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## THE BRAKE SYSTEM FOR THE 17 METER VERTICAL AXIS WIND TURBINE

Curtis W. Dodd and William N. Sullivan

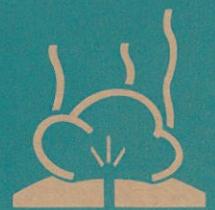
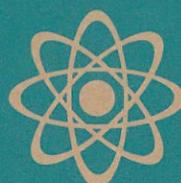
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THE BRAKE SYSTEM FOR THE 17 METER VERTICAL AXIS WIND TURBINE

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and  
William N. Sullivan - 5715

ABSTRACT

This report describes the hydraulic brake system on the 17-Meter Vertical Axis Wind Turbine, VAWT, located at Sandia Laboratories. A discussion of the design philosophy and operating procedure is given. Design details and a functional description of system components are included in this report.

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#### ACKNOWLEDGEMENTS

The turbine's hydraulic brake would not be installed and properly operating if it were not for the help of other individuals. Carl Longfellow, Robert Grover, and Ralph Rusk of 5715 were involved in the procurement and installation of the major mechanical parts of the braking system. Doyle Earnest and Gilbert Aragon of 9713 installed the high pressure lines and fittings. Tom Kain of 9563 fabricated the electrical controls. The conscientious support provided by these people is appreciated.

## 1.0 INTRODUCTION

The hydraulic brake system for the 17-M VAWT consists of a proportional brake and an emergency/parking brake. Under normal operating conditions the proportional brake is used to stop the turbine. If a situation exists which requires an immediate stop or if the proportional brake should fail for any reason, the emergency/parking brake can be applied by pushing one of the red mushroom push buttons located on site. If power to the brake system or motor/generator controls is lost the emergency brake is automatically actuated.

The emergency brake is designed as a passive system and it remains functional with or without power at the site. It also responds much more quickly than the proportional brake. The rapid brake response does, however, strain the turbine and so emergency brake use should be restricted to testing and actual emergencies.

Schematics of the brake hydraulic and electrical systems are given in Section 2.0. In order to assure that the brake system be used properly in conjunction with the electrical motor/generator controls the procedure contained in Section 3.0 should be used. Section 4.0 contains a summary of data on the major brake system components.

## 2.0 BRAKE DESCRIPTION

The brake system consists of the pump, the calipers and discs, and the electrical controls. This section contains schematic diagrams of the complete brake system as well as photographs of installed equipment.

### 2.1 Brake Hydraulic System

A schematic diagram of the hydraulic system is shown in Fig. 1. There are two sets of four calipers driven by the hydraulic system, one set for each brake disc. The left caliper set in the schematic is for the proportional brakes, and may be activated from the console over a continuous range of pressures from about 150 psi to 1800 psi. The right caliper set is for the emergency/parking brake; its calipers are powered by hydraulic fluid stored at a nominal pressure of 1200 psi in a bladder type nitrogen/oil accumulator. The emergency/parking brake is totally passive and remains functional even with no power at the site.

The design maximum pressure for this system is 2000 psi and care should be taken to avoid exceeding this pressure, as seal failures and leaks may result.

The proportional and emergency brake hydraulic systems are almost completely independent. The only connection between the two is through the normally closed balance valves. These valves permit using the proportional brake hydraulic system to charge the emergency brake hydraulic accumulator to its operational pressure.

The proportional brake portion of the brake system was designed and components supplied by the Wild Company in Denver, Colorado. There are three major components: a Vickers hydraulic pump, a remotely modulated relief valve, and a solenoid activated proportional brake release valve.

