windspeeds. The flow rate at 10 m/s windspeed was increased from 26 L/min for the standard pump to 46 L/min for the hydraulic variable stroke pump. Annual pumped water volumes calculated from the two pump curves show that the windmill with the hydraulic variable stroke pump would produce about twice as much water as the windmill with a standard pump. The flow rate at 10 m/s windspeed for the spring-mass variable stroke was 23 L/min compared to 13 L/min for the standard pump. This system used a smaller pump than the hydraulic variable stroke system.

INTRODUCTION

For over 100 years, windmills have provided water for livestock and home use in many areas of the United States. These windmills have been improved by using all steel rotors and enclosing the gears in an oil bath. Except for these two modifications, little has changed on these windmills since the early 1900's. Similarly, the pumps have not changed significantly. Urethane cups have replaced leather cups in the single-acting piston pump to provide longer life. Multibladed windmills start pumping water at a windspeed of approximately 3.5 m/s and reach peak flows at 9 to 10 m/s, depending on the furling spring tension (Kamand and Clark, 1988). The furling spring tension is normally adjusted to limit the maximum pump speed to 30 to 35 strokes per minute.

The single-acting piston pump which is used with mechanical windmills has a fixed-stroke length and requires constant operating torque from the windmill rotor. When available rotor torque exceeds that of the pump, the windmill rotor overspeeds almost in proportion to the windspeed. The pump does not take advantage of the extra power available at the higher windspeeds. If the pumping load could be increased as windspeed increases, the windmill would operate at its maximum efficiency for longer periods and more water could be pumped from the same sized windmill.

Three components of the single-acting piston pump can be changed to increase the load, resulting in more water pumped. These components are: increase the pump diameter, increase the pump speed, or increase the stroke length. It would be difficult to change the pump diameter as windspeed changes. The pump speed is increased to 30 to 35 strokes per minute as windspeed increases to 10 m/s, but about 35 strokes per minute appears to be the maximum speed for a piston to operate on the end of a 25 m to 50 m rod. The most feasible method to increase the load appears to be to change the stroke length as windspeed increases.

The concept of using a variable stroke on windmills is not new; several patents have been issued over the years. E. G. Harris was awarded a patent in 1899 for a stroke controller for windmills (Harris, Patent #617,877, 1899). Patents by W. T. Stockett (Patent #2,688,285, 1954) and D. E. Avery (Patent #4,392,785, 1983) are probably the most appropriate from recent years when considering variable stroke pumping. Although many patents have been issued, no variable stroke mechanism is available or marketed for water pumping windmills. The question is, are variable stroke systems not used because of unreliability or that they are not feasible? Therefore, the studies reported herein were conducted by the USDA, Agricultural Research Service, Bushland, Texas in cooperation with the West Texas State University, Alternative Energy Institute, Canyon, Texas to determine the benefits and feasibility of variable stroke mechanisms.

DESCRIPTION OF EXPERIMENTS

Two identical windmills were used for each test. They were located 50 m apart and were operated at the same pumping lift and with identical pumps. One windmill was operated as a standard windmill with a fixed stroke length and the other with the variable stroke mechanism. The windmills were 2.44-m multibladed windmills manufactured by Dempster Industries[1/]. Dempster windmills are typical upwind horizontal-axis windmills with 15 galvanized steel blades. The units are back geared at a ratio of 3.3 to 1 and the stroke length is fixed at 18 cm. For overspeed control, the rotor turns sideways into the wind which is called furling. The windspeed at which furling begins can be adjusted by changing the spring tension between the gearbox and tail vane. The windmills were erected on 10-m high steel towers.

The single-acting piston pump used three urethane sealing cups to lift the water from a 15 m deep sump. The pumps used for the hydraulic variable stroke tests were 7.3 cm in diameter and 4.8 cm diameter pumps were used for the spring-mass variable stroke tests. Back pressure regulator valves were used to control the discharge pressure and simulate different pumping depths for these comparison tests. Strokes per minute were counted by a custom made stroke counter and water flow was measured with turbine meters. All sensors had either a pulse or analog output signal.

Windspeed, wind direction, atmospheric pressure and air temperature were measured at 10-m height. All data were logged on a microprocessor and stored on cassette tape. Readings from each data channel were taken at one second intervals and averaged for one minute. The one minute averages were stored on tape and later transferred to a minicomputer for processing using the method of bins. Each data set contained approximately 20,000 one minute observations.

