R-92-06

KESWICK POWERPLANT VOLTAGE REGULATOR COMMISSIONING

FEBRUARY 1992

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Electric Power Branch

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
R-92-06		

4. TITLE AND SUBTITLE KESWICK POWERPLANT VOLTAGE REGULATOR COMMISSIONING	5. REPORT DATE February 1992 6. PERFORMING ORGANIZATION CODE D-3772
7. AUTHOR(S) Dmitry Shusterman, J. C. Agee	8. PERFORMING ORGANIZATION REPORT NO. R-92-06
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Denver Office Denver CO 80225	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Bureau of Reclamation Electric Power Branch Research and Laboratory Services Division Denver CO 80225	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche and hard copy available at the Denver Office, Denver, Colorado. Ed: TH

16. ABSTRACT

In 1991, the original voltage regulating equipment was replaced on all three units at Keswick Powerplant. J. C. Agee and D. Shusterman participated with Shasta Office personnel in commissioning the new voltage regulator during the week of July 29, 1991. This report describes the commissioning tests.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- *voltage regulators/ control equipment/ *commissioning /power system stability/ power system stabilizers

b. IDENTIFIERS-- Keswick Powerplant/ Shasta Office/ Denver Office Laboratories

c. COSATI Field/Group 09C ***COWRR:*** 0905 ***SRIM:***

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) *UNCLASSIFIED*	21. NO. OF PAGES 24
	20. SECURITY CLASS (THIS REPORT) *UNCLASSIFIED*	22. PRICE

R-92-06

KESWICK POWERPLANT VOLTAGE REGULATOR COMMISSIONING

by

Dmitry Shusterman
J. C. Agee

Electric Power Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

February 1992

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Keswick Powerplant houses three medium-size hydroelectric generators. Units 1 and 2 were uprated in 1990, and unit 3 was uprated in 1991. In addition, the original voltage regulators on all three units were replaced with new automatic voltage regulating equipment consisting of operational amplifier-type voltage regulating and limiting circuits, control relaying, and a thyristor-type power amplifier. The original rotating main exciter was retained.

J. C. Agee and D. Shusterman (Controls and Automation Section) participated with Shasta Office personnel in commissioning the new voltage regulator during the week of July 29, 1991.

CONCLUSIONS

The manufacturer provided the modifications necessary for satisfactory regulator performance. These modifications, identified during commissioning of units 1 and 2, included lead/lag modification of the regulator circuit, relocation of the field over-voltage relay from the exciter field to the main field, and installation of a contactor in the field discharge circuitry. Also, the modified add-on circuit board in unit 3 was replaced with the older version to provide better operation of the volts-per-hertz (V/Hz) limiter and to match parts in units 1 and 2.

A 49.9-ohm resistor was added to the current feedback circuit in all three units to increase dynamic range. The regulator settings on all three units were chosen to provide identical performance for consistent operation. Slight differences in potentiometer settings exist due to component tolerance.

REGULATOR ADJUSTMENT CRITERIA

Because the Keswick generators are rated under 50 megavolt-amperes, they are not equipped with a power system stabilizer (PSS). The absence of a PSS could allow the automatic voltage regulator to decrease the local mode stability margin if the regulator was adjusted to maximum response speed. Therefore, the regulators were tuned for moderate speed and a high damping level. Because these units do not share a common transformer, the regulators were set at zero droop. This setting will provide voltage regulation at the 6.9-kilovolt bus.

RATINGS AND CALIBRATIONS

Units 1, 2, and 3 at Keswick are rated 41.053 megavolt-amperes at 0.95 power factor. Rated voltage is 6.9 kilovolts, and rated current is 3435 amperes. Full megavolt-ampere output is obtained at a real power of 39 megawatts and a reactive power of 12.8 megavars.

The PT (potential transformer) ratio is 60:1, and the CT (current transformer) ratio is 5000:5. The voltage regulator terminal voltage transducer at regulator card test point 741 (TP741) has a base of 10 volts per unit.

Base field current of 360 amperes is required to produce rated terminal voltage on the air gap line of the generators (fig. 1). The field resistance at 25 °C is 0.252 ohm. At an operating temperature of 75 °C, the resistance was calculated at 0.302 ohm, providing a base field voltage of 109 volts.

Rotating exciter base field current of 6.2 amperes is required to produce 109 volts out of the exciter on the air gap line (fig. 2). The exciter field resistance is approximately 6.5 ohms at a typical operating temperature of 40 °C, resulting in a base exciter field voltage of approximately 40.3 volts.

At rated load (39 megawatts, 12.8 megavars), the main field current is approximately 760 amperes; therefore, the main field voltage is approximately 230 volts (at 75 °C). The exciter field current is approximately 18 amperes and the exciter field voltage is approximately 117 volts.

INITIAL STARTUP

Initial voltage application was successful on the first try. The generator and exciter saturation curves were verified to match figures 1 and 2.

OFFLINE PERFORMANCE

The added time constant of the rotating exciter produces marginal stability in the original unmodified regulator control system. This condition was corrected during previous commissioning tests by adding an RC (resistor- capacitor) network in the firing angle circuitry as shown in figure 3 [1][1]. The RC network consists of a 1-microfarad capacitor in series with a 49.9-kilohm resistor connected across the series combination of resistors R1141 and R1142. Report R-90-21 contains the analysis of the resulting control system. The manufacturer provided these modifications in the unit 3 regulator circuit board.

To improve system response, the gain of the voltage regulator was increased by adjusting gain potentiometer P604 on all three units from 60 percent to 70 percent. The frequency response of the closed-loop voltage regulating system for unit 3 with the unit off line at rated voltage and speed is presented in figure 4. Two responses are presented for settings of P604 at 60 percent and 70 percent. At a 70-percent setting, the bandwidth increased from approximately 1.3 hertz to 1.7 hertz, with a marginal increase in overshoot compared to the 60-percent response.

The frequency responses of all three units with P604 at 70 percent is presented in figure 5. The responses are similar. The step response of unit 3 at the final settings is presented in figure 6. The 10-percent to 90-percent rise time is 0.2 second and overshoot is 17 percent.

---

[1] Numbers in brackets refer to references at the end of the report.

The automatic (voltage) regulator minimum voltage reference was set by P104 to produce 60 percent of rated terminal voltage with the reference setter at minimum. The maximum voltage reference was set by P454 to produce 105 percent of rated terminal voltage with the reference setter at maximum.

The manual (current) regulator for this unit controls main field current. The modification (RC network) also acts on this controller to insert lead/lag compensation identical to that placed in the automatic (voltage) regulator circuit. The offline step response of the manual regulating system is presented in figure 7. The 10- to 90-percent rise time is approximately 1 second, and the overshoot is 10 percent (for increasing voltage).

The manual regulator minimum current reference potentiometer (P125) was set to produce 30 percent of rated terminal voltage (80 amperes of main field current). The maximum current reference potentiometer (P334) was set to produce 100 percent of rated (main) field current at full load and rated power factor, overexcited. This corresponds to a main field current of 760 amperes.

ONLINE PERFORMANCE

The unit was synchronized and loaded on the first attempt with no problems. The small-signal step response of the closed-loop automatic voltage regulating system with the unit online is presented in figure 8. The 10- to 90-percent rise time is approximately 0.8 second and the overshoot is 16 percent. The control system performance is well damped, with one overshoot.

Figure 9 contains the Bode plot of the online automatic voltage regulating system. The 3-decibel bandwidth is approximately 0.52 hertz, and the resonant peak magnitude is less than 2 decibels above the steady-state gain. Local mode resonance, occurring at a frequency near 1.8 hertz, is damped.

The reactive droop potentiometer (P108) was set to zero since the unit does not share a transformer with another unit. This setting provides voltage regulation at the machine terminals (6.9-kilovolt bus).

AUTOMATIC LIMITERS

The regulator is equipped with V/Hz (volts per hertz), minimum excitation, and maximum excitation limiters. These limiters act in the automatic voltage regulator mode only and take control under certain conditions. They do not function in the manual (current) regulator mode.

The V/Hz limiter limits the ratio of terminal voltage to speed. A frequency transducer monitors the terminal voltage to determine the unit speed (frequency). The transducer converts speed to voltage, which is then fed into the automatic regulator. The regulator then maintains the ratio of terminal voltage to speed.

The V/Hz limiter should be operated with a large loop gain (potentiometers P104 and P112 at high values). At low gain settings, the V/Hz ratio drifts too far from the preset value and prevents the limiter from coordinating with the V/Hz relay.

Unit 3 was originally equipped with a modified add-on board. One of the modifications on this board reduced the value of capacitor C301 from 22 microfarads to 2 microfarads. Previous experience showed that this low value of C301 forces the limiter into oscillations at the high gain settings. Therefore, the original add-on board No. A1-401-340-010 was replaced with the older version No. A1-401-340-003.

To provide for maximum V/Hz gain, P104 was set to 100 percent, and the range was set to 100 percent on P112. The V/Hz limiter was set at a ratio of 1.06 per unit via potentiometer P405. The limiter performance was tested by increasing the automatic regulator output to maximum and then lowering speed. The limiter maintained a ratio of 1.06 per unit (±0.01) at all speed values (see table 1).

Table 1. – Volts/hertz limiter data.

PT[1] (volts)	Freq[2] (hertz)	PT[1] (pu)	Freq[2] (pu)	V/Hz (pu)
118.7	58.3	1.03	0.972	1.062
115.0	56.3	1.00	0.938	1.066
111.4	54.1	0.97	0.900	1.074

[1] PT base 115 volts.
[2] Frequency base 60 hertz.

