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COAST GUARD EVALUATION OF A WAVE ACTIVATED TURBINE GENERATOR BU--ETC(U)
SEP 77 D J HILLIKER , W E COLBURN

UNCLASSIFIED CGR/DC-22/77 USCG-D-84-77 NL

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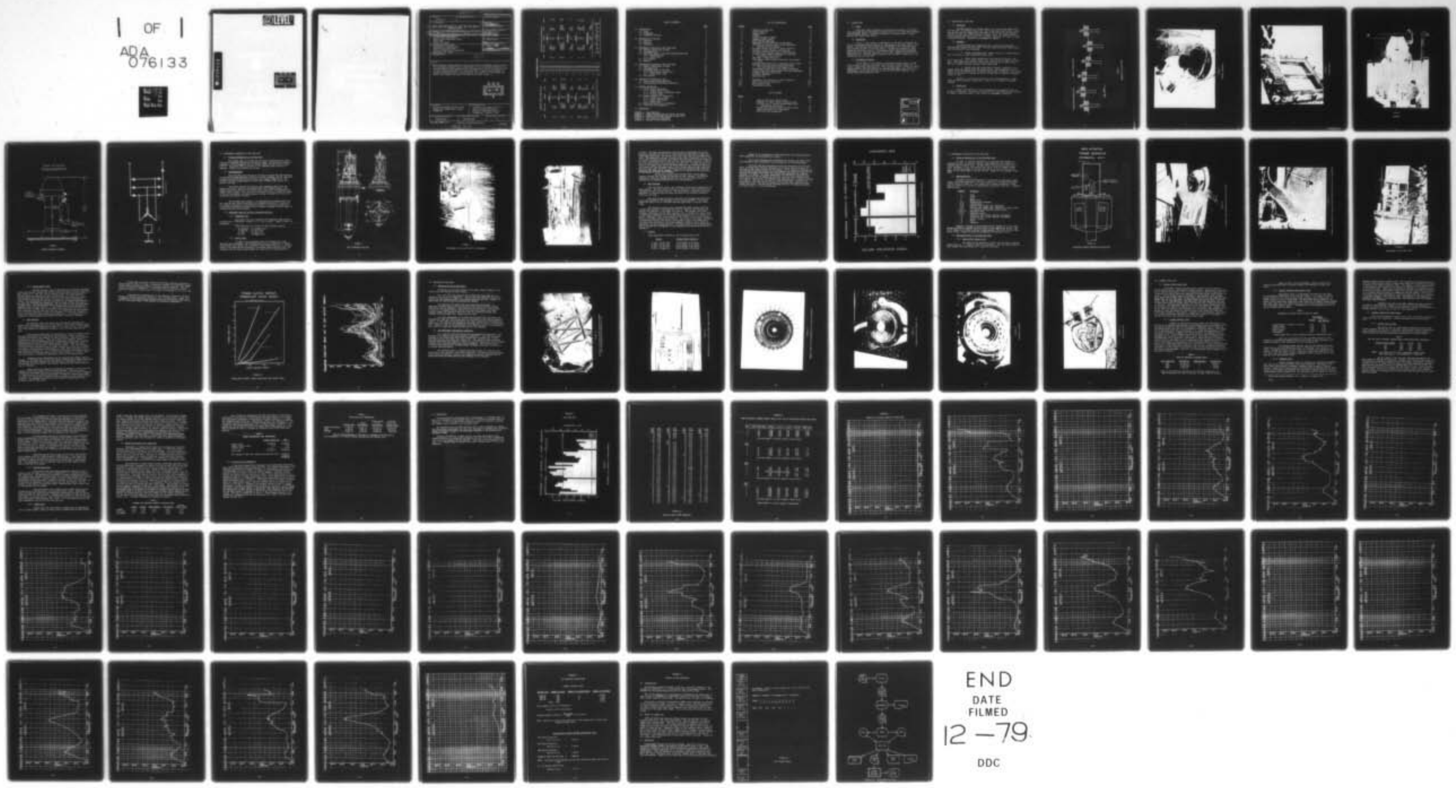

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16. Abstract

Wave activated turbine generator buoys were tested at Chesapeake Light (14 miles off Cape Henry, Virginia) and in Boston Harbor. The buoys were instrumented to record cumulative power generated and later modified to record sea state as well as other variables pertinent to turbine operation. Results are presented as long-term power generation, power generation as a function of wave height and period, and transfer functions from spectral analysis of data.

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METRIC CONVERSION FACTORS

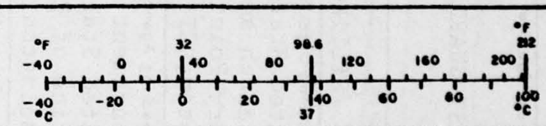
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

1.1 Scope

This final report documents the testing and evaluation of the WATG (Wave Activated Turbine Generation) conducted by the U. S. Coast Guard Research and Development Center. The WATG was tested in its application as a buoy-mounted (not fixed) power source.

1.2 Background

The U. S. Coast Guard's investigation of the WATG is one phase of a search for alternative power sources for buoy-mounted and remote aids to navigation. Many devices which harness the wave energy of the ocean have been conceived and the WATG is one such device. The WATG was invented by Yoshio Masuda and developed jointly by Nichinokogyo Kaisha Limited and Ryokuseisha Corporation with technical direction from the JMSA (Japanese Maritime Safety Administration). The JMSA has successfully used the WATG to power some of its navigational buoys since 1965.

1.3 Evaluation Criteria

If the WATG is to be used as a buoy-mounted power source, it must first be able to generate sufficient power for most currently used aids. A typical lighted buoy requires about 1 watt (average) power. Second, it must be rugged enough to function reliably in a marine environment with little or no maintenance. Third, the WATG must be cost effective when compared to the primary batteries presently in use.

2.0 DESCRIPTION OF THE WATG

2.1 Operation

The WATG operates in a manner similar to a Coast Guard whistle buoy. The buoy has a cylindrical center tube, open to the sea at the bottom. As the buoy heaves, the air trapped above the water in the center tube is exhausted through a turbine and intakes through a flapper valve. The turbine drives a small alternator and the AC output is rectified, regulated, and used to charge a lead-acid battery. Operation is diagrammed in Figure 1.

2.2 Physical

The WATG tested was a Ryokuseisha TG-4 procured from Tidelands Corporation in August 1973 for $3700. The WATG mounts above the hollow center tube and consists of the following:

1. Flange, converging duct, intake valve port, turbine exhaust port, and hoods to cover turbine and intake valve.

2. Intake valve consisting of one door and two ports. The total intake area is 25.5 square inches (164.7 cm^2) with the intake door fully open. The intake valve acts as a check valve allowing air to flow in only. The door is made of plastic and has a hard rubber seal.

3. Turbine that has an alternator directly connected to the turbine shaft and mounted above the turbine rotor. The turbine rotor is 7.9 inches (20 cm) in diameter, has 32 blades, and is made of aluminum. The turbine stator is also made of aluminum and has 18 nozzles with an area of 2.9 square inches (19 cm^2).

Figures 2, 3, and 4 are pictures of the turbine/generator, intake valve and entire assembly respectively. Figure 5 is a drawing of the WATG assembly.

2.3 Electrical

Power is generated by a 12-volt three-phase AC alternator rated at 60 watts at 5000 rpm. Its output is rectified by a three-phase bridge rectifier to charge a lead-acid battery. The circuit is diagrammed in Figure 6.

