THE HYDRAULIC WINDMILL*

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ABSTRACT

The hydraulic windmill pumps pressurized oil from rotor shaft level to the ground where a motor-generator produces electricity. Alternatively, the useful output may be heat. Rotor speed is governed by a flow valve. Over pressure, the result of high wind velocity, rotates the tail to move the rotor blades out-of-the-wind. Loss of oil pressure causes a brake to close as well as to swing the tail to its maximum distance from the rotor plane.

DISCUSSION

Advantages of the hydraulic transmission principle lie in the simplicity of rotor speed control and the governing of power output in higher-than-design wind regimes. These functions can now be obtained at low cost and high reliability.

We have made and tested two prototype models of 16-Ft. and 31-Ft. rotor blade diameter. Power outputs were determined by measuring oil flow and pressure. Specific power levels were sufficiently high to warrent the construction of the 71-Ft., two-bladed, horizontal rotor axis machine presently undergoing tests on a high ridge in Lebanon, N.H. (see Figure 1).

We had, initially, selected a downwind rotor position. Later, due to information released by the N.A.S.A. concerning unduly high cyclical rotor shaft torque stresses, we switched to the upwind rotor position with conventional tail.

The design shown in Figure 2 provides a crank-arm at the end of the rotor shaft to power a double-acting hydraulic cylinder. Full-wave rectification of this flow is made by four check valves attached to cylinder ports. The oil passes through the vertical mast about which the windmill rotates to face the wind. The sole rotating seal is the cylinder piston. (In other cases other types of pumps could be used.)

The pressurized oil passes to the ground where pressure variations are damped by a high-pressure accumulator. The pressure-compensated flow control valve limits the maximum oil flow rate to provide a constant rotor speed. A properly sized hydraulic motor drives the generator at the correct speed. Several hydraulic windmills may be operated in-parallel to power a single generator.

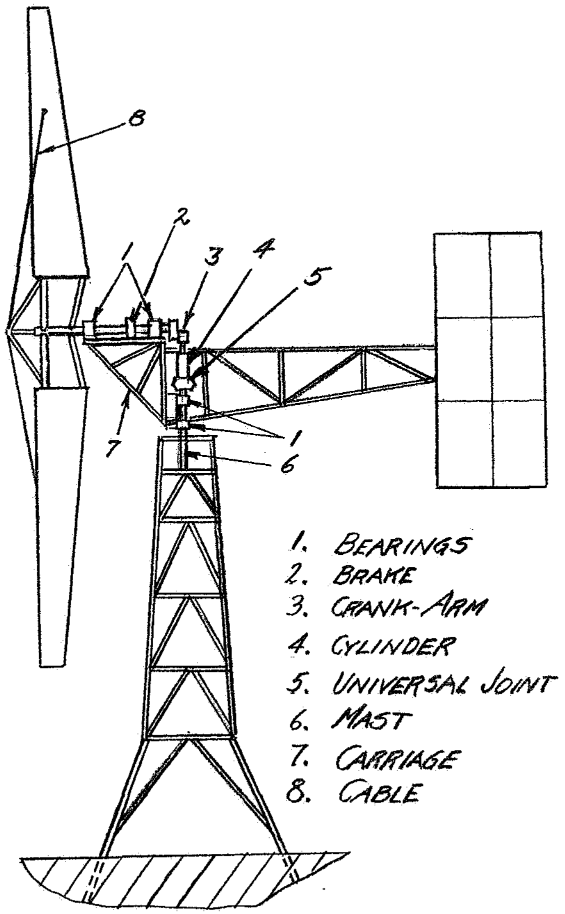

FIG. 1 - MAJOR ELEMENTS OF THE HYDRAULIC WINDMILL

From the motor the oil passes to a low-pressure accumulator pre-charged with nitrogen to a pressure sufficient to lift the oil to the cylinder and to power the tail-governor and safety devices.

Other components of the hydraulic circuit of Figure 2 include a manual shut-off valve which, when closed, assures an effective braking action to the allowable pressure rating of the hydraulic elements. Increase of pressure above this is limited by a pressure relief valve. A water pump

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or other mechanically powered device may be substituted for the generator.