The V/Hz loop gain on unit 1 was very low during testing. Subsequent testing of the unit 1 V/Hz limiter showed that its performance was unsatisfactory. Therefore, the settings of the V/Hz limiter on unit 1 were adjusted to equal the settings on units 2 and 3. The limiter operated satisfactorily during retesting.

The minimum excitation limiter prevents the generator from operating excessively underexcited. The capability curve on figure 10 contains the desired minimum excitation curve. Saturation of operational amplifiers in the limiter circuits limited the maximum setting of slope potentiometer P726 to 55 percent. This setting produces the rather steep slope seen on figure 10. Because of operational limits, the slope was tested at the lower breakpoint, then adjusted to the higher level.

The maximum excitation limiter has two functions. First, it provides a fixed instantaneous field current limit, allowing high-level excitation for a short time. Second, the limiter provides an inverse time characteristic after which the excitation limit is reduced to the rated value.

The instantaneous overexcitation was set via potentiometer P510, limiting overcurrent to 145 percent of rated field current. The timed field current limit was set to 100 percent through potentiometer P527. The time delay potentiometer P517 was set to produce the time delay shown in table 2.

Table 2. – Timed field current data (fig. 11).

% I_{fd} above setpoint	Time delay
10	8 sec
35.2	3 sec
50	2 sec

RELAY COORDINATION

The field overvoltage transfer to current regulator mode and lockout trip circuits were tested and timed. The field overvoltage transfer to current regulator mode was set at 130 percent of rated field voltage (300 volts) and a 15-second time delay. The field overvoltage lockout trip circuitry was set at 130 percent of rated field voltage and a 25-second time delay. The relay pick-up voltage was adjusted by setting the relay shunt resistor wiper to 83 percent (the relay operates at 250 volts). The shunt resistors for the field overvoltage relays on units 2 and 3 were set similarly. These coordination levels are presented in figure 11, along with the maximum excitation limiters and the short-time field current capability curve.

LOAD REJECTION PERFORMANCE

Load rejections were executed at 5 megawatts, 15 megawatts, 22 megawatts, and 36 megawatts, 12 megavars. The unit breaker trip of the 36-megawatt, 12-megavar load rejection is presented in figure 12. The unit breaker trip verified proper operation of the regulator phase back. The 36-megawatt, 12-megavar load rejection via the lockout relay (86) is presented in figure 13. This load rejection ensured proper operation of the thyrite discharge circuitry.

Load rejection testing detected a bridge single-phase condition, which was traced to a faulty 41E breaker. The 22-megawatt load rejection under the single-phasing condition is presented in figure 14(a). The 22-megawatt load rejection following correction of the condition is presented in figure 14(b). Overvoltage was reduced from 110 percent to 104 percent.

Results of the load rejections are summarized in table 3.

Table 3. - Load rejection performance.

Load	Overspeed (%)	Overvoltage (%)
5 MW Unit Brk Trip	100.5	101
15 MW Unit Brk Trip	114	101
22 MW Unit Brk Trip	127	102
22 MW 86 Trip	121	104
36 MW, 12 MVARS Unit Brk Trip	152	123 pre-rejection 103
36 MW, 12MVARS 86 Trip	147	124 pre-rejection 103

REFERENCE

[1] Agee, J. C., and G. K. Girgis, *Keswick Powerplant Unit 1 Excitation System Commissioning*, Bureau of Reclamation, Research and Laboratory Services Division, Electric Power Branch, December 1990.

APPENDIX

POTENTIOMETER SETTINGS FOR UNITS 1, 2, and 3.

Parameter	Comments	U1 (%)	U2 (%)	U3 (%)
		Main Regulator Board		
P1256	Gate Max Retard Lim	75	75	75
P1131	Reactive I Cal	72	70	70
P956	Freq/Volt Cal	70	70	70
P936	Real I Cal	70	75	70
P747	Freq/Volt Cal	55	60	50
P734	Vt. Feedback Cal	20	20	20
P726	Min Exc Limit Slope	42	50	55
P827	Min Exc Limit B.P.	45	55	55
P709	Min Exc Limit	50	50	45
P636	I Reg Limiter	55	50	55
P617	Min Exc Limiter Gain	100	100	100
P604	AVR Gain	70	70	70
P603	AVR Load	100	100	100
P527	If Timed Limit	42	42	42
P517	If Timed T.D.	90	100	100
P510	If Inst Limit	70	70	70
P454	Max V Ref	50	55	50
P337	I Reg Gain	0	0	0
P334	Max I Ref	60	65	56
P325	If Feedback Cal	8	10	7
P125	Min I Ref	8	7	10
P108	Reactive I Droop	0	0	0
P104	Min V Ref	5	3	2
SW 301-1	Lead Lag Adj (Res)	CLOSED	CLOSED	CLOSED
2	Lead Lag Adj (Cap)	CLOSED	CLOSED	CLOSED
3	Lead Lag Adj (Cap)	OPEN	OPEN	OPEN
		Auxiliary Board		
P132	Var Reg N/A	100	100	100
P136	Var Reg N/A	100	100	100
P336	Var Gain Adj N/A	0	0	0
SW147-1	P/F Var Reg Switch	OPEN	OPEN	OPEN
SW147-2	Auto Tracking On/Off	CLOSED	CLOSED	CLOSED
P405	Nominal V/Hz Adj	40	40	40
P104	V/Hz Gain	100	100	100
P112	V/Hz Range	100	100	100
P439	Reactive Line Drop	0	0	0
P443	Real I Line Drop	0	0	0
P446	Line Drop Range	0	0	0
Cur Reg Setter (Initial)		35	28	32
(Preset)		45	45	49
Volt Reg Setter (Initial)		67	67	67
(Preset)		89	89	89

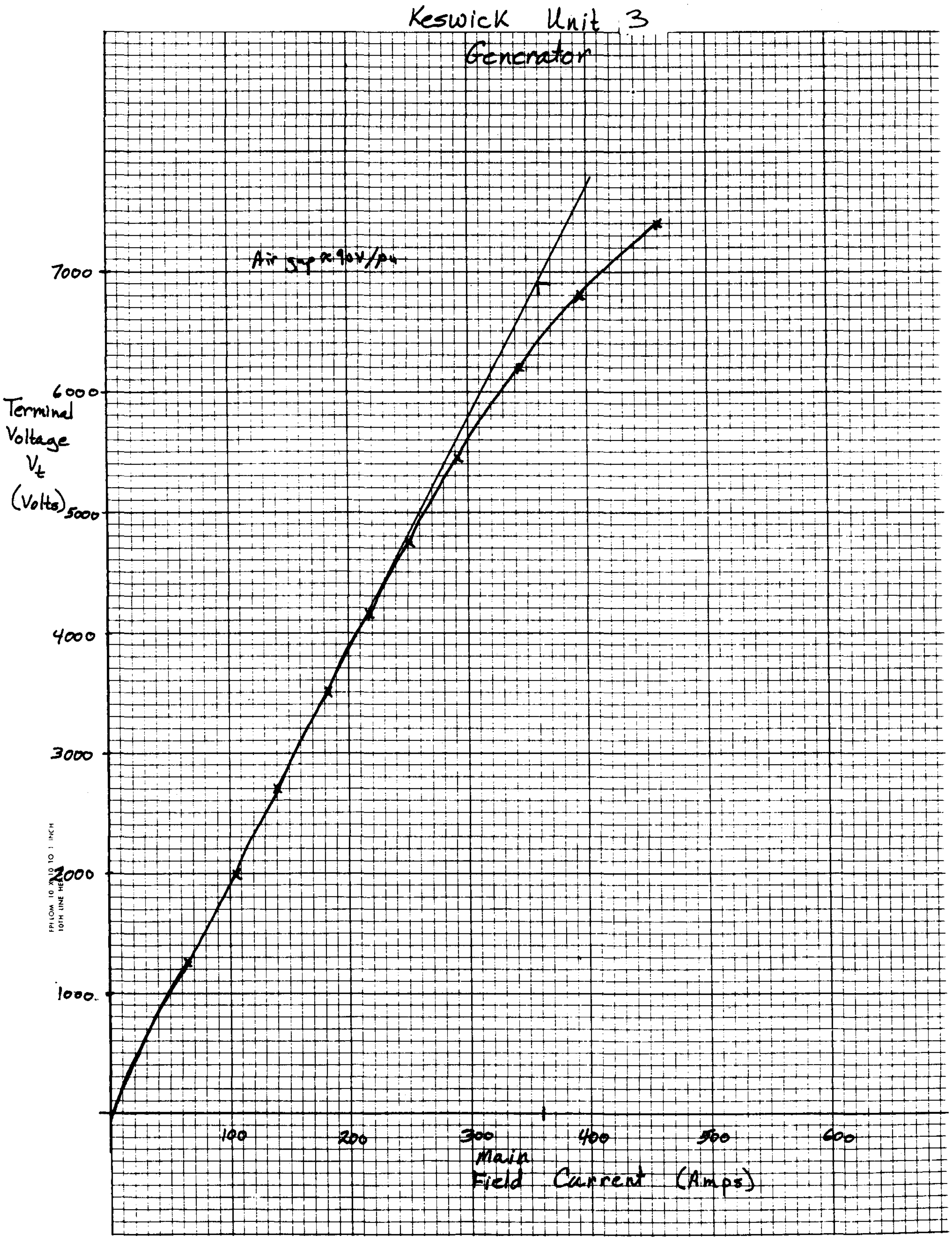


Figure 1. – Main field saturation curve.