Hydraulic Variable Stroke

The hydraulic variable stroke mechanism automatically varied the pump stroke length with windspeed. The control mechanism was installed between the gearbox and the piston pump, and was supported by the windmill tower as shown in Figure 1. The control system consisted of two single-acting hydraulic cylinders, pressure accumulator, needle valve, oil reservoir, an oscillating lever arm, and a spring. The vertical hydraulic cylinder was used as a pump and was driven by the reciprocating pump rod

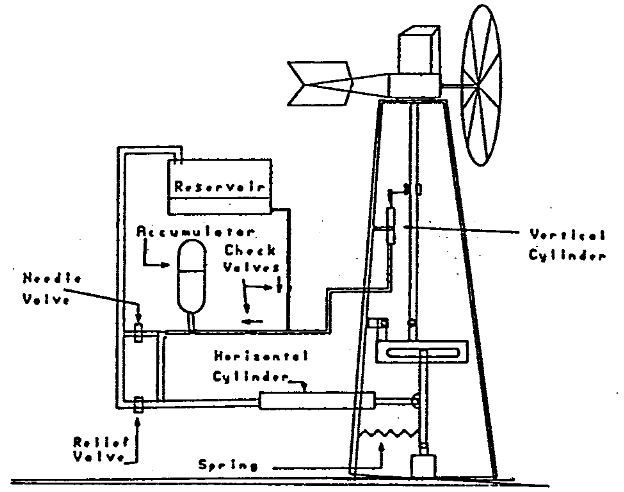

FIGURE 1. SCHEMATIC OF THE HYDRAULIC VARIABLE STROKE MECHANISM.

that connected the gearbox with the oscillating lever arm (Figure 1). As the windmill pump rod speed increased, more oil was pumped by the vertical hydraulic cylinder and the oil pressure was increased causing the horizontal hydraulic cylinder to push the lower pump rod away from the pivot point of the oscillating lever arm; thus causing a longer pump stroke length. The needle valve regulated the flow of oil from the pressurized system and allowed the pressure to be released when the windspeed slowed. As the windspeed slowed, the system pressure decreased and the horizontal hydraulic cylinder rod was pulled back by the spring, thus decreasing the pump stroke length.

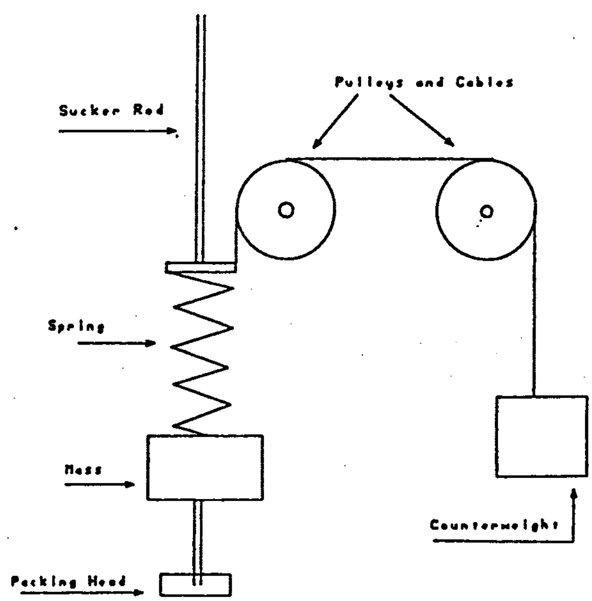

FIGURE 2. SCHEMATIC OF THE SPRING-MASS VARIABLE STROKE MECHANISM.

[1/] Mention of a trade name or product does not constitute a recommendation or endorsement for use by the USDA-Agricultural Research Service, nor does it imply registration under FIFRA as amended.

Spring-Mass System

A spring-mass system to increase the stroke length was constructed by replacing a portion of the sucker rod with a spring and mass as shown in Figure 2. The mass was added to cause the spring and mass to reach a resonance at 25 to 30 strokes per minute. When the spring resonance is reached, the lower rod would have a stroke length almost twice as long as the upper pump rod. The added mass was counter weighted to allow the unit to begin pumping at the normal windspeed. At low windspeeds, the stiff spring and mass act like the solid rod and the stroke length was not affected.

RESULTS

The benefits of increased stroke length can be easily shown by comparing the relationship between stroke speed and water flow. This comparison is shown in Figure 3 for the hydraulic variable stroke system and Figure 4 for the spring-mass variable stroke system. In each of these figures, the variable stroke system pumped more water for the same stroke speed than did the standard or non-variable stroke system. The non-linear relationship of the variable stroke also indicates increased loading of the windmill rotor. In Figure 3, data show the hysteresis that occurs in the system as windspeed increases and the rotor speed slows due to furling of the rotor. The spring system did not exhibit hysteresis.