Figure 3 illustrates an alternative design which produces heat in place of mechanical energy. Rotor speed is limited by controlling the differential flow from the cylinder. The increased amount of flow on the piston down-stroke (equal to the rod displacement volume) must pass through the flow control. A desurger is required to provide smooth valve action. As accurate speed control is not necessary, the cost of a windmill producing heat is much less than that generating electricity. Efficiencies are much greater as losses in the circuit appear as useful output--heat. We estimate that a given size windmill will produce about 60% more energy when the output is heat rather than electricity.

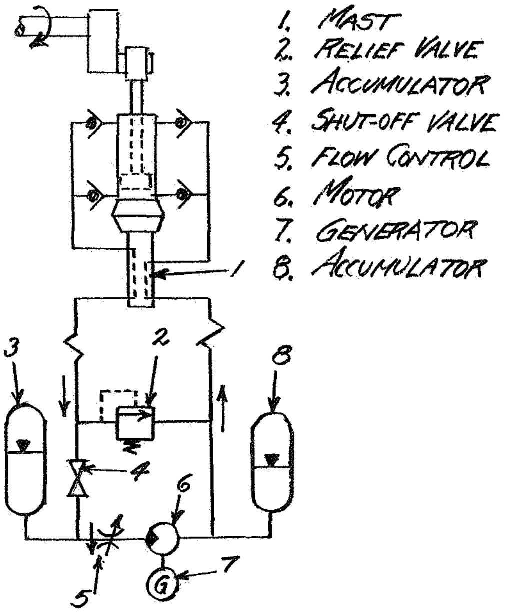

FIG. 2 — THE HYDRAULIC CIRCUIT FOR GENERATING ELECTRICITY

To make a windmill heat generator practical, means should be available for heat storage during the summer for cases where the heat is only utilized during cold months. Storage in the ground appears feasible. Several groups are studying the use of relatively non-permeable aquifers for heat storage.

In solid rock such as granite each 100 feet of 8-inch diameter well bore will accept over 5 KW of heat. Thus, 50 KW of heat can be "pumped" into rock using 5 wells each somewhat over 200 feet deep and spaced correctly apart. The total heat stored over a 7-month season by a 71-Ft. windmill in a region of adequate wind speeds amounts to nearly 80,000 KW-HR. It is thought that over 80% of this becomes available for later use. This is the equivalent of 2,000 gallons of oil burned in a boiler. To this should be added the heat generated during the 5 winter months.

Although this heat analysis is only speculative at this point, this use of wind energy must not be overlooked. In place of the heat equivalent of 2,000 gallons of oil the windmill would have produced about 50,000 KW-HR of electricity during the same 7-month period. At $1.20/Gal of oil the heat savings are $2,400. At $0.05/KW-HR the electric savings amount to $2,500. The heat-producing unit is less expensive than for electricity. Thus, heat generation could be the best use of the hydraulic windmill.

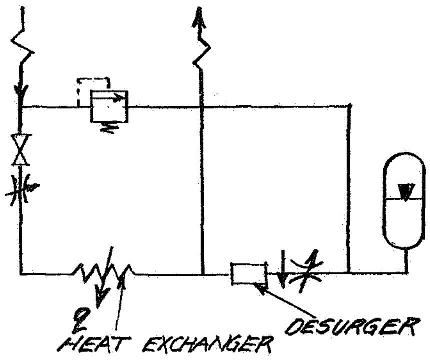

FIG. 3 - HYDRAULIC CIRCUIT FOR HEAT OUTPUT

Where speed control is governed by an impedance in the hydraulic circuit, maximum power output may be limited by matching the average peak oil pressure to a fixed pressure of lower value. This type of governor is sketched in Figure 4 where low and high-pressure cylinders are shown attached to the carriage. The tail support arm can move horizontally about a bearing mounted on the carriage. Oil pressure in the lower cylinder cavity is transmitted through a rifle drill hole.