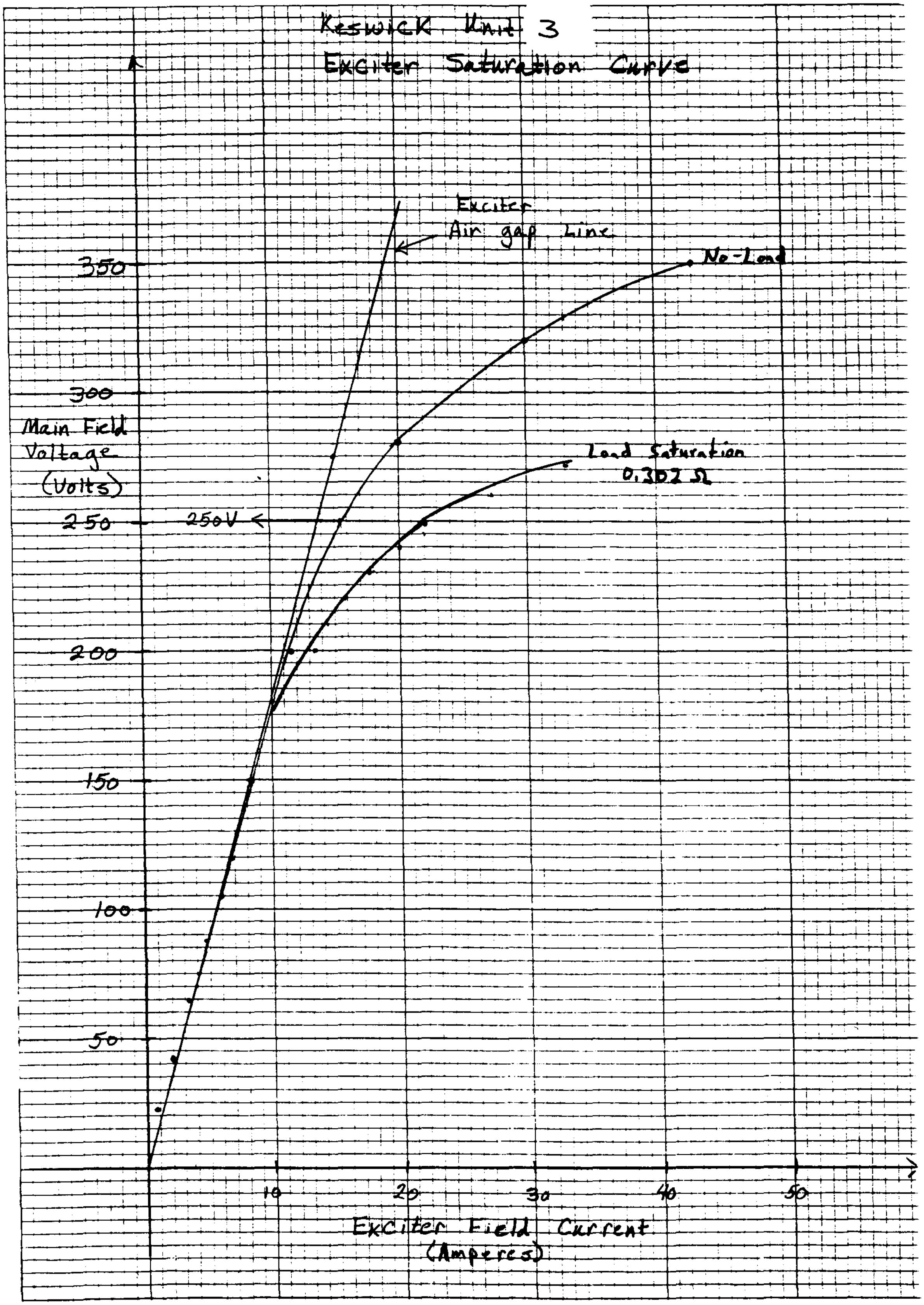


Figure 2. – Exciter field saturation curve.

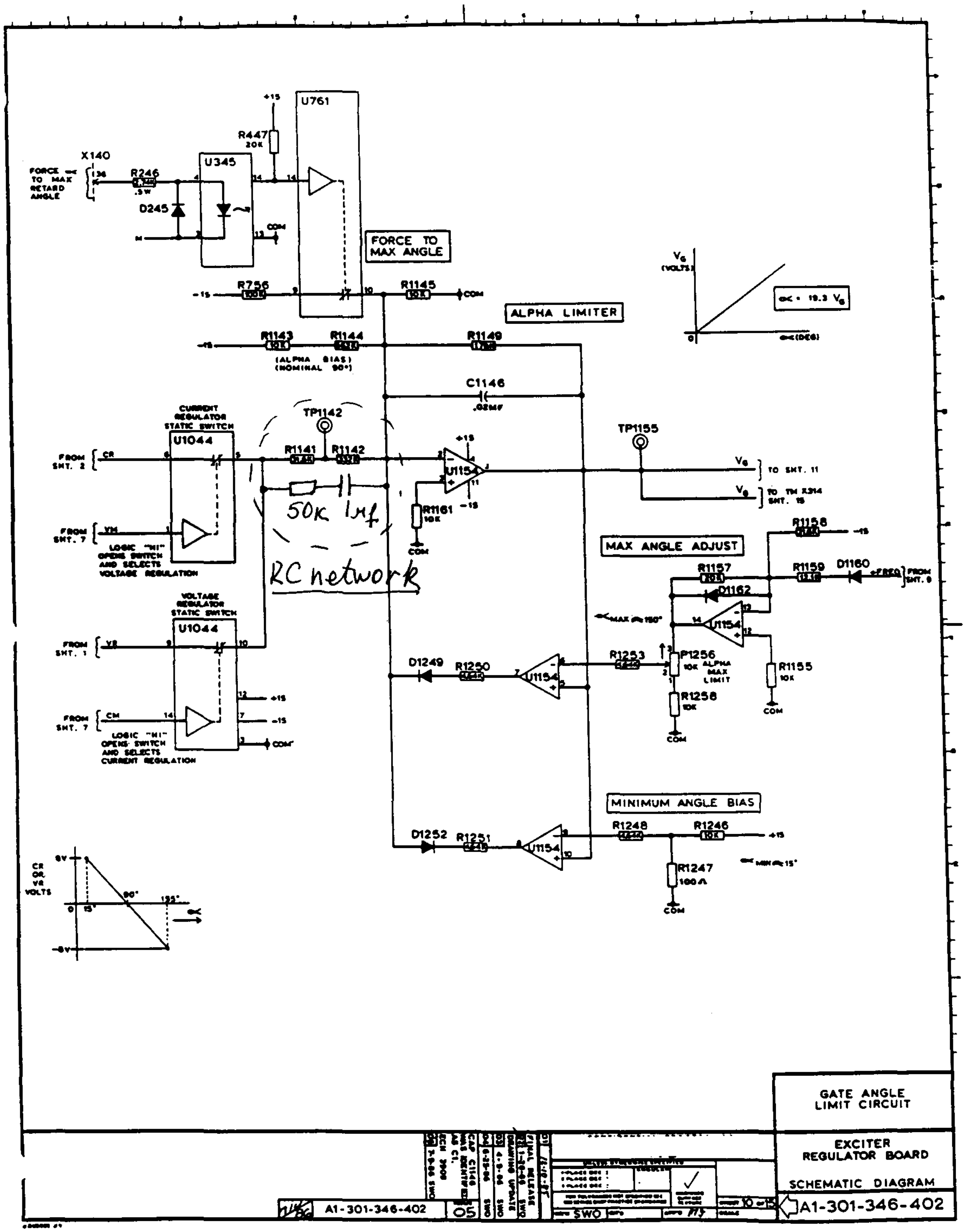


Figure 3. – RC circuit modification.

