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VARIABLE SPEED A-C MOTOR CONTROLLER FOR CANAL GATE HOISTS

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16. ABSTRACT

A variable speed-motor controller for application to control large radial gate operation was tested in the laboratory. It will provide satisfactory variable-speed operation on large gate hoists in hydraulic structures. Application pro and con are discussed. Other desirable features are noted.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Engineering and Research Center
Denver, Colorado

SI METRIC

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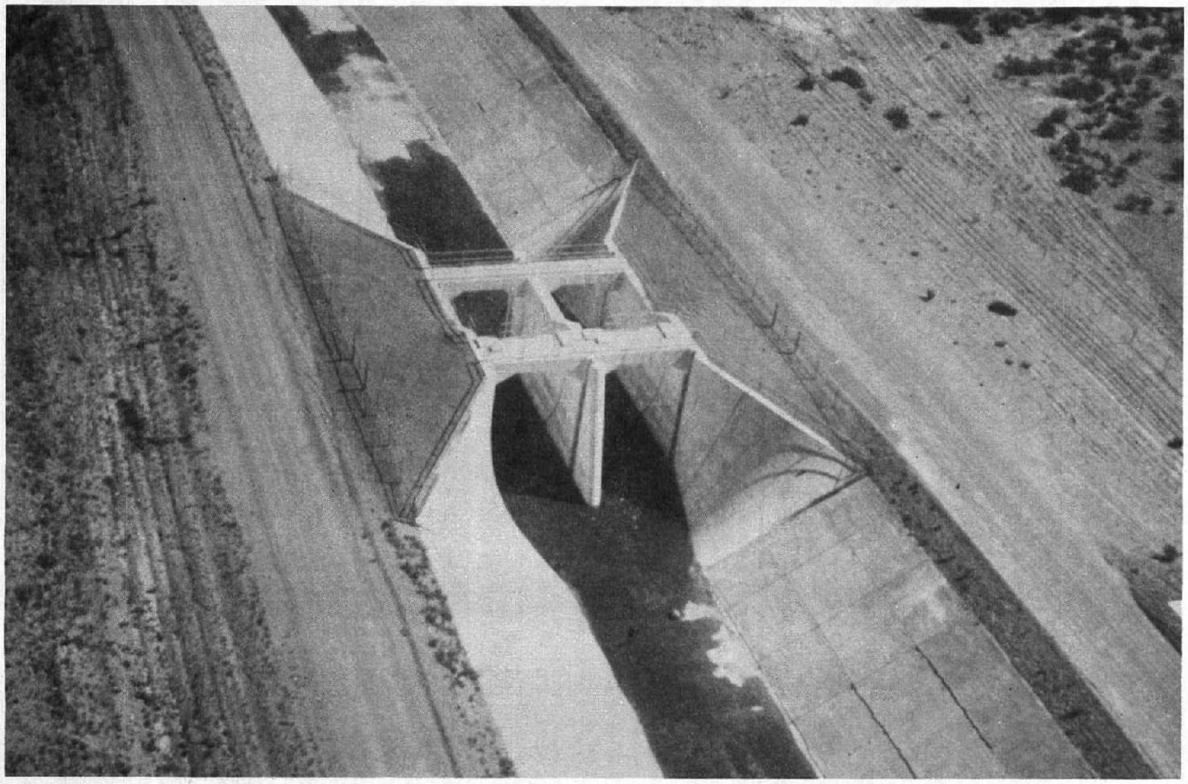

Frontispiece — Check structure on Reach 9 of the Granite Reef Aqueduct, Arizona. Typical radial gate structure in which a motor controller can be used — October 1981. P801-D-80199

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PURPOSE

The purpose of this study was to determine the operation and feasibility of using a variable-speed-motor controller in a canal gate operation system. The Bureau's standard radial gate design for spillway use is adapted to canal check structures. The Granite Reef Aqueduct conveys Colorado River water from the Buckskin Mountains to the Phoenix area for which there are many radial gates that require precise automatic and manual controls.

INTRODUCTION

In recent years, variable a-c motor drive controllers have been developed for operation in conjunction with 3-phase induction and synchronous motors. A variable-speed controller — with an a-c motor — provides a useful variable-speed drive which is safe, reliable, and convenient. In canal automation, a variable-speed drive has many applications. It provides a wide speed range for precise adjustment of canal gates and valves; it also provides variable speeds that can be programmed by computer for "gate stroking"[1] type of operation being developed at the Bureau's E&R Center laboratories. Certain features of variable-speed controllers make them desirable even if the variable speed is not required. *Torque limit* and *slow start* are features that extend motor and equipment life. Also, it allows numerous starts without damaging the motor and equipment. These features are desirable in algorithms such as "EL-FLO."[2] The intended application is for the standard USBR gate hoist having a 3-hp motor. A study was done in the application of a variable-speed controller to a gate hoist using a 3-hp motor. Hoist specifications follow.

Bureau of Reclamation standard radial gate system

A motor rated 3-hp, 1,750-r/min with 240-r/min gear head

Gear box ratios 50:5:4:1 = 1000:1 for cable hoist

Cable speed at 1.65 ft/min

Radial gate, 25,000 lb

2.08 hp calculated, 3 hp nameplate (60 percent over minimum design)

[1] Falvey, H.T., and P.C. Luning, *Gate Stroking*, REC-ERC-79-7, Bureau of Reclamation, Denver, Colo., 86 p., July 1979.

[2] Buyalski, Clark P., and Edward A. Serfozo, *Electronic Filter Level Offset (EL-FLO) Plus Reset Equipment for Automatic Control of Canals*, REC-ERC-79-3, Bureau of Reclamation, Denver, Colo., 145 p., June 1979.

It is anticipated that the Granite Reef Aqueduct will have a standard radial gate. The variable-speed drive is contemplated for the Granite Reef radial gate hoist system.