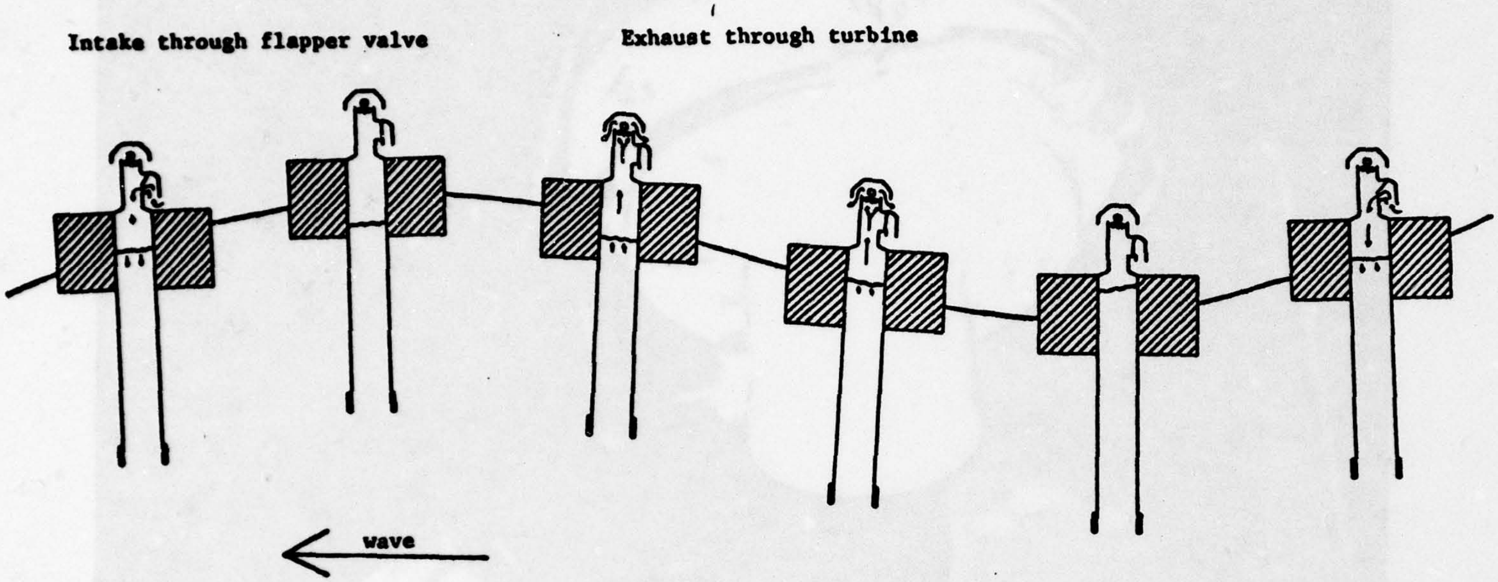


FIGURE 1

OPERATION OF WATG BUOY

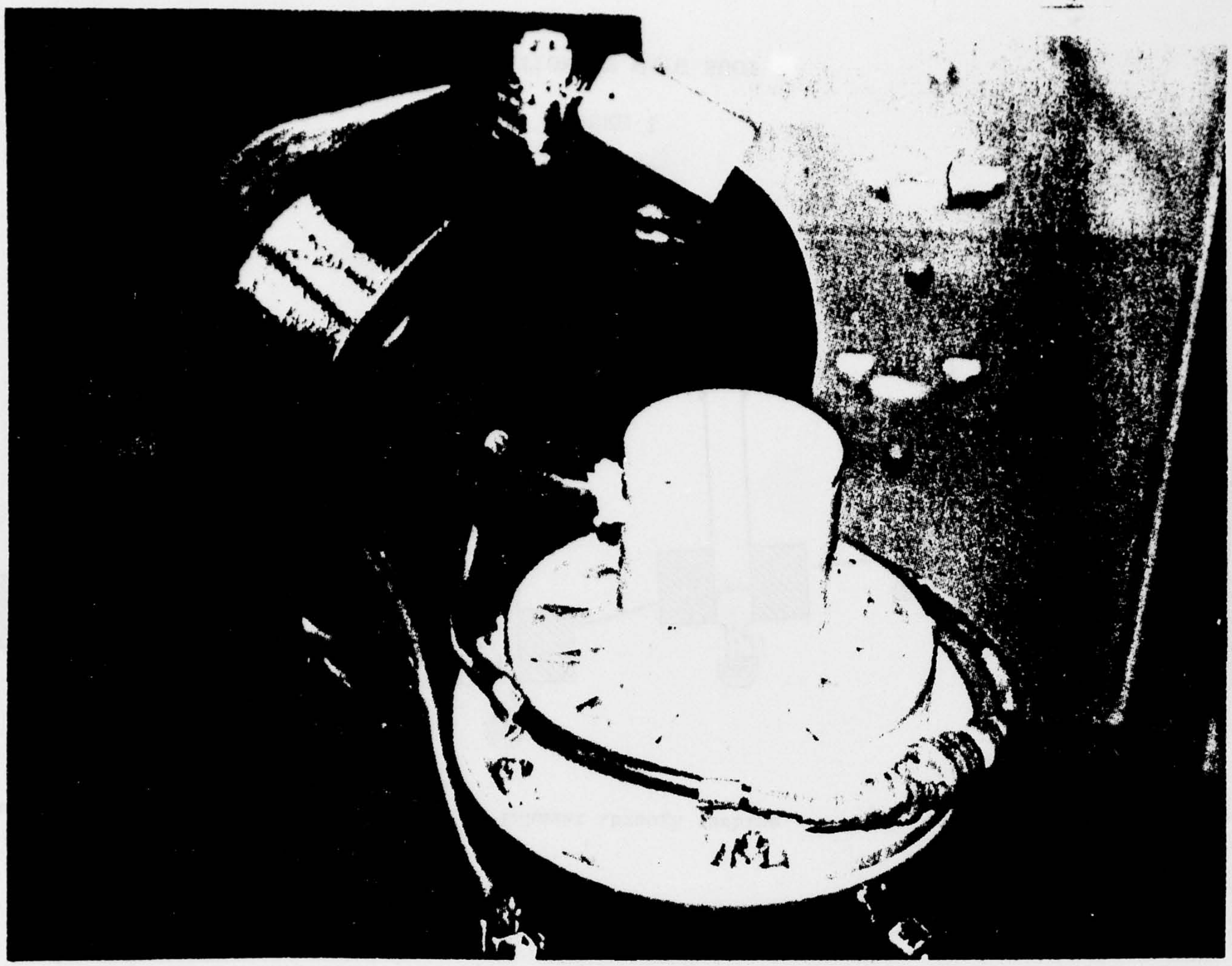


FIGURE 2

TURBINE GENERATOR

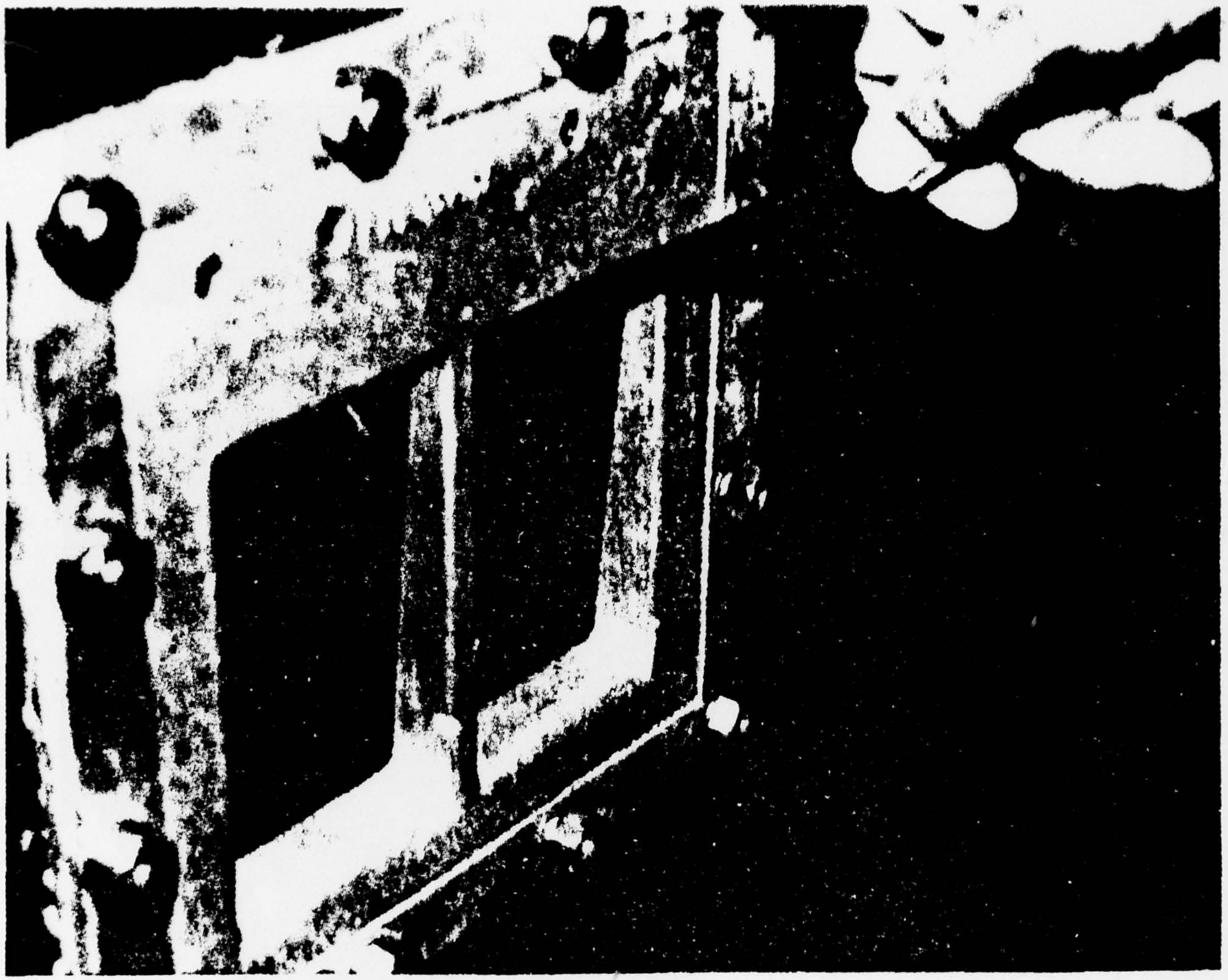


FIGURE 3

FLAPPER VALVE

FIGURE 4

ASSEMBLY

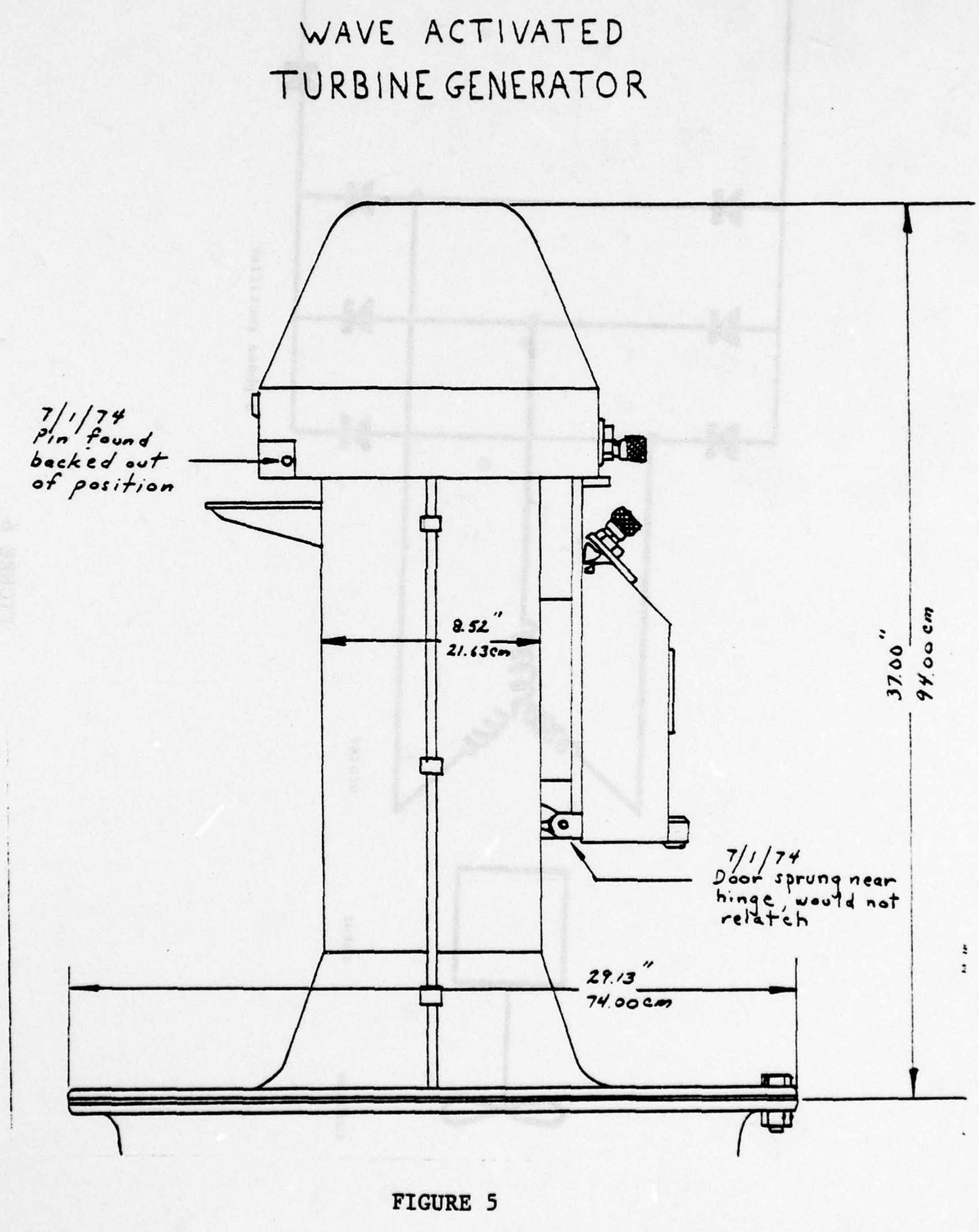


FIGURE 5

TURBINE GENERATOR ASSEMBLY

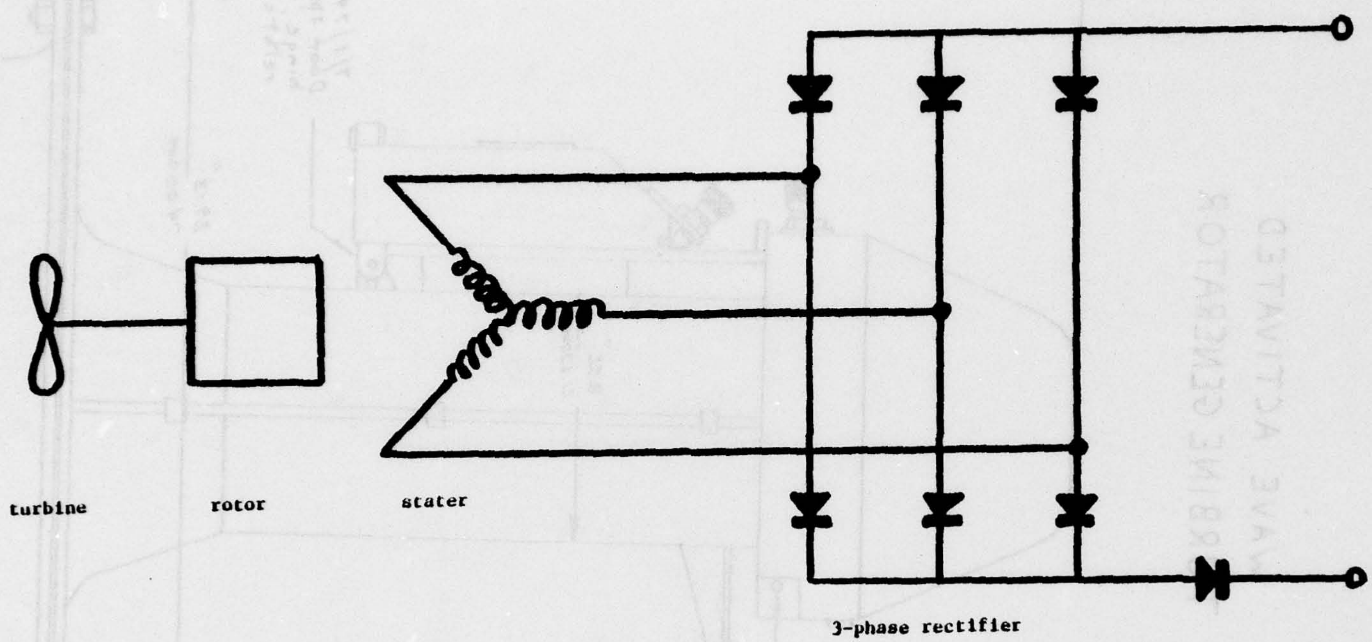


FIGURE 6

DIAGRAM OF WATG CIRCUIT

3.0 PERFORMANCE EVALUATION OF 8X33 WATG BUOY

3.1 Physical Description of the 8X33 Buoy

The initial test of the WATG was done using a fiberglass buoy manufactured by Tidelands Corporation of Houston, Texas. The buoy float section is octagonal, 8 feet in diameter, and the overall length of the buoy is 33 feet (10.6 m). The center tube is 20 feet (6.1 m) long and 2 feet (0.62 m) in diameter. Figure 7 is a drawing of the buoy.

3.2 Instrumentation

Three recorders were mounted on the buoy to record the time histories of cumulative current generated, cumulative current consumed, and the cumulative current discarded when the batteries were fully charged (dummy load). The recorders used were single-channel Rustrak chart recorders that record for a period of 60 days.

The current sensors were mercury tube coulometers that track the cumulative current. When the coulometers reach their maximum values, they change polarity and subtract the accumulating current until the minimum value changes polarity again. This results in a sawtooth data record where the slope of the curve represents the power generated (using a constant of 12 volts for conversion from current to power).

The recorders were mounted in an instrumentation package within the buoy cage and they could be switched on or bypassed as desired. A second set of recorders were used to interchange with those on board the buoy when the chart paper was exhausted because initial attempts to change the chart paper on a moving buoy were not successful.

3.3 Deployment Tests of the 8X33 Tidelands WATG Buoy

3.3.1 Chesapeake Test

The initial test was conducted near Chesapeake Light Station, 14 miles east of Cape Henry, Virginia, in 71 feet of water. Figure 8 shows the deployment.

Power generated was recorded for the following periods:

24 September - 22 November 1973
27 February - 23 April 1974
23 April - 20 June 1974
01 July - 05 August 1974

3.3.2 Boston Tests

In order to get performance data for operation in a more sheltered wave environment, the Tidelands WATG buoy was transported to Boston and deployed on 28 January 1975 as Boston's North Channel Buoy No. 1. The only repair to the WATG was the refitting of the intake valve protection hood. The Tidelands buoy did require some repairs but these were not associated with