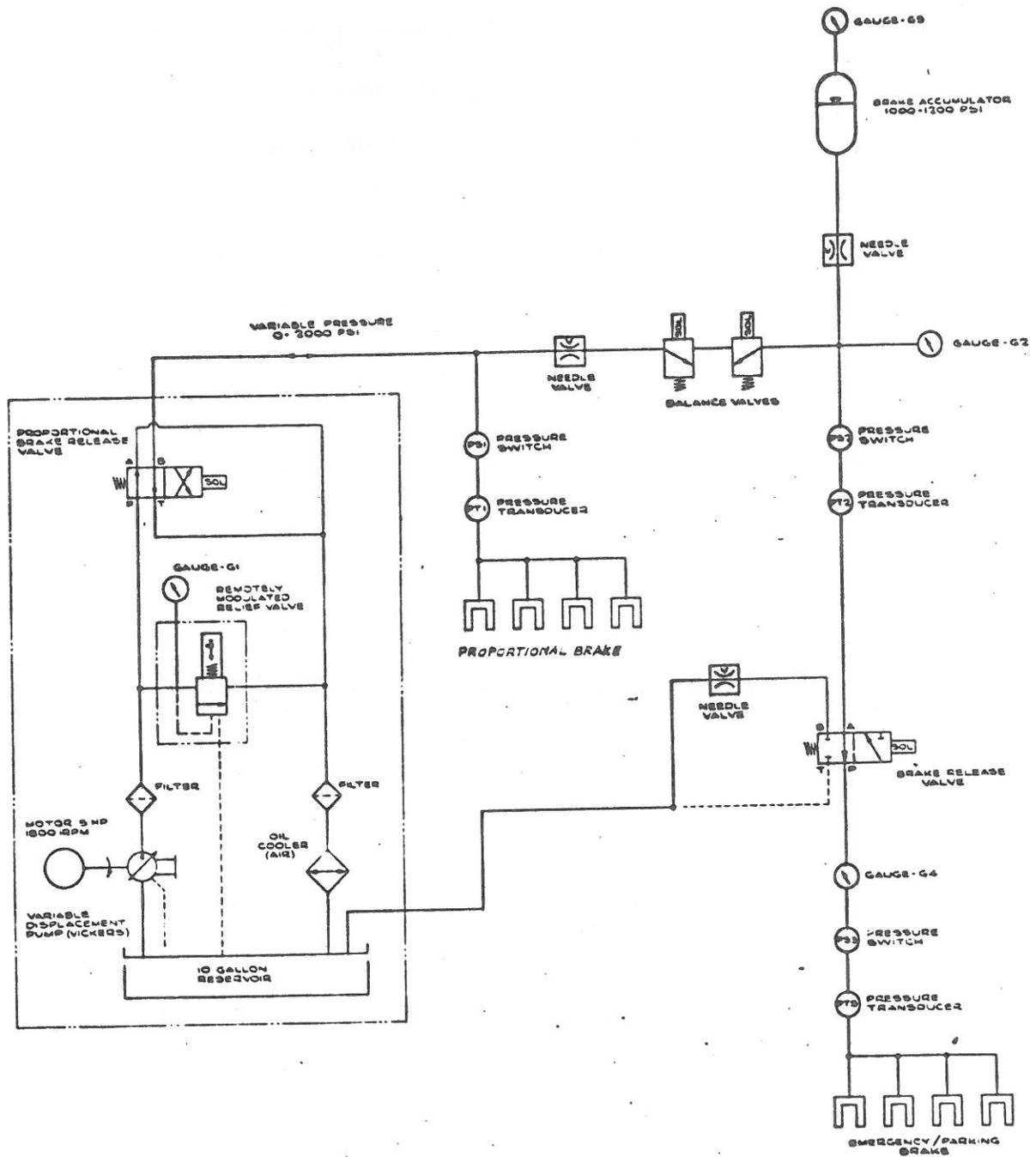


Figure 1. Schematic of Hydraulic System.

Pressure in the system is regulated by the modulated relief valve which is connected between the high pressure side of the pump and the fluid reservoir. The relief valve provides a variable flow resistance between the pump output and the reservoir and thereby varies the pressure of the pump output. The pump output pressure is monitored by gauge G1. The modulated relief valve is controlled by a variable current source operated from the console. The relief valve provides a range of pressures from about 150 to 2000 psi, the exact range depending on the displacement setting of the pump.

The solenoid activated proportional brake release valve is provided to insure that the pressure in the proportional system falls to zero when the pump is shut off. The normal position for this valve shorts the pump output and the brake line directly to the reservoir. When the release valve is activated, the pump output is connected directly to the brake line. The electrical system is wired so that the brake release valve is activated whenever the pump is turned on and is deactivated otherwise.

The pump is a Vickers variable displacement type, driven by an 1800 rpm induction motor. The pump operates at a fixed displacement, but the displacement may be adjusted with a handwheel on the pump body. This provides a flowrate adjustment for the pump between 0 and about 6 GPM. Increasing the flowrate tends to raise the entire range of proportional brake pressures; the handwheel is normally left at a fixed position which provides enough displacement to self start the pump, but not enough to exceed a pressure of 2000 psi. The pressure switch, PS 1, and pressure transducer, PT 1, are used for monitoring and controlling the proportional brake system from the console.

The major components for the emergency/parking brake system are the accumulator, the brake release valve, and the balance valves.