A number of variable-speed drives are available commercially; essentially, all rectify the a-c power available and — by using control semiconductors (transistors, silicon controlled rectifier, or Triacs) — provide a variable voltage and a variable frequency output. A number of manufacturers of variable-speed motor controllers are shown in appendix A.

All the controllers are similar in that they produce an output that increases in frequency and voltage beginning from zero volts and zero hertz to the desired output voltage (230 V) and frequency (60 or 66 Hz) as set by controls. All provide a torque limit feature — in reality, a current limit —adjustable to a maximum of 150 percent of rated current. The speed at which the output increases or decreases also is adjustable. The controls (reverse, speed, acceleration, and start/stop-reset) can be interfaced readily to a computer.

CONCLUSIONS

1. The 3-hp variable-speed motor controller tested is adequate to provide variable-speed operation on the hate hoists to be installed on the Granite Reef Aqueduct.

2. Noise interference produced by the controller is low enough to be used in the field without causing interference to microprocessor, electronic, and communication circuits.

3. The motor controller must be matched to the motor being controlled for horsepower rating and in revolutions per minute.

4. The Parajust (app. A) controller is temperature rated conservatively. It will provide cyclic duty at elevated temperatures.

APPLICATION

In this study the specific application was to provide a variable-speed to a radial gate hoist at an irrigation canal. The controller has a wide application in the area of hydraulics. Motor controller applications include:

- Other types of gates such as slide gates
- Motorized valves
- Circulating pumps
- Motors used in a laboratory for model studies to control headgates, tailgates, probe positions, etc.

A-C Versus D-C Variable-speed Drives

Conversion of a-c voltage to variable d-c voltage is required for both types of controllers; therefore, a controller is required in either case.

Advantages of d-c motors with controllers

+ Better low speed control (with closed loop control)
+ More efficient and economical for large horsepower rating (greater than 15 hp)

Disadvantages of d-c motors having controllers

- Greater d-c motor cost
- Greater maintenance for d-c motor brush replacement and cleaning
- Sparking commutator is an explosion/fire hazard for d-c motor
- Speed depends on load unless on a closed loop control

Advantages of a-c motors having controllers

+ Lower cost — particularly for induction motors
+ No brushes or slip rings on induction motors

Disadvantages of a-c motors having controllers

- Lower starting torque; however, this has advantages
- Inefficient use of electrical power with poor phase angle
- Ineffective cooling at low speeds, generally not a problem in intermittent operation

A 3-hp controller was tested in the laboratory. Testing was planned to investigate operation of the controller at:

- Varying voltages
- Short duration power losses
- Noise impressed on the line (resulting from controller operation)
- Effect of a high ambient temperature on the controller.

The Central Arizona Projects Office provided the E&R Center laboratory the Parametrics–Parajust motor controller (app. A).

TEST PROCEDURES

Tests were devised to provide controller operating characteristics and to introduce noise into the power circuits. The most difficult part of the test series was installing equipment that provided a variable load on the motor. Various pump and motor combinations were tried. A hydraulic pump having a 3-hp, 3-phase, 230-V, 1750-r/min, motor was selected to provide a load for testing the controller. Several variable-load arrangements provided considerable insight into how the controller operated. Several other 3-hp motors rated at different speeds were tried. Results of preliminary tests are covered later in this report.

The test apparatus consisted of (fig. 1): A 1,750-r/min motor, a positive displacement hydraulic pump, pressure regulator, three-way valve, and pipe loop with a valve.

The motor and pump used are as described below:

Motor

Dyna Line (The Brown Brockmeyer Company, Dayton, Ohio)
MS M580, ES 7774, FR 213, CY 50/60, 3 ph, 3 hp, 208/220/440 volt, type PM, 1450/1750 r/min, 9/4.5 ampere, serial No. C3463077, temperature rise 40 °C, SF 1.15