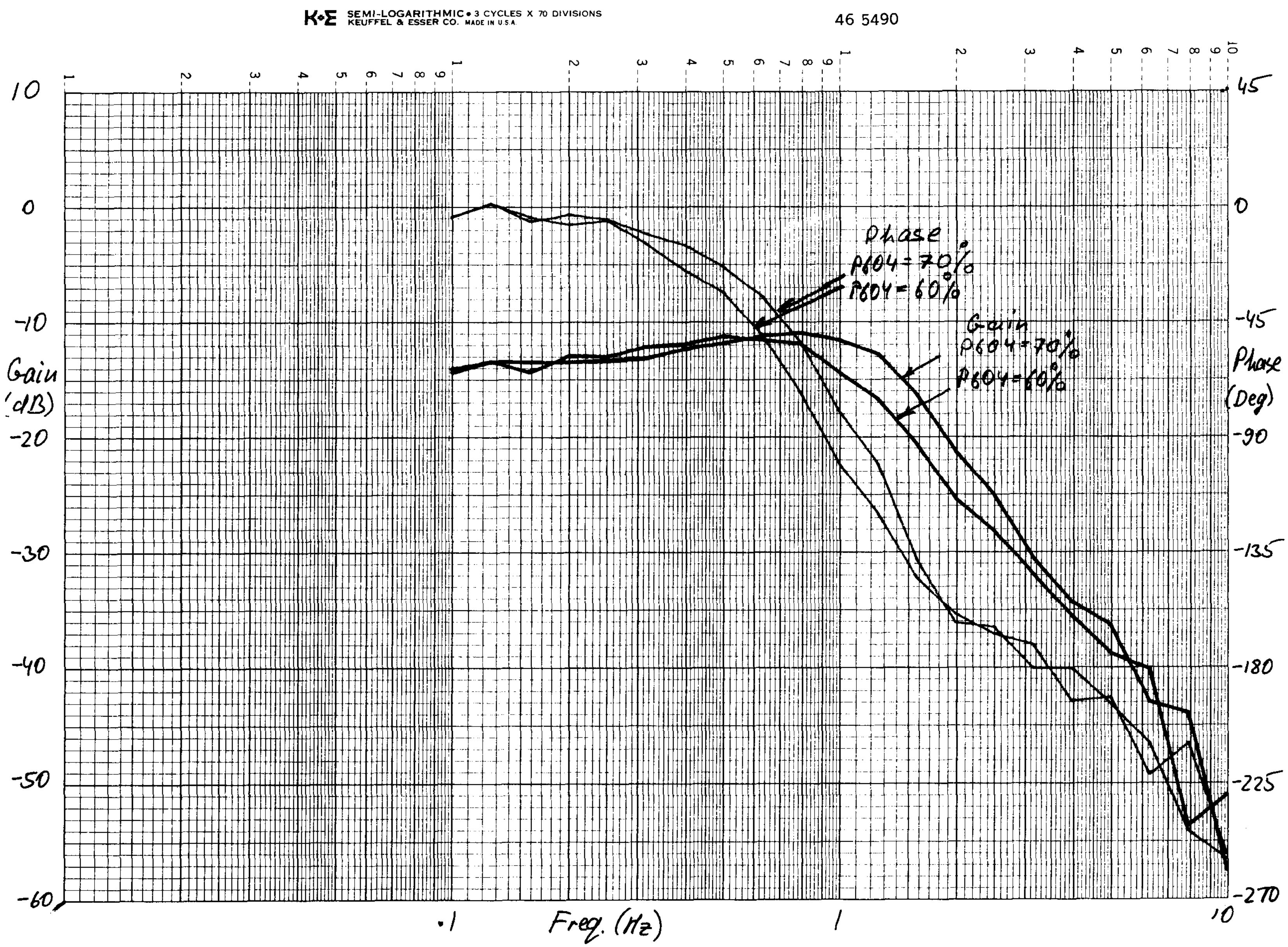


Figure 4. – Offline closed-loop frequency response for unit 3 (P604 = 60% and 70%).

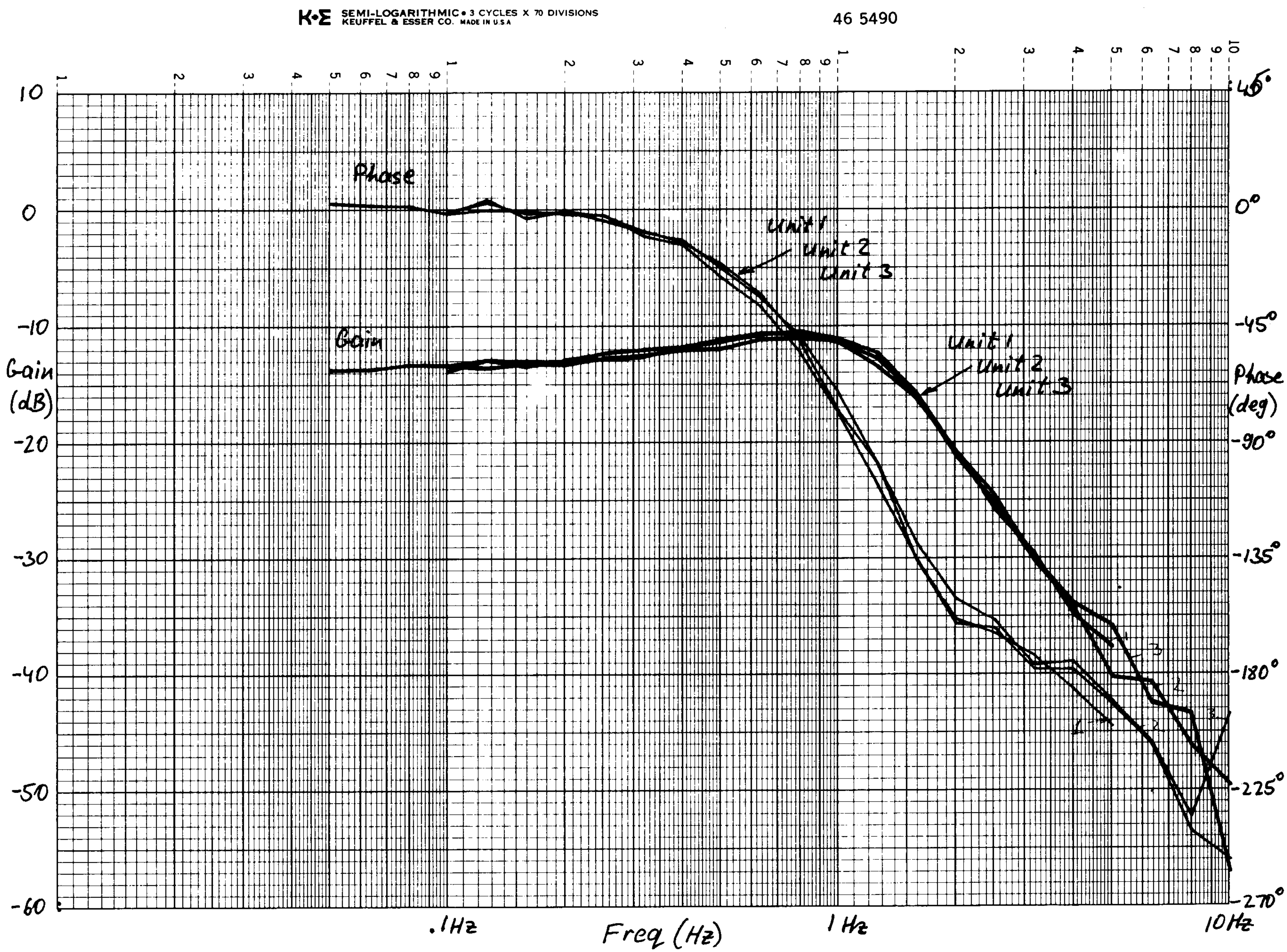


Figure 5. – Offline closed-loop frequency response for units 1, 2, and 3 (P604 = 70%).

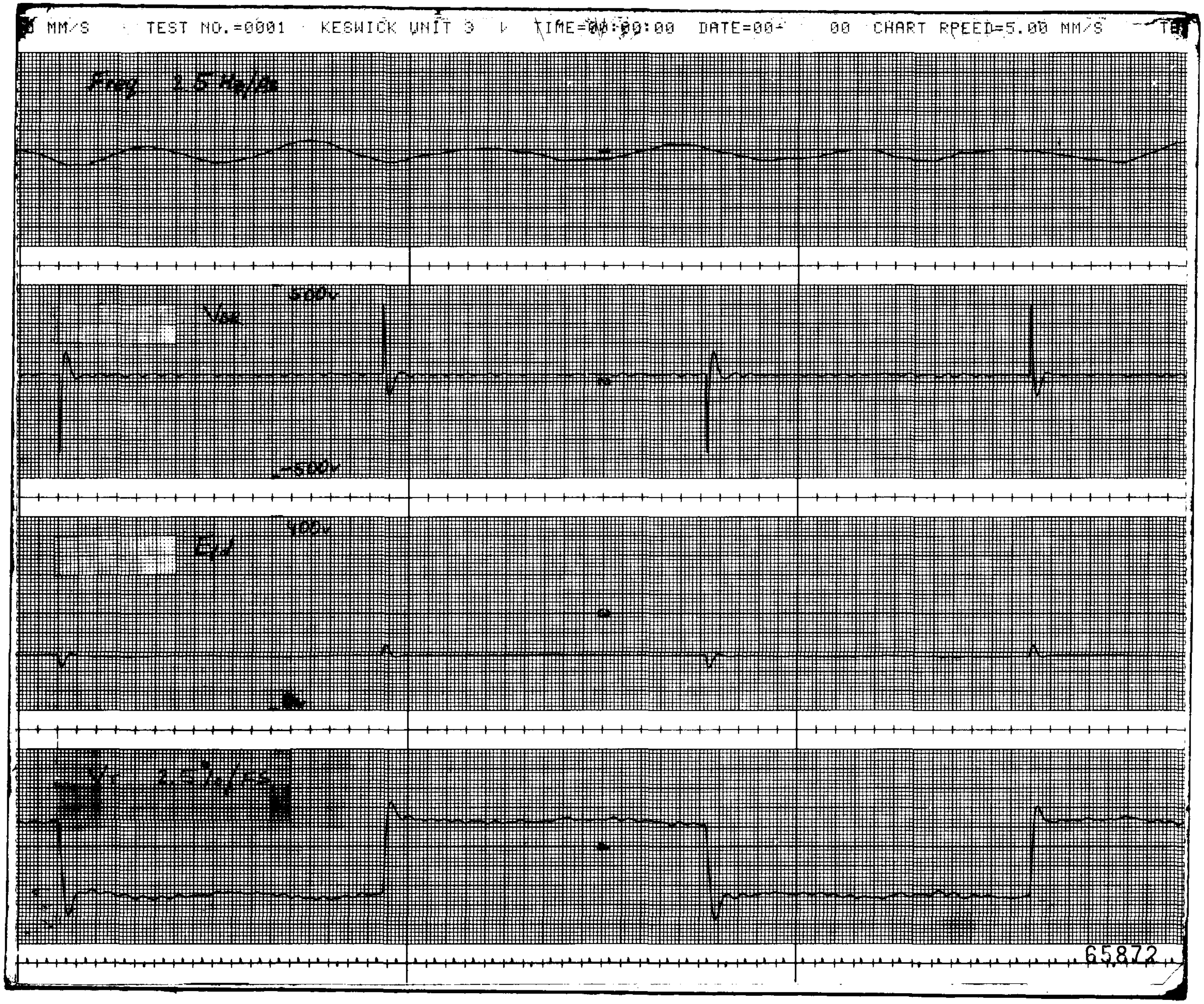


Figure 6. – Offline step response of auto regulator for unit 3 (final settings).