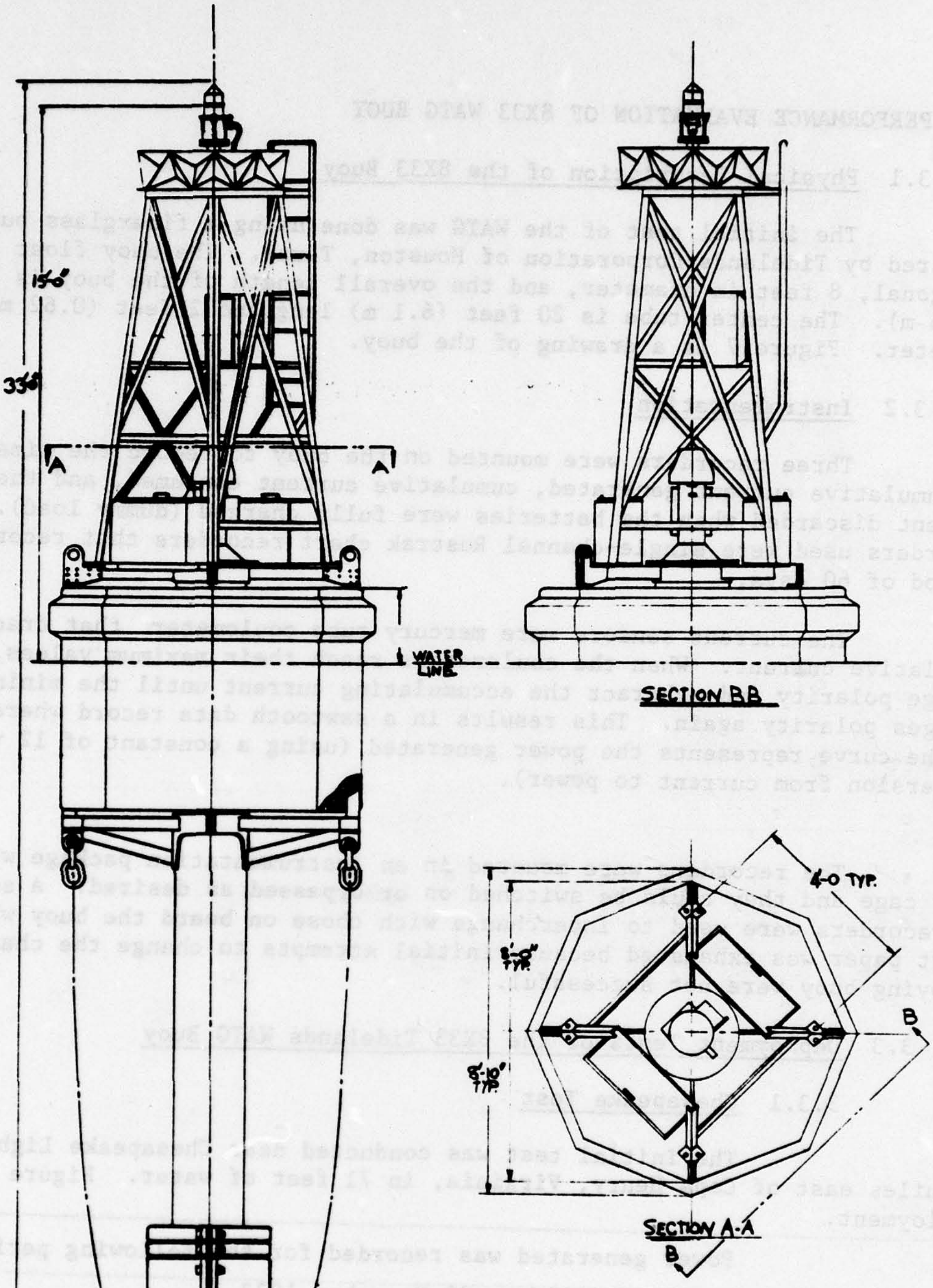


FIGURE 7

8X33 TIDELANDS WATG BUOY

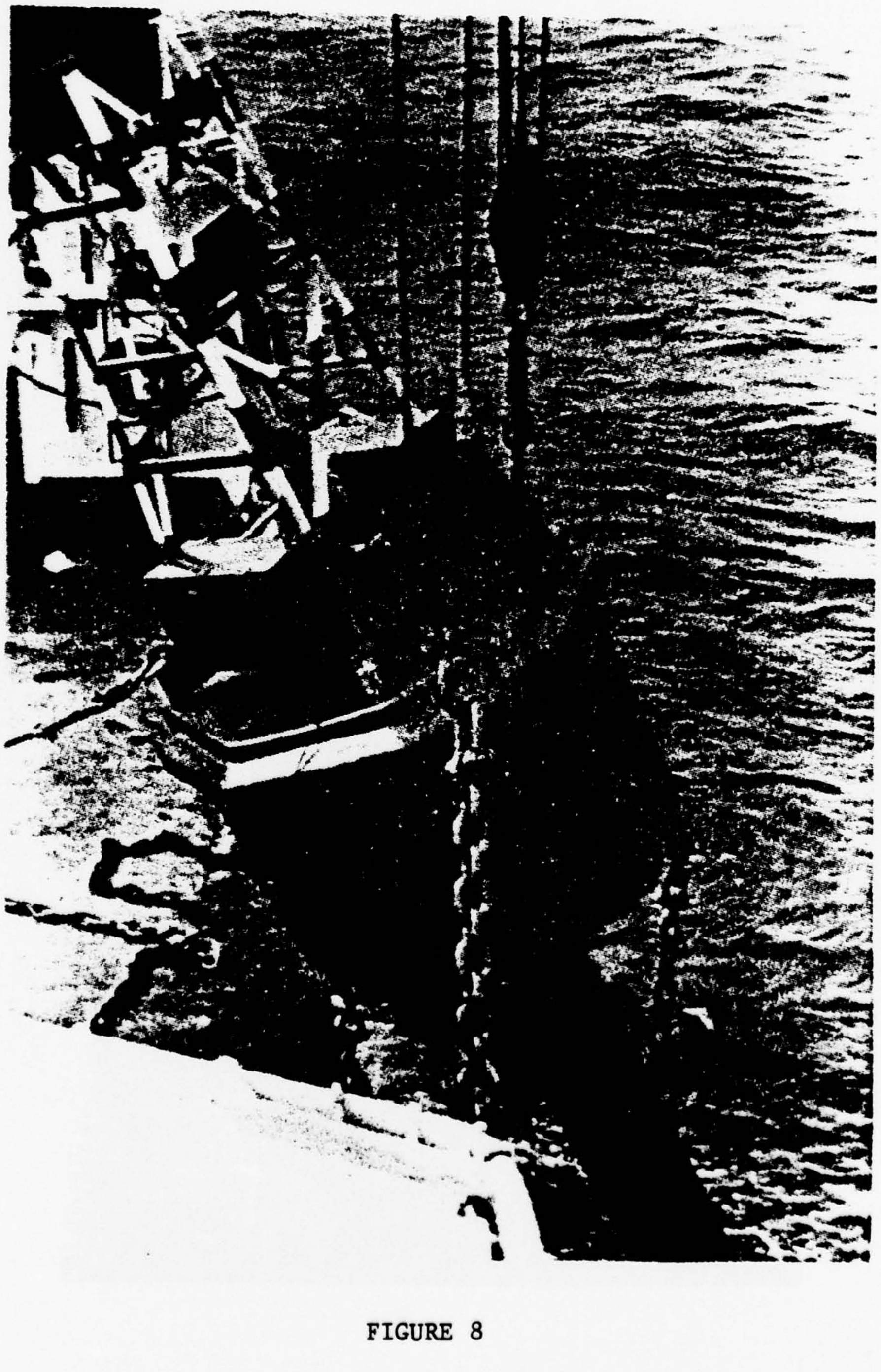


FIGURE 8

DEPLOYMENT OF 8X33 WATG BUOY AT CHESAPEAKE

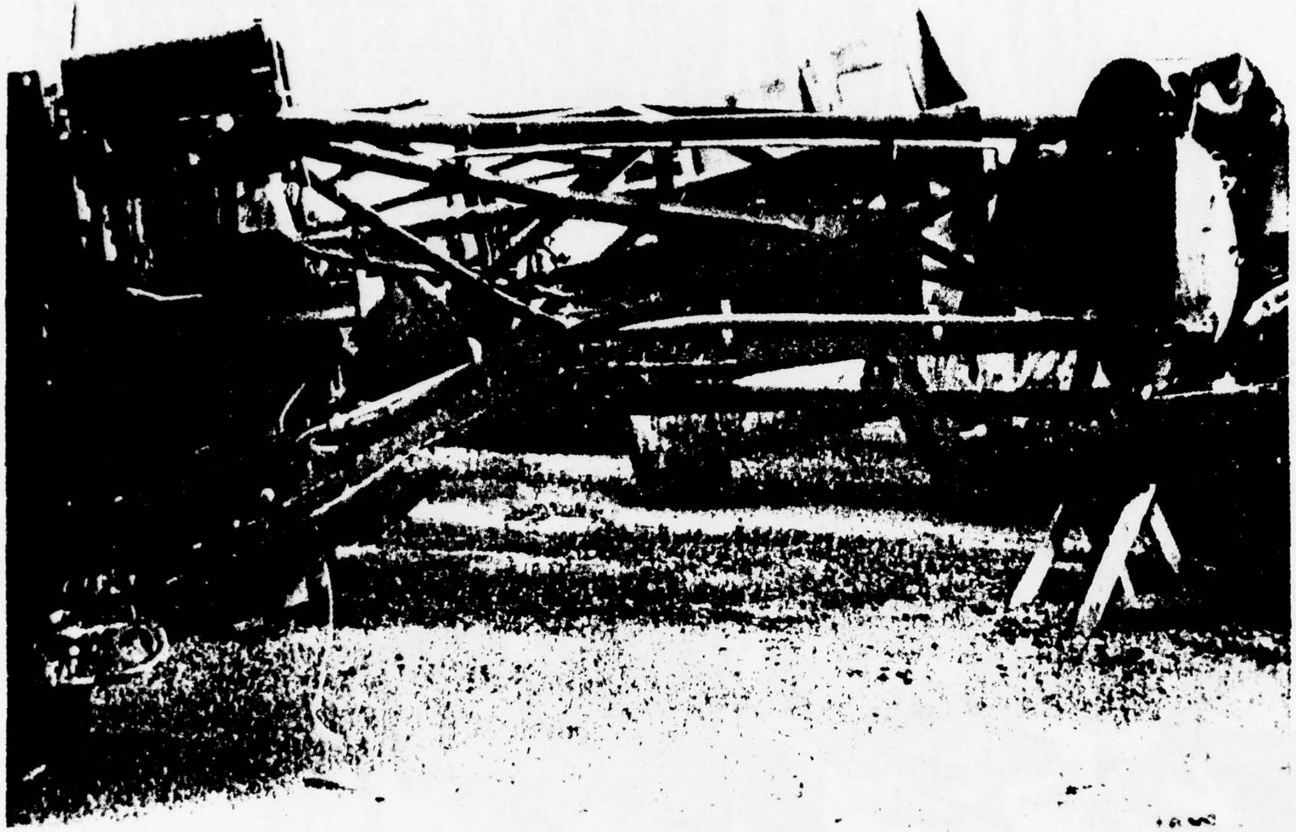


FIGURE 9

8X33 BUOY AFTER BOSTON NORTH CHANNEL DEPLOYMENT SHOWING COLLISION DAMAGE the WATG. The same instrumentation that was used at Chesapeake was recalibrated and installed on the buoy for monitoring the power output, dummy load (overcharge protection), and system total load (lamp load and instrumentation load). Instrumentation failure occurred shortly after deployment and thus only an estimate of power generated can be made. The batteries were fully charged at the time of deployment and on 4 May 1975 the light showed a decrease in intensity such that the buoy was rebatteried on 8 May 1975. The DHB-5 batteries are rated at 500 ampere hours and so the power generated was calculated from both this figure and from the manufacturer's test records under optimum conditions. The buoy cage, radar reflector, and battery box had sustained some collision damage but the WATG was not damaged. Figure 9 is a picture of the buoy after its deployment at Boston North Channel.

The Rustrak recorders were replaced with a Datel digital cassette recorder and the cage and battery box were replaced. The 8X33 was redeployed as Mass Bay Dumping Ground LB'DG' but no more useful data was obtained due to repeated problems with the instrumentation.

3.4 Data Analysis

From the Rustrak charts, the coulometer records were analayzed by two basic methods. The first was by reading the cumulative current generated and averaging for each 12-hour interval. The second was to calculate the current generation at selected times by using the slope of the recorded coulometer record at that time.

The first method was used to calculate the average power generated, total power generated, and histogram curve of power generated. The second method was used to try to correlate the power generation to the wave conditions.

The records of total current consumed and dummy current load were recorded and analyzed to determine the state of charge of the batteries and observe the operation of the dummy load circuit. The average total power consumed, calculated from the above records, was 13.4 Ah/day (6.7 watts) which is substantial compared with the average power generated of 11.49 Ah/day (5.75 watts). Because of this, the batteries did not reach a state of full charge and thus the dummy load was not activated. The record of the dummy load showed no appreciable current load except a very gradual change in the March/April data that could have been a very slight dumping of power or quite likely an instability in the recording devices. The power generated was tabulated daily and is included with histograms of power generated over seven-day intervals in Appendix A.

3.5 Results

Power generation recorded for the following periods was:

Period	Average Power Generated
24 Sep - 22 Nov 1973	12.97 Ah/day (6.49 watts)
27 Feb - 23 Apr 1974	15.07 Ah/day (7.54 watts)
23 Apr - 20 Jun 1974	09.89 Ah/day (4.94 watts)
01 Jul - 05 Aug 1974	05.94 Ah/day (2.92 watts)

Figure 10 is a histogram of power generation over 30-day intervals which summarizes the Chesapeake test results.

Due to the aforementioned instrumentation failure, the power generated during the Boston deployment was calculated in the following manner:

The total load was calculated as both the instrument load and light load. A second total load was calculated on the basis that the portion of electronics that failed did not use any energy. By not making an allowance for the reduction in battery capacity for cold weather and using the least battery capacity and highest total load, the average power generated was 9 ampere hours/day (4.5 watts). By being conservative on both battery capacity (700 ampere hours for the 500 ampere hour battery) and total load (failed portion not using any electricity), the average power generated was 4.5 ampere hours/day (2.25 watts). The load of the light (1.7 ampere hours/day, 0.85 watts) is significantly less than even the conservative average power generated figure during this period. The monitoring instrumentation is 12.8 ampere hours/day (6.4 watts) when it is fully operational.

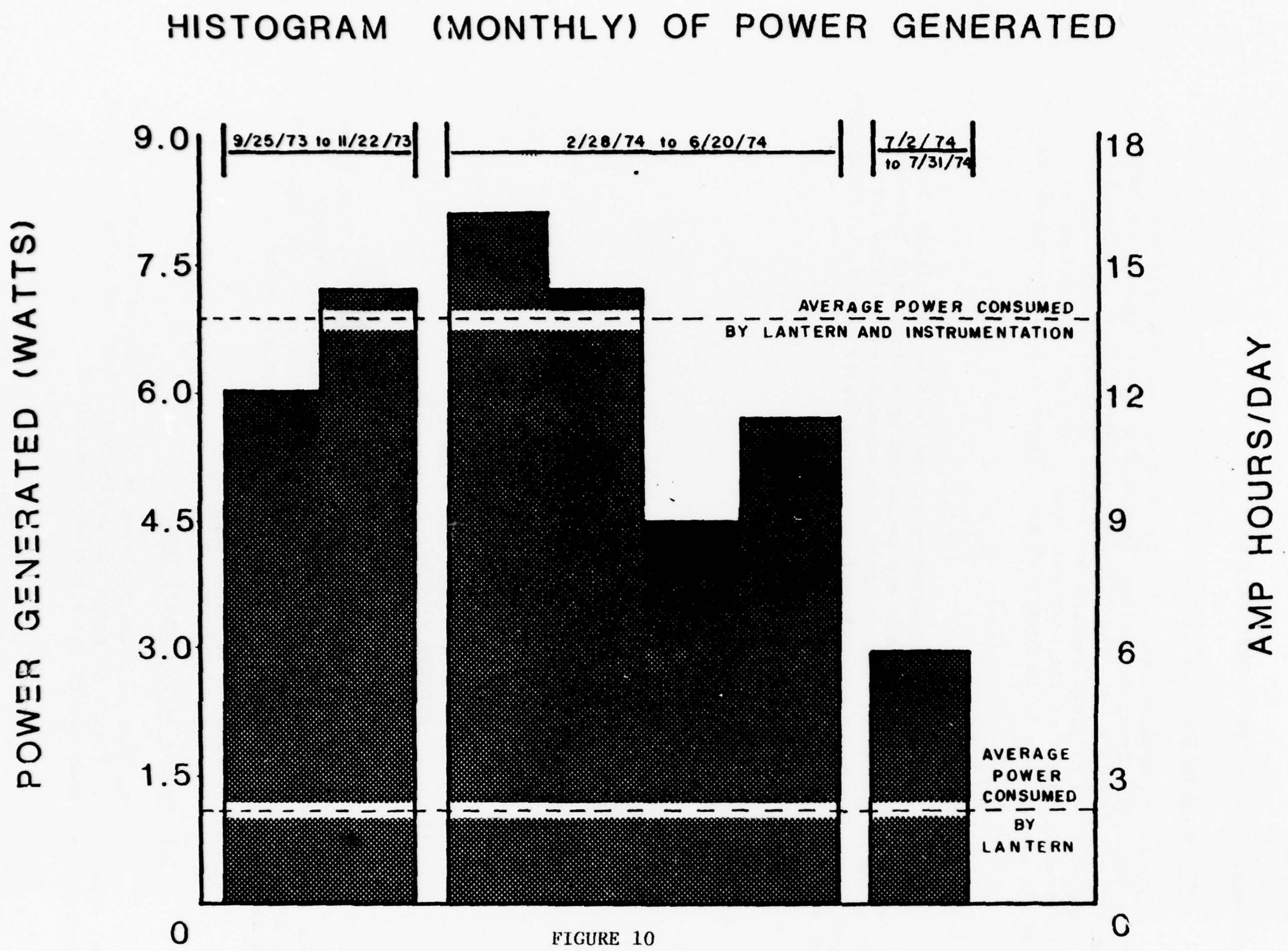


FIGURE 10

HISTOGRAM (30-DAY INTERVAL) OF POWER GENERATED

4.0 PERFORMANCE EVALUATION OF 8X26 WATG BUOY

4.1 Physical Description of the 8X26 WATG Buoy

In order to evaluate adaptability of available WATG hardware to existing CG buoys, an identical turbine (Ryokuseisha TG-4) was mounted on a standard 8X26 CG whistle buoy. The 8X26 LWB is constructed of steel with 8-foot diameter (2.43 m) float section and 2-foot (0.61 m) diameter center tube. The overall height of the buoy and cage is 26 foot (7.9 m) and the length of the center tube is 19 feet (5.8 m). Figure 11 is a drawing of the buoy.