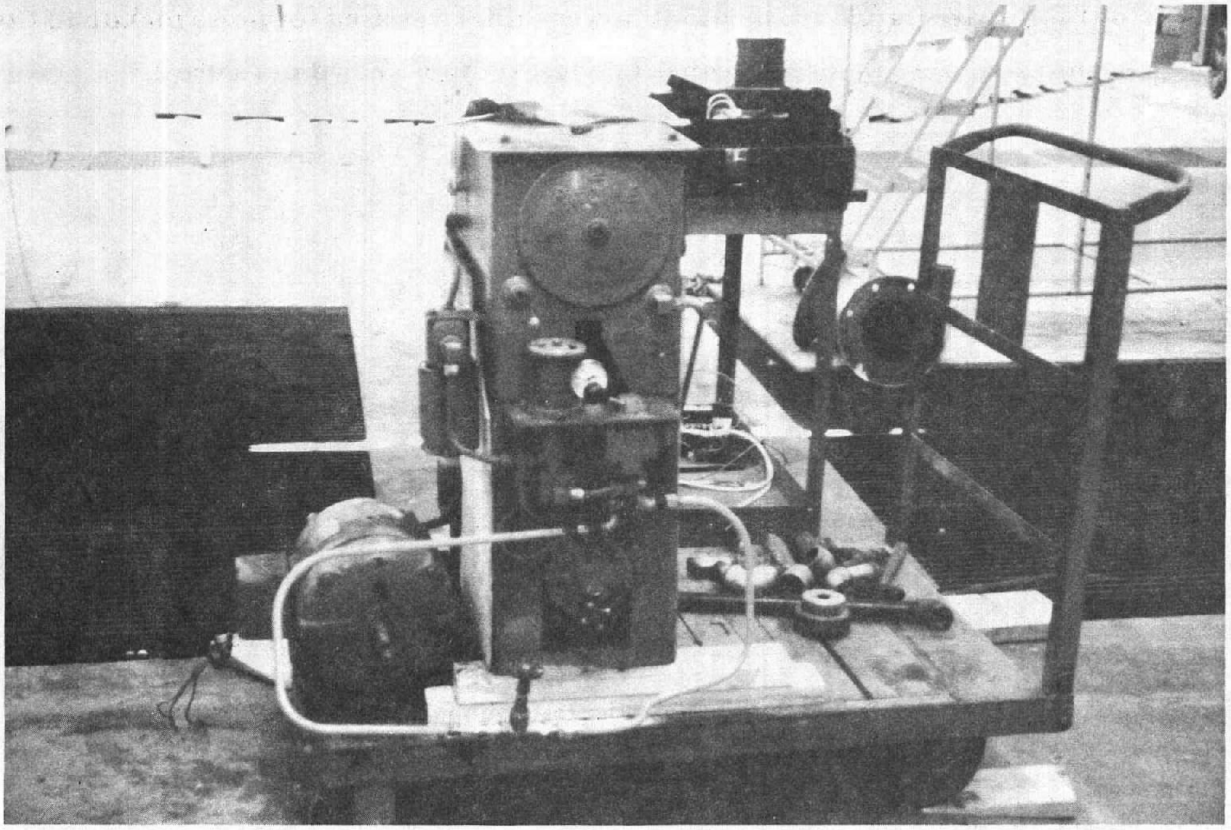


Figure 1. — Variable-load apparatus. P801-D-80200

Pump

Weather Head Company (Cleveland, Ohio)

PN 408-05045, MOD WO730A-01H45-15, serial No. 5524

Pump hydraulic pressure and output amperes to the motor were used to determine load. The following test equipment was used to obtain data:

1.	Data Technology Corp.	model 30A digital voltmeter
2.	Tektronics Inc.	model 434 storage oscilloscope
3.	Hewlett-Packard Co.	model 3582A spectrum analyzer
4.	General Electric Co.	clamp-on ammeter
5.	John Fluke Mfg. Co.	model 8020-A multimeters (2)
6.	John Fluke Mfg. Co.	model 80T-150 temperature probes (2)
7.	Superior Electric Co.	Powerstat™ 20 A variable transformer
8.	Hewlett-Packard Co.	model 7414 four-channel oscillograph
9.	– –	Bourdon tube pressure gauge

A 16-ft-long wire (taped to the input power cable) was used for noise pickup to the spectrum analyzer and oscilloscope. The test setup is shown in figure 2.

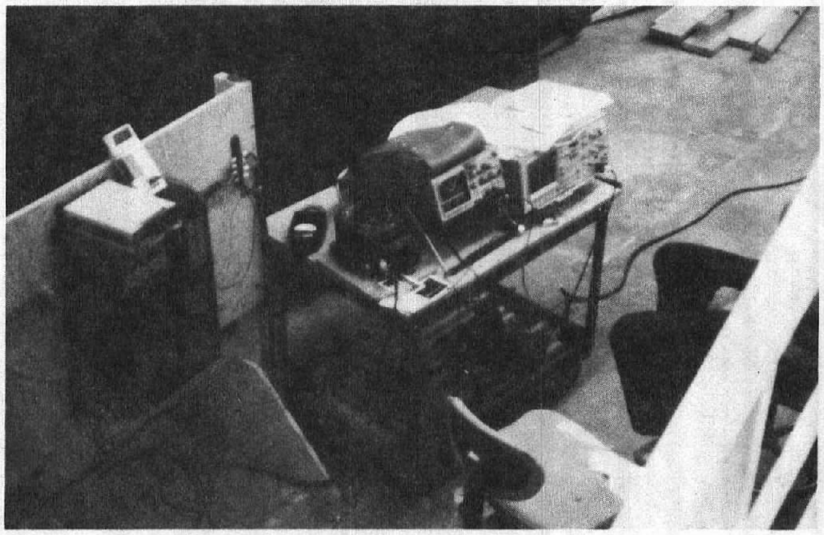


Figure 2. — Motor controller test equipment. P801-D-80293

The following tests were run:

1. Electrical noise measurements made under varying load and speed
2. Outside influence — fluorescent lights and a large d-c motor with controller
3. Noise tests with Corcom 30K6 filter installed in powerline
4. Load limit (electronic shear pin) at varying speed
5. Low voltage input for various speed and load conditions
6. Temperature tests at 40, 50, 60, and 67 °C (104, 122, 140, and 153 °F)

The controller input current, output current, output volts, and noise (measured with spectrum analyzer and oscilloscope) were used to monitor the tests in all cases except the temperature tests. Additional data such as hydraulic pressure (load) and controller input volts were included as required.

Noise Tests

Noise measurements were made at a particular pressure (load) and increasing the speed control in 20 percent increments. Four load settings were established: no load, one-third load, two-thirds load, and full load.

The noise generated was observed using both an oscilloscope and a spectrum analyzer. A wire taped along the powerline feed for about 16 ft picked up the noise signal. Standards or documentation are unavailable on motor controller noise, so comparison with other sources (d-c motor and fluorescent lights) was quite meaningful. Noise test results are in appendix B.

It was difficult to simulate noise in situ but, by comparison with common noise sources, apparently noise will be a minor problem. The noise tests were done without an isolation transformer, and the controller manufacturer recommends using a transformer to provide additional isolation and noise reduction. This will be provided in the field by the station-service transformer.

A Corcom 30K6 EMI 30-A filter was installed in the last series of noise tests; approximately 20 percent reduction in noise was noted. Appendix C shows a diagram of the Corcom filter. A filter can be included in the system but, it is not necessary, according to lab tests.

Low Voltage Test

The low voltage test was devised to monitor control operation and controller output. A variable transformer was used to reduce input voltage by increments until the controller stopped. Various load settings and speed increments were used. Appendix D shows low voltage tests.

Temperature Tests

Temperature tests were run with the controller installed in an insulated box heated with various combinations of incandescent lamps. Tests were run at 40, 50, 60, and 67 °C (104, 122, 140, and 153 °F) ambient temperatures. Temperature probes were used to monitor the controlled rectifier module and the controlled output module. The controller manufacturer recommends 40 °C maximum ambient temperature. However, ventilating the enclosure, or doubling its original volume, or using a larger controller will be suitable for 50 °C.