The accumulator (Vickers type A1-2050-20) is a vertical cylinder with approximately 10 gallon internal volume. The cylinder contains a bladder which is filled with nitrogen gas. Hydraulic fluid introduced to the lower portion of the cylinder may be stored under pressure by compressing the bladder. Because of the compressibility of nitrogen and the large volume of the accumulator, hydraulic fluid may be released to activate the calipers with relatively little loss of pressure.

The performance of the accumulator is a function of the hydraulic fluid pressure and the bladder precharge pressure; i.e., the nitrogen pressure when all the hydraulic fluid is drained. Performance curves are shown in Fig. 2. The point indicated on Fig. 2 is for currently used

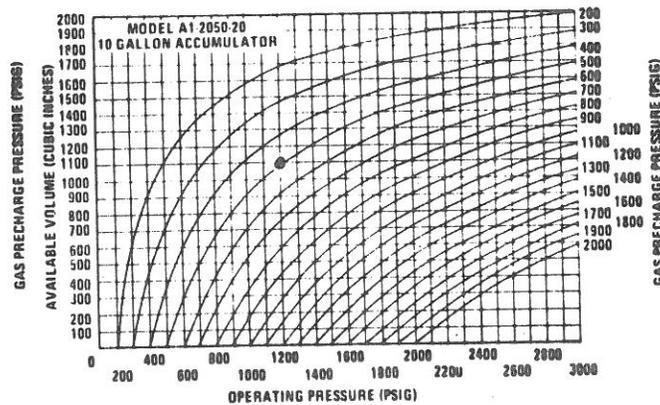


Figure 2. Accumulator Performance Curves.

nominal conditions with a precharge pressure of 500 psi and a working pressure of 1200 psi. The accumulator will contain approximately 1100 cu. in. (4.6 GAL) of fluid under these conditions. As hydraulic fluid is withdrawn, the pressure will fall along the lines of constant precharge pressure shown in the figure. Note that by changing the bladder pressure, the volume of hydraulic fluid in the accumulator, or both, a wide range of operating pressures may be realized.

The brake release valve is solenoid controlled and in the power off position connects the accumulator hydraulic side to the calipers. Activating the valve isolates the accumulator and opens the calipers to the reservoir, thus freeing the disc. The needle valve in the return line is to prevent hydraulic hammer in the lines upon brake release. The brake is applied by de-activating the release valve. The shock of the application is attenuated by the needle valve on the accumulator hydraulic side. Each application of the brake draws fluid from the accumulator to move the caliper pads from their retracted position to contact with the disc. For all four calipers, this amounts to approximately 40 cu. in. of fluid. From Fig. 2, this will result in an accumulator pressure loss of approximately 40 psi per brake application.

The transfer of fluid from the accumulator to the reservoir which occurs with each braking cycle necessitates periodic recharging of the accumulator. This is effected by starting the brake pump, adjusting the proportional brake pressure to exceed the accumulator pressure, and activating the balance valves. This will cause fluid to be pumped from the reservoir to the accumulator. Two balance valves are used because the type available only restrict flow in the direction of the arrows

when closed, and thus two valves are required to isolate the emergency and proportional brake systems.

Three bourdon tube gauges (G2, G3, and G4) are provided to monitor accumulator gas pressure, accumulator hydraulic pressure, and brake line pressure, respectively. A pressure transducer (PT 2) and two pressure switches (PS 2 and PS 3) are for console control and monitoring of the system.

All the components in the hydraulic system, except for the calipers and connecting hydraulic lines are located in the power shack on the turbine pad. In the power shack, a ten gallon hydraulic reservoir, proportional pump and motor, and a valve rack are mounted as a single unit. The valve rack has all the valves discussed above with the exception of the balance valves, which are in the hydraulic line between the valve rack and the accumulator. The accumulator is mounted vertically adjacent to the valve rack. A photograph of the complete system is shown in Fig. 3.

## 2.2 Brake Hardware Performance Characteristics

The braking system has two parallel discs mounted just above the turbine base structure on the main shaft of the turbine. The discs were machined from mild steel and are 36" diameter and 1" thick. The upper disc is devoted to the proportional brake system and the lower disc to the emergency brake.