4.2 Instrumentation

The 8X26 buoy was instrumented to record data on wave input, power output, and turbine operation. Data was collected by a 24-channel Metrodata recorder shown in Figure 12. All channels were scanned sequentially three times per second for a period of approximately six minutes each day. Parameters measured were:

Channel	Parameter
1	Clock
2	Clock
3	Clock
4	Manual data
5,17	External water pressure
6,18	Accelerometer
7,19	External wave height (Cap. wavestaff)
8,20	Internal wave height (Cap. wavestaff in center tube)
9,21	Air pressure differential across turbine
10,14,22	Alternator RPM
11,23	Generator current
12	Cumulative load current (mercury coulometer)
13	Cumulative gen. current (mercury coulometer)
15	Battery voltage
16	Blank
24	Indicator

Channels 5 through 11 were doubled with 17 through 23 so that those parameters would be measured twice per scan, or six samples per second. The six Hz sample rate created a record of approximately 2300 scans for each time series record. Figure 13 shows the transducers for Channels 5 and 7.

4.3 Deployment Tests of the 8X26 WATG Buoy

4.3.1 Boston North Channel Test

The 8X26 buoy was deployed on 20 May 1975 as Boston's Lighted Channel Buoy No. 4. Figure 14 shows the deployment. Data was taken daily and tape changes were made weekly for a period of one month.

WAVE ACTIVATED TURBINE GENERATOR EXPIRIMENTAL BUOY

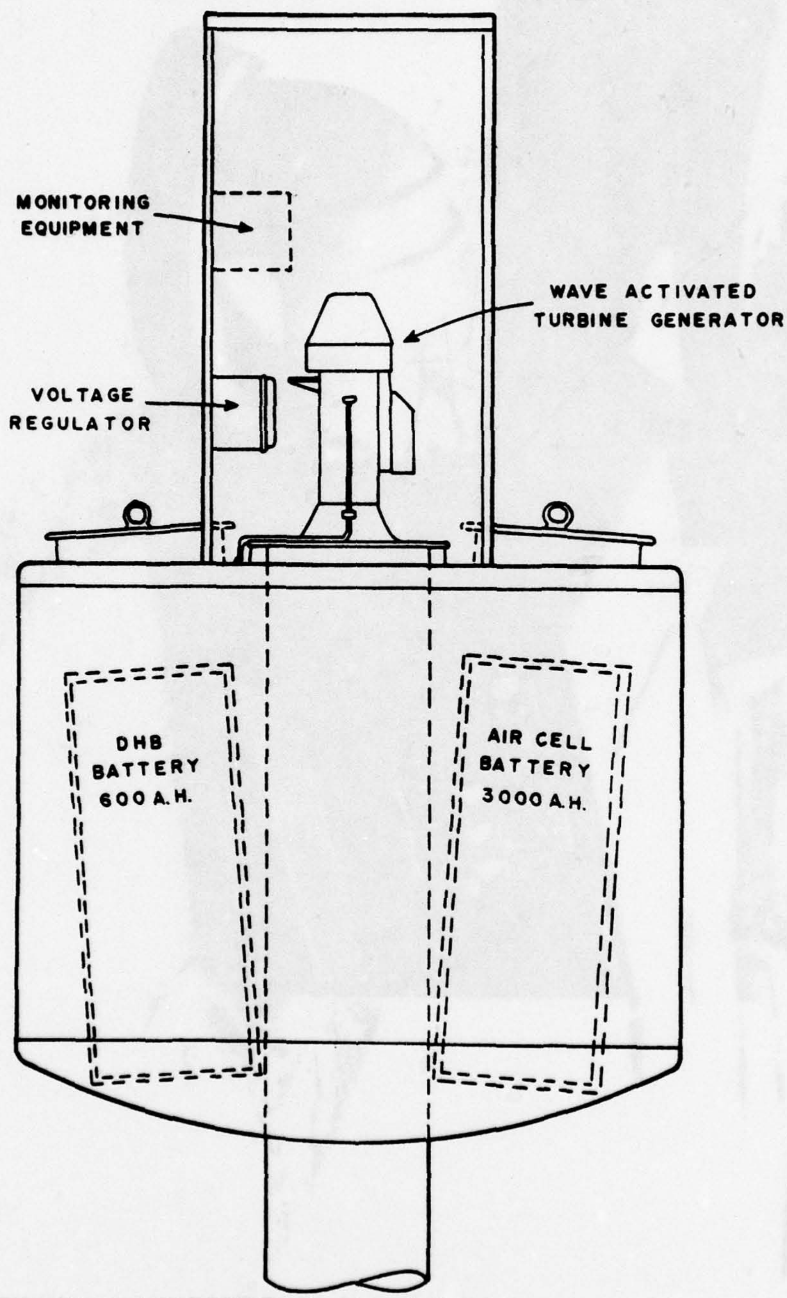


FIGURE 11

ELEVATION TURBINE GENERATOR INSTALLATION

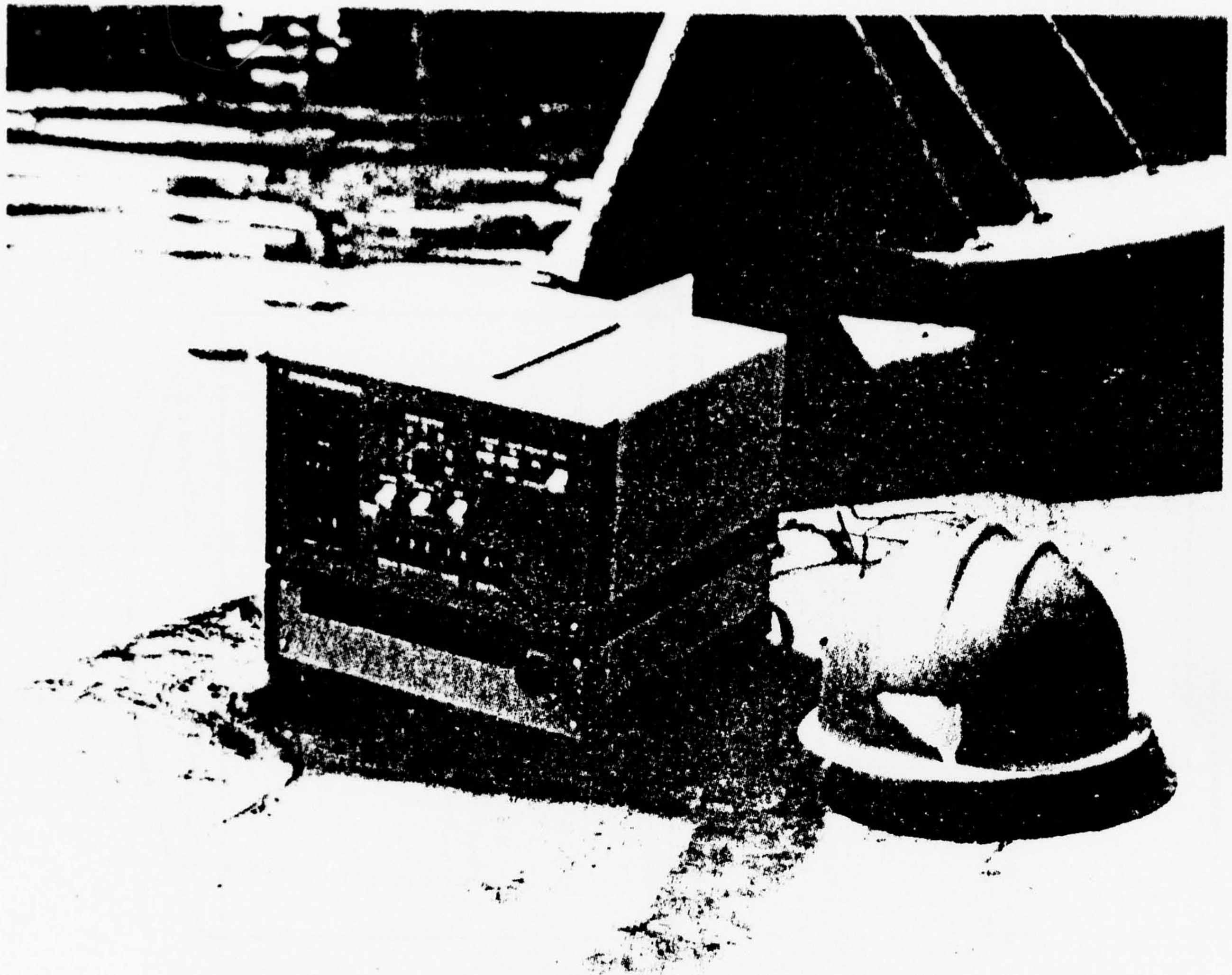


FIGURE 12

24-CHANNEL DATA RECORDER USED ON 8X26 WATG BUOY

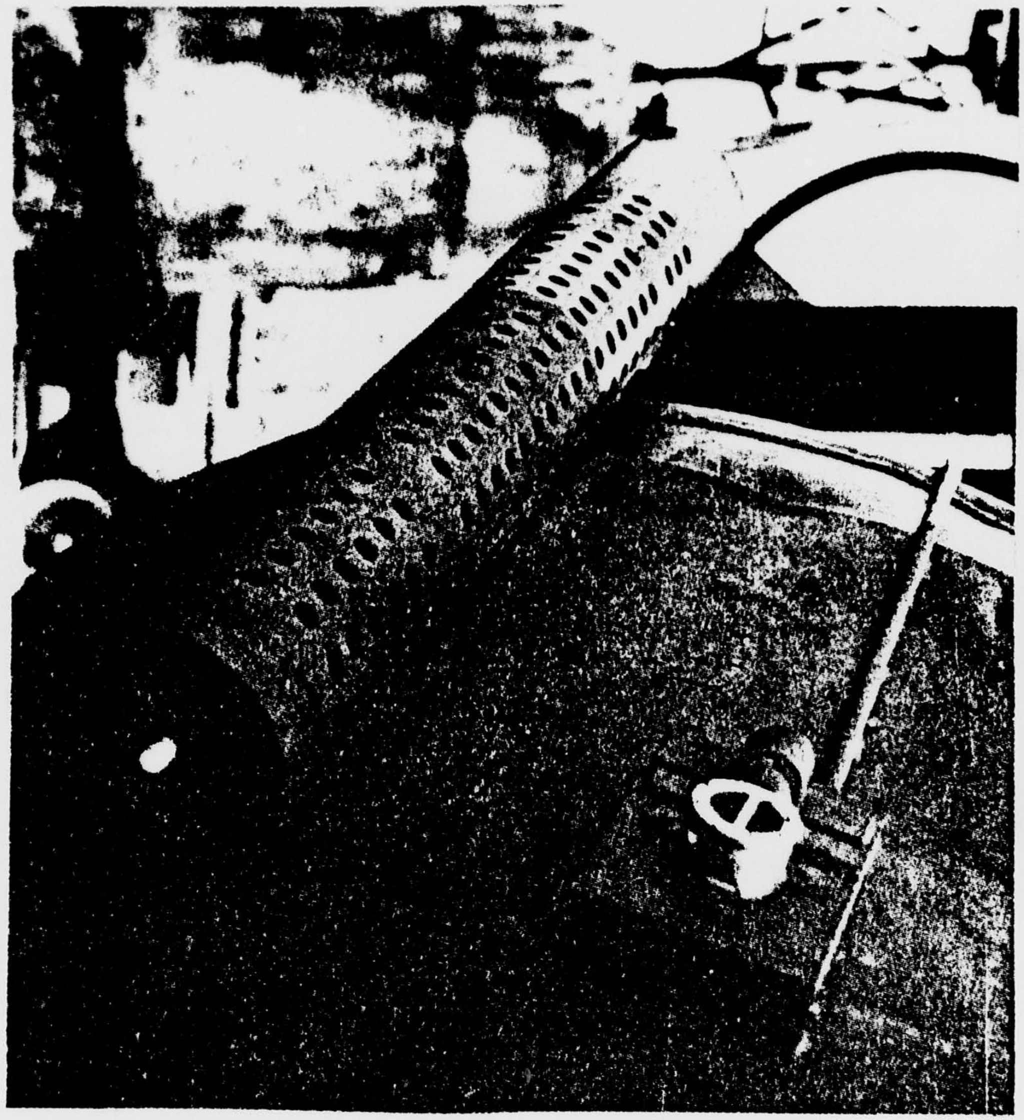


FIGURE 13

EXTERNAL WATER PRESSURE TRANSDUCER AND EXTERNAL WAVE HEIGHT (CAP WAVESTAFF)