Appendix E shows results of temperature tests. A Hewlett-Packard four-channel recorder provided a continuous record of temperature changes during the tests.

RESULTS

A motor controller devise installed, with the variable-speed feature, on radial gate hoists will improve gate operation. It offers numerous advantages:

- Better precision in setting the gates,
- Improved motor life,
- Stall protection,
- Protection for exceeding limits (by setting electronic shear pin),
- Additional automation capability in supervisory control, and
- Improved automatic control operations.

The controller tested has a design current based on a 3-phase, 3-hp, 230-V, 1,750-r/min motor. Nameplate data states 9.0-A running current. A review of various motor nameplate data show 10.0 A for a 1,150 r/min motor (the controller would not start this motor) and 7.7 A for a 3,500-r/min motor. The shear pin, set at 150 percent or approximately 14 A, did not trip the 3,500-r/min motor when starting under any starting condition. It appears that the tested 3-hp controller is designed for use with a 1,750-r/min motor. The electronic shear pin control could be lowered for use with the higher r/min 3-hp motors, but cannot be used with the 1,150-r/min motor.

The controller cannot exceed 150 percent design current; however, the electronic shear pin can be set to a lower current value. Current, which is a function of output voltage and frequency, is far less than the starting current when 230 V, 60 Hz are applied to the motor. A lower starting current extends life of the bearings, the motor windings, and the gear reduction assembly.

Variable speed allows the operator to select lower speeds for small gate position changes, particularly useful at low canal flow rates. Variable speed can be used for supervisory control and automatic control dictated by new control algorithms, such as *Gate Stroking*[1] and for initiating a slow gate movement to prevent abrupt changes in canal water surfaces.

The controller provides protection from low line voltage in two ways. First, it operates normally at reduced speeds where output voltage is less than the reduced input voltage and, second, it provides overcurrent protection (electronic shear pin) at higher speeds. When a motor is operated directly on the a-c line with reduced voltage at 60 Hz, overheating and high current result.

Noise introduced into the powerline is a major concern for the proposed controller use. Most testing of the controller included determining noise (app. B). A prominent result was the interference level contributed by fluorescent lights in the room adjacent to the controller test area. Electrical noise caused by lights was as high as that contributed by the controller. Also, during testing, several studies were in progress using Digital Equipment Company Minc LSI 11-23 computers and the Hewlett-Packard 9825 programmable calculator. With those computers operating, during the duration of the controller tests, observable noise related problems were not detected.

Motor literature indicates that, with output voltage proportional to frequency (0 to 100%, 0 to 230 V), the motor operates at constant torque. A check of recorded data verifies that the voltage-speed relation provides a constant torque output. The maximum speed, maximum voltage holds true for 100 percent speed set at 60 or 66 Hz and 1,750 or 1,925 r/min, respectively. Figure 3 shows results from two different tests and illustrates the voltage-frequency relation for various loads; however, note that the current changes with voltage (fig. 4). The 1,000-lb/in^2 run is an overload condition that causes an electronic shear pin to function.

Tests show that all factors — ambient temperature, run time, speed, and run/rest time — influence temperature. The main advantage of this type of controller is that the controller starts the motor at a constant torque. Therefore, the motor can be started repeatedly without damage.

Tests showed that temperature constraints are conservatively stated by the manufacturer of the controller. Rating selection must include analyses of speed, duration of run, and duration of rest. An off-the-shelf controller will provide