Each disc has four calipers connected hydraulically in parallel. The calipers are "shelf" items manufactured by Kelsey-Hayes (model Number 2500 H). The only modification made to these calipers is the addition of

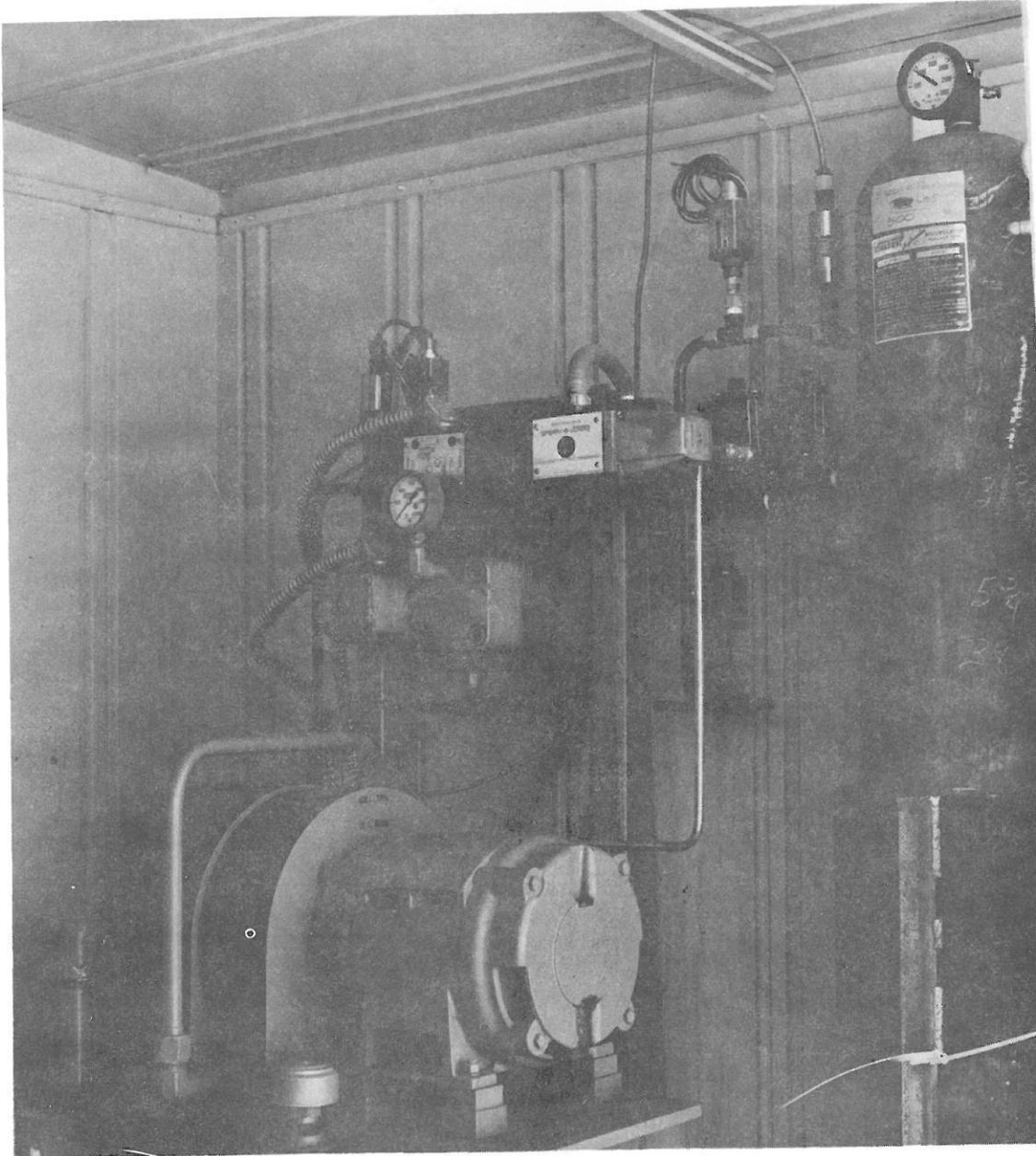


Figure 3. Brake Pump and Accumulator

return springs on the friction pads to prevent drag on the discs during turbine operation.

The torque capability of each disc with four calipers is shown as a function of pressure in Fig. 4. This curve is extrapolated from Kelsey-