Hydraulic Variable Stroke

The flow rate at which water was pumped during the tests with the hydraulic variable stroke system is shown in Figure 5. The pumping lift was 30 m for both the standard and the variable stroke units. The standard unit began pumping water at a windspeed of 3.5 m/s and reached a maximum flow of 26 L/min at a windspeed of 10.5 m/s. The variable stroke unit began pumping at a windspeed of 4.0 m/s and reached a maximum flow of 46 L/min at a windspeed of 11.5 m/s. The pumping rate was almost doubled with the hydraulic variable stroke. Figure 6 shows that a slight increase in pumping speed was observed during these tests with the variable stroke unit and was unsteady in the furling range. Also, the variable stroke system as configured for these tests was not responsive enough at low windspeeds, thus causing the pump to operate slower than the standard unit. Fine tuning adjustments were needed with the needle valve to increase the number of strokes at the lower windspeeds and decrease the number at higher windspeeds.

The overall efficiency (wind power to water pumped) of both a standard windmill and the hydraulic variable stroke windmill is shown in

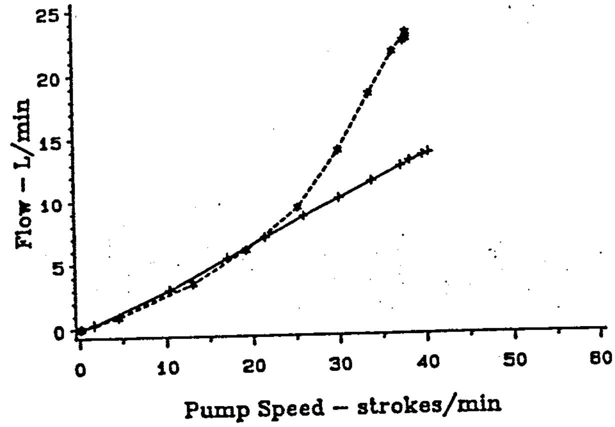

FIGURE 4. THE NON-LINEAR RELATIONSHIP BETWEEN PUMP SPEED AND WATER FLOW FOR THE SPRING-MASS VARIABLE STROKE MECHANISM AS COMPARED TO THE LINEAR RELATIONSHIP BETWEEN PUMP SPEED AND WATER FLOW FOR THE STANDARD WINDMILL PUMP.

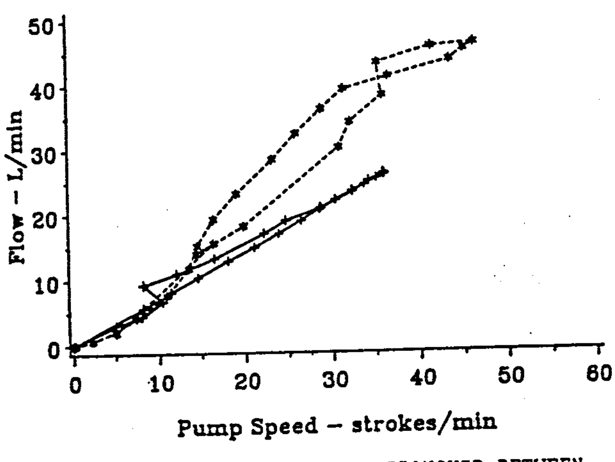

FIGURE 3. THE NON-LINEAR RELATIONSHIP BETWEEN PUMP SPEED AND WATER FLOW FOR THE HYDRAULIC VARIABLE STROKE MECHANISM AS COMPARED TO THE LINEAR RELATIONSHIP BETWEEN PUMP SPEED AND WATER FLOW FOR THE STANDARD WINDMILL PUMP.

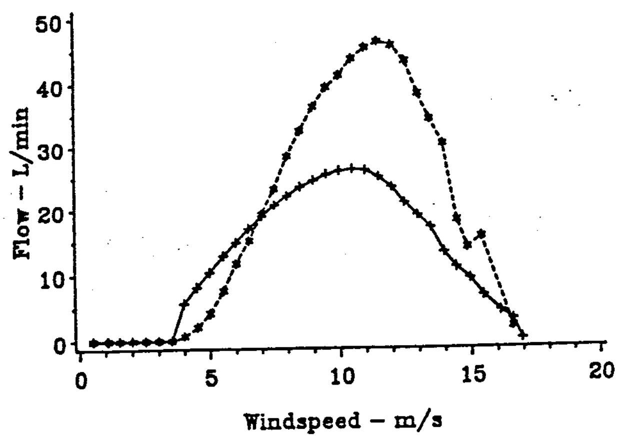

FIGURE 5. THE RATE OF WATER PUMPED AT DIFFERENT WINDSPEEDS FOR THE HYDRAULIC VARIABLE STROKE MECHANISM AND A STANDARD WINDMILL PUMP.