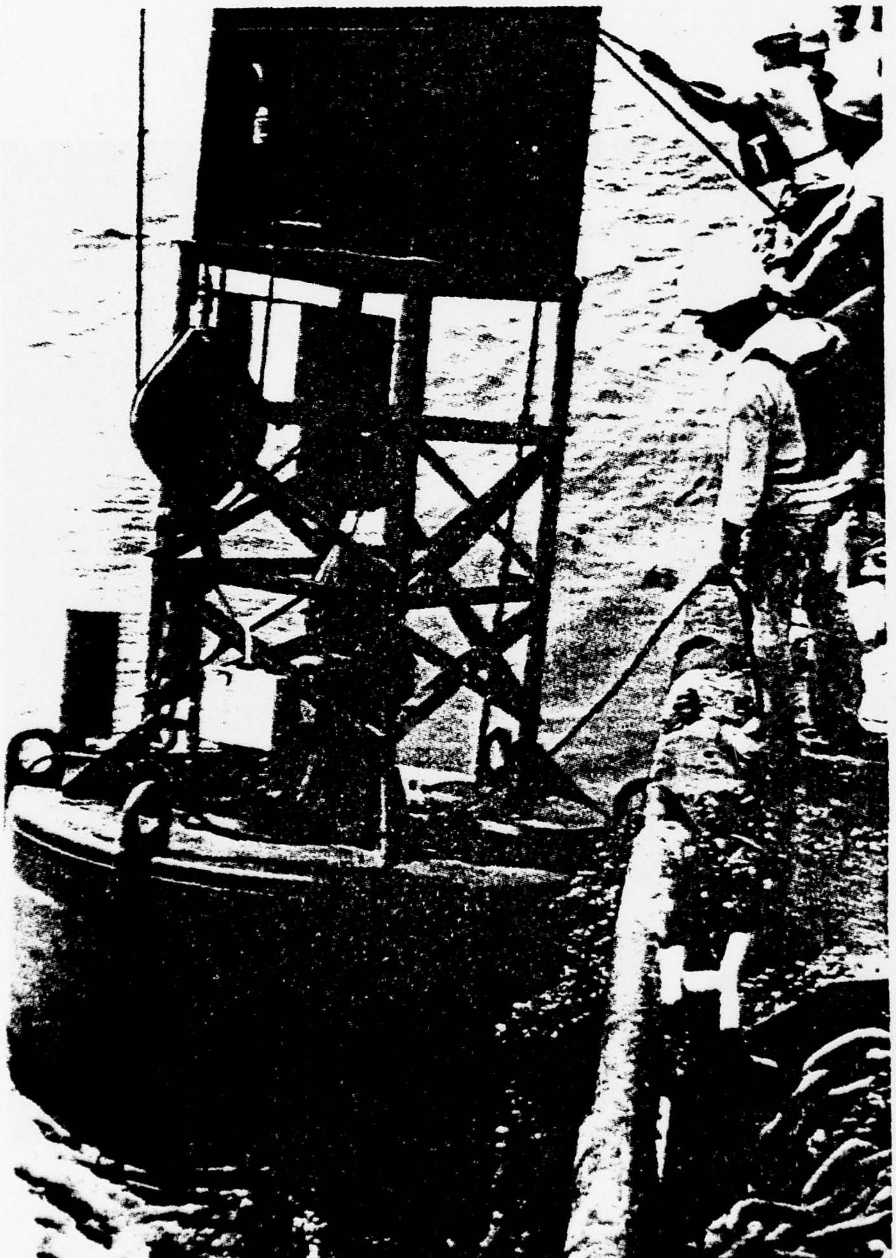


FIGURE 14

DEPLOYMENT OF 8X26 WATG BUOY

4.3.2 Boston Harbor Tests

The 8X26 CG buoy, with the same WATG and 24-channel instrumentation used earlier, was deployed as Mass. Bay Foul Areas LB "A" on 6 June 1976. When visited on 17 June 1976, the 24-channel recorder was found inoperative, and was removed and returned to R&DC for servicing. On 23 June 1976 the instrumentation was reinstalled and a series of data was taken with various sized orifices replacing the turbine to be used for turbine optimization studies. The instrumentation was then restarted in its normal monitoring mode. The data tape cartridge was renewed on 7 July, 19 July, 29 July 1976 and on 16 August 1976. The recording equipment was shut down as more than sufficient summertime data had been acquired. It was planned that the instrumentation would be turned on again later in the year to get data during fall and winter wave conditions, but this was never done due to rescheduling and some question as to the proper operation of some of the sensors. The buoy was relieved in January 1977 when its lamp was reported extinguished. Ice buildup during the unusually cold New England winter caused the buoy to partially submerge.

4.4 Data Analysis

The Metrodata tapes were copied and reformatted, separating the single scans (histogram data) and the six-minute, 6 Hz records (spectral data). Each tape contained approximately one week (6 or 7 days) of data. Tape changes had to work around the operational schedule of the A/N boats servicing the buoy.

Wave data was derived by the Tucker method: the accelerometer output was double-integrated and the height of the water with respect to the buoy (external wave sensor) was added to the buoy's position. Some difficulty was encountered in this analysis. There was a small, low frequency (period $\sim$2 minutes) oscillation superimposed on the accelerometer record which, although imperceptible in a plot of accelerometer output, became significant when double-integrated (displacement $\sim$ acceleration/(freq)^2). This low frequency oscillation could have been caused by slight variations in buoy pitch causing the rigidly, axially-mounted accelerometer to detect small variations in the gravitational acceleration. The low frequency oscillation was removed from the wave record with a high pass digital filter (time constant = 15 secs) so that the record could be conveniently analyzed by the zero upcrossing method.

Summing the buoy displacement and the external wave height posed no problem. It was noted that the buoy was close to waveriding as might be expected. The Response Amplitude Operator for the 8X26 buoy is essentially unity for periods down to three seconds[2] (the shortest significant wave period analyzed was 3.17 seconds).

Power output was computed by averaging the generator current over the 6-minute record and scaling it by the battery voltage. The power output, significant wave height and period are tabulated for each day's data in Appendix B. When the data are sorted by wave period, and power out versus wave height is plotted for each group of similar periods, a series of curves (Figure 15) is obtained. The frequency sensitivity of the system is demonstrated by the different slope of each curve.

These power curves were used with HO 700 data (percent occurrence of given height and period) to make a conservative estimate of the minimum (summer months) power the WATG will produce in exposed seacoast locations. The calculation is included in Appendix B. It was found that the WATG will produce sufficient power for a typical aid (>1.6 watts) in CG Districts 1, 3, 5, 7, and 8.

A more precise representation of the frequency response of the WATG system was obtained by spectral analysis of the 24-channel data. Figure 16 is a composite of the overall System Transfer Functions obtained from each record. The TF's from which Figure 16 was derived are included in Appendix C.

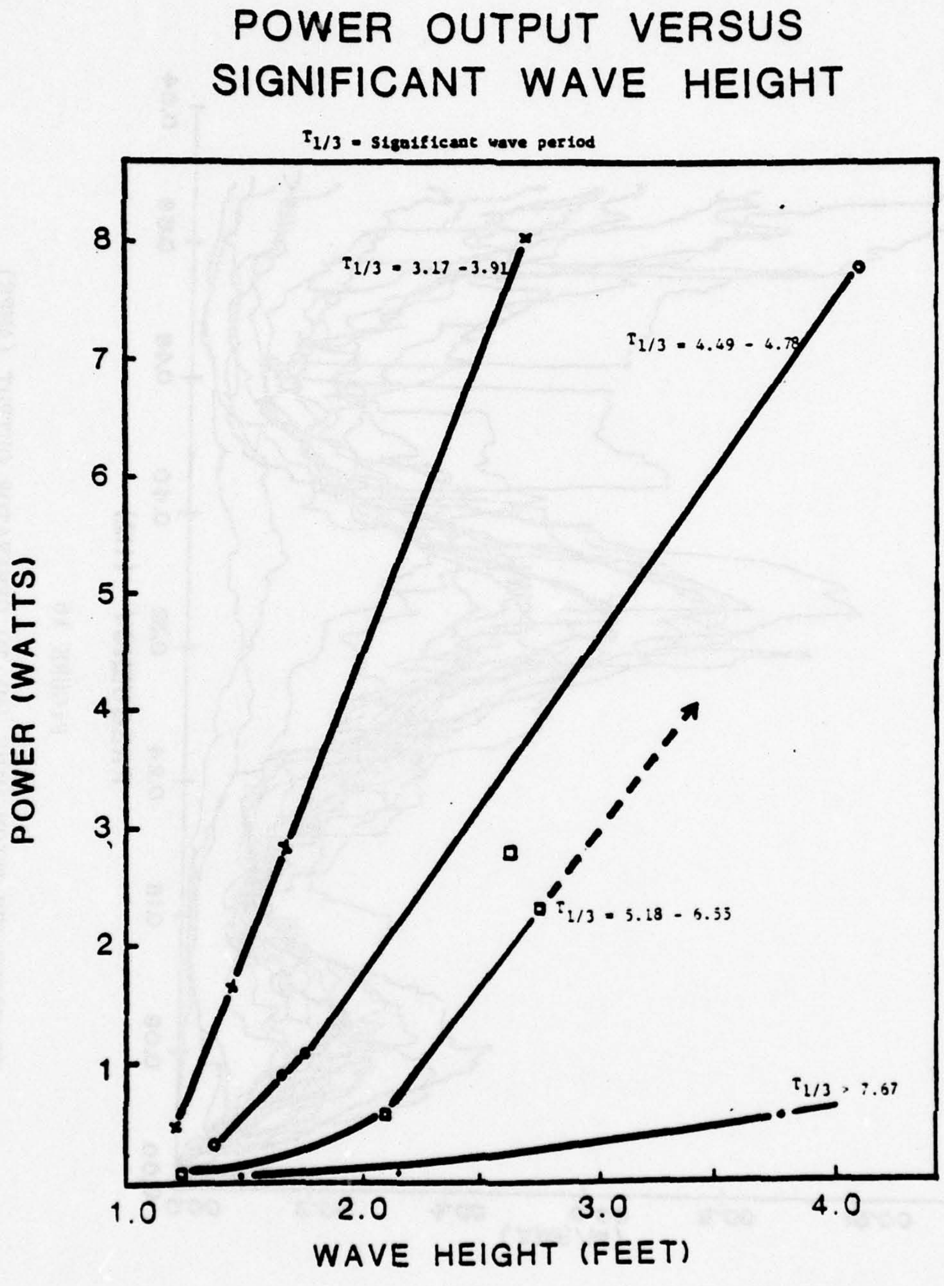


FIGURE 15

POWER OUTPUT (WATTS) VERSUS SIGNIFICANT WAVE HEIGHT (FEET)

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)

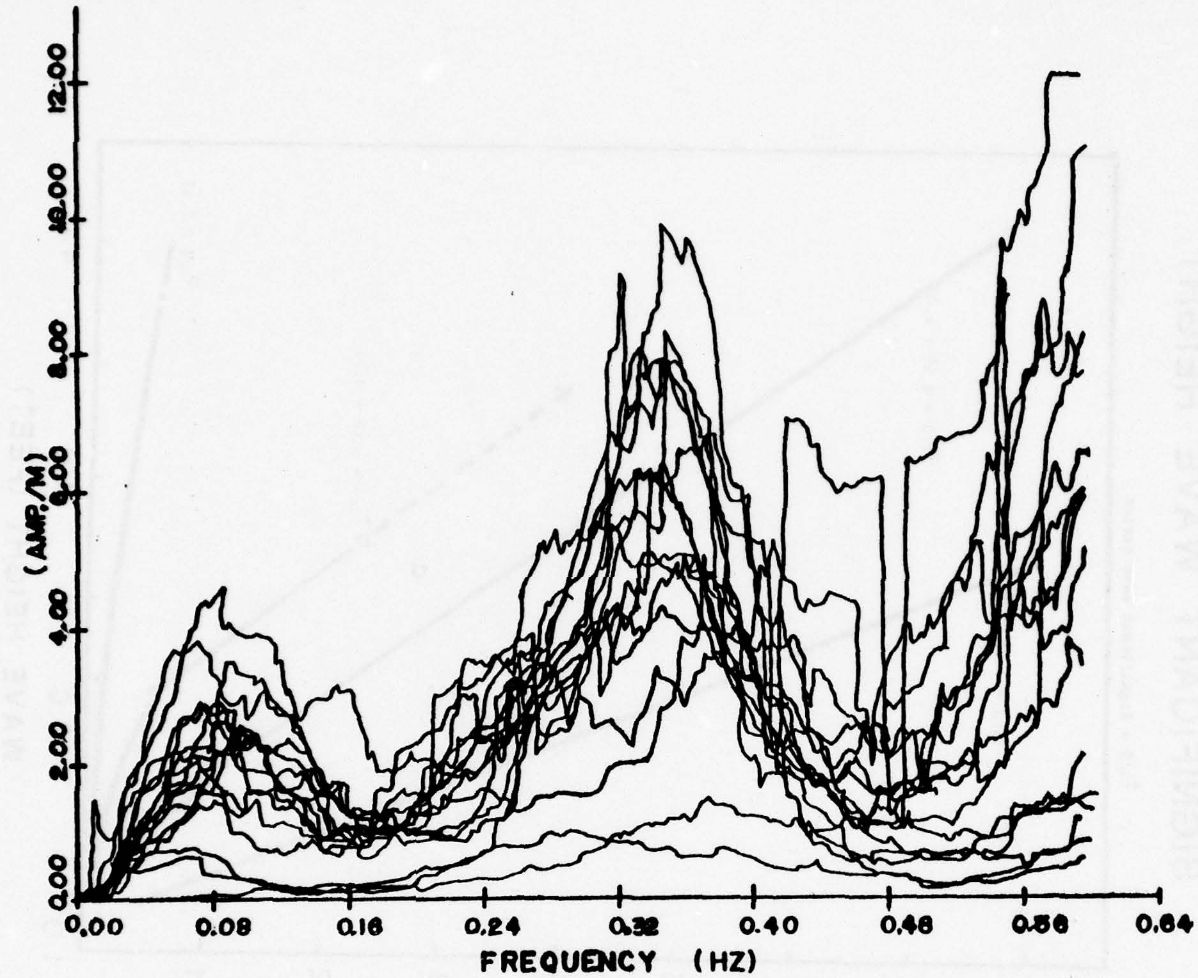


FIGURE 16

TRANSFER FUNCTION WAVE (M) TO GENERATOR OUTPUT (AMPS)

5.0 RELIABILITY EVALUATION

5.1 Observations During Deployment

Throughout the two-year testing of the WATG, physical damage to the turbine unit was observed on one occasion.

On 1 July 1974, the hood over the turbine was found askew and disconnected from one of its hinge pins. The set screw had apparently come loose and the pin had backed out until it no longer supported the hood. Luckily, no parts were lost and the hood was replaced and secured.

The hood over the intake valve was found open and warped. It apparently vibrated open or was forced open by wave action and then through wave action was bent downward. This hood would not relatch on 1 July because it was out of alignment and was secured with line until repairs were made. Physical damage was considered minor and could be prevented by using some standard locking methods (e.g., safety wire on nuts).

The final deployments of the 8X26 and 8X33 WATG buoy both ended with extinguished lamps but the failures were not attributed to the turbine generator itself. In both cases, water had gotten into extra junction and instrumentation boxes which were used for instrumentation and would not be used on an operational buoy. Figures 17 and 18 are photographs of the 8X26 buoy and its instrumentation box (hidden in caked ice) taken six days after it was relieved.

5.2 Post-Deployment Maintenance Inspection

On 5 June 1977 both WATG units were disassembled and inspected. Salt buildup on the turbine vanes was negligible (Figure 19). The lower alternator bearings on one turbine were badly worn (0.010-0.015") probably due to salt water getting past the rubber seal (Figure 20). The inside of both alternator housings showed some salt deposits (Figure 21) and both had grease on the windings (probably from twoo much grease used during assembly). After cleaning with tricloroethylene and drying, windings showed 200 MgOhm resistance to ground (up to factory specifications).

The rectifier units, a separate enclosure (Figure 22), were in poor condition for both turbines. Salt water had gotten in through the packing glands and corroded the interior. This is not viewed as an inherent problem with the system and should be corrected with some redesign of the housings.