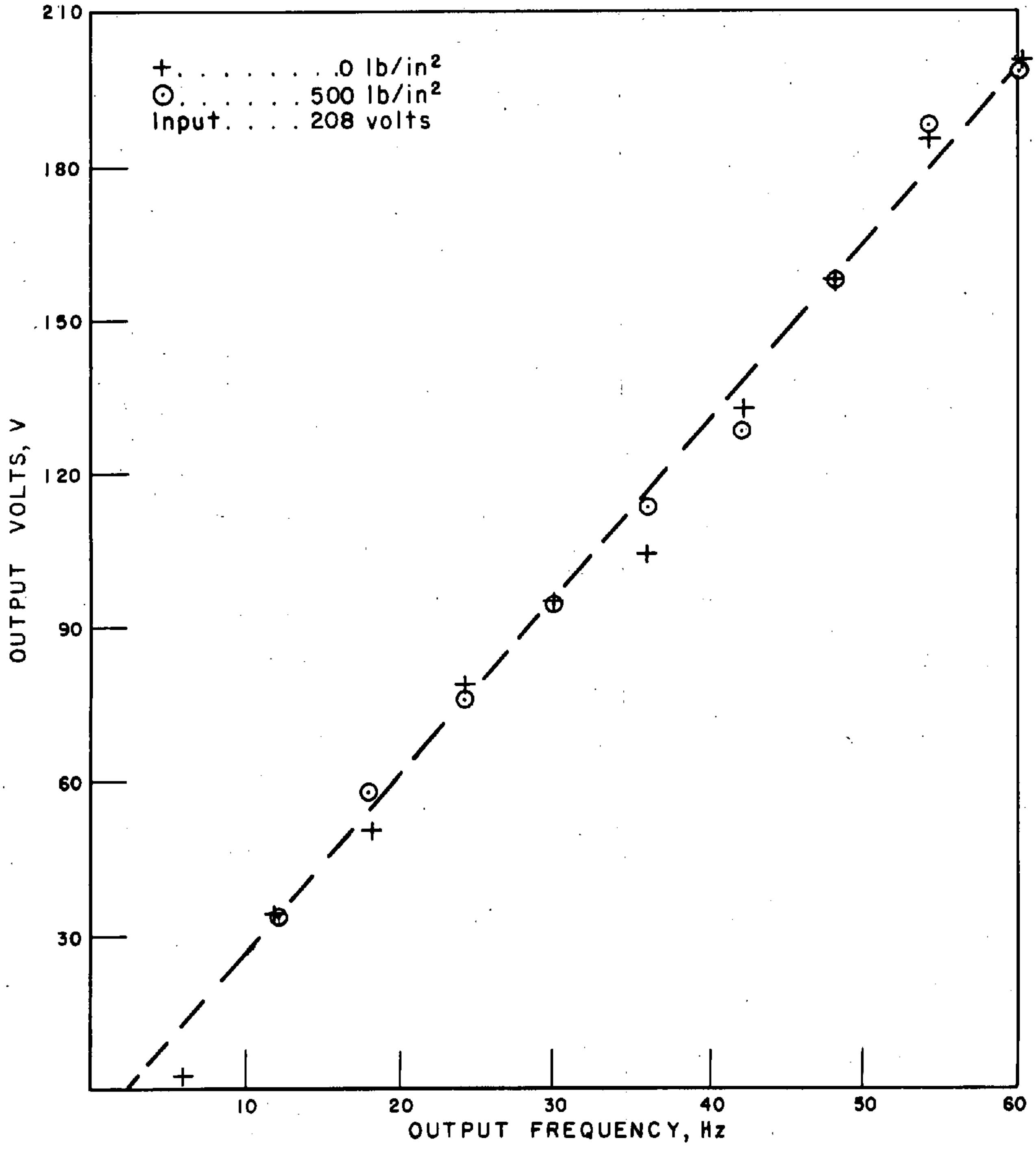


Figure 3. — Controller output volts versus output frequency for various loads — motor controller tests.

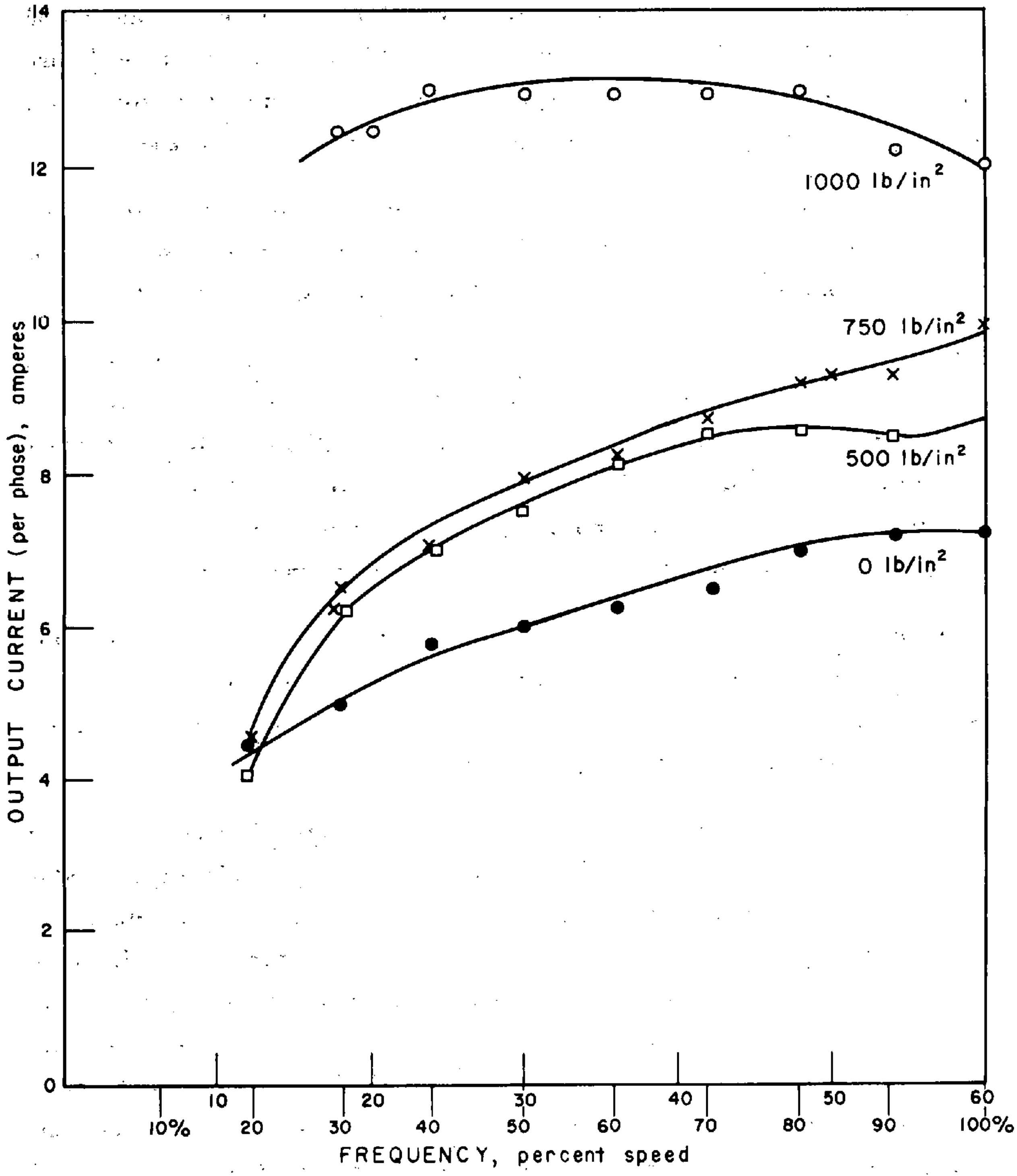


Figure 4. — Controller output amperes versus output frequency for various speeds — motor controller tests.

continuous service at 40 °C (104 °F). The manufacturer states this can be raised to 50 °C (122 °F) by drilling holes in the enclosure for ventilation, doubling the enclosure volume, or installing the next larger controller. In the standard enclosure, test results indicate that a continuous run at 50 °C did not cause any damage.