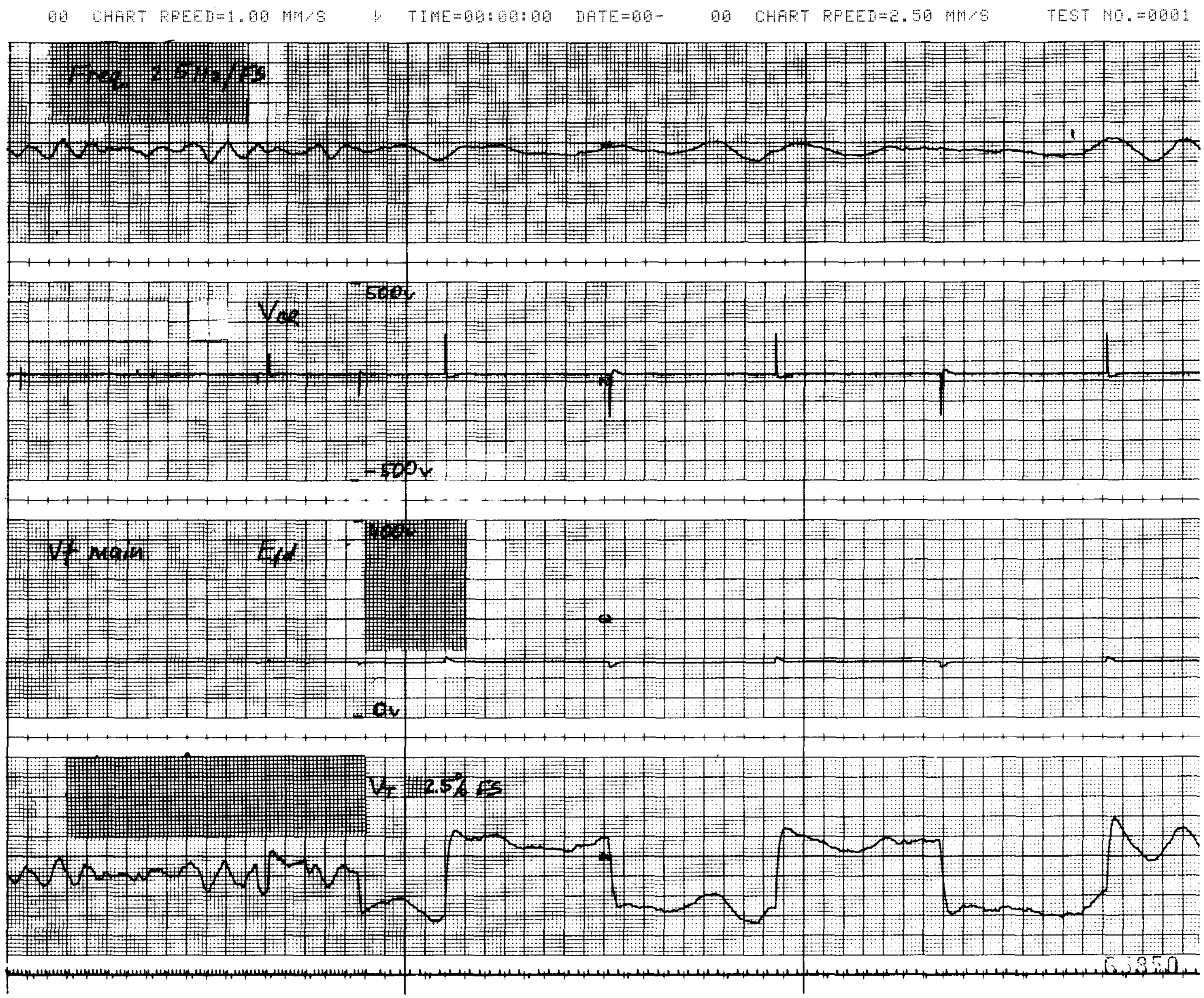


Figure 7. – Offline step response of manual regulator for unit 3 (final settings).

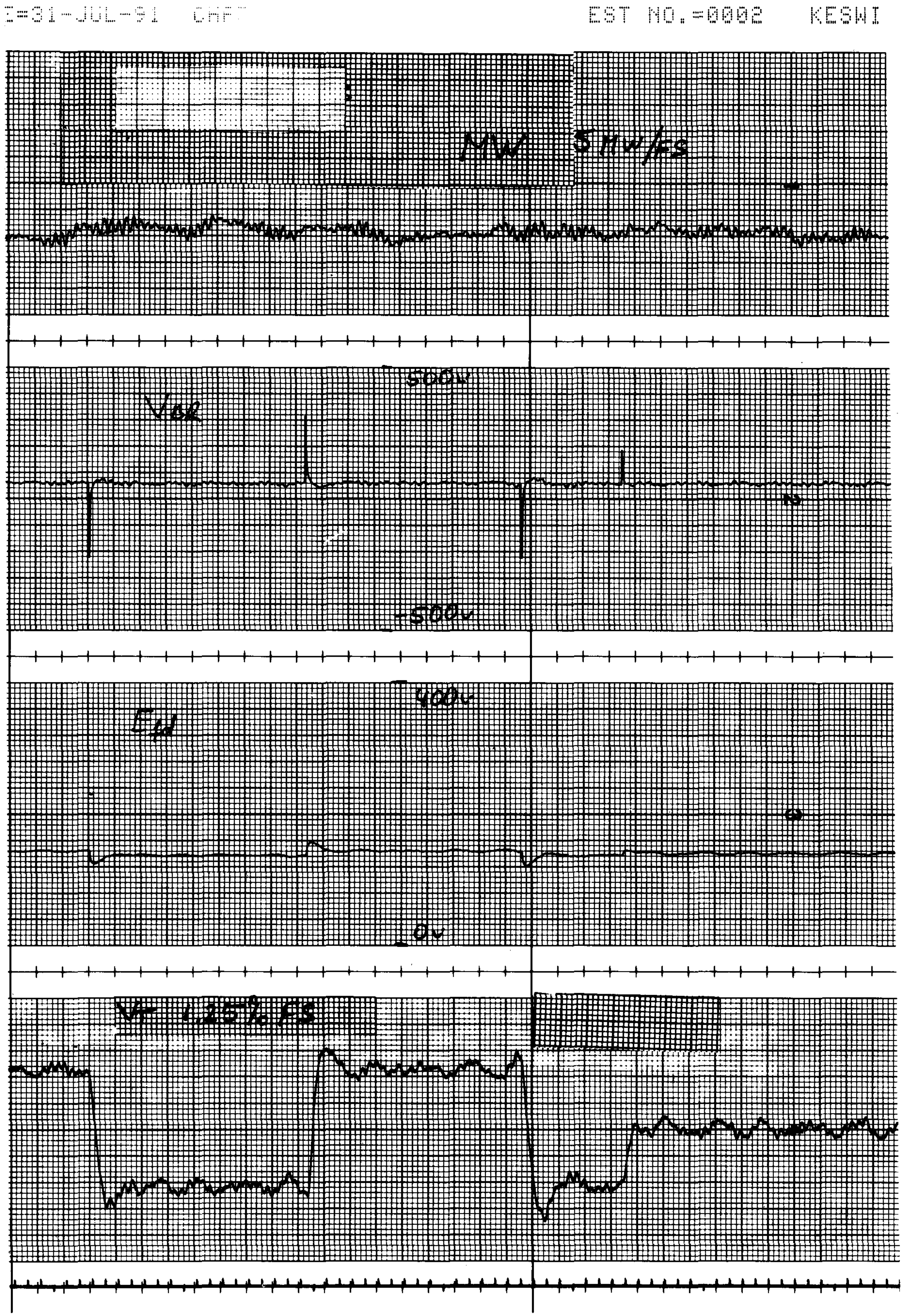


Figure 8. – Online step response of auto regulator for unit 3.

