JULY 1981

MASTER

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**HYDRAULIC WIND ENERGY
CONVERSION SYSTEM**

**REPORT SUBMITTED TO THE DEPARTMENT OF ENERGY,
APPROPRIATE TECHNOLOGY DIVISION,**

BY

**JACOBS ENERGY RESEARCH, INC.
(JERICO)**

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

ep

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	PAGE
SUMMARY.....	1
DESCRIPTION AND PROCEDURE.....	3
RESULTS.....	5
CONCLUSION AND SUGGESTION.....	6
APPENDIX.....	8-9
(A) SAMPLE CALCULATIONS.....	8
(B) GRAPHS, DIAGRAMS, TABLES.....	9

SUMMARY

The purpose of this research was to design, build and test a hydraulic wind energy system. This design used a three bladed turbine, which drove a hydraulic pump. The energy is transmitted from the pump through a long hose and into a hydraulic motor, where the energy is used. This wind system was built and tested during the winter of 1980-1981.

The power train included a five meter, three bladed wind turbine, a 9.8:1 ratio gearbox, a 1.44 cubic inch displacement pump with a small supercharge gear pump attached.(Fig. 5) The hydraulic fluid was pumped through a 70', 3/4" I-D-high pressure flexhose, then through a volume control valve and into a 1.44 cubic inch displacement motor. The fluid was returned through a 70', 1" I-D-flexhose.

The whole assembly was placed on a flatbed trailer and pulled down the road under various conditions.(Fig. 6) We found the output at various windspeeds and the windspeed needed for starting.

The overall efficiency of this system was acceptable. The wind-speed needed for starting was much higher than expected, largely because of the pressure developed in the supercharge line.

As a result of this research, JERICO feels that this system would not be practical to market in the small output range; especially when converting the wind energy to electricity. The three basic reasons for this are as follows:

1. The higher windspeed needed for start up
2. The extra cost of materials involved
3. The greater inefficiency introduced.

There may still be a use for hydraulic power transmission in the wind market for larger systems, especially direct water or space heating.

DESCRIPTION AND PROCEDURE

The testing was done by assembling the system on a flatbed trailer and pulling it over a road behind a pickup. This testing method introduced error because of the wind turbulence coming off the truck. When we compared this trailer method of testing our D.C. generator vs. actual tower operation, we found, suprisingly a slightly higher output on the trailer. This could be due to error in the measuring instruments (pickup speedometer, etc.) or increase in windspeed as it passes over the truck. Also, the highest windspeed we could obtain was about 28-30 mph, because of the instability of the assembly, the bumps in the road and the overhead wires. (We tried to obtain use of the local runway, but were refused permission.)

We measured the rotational speed of the turbine with a bicycle speedometer attached to the low speed shaft. The speedometer mph reading was calibrated into RPM's. Some error was introduced due to the vibration in the needle.

A dummy load was applied to the hydraulic system by controlling the line pressure with a volume control valve placed in front of the hydraulic motor. (Fig. 7) Knowing the rotational speed of the shaft and the pressure in the line, we found the power output of the pump.

Eight test runs were made over a period of three weeks. We were able to get useful data from four of the runs. During each test we recorded shaft RPM and windspeed. We also tested for start up windspeed under various conditions of the hydraulic system and various positions of the blade governor.

The governor can be set at the blade pitch for a higher torque starting position or at the normal operating pitch. (Fig. 8) This was checked for the effect on start up windspeed.

Initially, we had hoped to test for the effect low temperatures had on start up windspeed. However, because of the warm winter and the lateness of season when we started testing, the temperatures never fell below 10 degrees fahrenheit. As a result, the temperature played no significant part in windspeed needed for start up.

RESULTS

The power curve of the hydraulic wind system is given in Appendix B, Fig. 2. This shows the efficiencies of the system up to the volume control valve to be quite acceptable. If we were to go through the hydraulic motor and generator for producing electricity, another 25% would be lost. This makes the power curve less attractive.

Plotted in Fig. 3, is the maximum theoretical output of a 5 meter turbine system; the measured output from the trials and the output assuming 25% loss in the hydraulic motor and electrical generator.

The chart of start up windspeed under various conditions of the governor and hydraulic system is given in Fig. 4. This shows that under most operating conditions, the start up windspeed for this system would be unacceptable. This is largely due to the quick pressure buildup in the supercharge line. If the line starts empty, the start up windspeed is acceptable (10-13 mph) with the governor in the high torque position. If the supercharge line is full, but under no pressure, the start up windspeed is much higher; nearly 20 mph. If some pressure is built up, the start up windspeed approaches 30 mph.