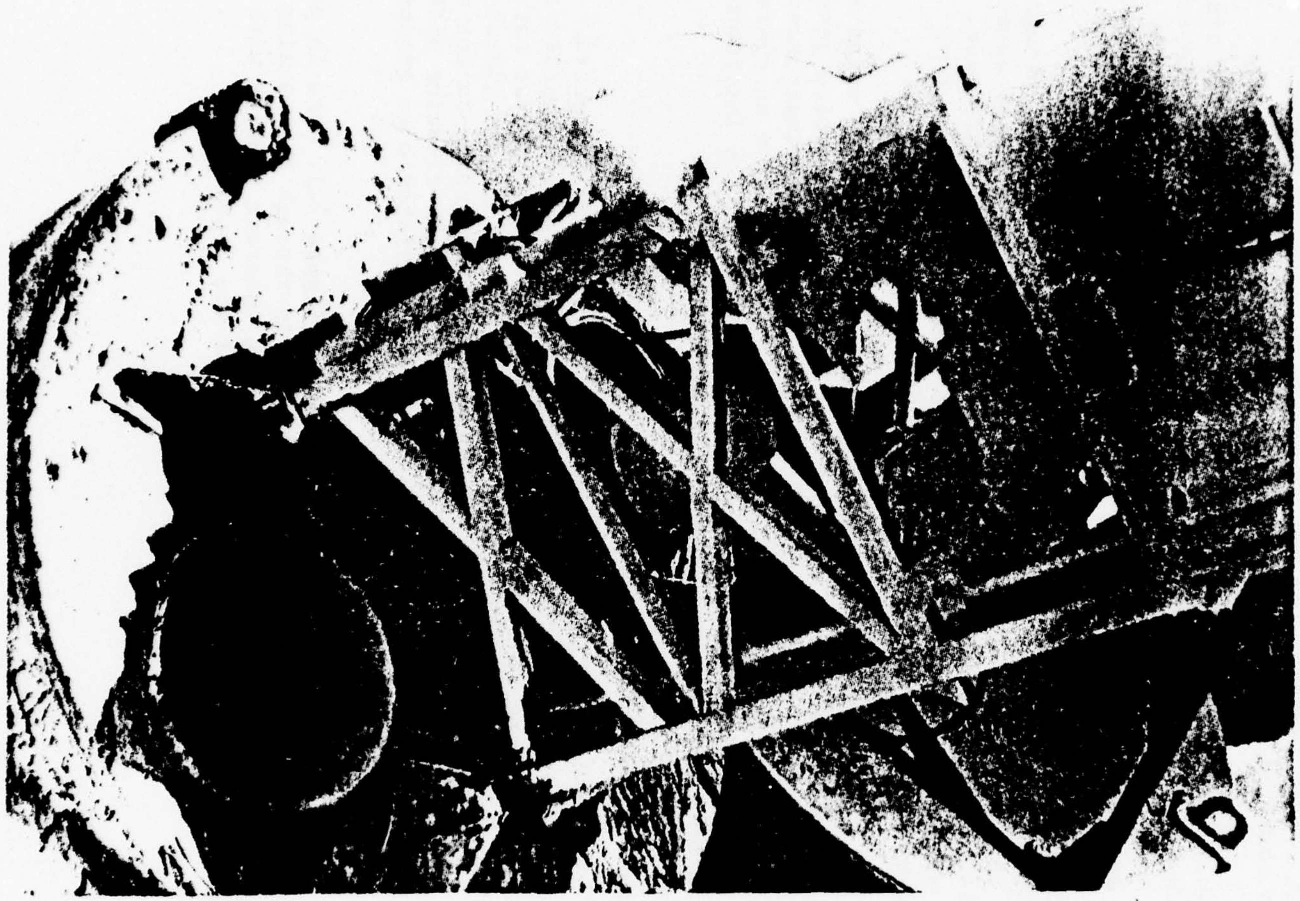


FIGURE 17

8X26 WATG BUOY AFTER BOSTON HARBOR DEPLOYMENT
(NOTE INSTRUMENTATION BOX HIDDEN IN ICE)