The low-pressure cylinder "sees" the low-pressure accumulator pressure less the hydrostatic pressure drop in the oil column. A 4-inch diameter cylinder operating at a net pressure of 50 PSIG applies a force of 630 pounds against the movable tail. This force will keep the tail in the "running" mode until a greater counterforce is produced by the high-pressure cylinder. Selecting a cylinder having a 1-inch effective area on its rod side, an average operating peak pressure above 630 PSIG will commence to move the blades out-of-the-wind. When this high maximum pressure drops due to a lowering of wind velocity the adjustable valve allows the tail to move toward its "running" position.

It is, of course, always possible that the hydraulic circuit could lose a large amount of oil by line leakage or damage to an element. The operation of both speed and power governors would cease. A "fail-safe" mechanism has been incorporated into the design. The tail rotates into its "running" position only when a set oil pressure value is exceeded. Below this, a counterweight (not shown in the figures) pulls the tail to its furthest position from the rotor axis. In addition, the brake mechanism is activated automatically. The brake is also designed to operate when undue vibrations are sensed by a weight held in unstable equilibrium.

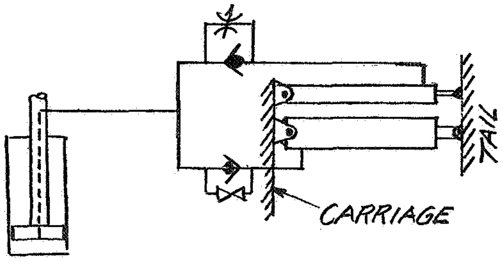

FIG. 4 - TAIL GOVERNOR

CLOSURE

The design of the 71-Ft. hydraulic windmill has attempted to reduce costs while maximizing reliability. These considerations preclude the use of feathering blades, limit the number of blades to two, and reduce communication between rotating structures and the ground to the oil column itself. Judgement of the relative success of these design parameters must await results of the testing period which is only now commencing.

QUESTIONS AND ANSWERS

J.A. Browning

From: J. Tangler

Q: For heating, how does your rotor load match compare to a system using a heat churn? Also, which approach do you consider more cost effective and why?

A: *Larger amounts of heat can be handled easily. In addition, positive speed control and overpower condition control are inherent. Mechanical output, or electric, is possible. I believe the hydraulic unit more cost effective.*

From: A.D. Garrad

Q: How lossy do you expect your hydraulic transmission to be?

A: *About 80% for a cylinder pump-to-motor combination for shaft power production. Nearly 95% for heat using generous amounts of thermal insulation.*

From: J.A.C. Kentfield

Q: What is the blade airfoil section? Do you require a high torque-at-low-speed characteristic?

A: *We have used a delta cross-section blade realizing higher efficiency would have resulted with other designs. It was simpler to construct. High torque-at-low speed characteristic is best.*

From: F.S. Stoddard

Q: Do you have any idea what the overall transmission efficiency is?

A: *Answered above.*

From: R. Shaltens

Q: What is blade construction? What diameter? kW output?

A: *Steel tube truss design with cross-bracing. Tubing covered with plywood which, in turn, has fiberglass-epoxy coating. The rotor diameter is 72 ft. We have designed for about 20 kW in a 15 mph wind.*

From: F.W. Perkins

Q: How much does the machine cost, especially compared to an electric machine?

A: *Considerably less. Speed control accuracy is not required. Also, the high-pressure accumulator, hydraulic motor, and generator are absent. Absolute cost figures for commercial designs in large quantities cannot, yet, be estimated.*

From: Anonymous

Q: What airfoil section is used for the rotor blades?

A: *Answered above.*

From: W.C. Walton

Q: Do you think the failures Waldron showed were due to lack of sophistication or to failure to apply basic engineering?

A: *Lack of sophistication probably results in lowering overall efficiency values--not to the failures reported. Basic engineering includes good design, model making and testing, and redesign. The large amount of funding (internal or external) has not been available to small, new organizations. Certainly a small windmill can achieve optimum design more easily than a large one. Sponsors have skipped this important step of a well thought out engineering program. Perhaps, they should have included this step rather than placing the blame elsewhere. Listening to the majority of the presentations it becomes evident that a major conceptual advancement can only come from the engineering entrepreneur.*