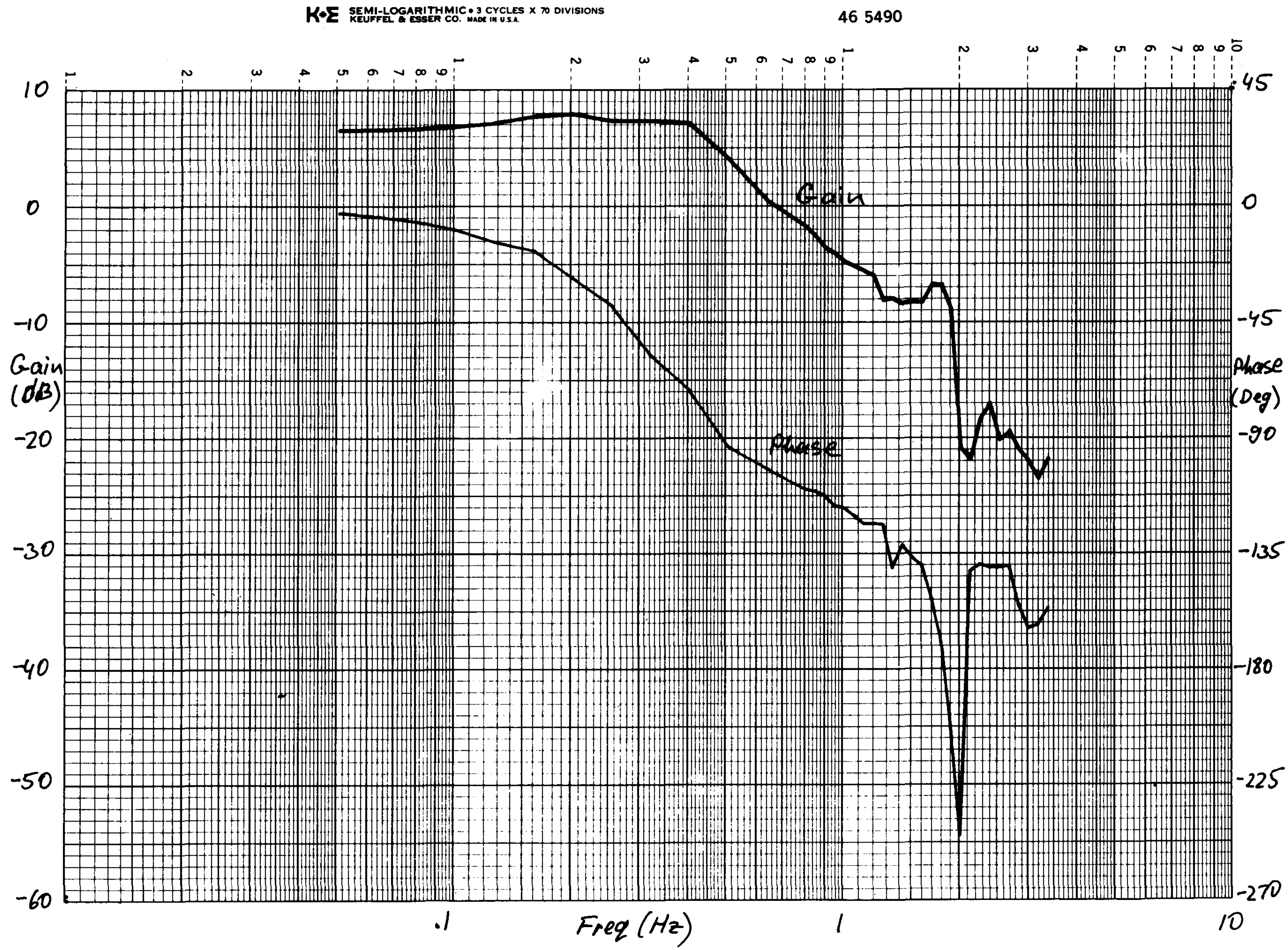


Figure 9. – Online frequency response for unit 3.

7-1654 (7-73)
Bureau of Reclamation

COMPUTATION SHEET

BY	DATE	PROJECT Keswick	SHEET ____ OF ____
CHKD BY	DATE	FEATURE Unit 1	

DETAILS Loss of Field, Minimum Excitation & Generator Capability

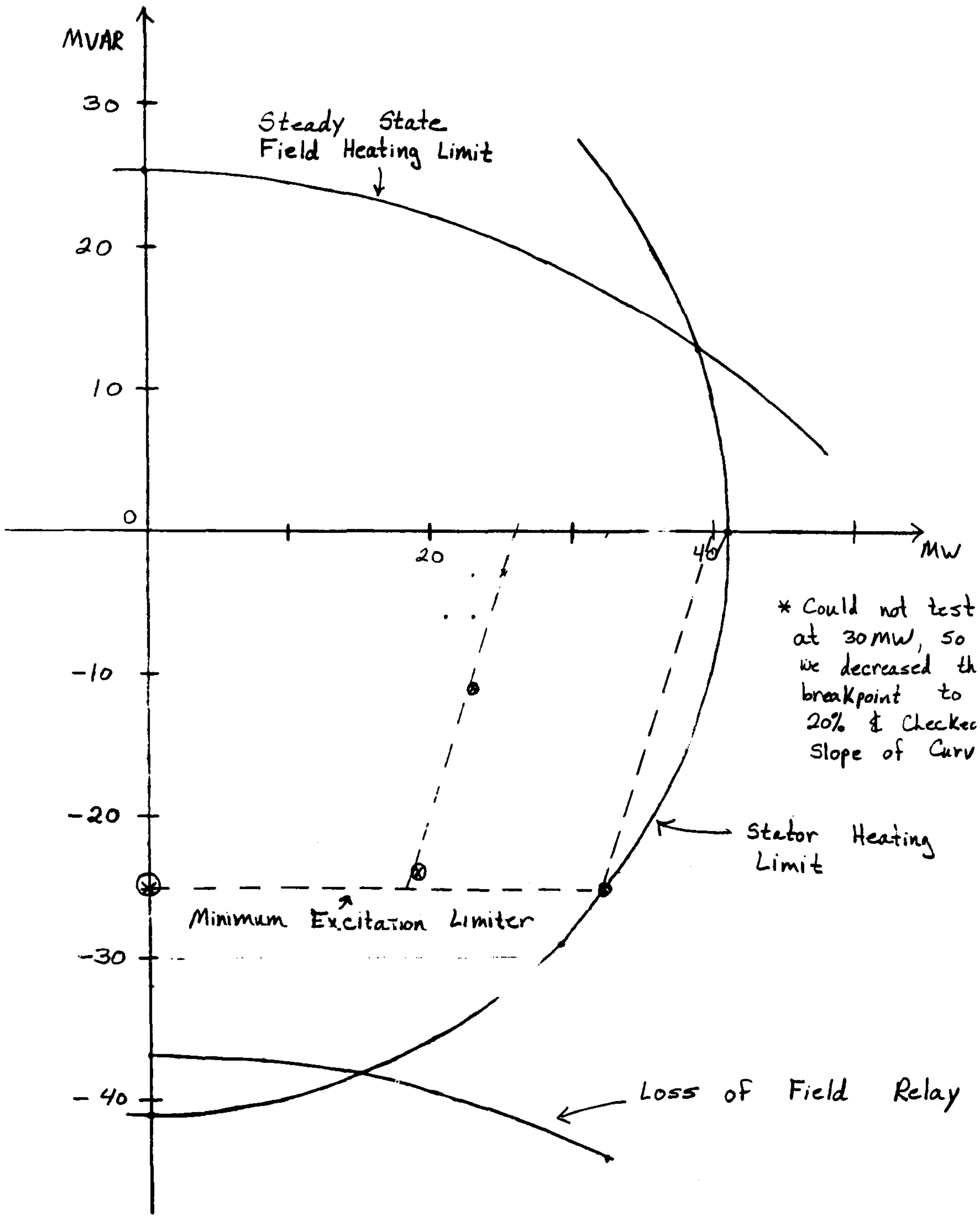
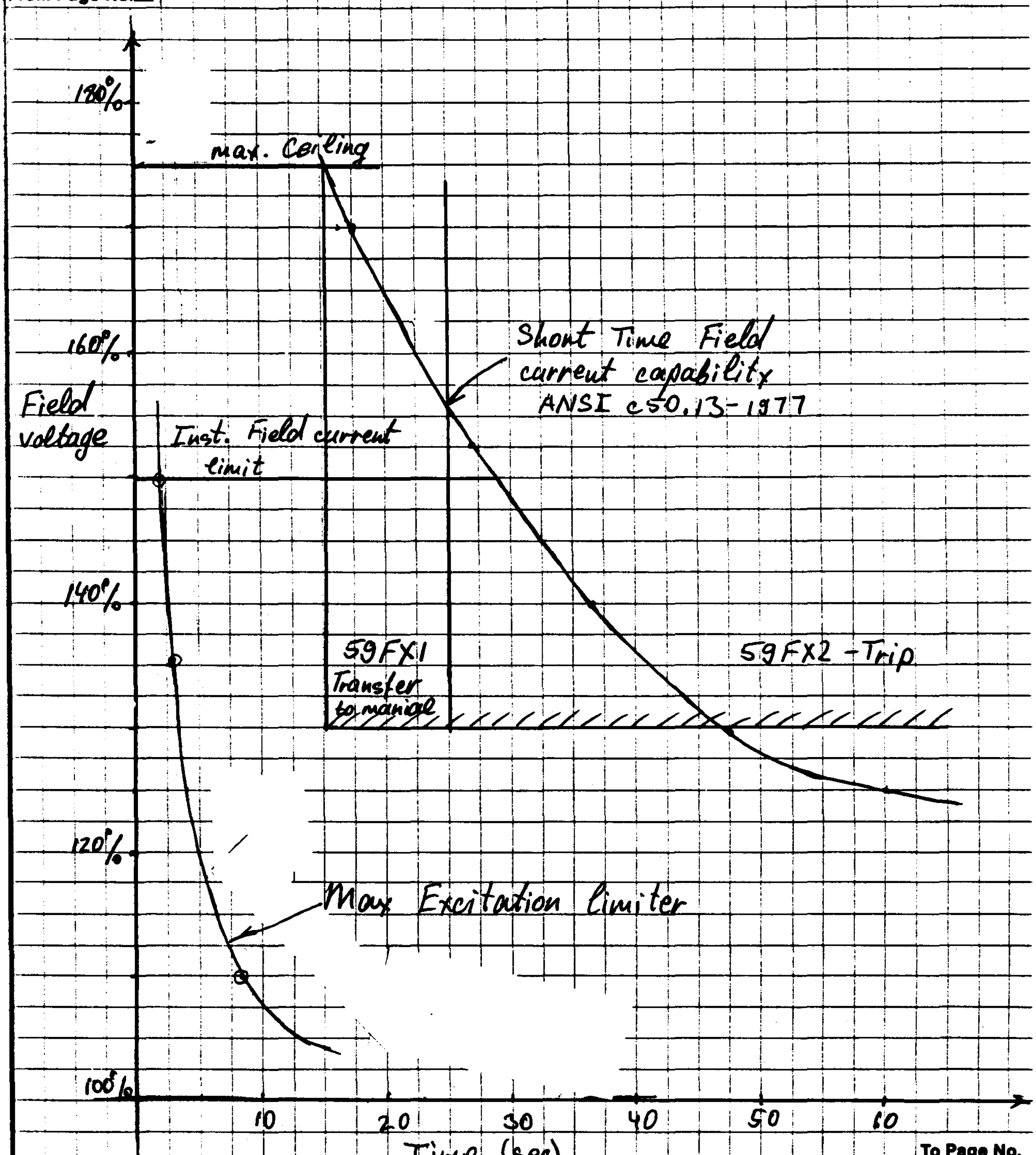