CONCLUSION AND SUGGESTIONS

JERICO has found from this research, that a hydraulic drive train can be used in conjunction with a wind turbine for production of usable energy. There are several advantages with hydraulics, which are listed below:

1. Low maintenance and light weight on tower top
2. Speed control and constant output
3. Readily available hardware

We have also found several problems with hydraulics, which are listed below:

1. Introduction of inefficiencies (approximately 20% for a highly efficient system and up to 40% for a low efficiency system)
2. Added cost - from \$500 to \$2,000 per system
3. Higher start up torque needed

The problem with high start up windspeed can be solved by an automatic drain on the supercharge line or getting rid of the supercharge pump. This latter method might decrease the efficiency of the system, and could cause cavitation at the inlet port.

This research suggests that for generating electricity, especially for smaller machines, a hydraulic drive train is not practical. This is due to the extra cost introduced and the added power losses. As the size of the machine increases, these drawbacks may become less significant and the advantages may be more prominent.

Another use for a hydraulic wind system may be in the area of space and water heating. This would solve several of the following problems associated with hydraulics:

1. Expense - the much less expensive gear pump could be used.
2. Efficiency - most all inefficiencies are converted to heat. If the system is kept well insulated, all energy could be changed to heat.
3. High start up windspeed - the research suggests that without the supercharge pump, start up windspeeds are acceptable. This would be possible with a low cost gear pump.

More work should be done in the area of low temperature operation.

JERICO intends to continue the research with hydraulic wind systems, both in the area of heating and large electrical systems. This will be done on a limited basis over the next few years.

APPENDIX A

SAMPLE CALCULATIONS

1. Given pressure and rotational speed of turbine shaft, find the output in KW of pump.

eq. 1. $HP = (RPM) (Displacement) (Pressure) (2.52 \times 10^{-6})^*$

eg. turbine shaft speed equals 150 RPM

9:81 gear ratio on gearbox

∴ pump shaft speed equals $(150) (9.8) = 1470$ RPM

pump displacement = 1.44 in. /rev.

pressure = 700 psi

substituting in eq. 1

$$\begin{aligned} HP &= (1470) (1.44) (700) (2.52 \times 10^{-6}) \\ &= 3.73 \end{aligned}$$

$$KW = (.746) (HP)$$

∴ output in KW = $(.746) (3.73)$

$$= 2.8 \text{ KW}$$

*derived from equations found in "Fluid Power Designers
Lightening Reference Handbook" Fourth Ed.

APPENDIX B

CHARTS, GRAPHS AND DIAGRAMS

OUTPUT

TRIAL DATE AND TIME	WINDSPEED MPH CORRECT FOR PREVAILING WIND	LINE PRESSURE PSI	RPM TURBINE/PUMP	OUTPUT KW
1. Feb. 23 5:00 PM	15	400	100	1.1 KW
	20	700	150	2.8 KW
	25	1050	200	5.5 KW
2. Feb. 24 3:00 PM	15	450	100	1.2 KW
	20	750	150	3.0 KW
	25	1200	200	6.3 KW
3. Feb. 27 9:00 AM	15	400	100	1.1 KW
	20	700	150	2.8 KW
	25	1100	200	5.8 KW
4. March 3 9:00 AM	15	400	100	1.1 KW
	20	700	150	2.8 KW
	25	1100	200	5.8 KW

Fig. 1 - Data from four trials

Fig 2

Fig 3

FIG. 4 START UP WINDSPEEDS

TRIAL DATE AND TIME	START UP WINDSPEED CORRECTED FOR PREVAILING WIND	HYDRAULIC LINE CONDITION		GOVERNOR POSITION
		MAIN	SUPERCARGE	
1. Feb. 23 11:00 AM	13 mph	No Load Empty	Empty	High Torque
2. Feb. 23 5:00 AM	15 mph	No Load Empty	Empty	High Torque
	20 mph	No Load Empty	Empty	Low Torque
3. Feb. 24 3:00 PM	20 mph	No Load Full	Full	High Torque
	25 mph	No Load Full	Full	Low Torque
4. Feb. 27 9:00 AM	22 mph	No Load Full	Full 20-30psi	High Torque
	28 mph	No Load Full	Full 20-30psi	Low Torque
5. March 9:00 AM	25 mph	No Load Full	50 psi	High Torque
	No Start	No load Full	50 psi	Low Torque

Fig 5-Power Train

Fig 6-Test set up

Fig 8-Volume control valve

A

B

C

Fig 8 - Blade pitch change: A-High torque start; B-Normal operating position; C-Governing position

5 KW Wind Generator

ROUTE 1, Box 1710
 ADDISON, MINN. 56511
 DENNIS JACOBS
 1-218-488-6071

HC. 10/29/80
 CLINT

Fig 9- Schematic of hydraulic system