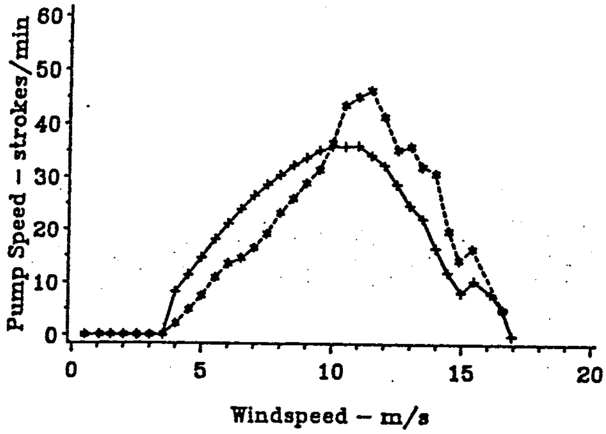

FIGURE 6. THE PUMP SPEED AT DIFFERENT WINDSPEEDS FOR THE HYDRAULIC VARIABLE STROKE MECHANISM AND A STANDARD WINDMILL PUMP.

Figure 7. The efficiency curve for the standard windmill shows a peak at 4.5 m\s windspeed and then declines to less than 1%. The efficiency for the variable stroke is much flatter and extends out to a higher windspeed, thus making the average efficiencies almost identical.

Spring-Mass System

The flow rate at which water was pumped during the tests with the spring-mass variable stroke system is shown in Figure 8. These pumps were smaller than the ones used for the hydraulic variable stroke comparison; therefore the pumping rates are less. Again, the pumping lift was the same for each pump. The peak flow for spring-mass system was 23 L/min at a windspeed of 10 m/s compared to a peak of 13 L/min at a windspeed of 10.5 m/s for the standard unit. This variable stroke system also pumped almost twice as much water as the standard unit at a windspeed of 10 to 11 m/s. The spring-mass

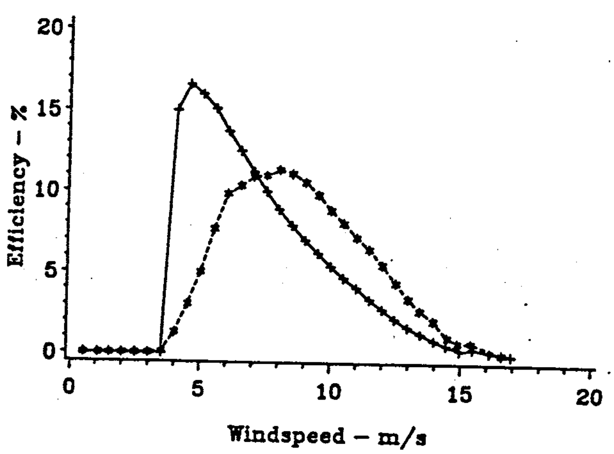

FIGURE 7. THE OVERALL EFFICIENCY (WIND POWER TO WATER PUMPED) FOR THE HYDRAULIC VARIABLE STROKE MECHANISM AND STANDARD WINDMILL PUMP AT DIFFERENT WINDSPEEDS.

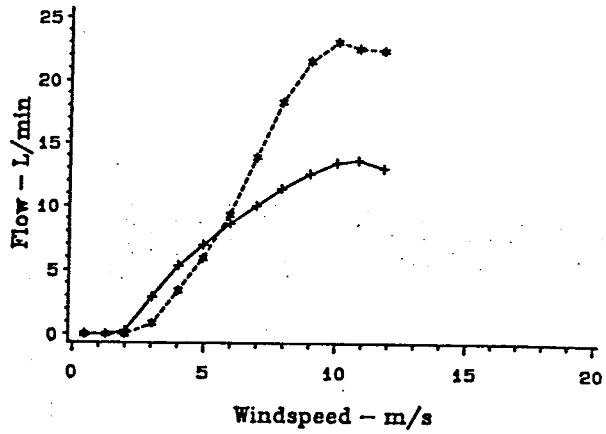

FIGURE 8. THE RATE OF WATER PUMPED AT DIFFERENT WINDSPEEDS FOR THE SPRING-MASS VARIABLE STROKE MECHANISM AND A STANDARD WINDMILL PUMP.

variable stroke system pumped slightly less water at low windspeeds, but greatly exceeded the standard unit at moderate windspeeds. Figure 9 shows that the pump speeds were almost identical for the test conducted. The slight difference at windspeeds of 3 to 4 m/s was caused by not having the mass exactly counter-balanced. Once the spring-mass system was moving, it moved at the same rate as the standard unit.