Figure 10. – Generator capability curve.

TITLE ____________ Project No. ____ Book No. ____

From Page No. ___



To Page No. ___

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by	

Figure 11. – Maximum excitation limiter coordination curves.

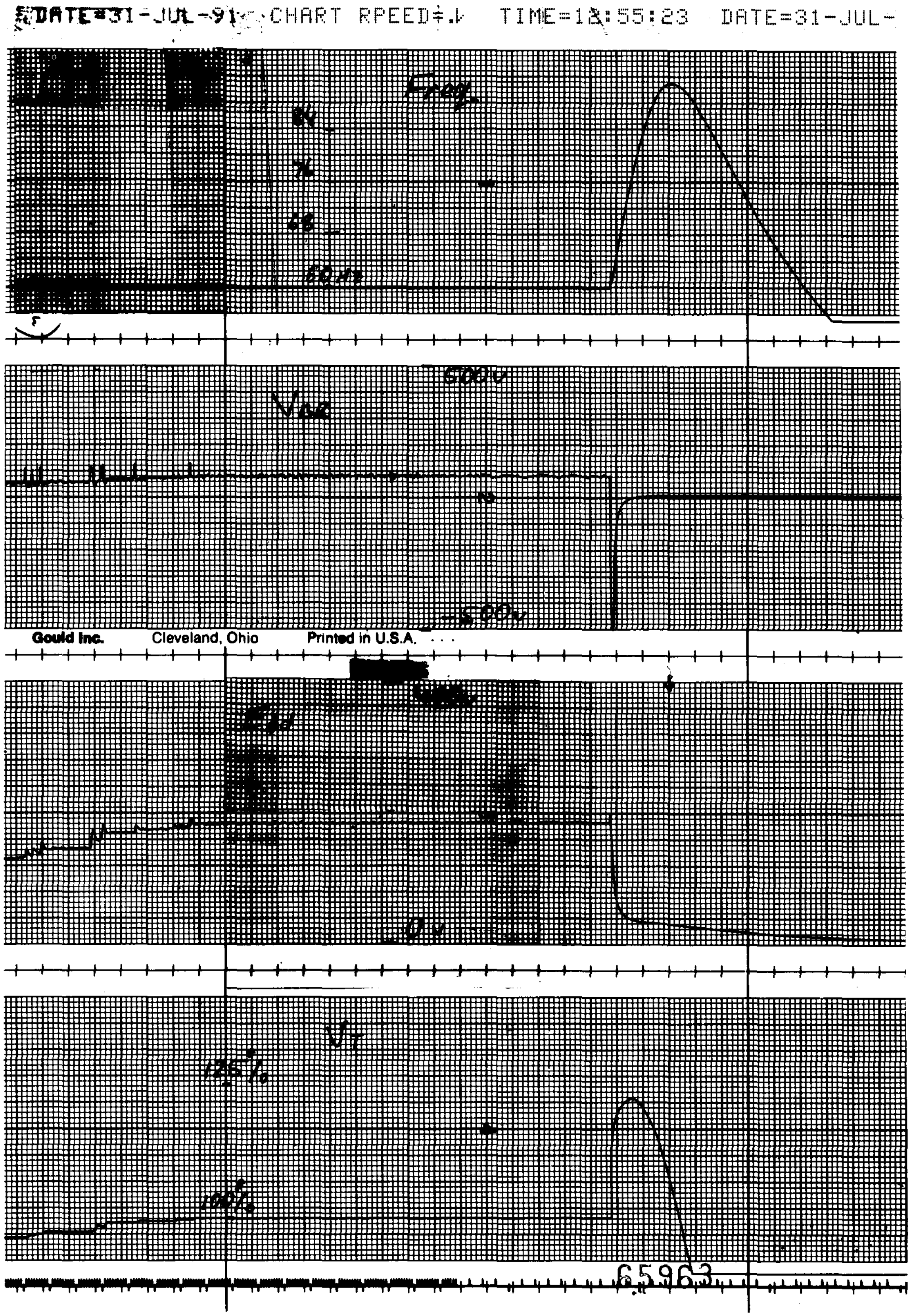


Figure 12. – Load rejection (unit breaker trip, 36 MW, 12 MVAR).

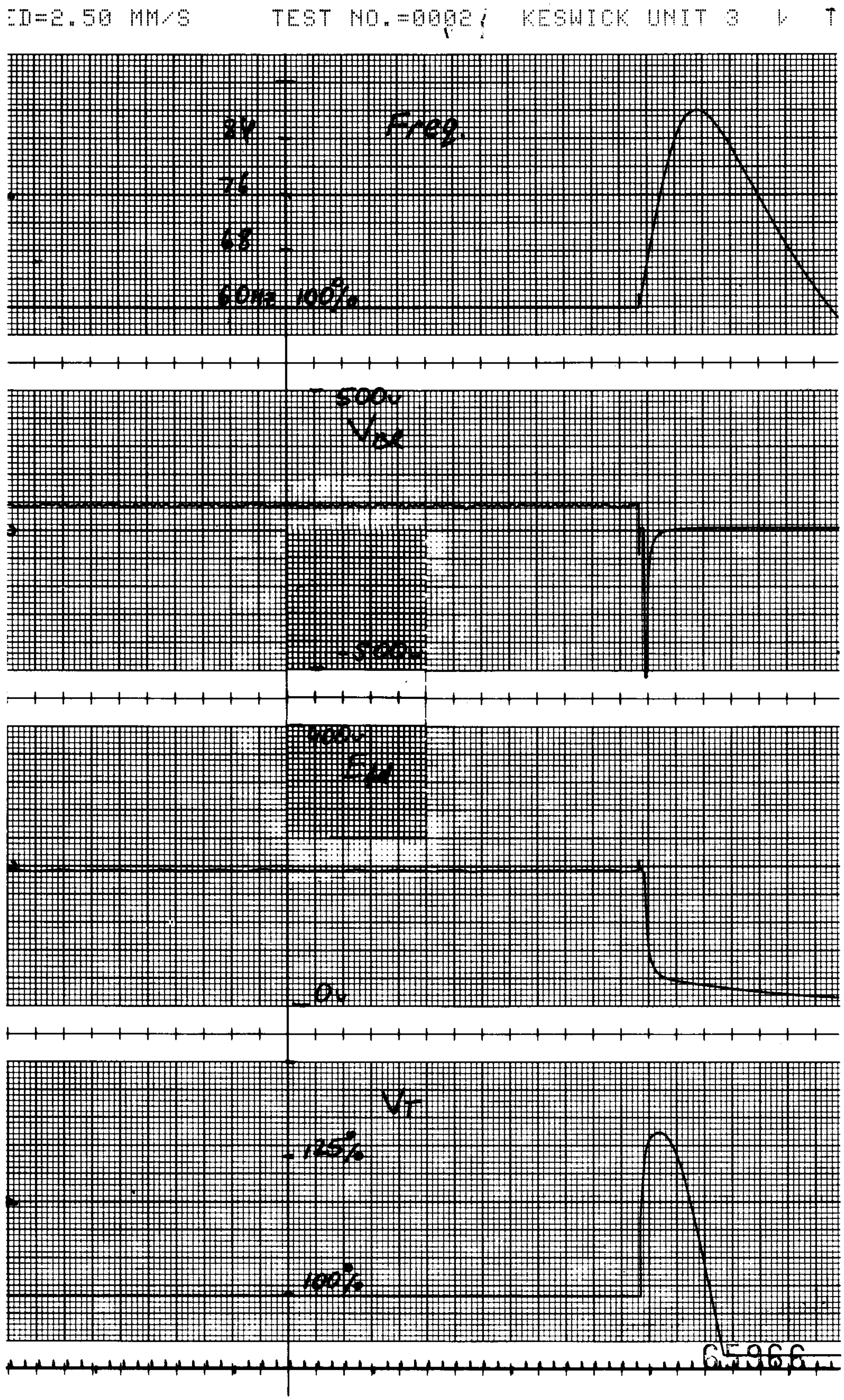


Figure 13. – Load rejection (lockout relay trip, 36 MW, 12 MVAR).