The most probable damage to the controller at high temperature would be the shortened life of the filter capacitors. Relocating these capacitors from the top to the bottom of the enclosure at the factory will decrease exposure to heat.

The Parajust controller functions well for automation. The start-stop/reset can be replaced with a single contact for run-stop. Reverse is accomplished also with a single contact (open-forward/closed-reverse). The controller speed is provided by a 0- to 10-V signal. A control module also is available to provide isolation as well as to accommodate a variety of other input signals. An additional set of contacts is available for controlling the electric brakes if motor braking is required.

Standby power cannot be switched in while the Parajust is running as this would cause the shear pin to function and require a reset. The transfer should be made while the controller is off, or restart the controller after power is reapplied if the controller was running when failure occurred.

Parajust or other type controllers meet field installation requirements on Bureau of Reclamation canal facilities. Concrete block or fabricated building can be used at each installation. A building provides more constant ambient temperature as opposed to an open installation. As noted earlier, temperature is the main constraint for a 3-hp controller with the 3-hp motor radial gate hoist system and can be designed for cooling. Tests show Parajust temperature ratings to be quite conservative for the continuous run at 50 °C (122 °F) without modification. Intermittent duty — typical of canal installation — allows even higher ambient temperatures for the same semiconductor case temperatures. Case temperature of the controller semiconductors is a function of:

- Ambient temperature,
- Duration of run time,
- Percent run to rest time, and
- To a lesser degree, percent speed.

By providing a *soft start* (controlled current), the controller, can be cycled many times without causing overheating or mechanical stress. A soft start has constant starting torque or limited current start. During the tests, the starting current generally was equal to the normal running current. The low starting current virtually eliminates resistance heating associated with normal motor starting current of 6 to 10 times rated current. The associated constant starting torque eliminates damaging mechanical forces normally present in starting motors. However, low speeds inhibit cooling of most a-c motors. For extended periods of low speed operation it may be required to design for high temperature windings and/or forced cooling.

APPENDIX A

Manufacturers/Suppliers of A-C Variable-speed Motor Controllers

Allen Bradley — PTI Controls
Allen Bradley (414) 671-2000
1201 South Second Street
Milwaukee, WI 53204

General Electric Company
Electronic Comp. Sales (315) 456-2196
Building 23, Room 218
One River Road
Schenectady, NY 12345

Incom-Fincor Controls
Fincor Controls (717) 757-4641
3750 East Market Street
York, PA 17402

Lovejoy Electronics — MPR-IV
Lovejoy Electronics, Inc. (312) 968-7089
2655 Wisconsin Avenue
Downers Grove, IL 60515

Parametrics — Parajust
Parametrics (203) 795-0811
284 Racebrook Road
Orange, CT 06477

Note: This is a partial list of many manufacturers and suppliers and is not intended to be a summary.

APPENDIX B

Noise Tests Results

Electrical noise data were taken under a variety of conditions in the laboratory at various loads and percent speed. Noise runs appeared to be inconsistent until the background noise in the laboratory was investigated. External sources, such as fluorescent lights, and the d-c motor on the low ambient test facility, were checked. Lights contributed significantly to noise, whereas the d-c motor attenuated the noise — perhaps by lowering the source impedance *seen* by the controller. Runs were made both with fluorescent lights on and off.

In these tests, noise noted was in the audible spectrum with most of the energy in the range of the output frequency to 300 Hz and then the energy level decreased to levels below the background noise at 10,000 Hz and above.

Noise level is greatest at 20 to 60 percent speed. Noise level caused by fluorescent lights is about the same level as that produced by the controller. The level is highest at a load of about 2 hp. The design rating for the gate hoist motor is 2.08 hp. Results are shown in table B-1.

Addition of the Corcom series K filter provides some improvement by reducing the noise level to approximately 66 percent of the noise level without the filter. This addition could be added easily at a later time if noise is found to be a problem.

From test results, it is believed that electrical noise introduced by the controller will not be a problem for the considered application.

Table B-1. — *Noise test results — motor controller tests*

Run No.	Frequency set	Lights	Load, lb/in²	Speed, %	Total [1]VA	Secondary ampere	Secondary volt	[2]Noise millivolt peak-to-peak
1	66	On	Friction (no load)	Controller off	0	0	0	16
				0	1.7	0.1	10	40
				20	272.8	4.5	35	44
				40	763.8	5.75	78.7	40
				60	1229.7	6.25	113.6	40
				80	1915.6	7.0	158	36
				100	2598.1	7.50	200	40
2	60	On	500 (2 hp)	20	235.1	4.0	34	100
				40	987.2	7.0	74	80
				60	1629.0	8.25	114	80
				80	2311.4	8.5	157	60
				100	2559.1	7.5	197	40
3	60	On	750 (3 hp)	20	265	4.5	34	28
				40	897.2	7	74	24
				60	1543.3	8.25	108	26
				80	2451.3	9.25	153	26
				100	3325.5	10	192	28
4	60	On	1000 (4 hp)	30	1104.2	12.5	51	100
				40	1553.7	13	69	90
				60	2341.7	13	104	80
				80	3400.0	13	151	70
				100	3886.7	12	187	40
5	60	On	250	20	[3]	4.75	32.0	18
				40	[3]	6.25	72.8	20
				60	[3]	7.75	117	20
				80	[3]	8.5	156	22
				100	[3]	8.5	203	26
6	60	On	500	20	[3]	5.75	359	20
				40	[3]	6.75	77	18
				60	[3]	8.50	115.6	18
				80	[3]	9.25	160	18
				100	[3]	9.00	200	22