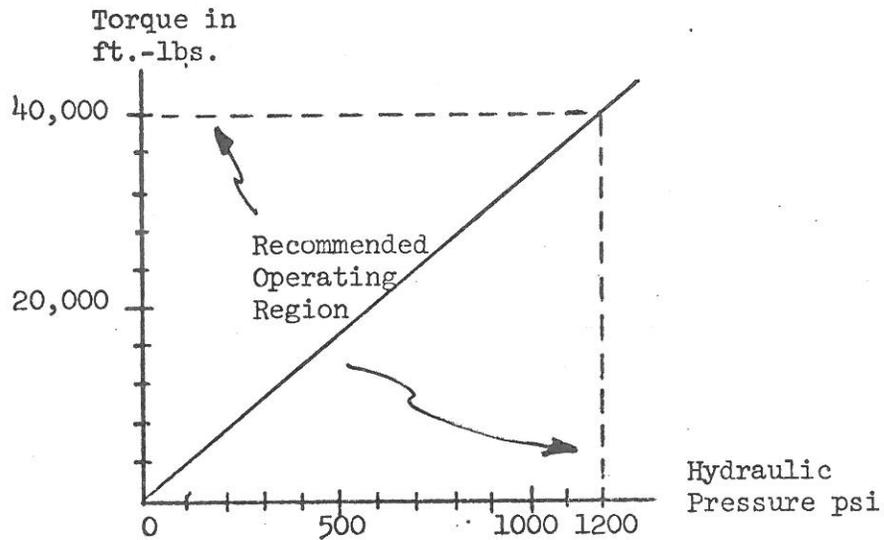


Figure 4. Torque Capability of Brake Discs

Hayes data for a single caliper acting on a 30" disc. The extrapolation assumes that braking torque is proportional to the number of calipers and the disc radius.

The actual braking torque required to stop the turbine depends on the aerodynamic torque applied. The maximum possible aerodynamic torque is a function of the turbine rpm. Table 1 indicates these aerodynamic torques and a recommended minimum brake torque for various turbine speeds. Also indicated are turbine stopping times for brake torques set at the recommended minimums. These times are calculated for a no-wind condi-

Table 1. Brake Torque Requirements

Turbine RPM	Maximum Aerodynamic Torque (Ft-Ibs)	Minimum Recommended Braking Torque (Ft-Ibs)	Minimum Req'd Hydraulic Pressure (PSI)	Stopping Time (SEC) @ Recommended Torque	Minimum Stopping Time (SEC) Three Blade
75	39,375	47,250	1,430	3.3	5.0
60	25,200	30,240	920	4.2	6.4
55	21,175	25,410	770	4.5	6.7
50	17,500	21,000	640	5.0	7.5
45	14,175	17,010	510	5.5	8.2
40	11,200	13,440	407	6.2	9.3
35	8,575	10,290	310	7.1	11.0
30	6,300	7,560	229	10.0	15.0

tion. Worst case wind conditions will approximately double the stopping times.

Note that the nominal setting of 1000-1200 psi in the emergency brake accumulator will provide enough stopping power for any turbine rpm below 60. Should there be any reason to run above 60 rpm, the accumulator pressure should be raised accordingly.

### 2.3 Electrical Control System

The electrical controls consist of brake actuating relays, interlocks with the motor/generator controls, and alarms. The operating procedures in Sections 3.1 to 3.3 describe the function of the electrical components mounted on the control panel. The relays and transducers used in conjunction with these make up the brake control system.

A schematic of the brake control panel is shown in Fig. 5. Rather than go through a step-by-step sequence of the relay actions, Table 2 describes the function of each relay. The items not contained in this table include the pressure and disc temperature transducers. These transducers are part of the control system and information about them is contained in Section 4.0, Manufacturer's Data.

All the system relays and controls are located behind the main control panel in the control building.



Table 2. Brake Control System Components

	<u>FUNCTION</u>
	<u>BRAKE COMPONENTS</u>
BAPBL,2,3	Brake Apply Push Button
BPPB	Brake Release Push Button
BRR1	Brake Release Relay One
BRR2	Brake Release Relay Two
BRTDR	Brake Release Time Delay Relay
DTAR	Disk Temperature Alarm Relay
ERAR	Emergency Brake Alarm Relay
EBPB	Emergency Brake Pressure Buzzer
PRAR	Proportional Brake Alarm Relay
PBB	Proportional Brake Buzzer
PBR	Proportional Brake Relay
PERPB	Proportional Buzzer Release Push Button
POBR	Power On Brake Relay
SNS	Sync Normal Switch

Pushing any of these normally closed push buttons applies the emergency/parking brake. The brake will stay on, but can be released at any time by pushing the Brake Release Push Button, BRPB.

This is used to release the emergency/parking brake. The brake will stay released for 1.8 to 180 seconds as set on the Brake Release Time Delay Relay, BRTDR.

Contacts 3 and 1 of this relay are an interlock for the Brake Release Push Button. When contacts 7 and 6 go to the closed position, the emergency brake is released for 1.8 to 180 seconds.

When this relay is energized, power goes to the brake release valve and a fault condition is removed from the main turbine motor/generator controls.