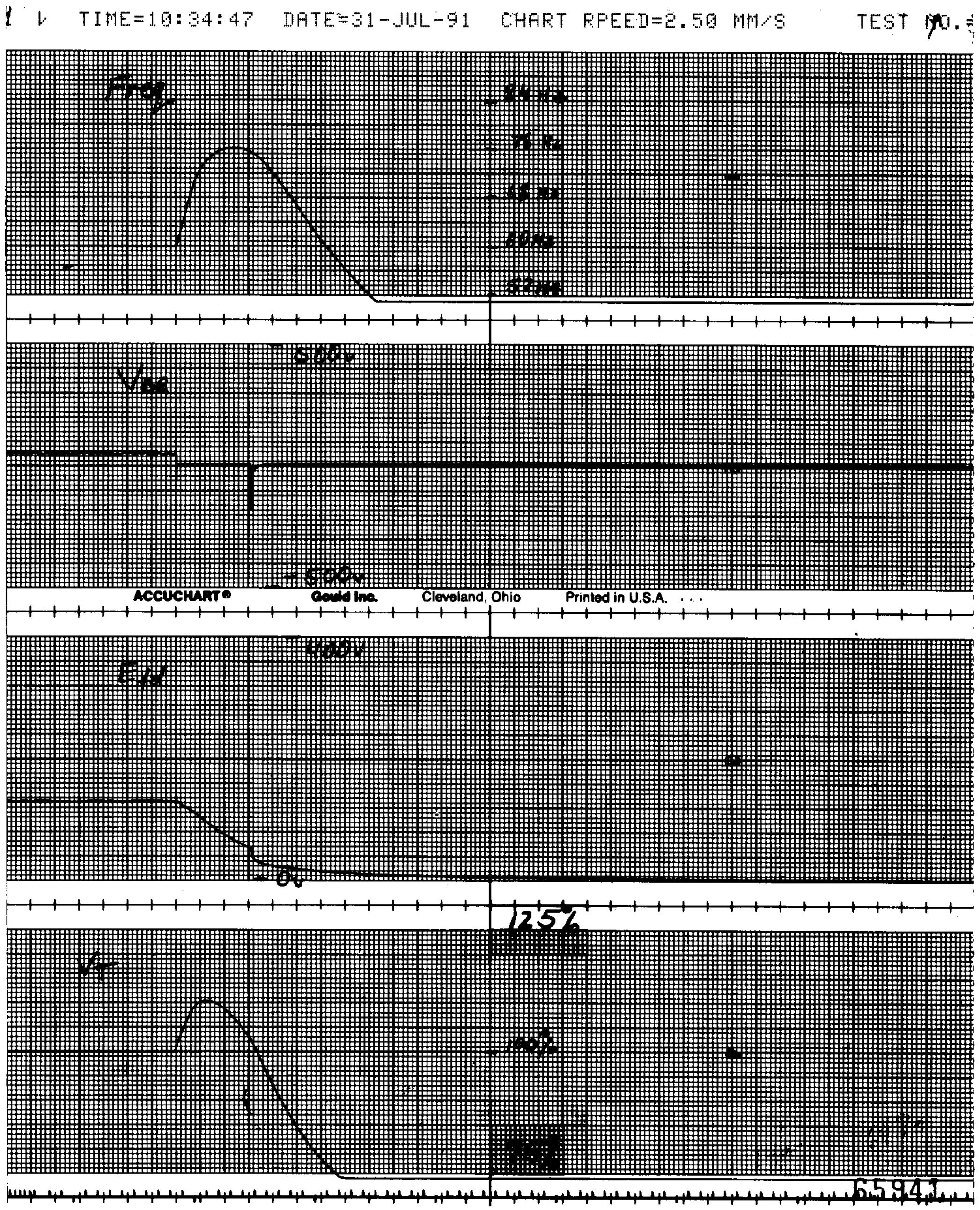


Figure 14(a). – Load rejection, single-phasing condition, 22 MW.

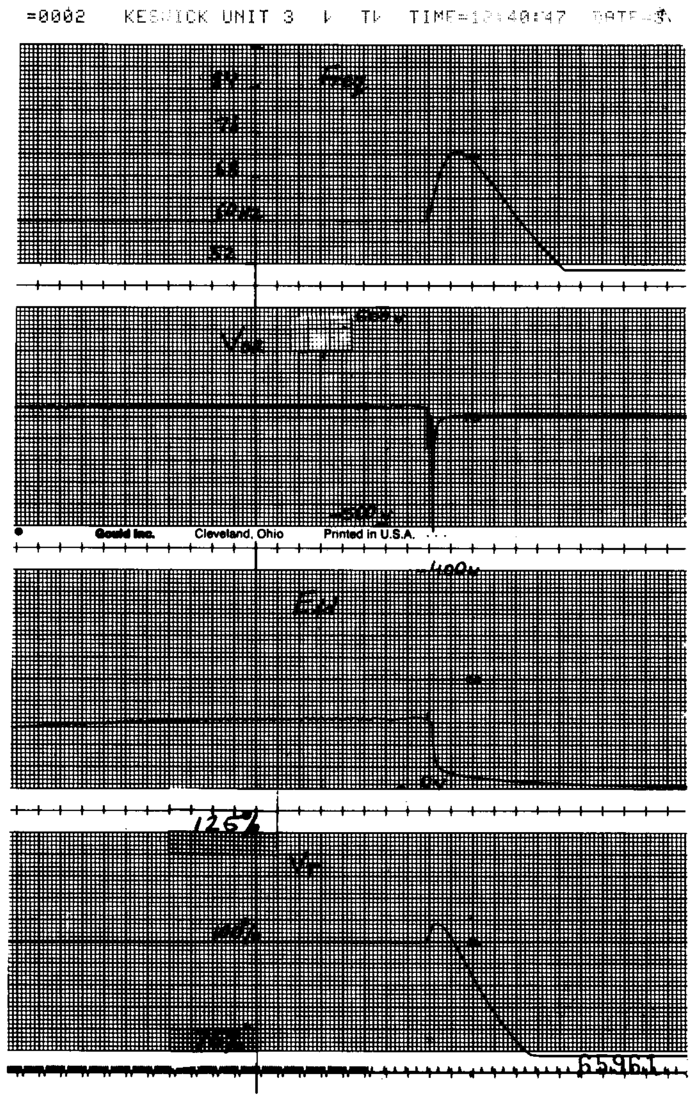


Figure 14(b). – Load rejection, normal conditions, 22 MW.

APPENDIX

POTENTIOMETER SETTINGS FOR UNITS 1, 2, and 3.

Parameter	Comments	U1 (%)	U2 (%)	U3 (%)
Main Regulator Board				
P1256	Gate Max Retard Lim	75	75	75
P1131	Reactive I Cal	72	70	70
P956	Freq/Volt Cal	70	70	70
P936	Real I Cal	70	75	70
P747	Freq/Volt Cal	55	60	50
P734	Vt. Feedback Cal	20	20	20
P726	Min Exc Limit Slope	42	50	55
P827	Min Exc Limit B.P.	45	55	55
P709	Min Exc Limit	50	50	45
P636	I Reg Limiter	55	50	55
P617	Min Exc Limiter Gain	100	100	100
P604	AVR Gain	70	70	70
P603	AVR Load	100	100	100
P527	If Timed Limit	42	42	42
P517	If Timed T.D.	90	100	100
P510	If Inst Limit	70	70	70
P454	Max V Ref	50	55	50
P337	I Reg Gain	0	0	0
P334	Max I Ref	60	65	56
P325	If Feedback Cal	8	10	7
P125	Min I Ref	8	7	10
P108	Reactive I Droop	0	0	0
P104	Min V Ref	5	3	2
SW 301-1	Lead Lag Adj (Res)	CLOSED	CLOSED	CLOSED
2	Lead Lag Adj (Cap)	CLOSED	CLOSED	CLOSED
3	Lead Lag Adj (Cap)	OPEN	OPEN	OPEN
Auxiliary Board				
P132	Var Reg N/A	100	100	100
P136	Var Reg N/A	100	100	100
P336	Var Gain Adj N/A	0	0	0
SW147-1	P/F Var Reg Switch	OPEN	OPEN	OPEN
SW147-2	Auto Tracking On/Off	CLOSED	CLOSED	CLOSED
P405	Nominal V/Hz Adj	40	40	40
P104	V/Hz Gain	100	100	100
P112	V/Hz Range	100	100	100
P439	Reactive Line Drop	0	0	0
P443	Real I Line Drop	0	0	0
P446	Line Drop Range	0	0	0
Cur Reg Setter (Initial)		35	28	32
(Preset)		45	45	49
Volt Reg Setter (Initial)		67	67	67
(Preset)		89	89	89

☆ U.S. GOVERNMENT PRINTING OFFICE: 1991—673-185/60,003 REGION NO. 8

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.