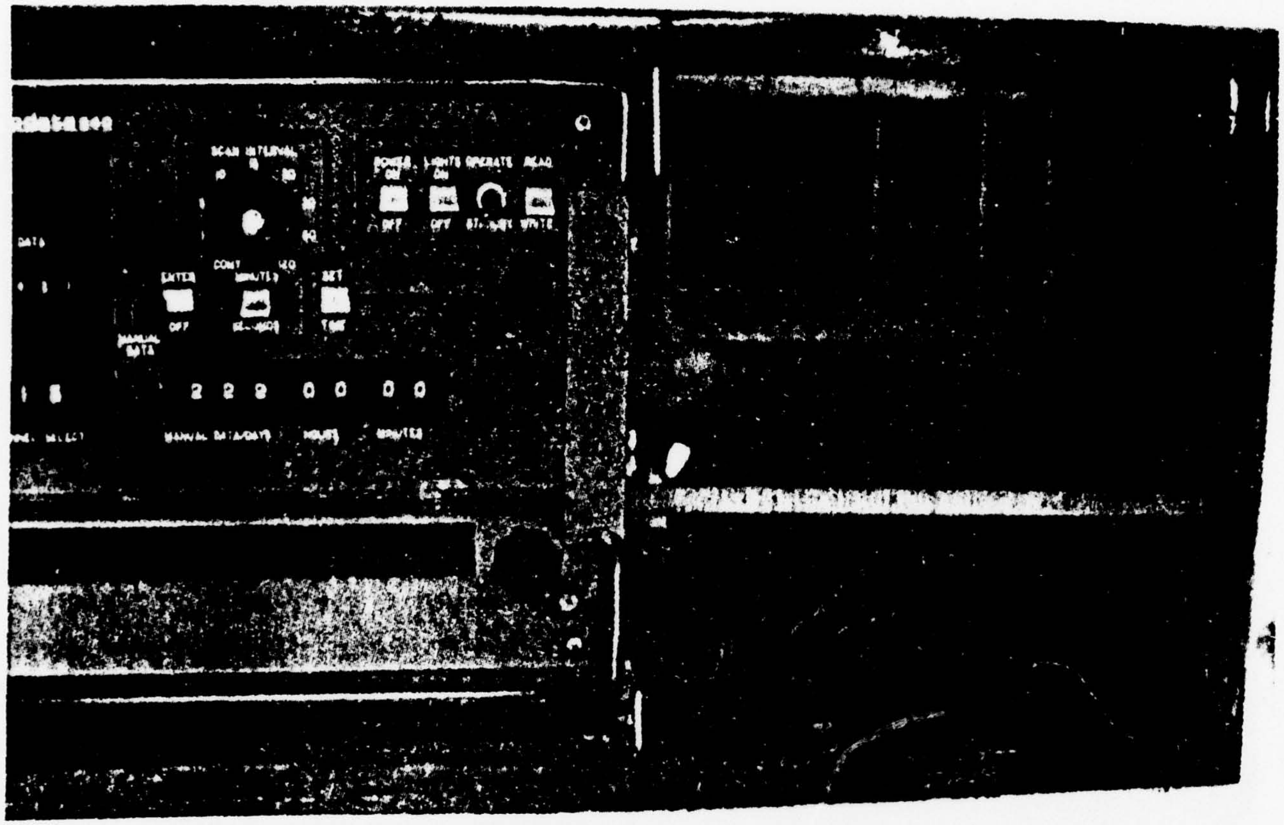


FIGURE 18

INSTRUMENTATION BOX AFTER BOSTON HARBOR DEPLOYMENT

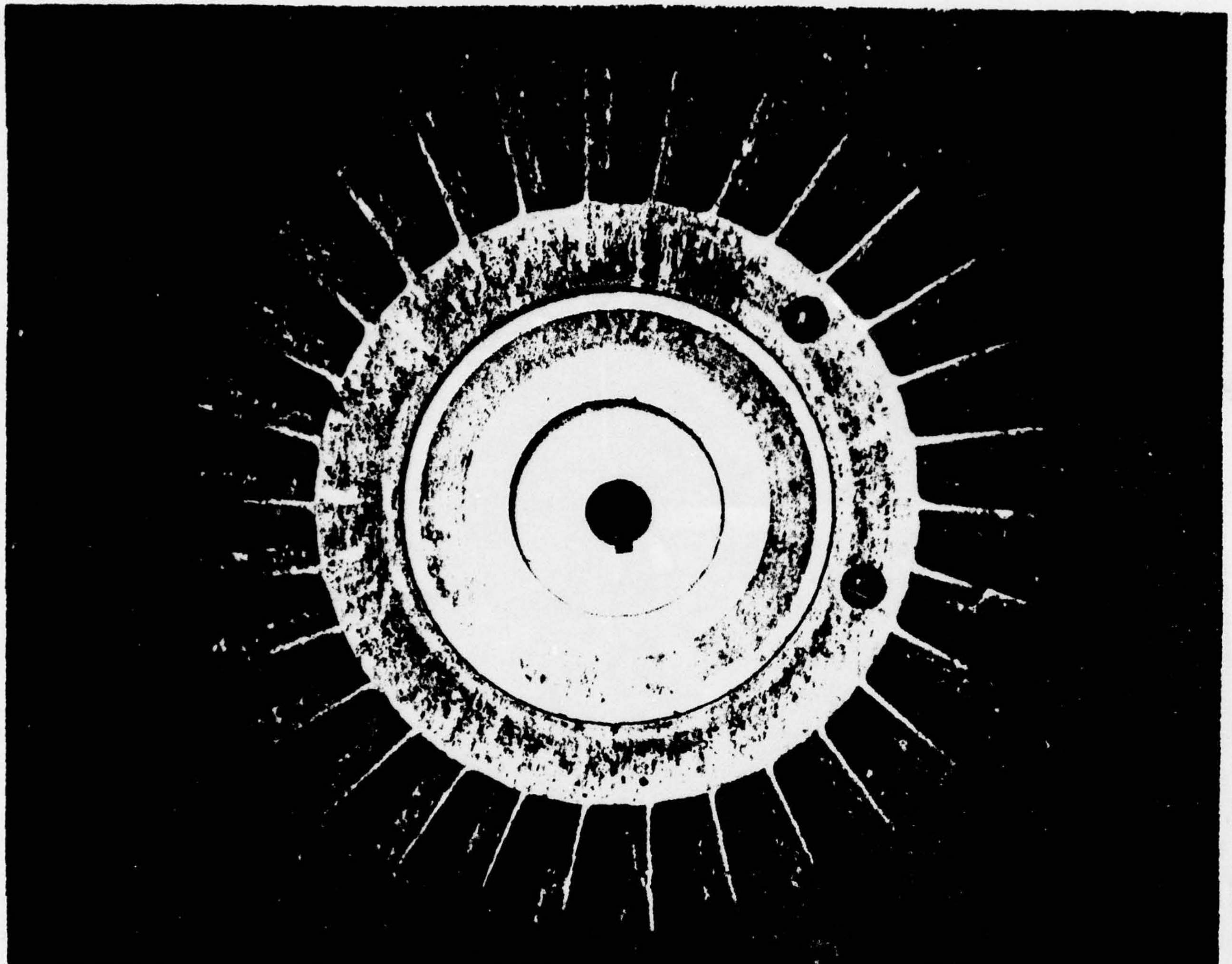


FIGURE 19

TURBINE VANES AFTER APPROXIMATELY TWO YEARS DEPLOYMENT

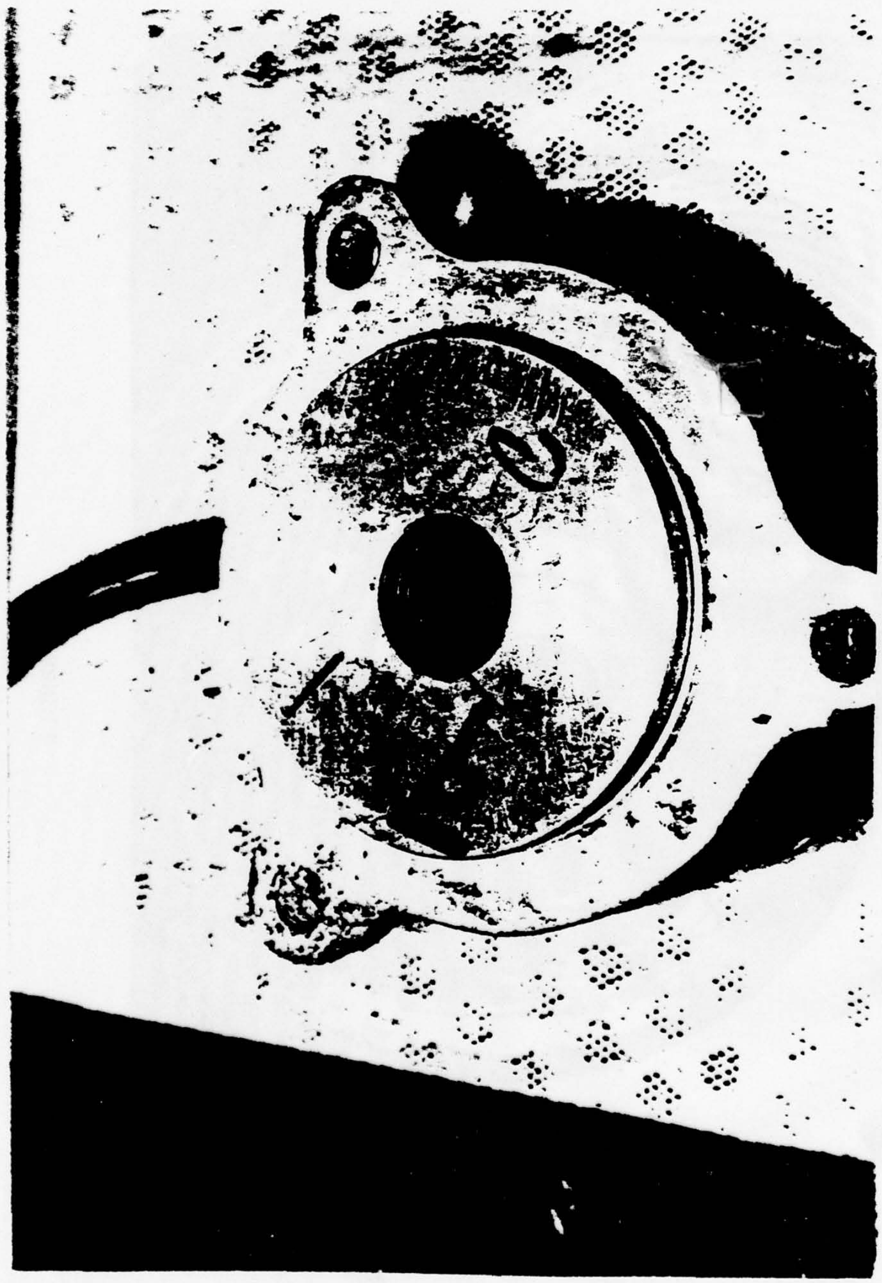


FIGURE 20

ALTERNATOR HOUSING SHOWING SEAL

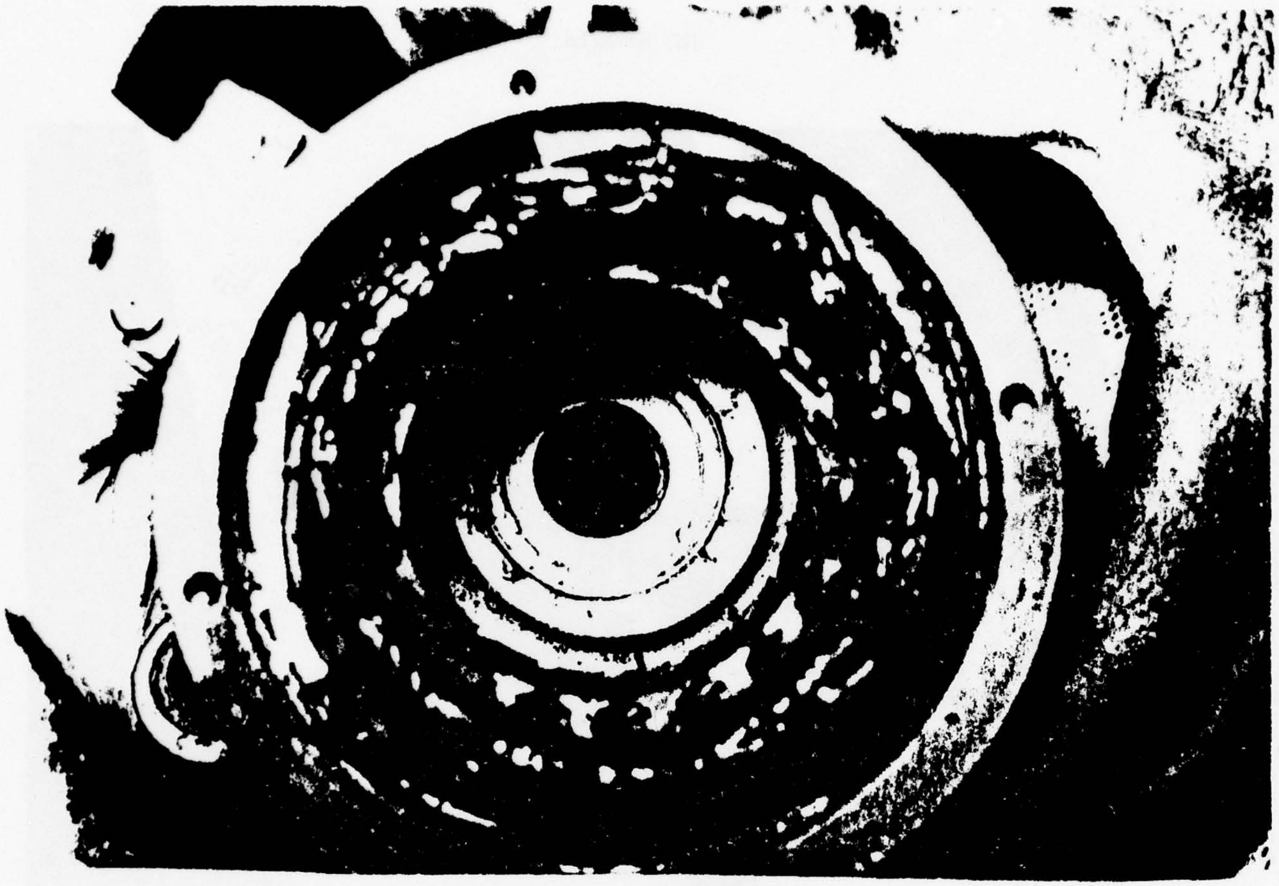


FIGURE 21

ALTERNATOR WINDINGS

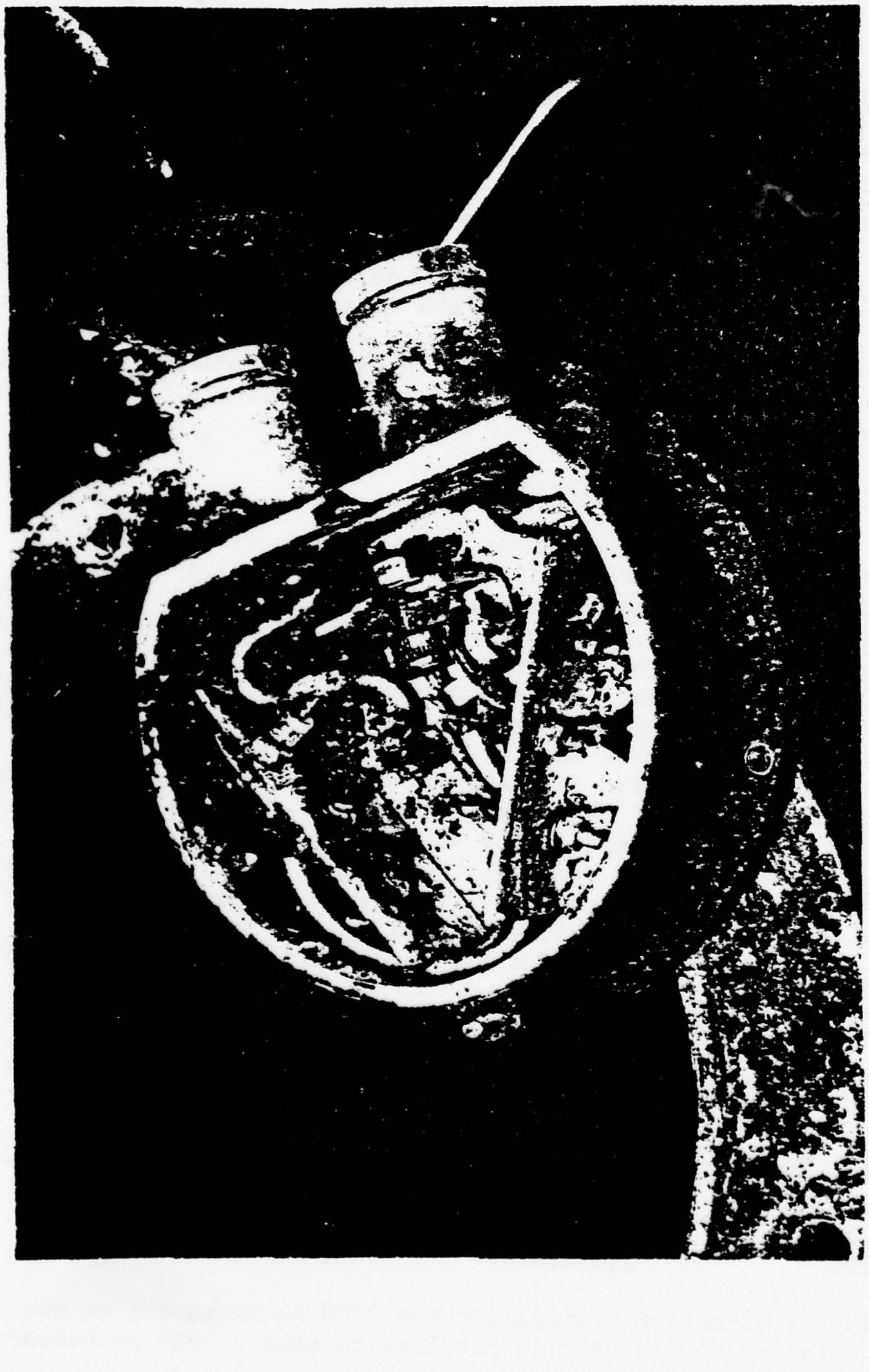


FIGURE 22

RECTIFIER UNIT

6.0 ECONOMIC EVALUATION

6.1 Present Power Source Data

The present system of powering small lights and buoys uses air-depolarized batteries. Excluding the Second District, approximately 65 percent of all lighted aids exhibit a FL 4(.4) characteristic, which is equivalent to a 10 percent duty cycle, while the remaining 35 percent exhibit other characteristics. This 65 percent figure corresponds to approximately 6700 flashing aids, about 4250 of which are 0.55 amp lamps, 1625 are 0.77 amp lamps and about another 825 are 1.15 amp lamps. To power these aids, three types of battery racks, rated at 1000 amp-hours, 2000 amp-hours, and 3000 amp-hours, are used. Of these three types of battery racks, the 1000 Ah size is used 65-70 percent of the time. The remaining 30 percent or so of the lighted navigational aids are powered about equally by 2000 Ah and 3000 Ah battery racks. Using 11,526 as the number of lights in use throughout the Coast Guard, and assuming that 70 percent of these are powered by 1000 Ah battery racks means that there are 8,068 lights powered in this manner. Assuming that the remaining 3,458 lights are equally distributed indicates that there are currently 1,729, 2000 Ah battery racks and 1,729, 3000 Ah battery racks in use.

6.1.1 Primary Battery Costs

Primary air-depolarized battery costs vary according to the Ah size of the battery rack purchased, the shipping location and whether or not the battery is pre-activated before shipping. Presently, 1000 Ah batteries from McGraw-Edison cost the U.S. Government $1,620.63 per pallet. This figure is for batteries which are pre-activated (i.e., water has been added to each cell before shipment), a common Coast Guard practice, and shipped to Zone 1 (northeast U.S.). Since shipping costs vary by only a few dollars per pallet depending upon the zone to which they are sent, this figure is taken to be representative of all districts. Furthermore, a pallet is simply a shipping volume quantity; the number of racks contained in one depends strictly on the size of the battery. As an example, 1000 Ah batteries come six racks to a pallet, while 3000 Ah batteries come only four racks to a pallet. Batteries may be shipped in less than pallet quantities, but the cost per battery increases noticeably; for this reason, all battery costs in this analysis will be based upon full pallet purchases. Costs for the three battery racks currently in use are given in Table 1.

TABLE 1

COSTS OF VARIOUS Ah BATTERY RACKS

Size (amp-hour)	Cost/Pallet	Number/Pallet	Cost/Battery
1000	$1,620.63	6	$270.11
2000	3,241.26*		540.22
3000	2,631.61	4	657.90

*This is the effective cost/pallet for 2000 Ah batteries as two 1000 Ah batteries are used in parallel to make a 2000 Ah battery.

Based on actual field measurements, these air-depolarized batteries have been found to have an average life expectancy of about two years.

6.1.2 Primary Batteries Maintenance Costs

Maintenance costs on navigational aid buoys are very high, far exceeding the amortized cost of the buoy itself. As a result of this 21 percent failure rate of buoys using primary batteries, the average number of tender visits to a buoy is quite high. The Booz-Allen Applied Research, Inc., report of 1970 found that, based upon forms filled out by tenders during calendar year 1968, there were 2.97 tender visits per year to both exposed and protected and semi-exposed lighted buoys.[1] A breakdown as to the accounting of the 2.97 visits is shown below in Table 2.

TABLE 2

BREAKDOWN OF TENDER VISITS TO BUOYS BY NEED[2]

	ENVIRONMENT	
	Exposed	Protected & Semi-Exposed
Average Number of Visits to Aid/Yr*	2.97	2.97
Annual Visits	1.00	1.00
Interim Visits	1.00	1.00
Check/Inspect	0.76	0.76
Discrepancy	0.21	0.21

*This number has not been confirmed using an independent source.

Since it is generally felt that the WATG system will work primarily in exposed environments (where wave action is most favorable), only figures relating to that environment will be considered here.

The average annual per buoy cost for the tenders servicing these buoys in this environment was $2850 in 1968 based on an average of 2.97 visits. Assuming an annual inflation rate of 6 percent, this operating cost equates to $4286 per buoys in 1975. Using this figure and assuming that the 2.97 visits per year figure remained unchanged in 1975, then the cost in that year per visit per buoy was $1443.

6.1.3 Disposal Costs

Battery disposal costs are currently an additional maintenance cost only in the first and Seventh Coast Guard Districts. Presently in the First Coast Guard District, contracted disposal costs run about $2.50 per battery. Since 1000 Ah racks contain five batteries and 2000 and 3000 Ah racks contain ten batteries, the disposal cost per buoys is either $12.50 or $25.00. These disposal costs represent only the contracted costs of removal by a private

[1]Booz-Allen Applied Research, Inc., report of 7 January 1970.

[2]Ibid.

disposal service from a stockpile area. Not included in the disposal figure is the Coast Guard-incurred cost of transporting these spent batteries from a buoy location to the central collection point. For example, in Coast Guard District 1, approximately 6600 batteries are disposed of annually at an estimated cost of $16,500 per year. These spent batteries are gathered from lighted buoys and collected at Support Center Boston, where they are then picked up and disposed of at licensed landfill sites by a commercial trucking company. The cost of this service has risen approximately ten percent each year, and it is expected to increase steadily in the years to come. Furthermore, as EPA regulations become more stringent, it is expected that these disposal costs will spread to all Coast Guard districts.

Assuming 70 percent of the 3893 lighted buoys now in service use 1000 Ah racks and thus, contain five batteries, while the remaining 30 percent are either 2000 Ah or 3000 Ah racks and thus, contain ten batteries, an average disposal cost per buoy is $16.25. (See Appendix D.)

6.2 Economic Analysis of WATG System

Costs for an alternative energy source, such as the WATG, may also be broken down into two categories: initial procurement cost and maintenance cost.

6.2.1 Initial Cost of WATG

The initial cost of a WATG system comprises the cost of the turbine assembly and the cost of secondary batteries which store the electrical power produced by the turbine. Prices for various model turbines bought in various quantities from the Ryokuseisha Corporation are listed in Table 3.

TABLE 3

COST PER UNIT OF VARIOUS TURBINE MODELS FROM RYOKUSEISHA CORPORATION

QUANTITY/MODEL NUMBER	TG-2	TG-103	TG-4
100	3345	2555	2885
200	3180	2385	2760
400	3055	2260	2675

NOTE: All prices are CIF (cost, insurance, freight) East Cost (duty paid). All prices as of 7 July 1976.

The TG-4 model is the unit which has been purchased by the Coast Guard for testing and evaluation. However, this model has since gone out of production having been replaced by the TG-103 model. Preliminary information received by the U. S. Coast Guard R&D Center from the Ryokuseisha Corporation indicates that the Model TG-103 is a modified Model TG-4, so we feel this new model will perform as well or better than the old TG-4 model. For the purpose of this report, initial cost estimates will be based on the TG-103 figures. Figures relating to performance will be based upon measured data from the Coast Guard TG-4 model.

It is apparent from Table 4 that the cost per unit decreases with the number of units purchased, and for this reasons, it is necessary to estimate in round figures about how many WATG systems might be used by the Coast Guard on its lighted buoys. The WATG fifth interim report of March 1976 indicated that this system will successfully be able to power a minimum of 318, 8X26 Coast Guard buoys in the First, Third, Fifth, Seventh, and Eighth Coast Guard Districts. By including other class buoys as well as other districts, it is a virtual certainty that there are at least 400 buoys which might successfully be fitted with WATGs. By purchasing only one-half the total amount at a time, a cost of $2385 per turbine will be assumed in this analysis.