Determines the amount of time the emergency brake will be released. It is adjustable from 1.8 to 180 seconds.

If the proportional brake disk temperature exceeds 800°F when the pump pressure is 200 psi or greater, this relay causes the proportional brake buzzer to sound.

If the accumulator pressure drops below 1000 psi, this relay actuates the Emergency Brake Pressure Buzzer and Emergency Brake Pressure Low Light.

Sounds when pressure in accumulator is below 1000 psi.

Is energized when the proportional brake pressure is above 200 psi. The proportional brake buzzer sounds when this relay is energized.

This buzzer is on when the proportional brake pressure is above 200 psi.

When the relay is energized, power to the motor and generator is shut off. Contacts 9 and 11 release the emergency brake.

The proportional brake buzzer is shut off when the button is depressed.

Unless this relay is energized a fault shows up on the turbine motor/generator control panel and the motor cannot be started.

When in the normal mode with the proportional brake pressure above 200 psi, the motor and generator are disconnected from the power line. In the sync mode with the proportional brake used for speed control the motor and generator remain connected to the line.

### 3.0 OPERATING PROCEDURE

Operating the brakes consists of using the proportional brake for routine stopping and synchronizing, charging the accumulator, and applying and releasing the emergency parking brake. A picture of the brake control panel is shown in Fig. 6.

Three power supplies are required for normal operation of the brake system. The control panel requires 110 VAC and a DC source for the pressure transducers. Three phase 220 VAC is required to operate the hydraulic pump. The blue light on the panel labeled MODULATOR VALVE indicates that the 110 VAC is available. The pressure dial for the brake accumulator should read around 1000 psi if the DC supply is on. The three phase 220 VAC is on if the proportional brake pump light comes on after pushing the pump "ON" panel button. The 110 and 220 AC power is controlled by the breakers located in the control building circuit box on the south wall. The DC supply is in the anemometer instrument rack in the east end of Bldg. 899.

#### 3.1 The Proportional Brake

The section will describe how the proportional brake can be used for normally stopping the turbine and for getting the synchronous generator on line. When the proportional brake is used for normal stops, the induction motor or synchronous generator is automatically removed from the line when the proportional brake pressure reaches 200 psi. This will prevent the synchronous machine or induction motor from producing torque in opposition to braking action.

The following procedure will allow proper use of the proportional brakes for normally stopping the turbine:

17-M VAWI CONTROLS  
HYDRAULIC PROPORTIONAL & EMERGENCY BRAKE  
ELECTRICAL CLUTCH & BRAKE

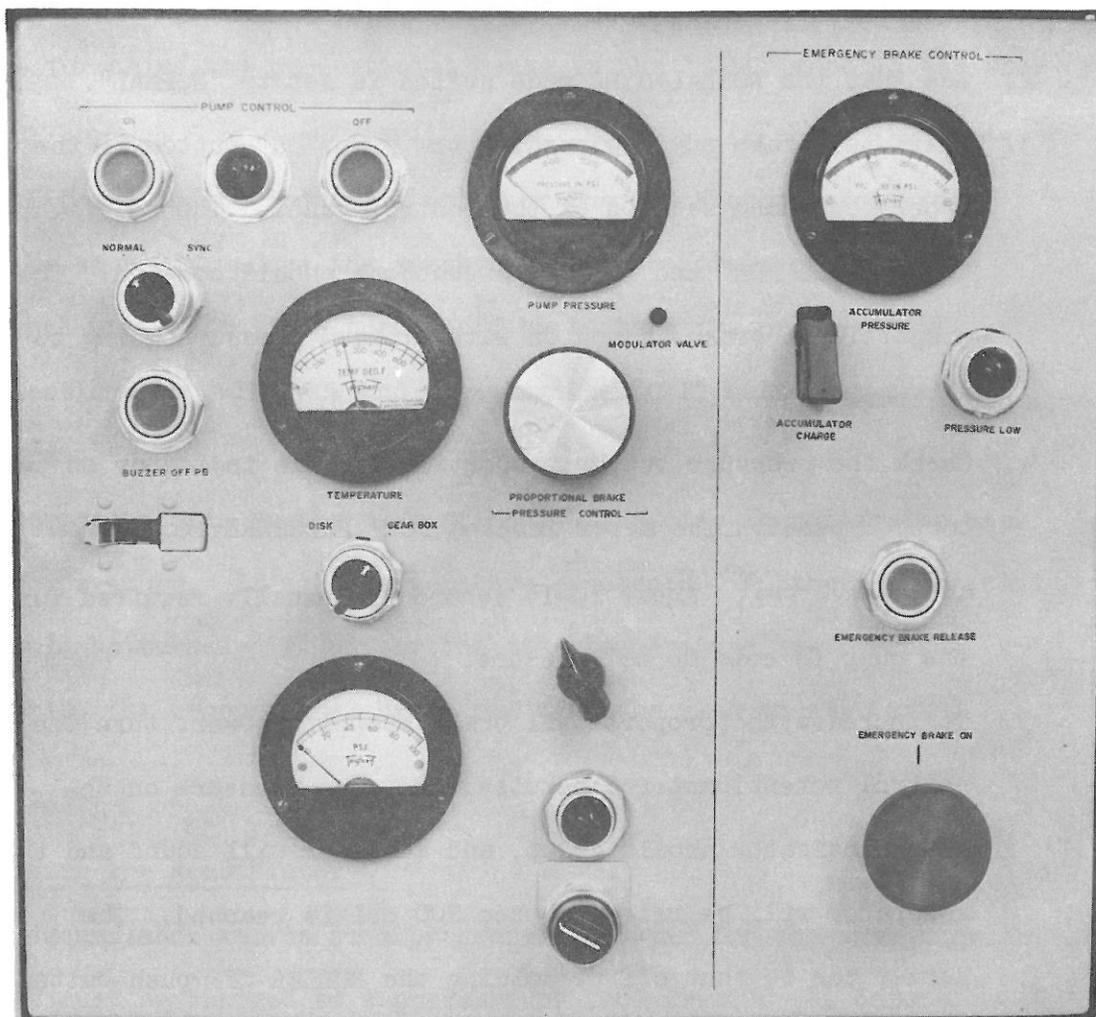


Figure 6. Brake Control Panel

1. Check the proportional brake control potentiometer for full counterclockwise, CCW, rotation. This control is labeled PROPORTIONAL BRAKE PRESSURE CONTROL. If this control is set incorrectly, damage to the turbine could result.
2. See that the NORMAL-SYNC mode switch is set to "NORMAL".
3. Start the brake pump by pushing the pump "ON" button in the upper left hand section of the control panel. The red light between the "ON" and "OFF" push buttons should come on. The proportional brake is now on with minimum pressure going to its calipers.
4. Check the pressure on the proportional brake indicator on the control panel. The meter labeled PUMP PRESSURE should read around 150 psi. About 10-15 seconds is usually required for the pump to come up to pressure.
5. To increase the proportional brake stopping power, turn the control potentiometer clockwise, CW. The pressure on the panel indicator should go up, and a buzzer will sound and the generator will be released when 200 psi is reached. The buzzer can be shut off by holding the BUZZER OFF push button. Ordinarily, the 200 psi pressure is adequate to stop the turbine, but more should be applied if the turbine RPM does not fall off. Pressures above 1000 psi are not advised.
6. After the turbine has reached a complete stop, turn the proportional brake control potentiometer fully CCW and push the pump "OFF" button. The red indicator pump light should go off.

If the proportional brake is to be used for reaching the 1800 rpm speed of the synchronous generator, the proportional brake control should be turned from the "NORMAL" mode to the "SYNC" mode. This will only work when sufficient wind for driving the turbine is present. The procedure for using the proportional brake in the "SYNC" mode is the same as steps 1 through 5 of the "NORMAL" mode. However, in the "SYNC" mode, electrical power to the induction motor or the synchronous generator will not be shut off. Once the synchronous generator is on line, the proportional brake should be turned off by turning the proportional brake potentiometer fully CCW and pressing the "OFF" button on the pump control.

A thermocouple is on the proportional brake disc to notify the user of disc temperature. If disc temperature exceeds 800°F, the proportional brake should be turned off. After the disc temperature has dropped sufficiently, the proportional brake can again be used in the "SYNC" mode.

### 3.2 Charging the Accumulator

The accumulator serves as a pressure reservoir for the emergency brake. It must be charged to a pressure of 1000 to 1200 psi before starting the VAWT. If the pressure is below 1000 psi, the pressure low buzzer and light will go on. To charge the accumulator, turn on the proportional brake when the VAWT is stopped, as described in Section 2.1. Adjust the pressure on the proportional brake to its maximum value, about 1800 psi. Then activate the balance valves by lifting the red switch cover and holding the switch labeled ACCUMULATOR CHARGE in the

charge position. The accumulator pressure should slowly increase. As soon as the accumulator pressure reads 1200 psi, release the ACCUMULATOR CHARGE switch.

Then, rotate the proportional brake potentiometer fully CCW and turn off the brake pump.