The curves of the overall efficiency (wind power to water pumped) are similar to the ones for the hydraulic variable stroke system, except that the levels are lower because of the pump size and smaller pumping lift (Figure 10). Again, the variable stroke system had a flatter efficiency curve, thus making the efficiency over all windspeeds average about the same.

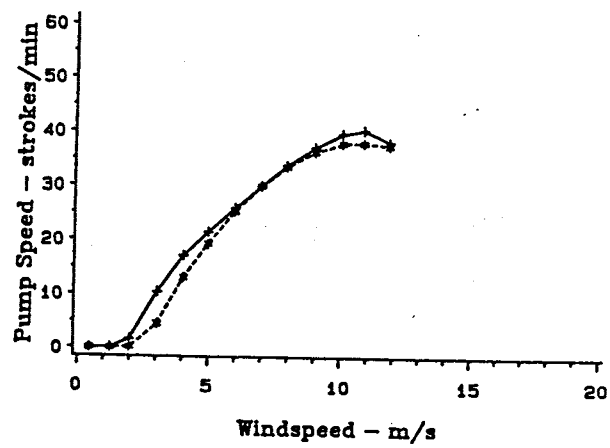

FIGURE 9. THE PUMP SPEED AT DIFFERENT WINDSPEEDS FOR THE SPRING-MASS VARIABLE STROKE MECHANISM AND A STANDARD WINDMILL PUMP.

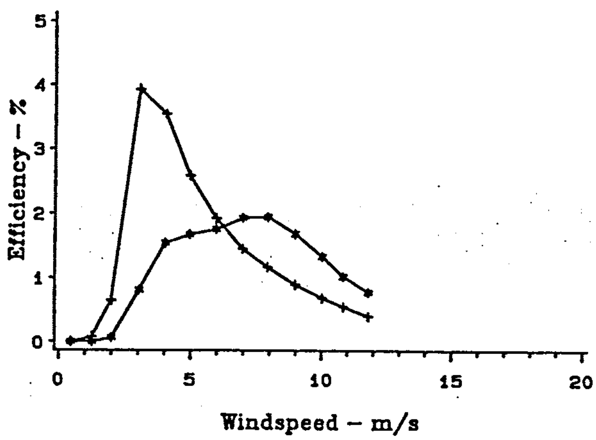

FIGURE 10. THE OVERALL EFFICIENCY (WIND POWER TO WATER PUMPED) FOR THE SPRING-MASS VARIABLE STROKE MECHANISM AND STANDARD WINDMILL PUMP AT DIFFERENT WINDSPEEDS.

SUMMARY AND CONCLUSIONS

Two variable stroke mechanisms were field tested on multibladed mechanical windmills and compared to standard windmills operating under the same windspeed and pumping conditions. A hydraulic system used two hydraulic cylinders, a pressure accumulator, an oscillating lever arm, and other hardware to increase the stroke length as the windspeed increased. The system increased the flow rate at a windspeed of 10 m/s from 26 L/min for the standard unit to 46 L/min for the hydraulic variable stroke mechanism. The spring-mass variable stroke system also showed an increase of almost twice as much water pumped at a windspeed of 10 m/s.

These tests clearly show the advantage of increasing the stroke length as windspeed increases. More water is pumped, the windmill continues to be loaded, and furling is delayed as compared to standard windmills. The spring-mass system is a simple solution for increasing the stroke length, but the mass and counter weight become significantly large for pumping depths of 30 m or more. The configuration of the hydraulic system needs additional study and design. We had problems with controlling the stroke length with a single-acting hydraulic cylinder and spring. A dual-acting hydraulic cylinder may provide better positioning of the lower pump rod in the oscillating lever arm. We feel that this hydraulic variable stroke system has the potential to greatly improve the performance of many mechanical water pumping windmills.

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REFERENCES

1. Avery, Don E. "Proven and projected improvements in wind powered pumping systems." Proc. of Windpower '88, AWEA, 1988, 25-31.

2. Harris, Elmo G. "Automatic regulator for wind-wheels." US Patent No. 617,877, 1899.

3. Kamand, F. Z., R. N. Clark, and R. G. Davis. "Performance evaluation of multibladed water pumping windmills." Proc. of Windpower '88, AWEA, 1988, 281-289.

4. Stockett, Wiley T. and Sessal D. Allen. "Variable stroke control windmill." US Patent No. 2,688,285, 1954.