Table B-1. — *Noise test results — motor controller tests* — Continued

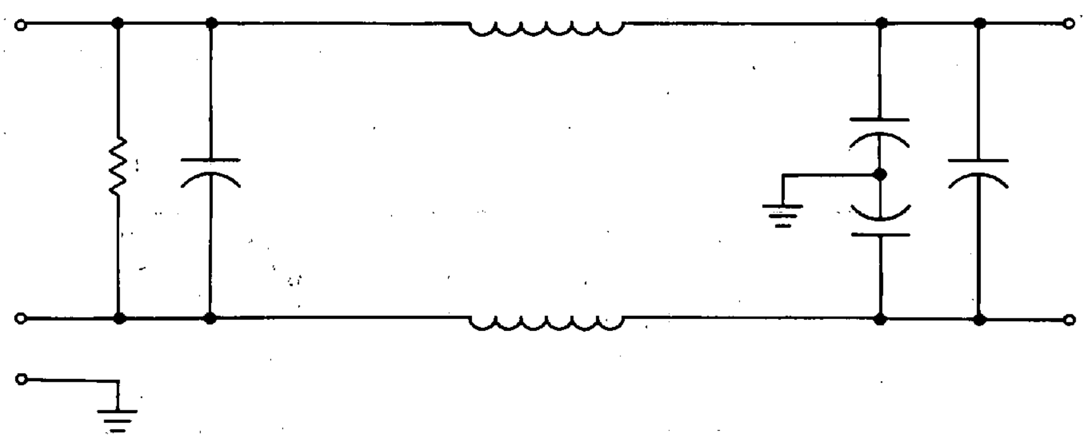
Run No.	Frequency set	Lights	Load, lb/in²	Speed, %	Total [1]VA	Secondary ampere	Secondary volt	[2]Noise millivolt peak-to-peak
7	60	Off	250	20	[3]	4.5	34.6	12
				40	[3]	6.0	77.8	14
				60	[3]	7.25	116.7	18
				80	[3]	7.75	160	10
				100	[3]	7.75	203	8
8	60 w/filter	Off	500	20	[3]	5	379	10
				40	[3]	7.75	77.0	12
				60	[3]	8.75	116	12
				80	[3]	9.25	157	10
				100	[3]	9	201	10
9	60 w/filter	On	250	20	[3]	4.75	40	18
				40	[3]	6.75	79	18
				60	[3]	8.00	120	18
				80	[3]	8.50	159	18
				100	[3]	7.5	202	18

[1] Total volt-amperes $=\sqrt{3}$ (Line volt-amperes)
[2] Frequency was related to the output and the 60 Hz input. The predominant frequency was the 3d harmonic and decreased in strength as the frequency increased above 400 Hz.
[3] Data not recorded, initial tests.

APPENDIX C

Corcom Series K filter

Part No. 30K6 30A



Frequency, MHz	0.15	0.2	0.5	10	20
Attenuation, db	15	20	30	55	55

Leakage at 250 V a.c.	line to ground	0.5	milliamperes
Test voltage	line to ground	2250	volts d.c.
	line to line	1450	volts d.c.

Operating voltage .... 115 to 250 volts a.c.

Operating frequency .... 50 to 400 Hz

Figure C-1. — Corcom filter details — motor controller tests.

APPENDIX D

Low Voltage Tests

The low voltage test provided answers to two questions:

1. Operation of the control logic, and

2. Operation of the motor.

The control logic functioned properly throughout the test. When the controller could not provide the output voltage appropriate for the percent speed as noted in table D-1, the motor would draw excessive current and cause the electronic shear pin to trip. This current becomes a function of both speed and, to a lesser degree, motor speed and motor load. If low voltage is a common problem in parts of the field installation, an upper limit on motor speed could be set by the canal microprocessor controller or by a manual setting to match line voltage.

The shear pin and motor speed control provide two beneficial characteristics:

1. They prevent the motor from overheating from low voltage, and

2. They allow operation at lower speeds when a low voltage condition exists.

From figure 2, speed percent appropriate for low line voltage can be determined.

Table D-1 shows test results. Note that, at 50 percent speed, the input voltage to the controller can be reduced to 150 volts (65% rated voltage input) and still operate the canal gate.

Table D-1. — *Summary of controller low voltage tests*

Controller input, volts	Controller input, current	Controller output, volts	Controller output, current	Motor load, lb/in²	Motor speed, %
212	9.5	--	--	500	50
200	9.2	--	--	500	50
190	9.0	--	--	500	50
180	8.3	--	--	500	50
170	7.6	51.4	6.7	500	50
160	7.1	47.5	6.3	500	50
155	6.8	45.6	6.2	500	50
150	6.1	43.7	6.1	500	[1]50
170	--	160	14	--	[2]100
150	--	160	14	--	[2]75

[1] Motor and controller continued to operate with little degradation to 150 volts.

[2] Controller electronic shear pin tripped because of overcurrent.

APPENDIX E

Heat Tests

A series of heat test runs were made with the variable speed a-c motor controller standard enclosure.

1. Continuous run at rated hp, 80 percent speed, 40 °C (104 °F) ambient temperature
2. Continuous run at rated hp, 50 percent speed, 50 °C (122 °F) ambient temperature
3. Twenty percent run (2-min run and 8-min rest) at rated hp, 80 percent speed, 60 °C (140 °F) ambient temperature
4. Twenty percent run (1-min run and 4-min rest) at rated hp, 80 percent speed, 60 °C (140 °F) ambient temperature
5. Twenty percent run (1-min run and 4-min rest) at rated hp, 40 percent speed, 60 °C (140 °F) ambient temperature
6. Thirty-three percent run (0.5 and 1-min) at rated hp, 80 percent speed, 50 °C (122 °F) ambient temperature
7. Twenty percent run (1-min run and 4-min rest) at rated hp, 40 percent speed, 66 °C (152 °F) ambient temperature

An insulated box heated by incandescent lamps was used to obtain the ambient temperatures required. The ambient temperature was measured at the middle of the box and outside of the controller enclosure.

Figure E-1 is a derating curve for a typical high-power silicon transistor. For use in the controller at 93 °C (200 °F) — the temperature selected as the maximum device temperature to be allowed during the tests — the curve shows 63 percent of maximum power dissipation.