### 3.3 Releasing and Applying the Emergency/Parking Brake

Before the turbine can be started, the emergency brake must be released. This is done by pushing the EMERGENCY BRAKE RELEASE push button. If the brake is not released, a fault condition will show up on the motor/generator control panel. To clear this fault indication, the brake must be released, then the fault clear button on the motor/generator control pushed.

If a situation exists where the turbine must be stopped immediately, push the EMERGENCY BRAKE ON button. It will automatically stay on under normal circumstances. An exception is the case where the EMERGENCY BRAKE RELEASE button has been pushed and is in its time cycle. Under this circumstance, the EMERGENCY BRAKE ON button must be held to keep the emergency brake on. When the emergency brake is on, power to the motor and generator is automatically shut off.

#### 4.0 MANUFACTURER'S DATA

In this section information is contained which could allow for duplication of the brake system as it is installed on the 17 M VAWT. However, the purposes for supplying this manufacturer's data is (1) to have a permanent record of the brake hardware attached to the brake report, (2) to allow for evaluation of the design based on specific hardware, and (3) to serve as a reference for use when designing brakes for larger VAWTs. It is supplied in Table 3, with identification numbers, source, and comments.

Table 3

Identification	Source	Comments
Accumulator, Vickers Model AL-2050-20	Sperry-Vickers Troy, Michigan	This 10-gallon accumulator is used to store pressure for the emergency brake.
Needle Valve Model N-305	Deltroc	Used to attenuate shock at various points in hydraulic system.
Balance Valve Model 1650-4-120/60	Womac	Two are used in charge line between accumulator and pump.
Release Valve Vickers #DG452-01-2A-50		For emergency brake release.
Brake Calipers Model 2500HR6	H-H Products Division Kelsey-Hayes Company 5800 W. Donges Bay Rd. Mequon, Wis., 53092	Can be used with discs 12 to 36 in. dia. and up to 1 in. thick. One-stop energy absorption capacity with 18 x 1/2 in. thick disc - 1,608,000 ft. lbs. This is the largest caliper available in Kelsey-Hayes catalog HH39-23M 9/71. Must specify disc thickness when purchasing.
Thermocouple Model CT-810-C-B-CX	Hycal Engineering	For measuring disc temperature. A DC supply is required.
Power Supply for Electrically Modulated Valves, Model Series EMCS-BB-10	Sperry-Vickers Troy, Michigan	The potentiometer control on this supply is used to control the modulator valves that controls pump pressure. The potentiometer was removed from the power supply box and mounted on the control panel and labeled PROPORTIONAL BRAKE PRESSURE CONTROL.

Table 3 (cont'd)

Identification	Source	Comments
Hydraulic Pump Model PVB5-FLDWY-2041-10	Vickers	A schematic of the pump system is shown in Fig. 1 of the text. The pump is capable of supplying 6 gpm at 2000 psi.
Switches and Lights on Control Panel	Square D Company Park Ridge, Ill.	These are class 9001 push buttons, selector switches, and pilot lights. They can be purchased at most electrical supply companies.
Brake Release Valve, Model DGS4-012A-50	Vickers	Proportional brake release valve.
Pressure Gauge	AMETEX	For pressure reading at pump location.
Pressure Transducers Model A-10CP	Sensotec, Inc.	These transducers are used to monitor the pressure at the pump, accumulator, and emergency/parking brake calipers. A power supply of 10 volts is needed for these transducers. An output of 0-5 DC corresponds to 0-2000 psi.
Relay, KP13	Square D Company Park Ridge, Ill.	These 3 PDT relays are used in the control system. Except for the one timing relay and 3 alarm relays, they perform all the functions. Each has a pilot light to indicate the coil is energized and a manual operate option. Pick-up time is 14 ms and drop out 9 ms. The contacts are rated to continuously carry 10 amperes. See Fig. 5 for pin identification.

Table 3 (cont'd)

Identification	Source	Comments
Timing Relay JA-5	Square D Company Park Ridge, Ill.	The time is knob adjustable from 1.8 to 180 seconds on this 2PDT relay. It is relay BRTDR on the schematic diagram. See Fig. 5 for pin identification.
Alarm Relay AP1000	Action Instruments Co., Inc. 8601 Aero Drive San Diego, CA, 92123	Note that this relay is normally energized; and deenergizes at set point or with power failure.
Pressure Switch Model 698GCEM6	Custom Component Switches, Inc.	PS1, PS2, and PS3 on hydraulic system.
Buzzer	Square D Company Park Ridge, Ill.	

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