A continuous run was made at 49 °C (120 °F) ambient temperature. The run resulted in about 93 °C on the power transistors and the controlled rectifier. The temperature rise results in a 47 percent derating for the silicon power devices. From this test, it seems that the controller is rated conservatively for the 40 °C ambient.

After the 49 °C test, a number of runs were made using 93 °C as a maximum condition. Table E-1 shows the test results and indicates that a number of approaches may be used to accommodate higher ambient conditions and to allow safe controller operation. The manufacturer's literature states that 49 °C ambient can be accommodated by using a larger enclosure or by providing the enclosure with ventilation. This change also could be used to accommodate the higher ambient field conditions.

Tests revealed several other aspects of the motor-controller system. The motor tends to overheat on long low-speed runs. Overheating is due to loss of cooling air at low speeds. Motors are available having high-temperature windings and/or external cooling.

The increase in slippage at low speeds (20 to 40%) was noticed also. Repetitive starts at 80 percent speed did not cause the motor to overheat.

For long runs at slow speeds, jogging (on-off) could be considered as the motor does not rotate below 10 or 15 percent.

Table E-1. *Summary of temperature tests — motor controller*

Test No.	Ambient temperature, °F	Ambient temperature, °C	Duty time Per-cent	Duty time Run min.	Duty time Rest min.	Speed, %	Load, hp	Rectifier temper-ature, °F	Rectifier temper-ature, °C	Control module temper-ature, °F	Control module temper-ature, °C
1	104	40	100	Contin.	--	80	3	163.4	73	161.6	72
2	122	50	100	Contin.	--	50	3				
3	140	60	20	2	8	80	3	203.0	95	199.4	93
4	140	60	20	1	4	80	3	195.0	91	188.0	87
5	140	60	20	1	4	40	3	186.8	86	182.2	83
6	122	50	33	0.5	1	80	3	138.2	59	138.2	59
7	152	67	20	1	4	40	3	203.0	95	197.6	92

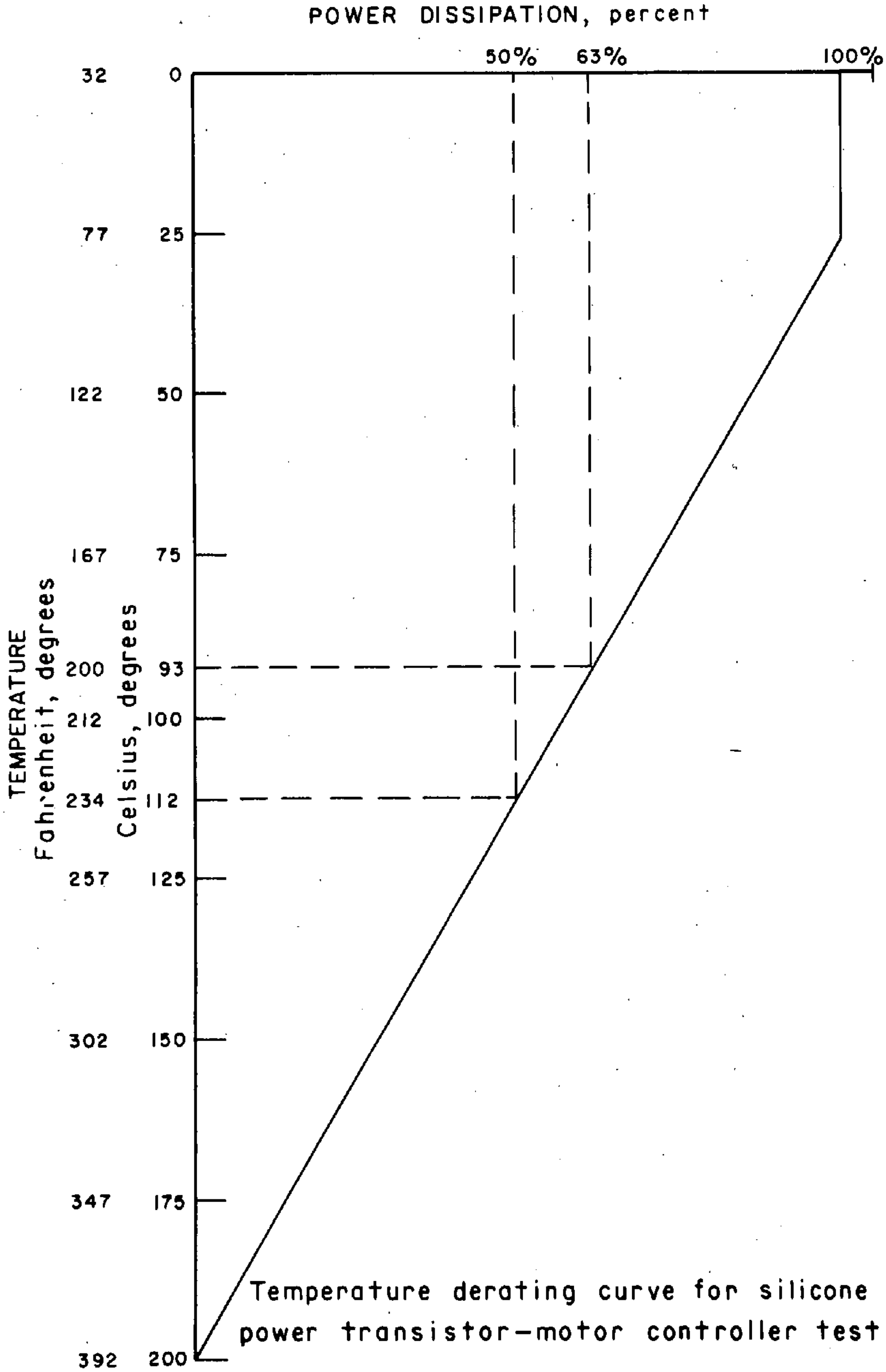


Figure E-1. — Temperature derating curve for silicon power transistor — motor controller tests.

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