To store energy produced by a WATG system, a 12-volt battery rated at approximately 100 Ah will be needed for each turbine unit. At the present time, we plan to use lead-acid batteries to store the energy produced by the turbine. Presently, there are a variety of lead-acid batteries which could meet the 12-volt, 100 Ah requirements. Such batteries range in cost from $0.22 to $6.78 per Ah. However, a representative cost for a battery which would reliably meet the above requirements for an average life of six years would be approximately $1 per Ah. Therefore, initial costs would be approximately $100 per buoy.

Combining initial turbine costs with battery costs yields a total purchase price for a WATG system of $2485 per buoy. This figure only includes the cost of the batteries and the turbine and does not include any time and/or expenses incurred in mounting such a system onto a Coast Guard buoy. The installation cost for mounting a WATG on an 8X26 *lighted whistle* buoy is less than $50, however.

6.2.2 Turbine Maintenance

The present Coast Guard WATG systems has been in use for a period of over two years, and to date no mechanical (i.e., turbine) failures have taken place. The Ryokuseisha Corporation of Japan, the manufacturers of the turbine, have informed the Coast Guard that they have had WATG buoys running successfully since 1965. To date, however, no data on the failure rate of these buoys has been available. Because of the lack of data in this matter, it is difficult to determine a turbine failure rate for this device. For the purpose of this report, an arbitrary annual (conservatively high) failure rate of five percent will be assumed.

Turbine failures can be caused by two things--either the air turbine fails or the controller, an electrical device, fails. Replacement costs for these two items from the Ryokuseisha Corporation are $56 for the air turbine and $26 for the controller. Assuming that neither of these devices is more subject to failure than the other, and that both will not fail at the same time, the average turbine failure cost is $41. At a five percent failure rate, this represents a cost of $2.05 per buoy per year.

6.2.3 Tender Costs

Tender costs are also subject to change with the implementation of a WATG system. First, by using a more reliable energy storage system, tender visits and, thus tender costs, can be reduced. (See projected savings section.) Secondly and perhaps equally important, is the fact that the WATG is a simple system, all of the component parts of which are easily carried by hand, compared with primary battery racks which weigh 350 pounds. This means that repairs can be made more simply and easily by A/N repair crews. Furthermore, because of this fact, the practice of sending a large buoy tender to a buoy site, except in cases where either the hull, superstructure or ground tackle of the buoy needs attention, or weather conditions require a significant sea-keeping capability, may be supplemented by smaller, less costly to run vessels. The possibility of implementing this procedure has not been sufficiently studied at this point to be included in the projected savings section. Therefore, for this report, tender costs will remain unchanged at $1443 per buoy per visit, but the number of visits is expected to be greatly reduced.

6.3 Annual Maintenance Cost Comparison

Maintenance on exposed buoys powered by air-depolarized batteries presently cost approximately $4286 in tender costs. In addition, battery failures account for 21 percent of all buoy failures. If, in every cast of buoy battery failures, the battery has to be replaced, then this represents an annual cost of $77.45 per buoy. The cost is a weighted average battery cost based upon the number of various Ah batteries in use times the 21 percent battery replacement rate. (See Appendix D.) Therefore, present-day (1975) annual maintenance costs for batteries and tender support is $4363 per buoy.

By converting to a WATG system, battery replacement costs will be $5 per buoy based upon an assumed five percent failure rate and $100 initial cost. In addition, turbine failures will result in an annual cost per buoy of $2.05 based on a five percent failure rate. Tender costs will depend upon the reduction in the number of buoy visits per year. Referring to Table 3, it can be seen that on the average one annual visit and one interim visit is made to a buoy each year. Until such time as the bulb life on a buoy can be extended, it is doubtful that the number of annual visits can be significantly reduced with the implementation of a WATG or any other alternative energy system. However, because of the increase in the life expectancy, reliability of the WATG system, as compared with primary batteries, it is estimated that this interim visit will now only have to be made once every three years. This estimate is derived from the greatly increased reliability of the system. Because there is no data to the contrary, estimates of and check/inspect visits will remain at 0.76. Discrepancy visits correspond to the number of battery failures which have been previously shown to be about five percent with the WATG system compared with 21 percent for primary batteries, and this number will be reduced accordingly. The net result of these reduction in buoy visits is an average annual visitation rate of 2.14. The above information is detailed in Table 4.

TABLE 4

PRESENT AND PROJECTED TENDER VISITATION RATES

	Annual	Interim	Check/Inspect	Discrepancy	Average Yearly Total
Present	1.00	1.00	0.76	0.21	2.97
Projected	1.00	0.33	0.76	0.05	2.14
Net Change	0	-0.67	0	-0.16	-0.83

Such a figure is conservative and with more data as to the actual reliability of this system, the visitation rate, particularly in the interim and check/inspect categories, should greatly decrease, hopefully to a number just slightly greater than one. Nonetheless, using a 1975 figure of $1443 as the tender cost per buoy visit, projected tender costs will be $3088.02. This brings the total annual maintenance cost of a WATG system to $3095.07. The minimum net savings resulting from this change from primary batteries to the WATG is derived in Table 5. Savings are projected to be $1268.38 per buoy annually.

TABLE 5
ANNUAL MAINTENANCE COST COMPARISONS

	Primary Batteries	WATG
Tender costs	$4,286.00	$3,088.02
Battery failure costs	77.45	5.00
Turbine costs	--	2.05
TOTAL COSTS	$4,363.45	$3,095.07
Net savings of WATG over primary batteries per buoy		$4,363.45
		- 3,095.07
		$1,268.38

6.4 Life Cycle Cost Comparison

It has been conservatively estimated by the Ryokuseisha Corporation that a WATG system will last at least 20 years. With careful maintenance, this estimate could easily be extended; however, for the purpose of this report, a life expectancy of only 12 years, the length of time the Japanese have had a turbine in service without a failure, will be assumed. Over this 12-year period, the initial cost per buoy will be $2485 for the WATG system with an additional $3095.07 in annual maintenance costs. This compares with an initial weighted average cost of $368.80 for primary air-depolarized batteries with an annual maintenance cost of $4363.45. The present value of 12 years of maintenance on a WATG system using a 6 percent interest rate at an annual cost of $3095.07 is $25,949.07. Similarly, the present value of 12 years of annual maintenance on primary air-depolarized batteries is $36,583.16. By adding in the initial cost of each system, it can be seen that the total cost of primary batteries over a 12-year period is $36,951.96. This compares with $28,434.07 for the WATG system or a savings of $8,517.89 per buoy over the life of the system. This data is summarized in Table 6. These savings figures do not include any consideration as to the scrap value of a WATG at the end of its assumed 12-year life.

TABLE 6

LIFE CYCLE COST COMPARISONS

	Initial Cost	Annual Maintenance	Present Value 12-Year Maintenance	Lifetime Total Cost Present Value
Primary Batteries	$ 368.80	$4,363.45	$36,583.16	$36,951.96
WATG	2,485.00	3,095.07	25,949.07	28,434.07
Savings	-2,116.20	1,268.38	10,634.09	8,517.89

For an initial purchase of 200 units, as assumed in Section 6.2.1, this represents a 1.7 million dollar savings over the 12-year life.

7.0 CONCLUSIONS

The wave-activated turbine generator, when adapted to a standard 8x26 CG buoy, in an exposed or semi-exposed location, will produce sufficient power for the optic. In fall and winter months when wave activity is greater, the WATG will produce well in excess of the necessary power.

Our experience with the WATG indicates that it can be expected to operate two years without maintenance and that this time might be extended with relatively simple refinements to improve the watertight integrity of the rectifier and alternator cases.

Although the WATG has a higher initial cost than the presently used primary batteries, its projected maintenance costs are such that a significant life cycle cost savings could be realized. Also, due to the simplicity of the unit, it is expected that a suitable WATG could be manufactured for less than $1000/unit.

APPENDIX A

DATA FROM 8X33

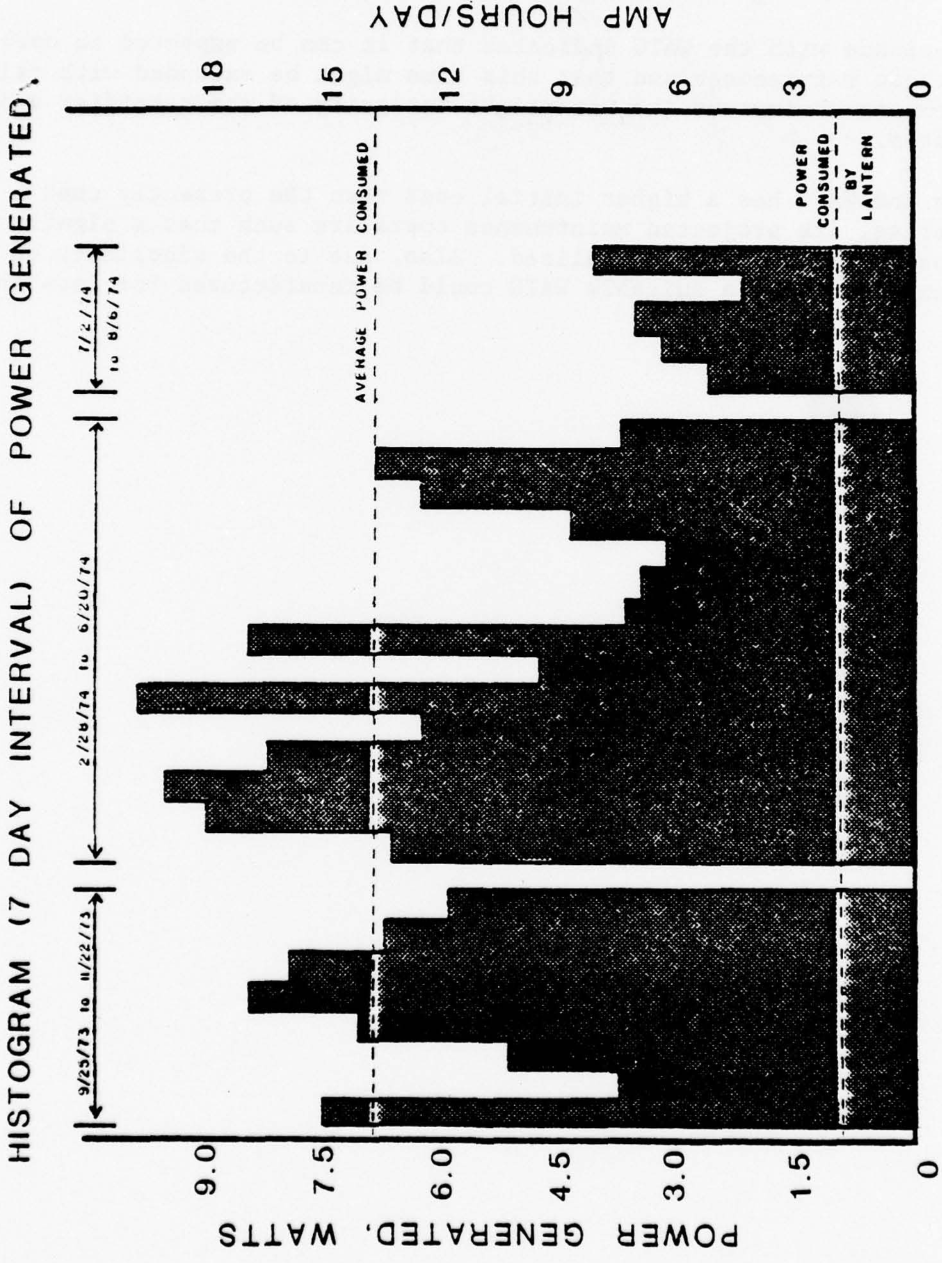


FIGURE A-1

HISTOGRAM (7 DAY INTERVAL) OF POWER GENERATED

Daily Date	Power Ah/Day	Daily Date	Power Ah/Day	Daily Date	Power Ah/Day	Daily Date	Power Ah/Day
1973		1973		1974		1974	
09/25	20.55	11/16	19.04	04/14	13.10	06/06	11.68
26	18.96	17	12.98	15	12.43	07	11.10
27	8.66	18	10.45	16	12.07	08	24.35
28	5.90	19	6.42	17	0.56	09	9.72
29	5.86	20	11.72	18	1.17	10	7.72
30	21.03			19	16.34	11	12.82
10/01	20.10	1974		20	10.01	12	5.76
02	11.38	02/28	22.29	21	14.02	13	7.97
03	4.27	03/01	13.64	22	17.32	14	5.91
04	3.57	02	4.78	24	28.79	15	4.83
05	8.66	03	10.40	25	26.88	16	11.83
06	18.51	04	15.96	26	9.37	17	7.66
07	4.79	05	20.95	27	8.55	18	3.91
08	2.93	06	4.94	28	8.39	19	12.90
09	7.32	07	14.68	29	6.48	20	12.14
10	7.44	08	10.96	30	4.01	07/02	3.60
11	18.79	09	17.35	05/01	9.05	03	4.47
12	7.96	10	9.98	02	8.62	04	10.04
13	7.27	11	17.30	03	7.25	05	7.30
14	10.73	12	24.30	04	5.05	06	6.79
15	13.42	13	31.93	05	10.45	07	1.59
16	14.07	14	21.62	06	6.32	08	0.26
17	19.73	15	8.85	07	10.40	09	0.77
18	14.32	16	15.80	08	9.05	10	4.84
19	12.52	17	29.45	09	3.96	11	10.86
20	7.72	18	19.31	10	No Data	12	10.42
21	18.63	19	11.99	11	No Data	13	6.27
22	10.16	20	25.13	12	4.48	14	3.35
23	8.13	21	20.33	13	5.87	15	8.44
24	22.99	22	18.85	14	8.75	16	4.26
25	27.18	23	8.65	15	9.93	17	4.53
26	17.17	24	16.37	16	5.76	18	7.56
27	9.63	25	24.66	17	5.04	19	10.65
28	10.98	26	14.93	18	8.28	20	12.56
29	18.76	27	7.46	19	11.58	21	3.54
30	18.27	28	9.98	20	2.11	22	7.36
31	12.16	29	24.14	21	11.37	23	4.16
11/01	20.87	30	23.17	22	13.49	24	4.11
02	15.17	31	19.29	23	12.04	25	3.55
03	13.34	04/01	6.26	24	5.04	26	4.12
04	9.96	02	12.48	25	6.01	27	3.90
05	19.29	03	12.33	26	6.69	28	3.91
06	20.75	04	15.36	27	29.50	29	4.31
07	5.69	05	18.80	28	16.67	30	8.59
08	3.32	06	25.74	29	12.36	31	4.57
09	22.38	07	18.96	30	6.28	08/01	4.21
10	24.66	08	13.15	31	8.70	02	8.24
11	10.37	09	22.87	06/01	5.04	03	12.97
12	6.46	10	22.40	02	4.83	04	10.90
13	11.07	11	4.00	03	16.52	05	4.78
14	6.67	12	14.79	04	13.02	06	2.00
15	13.50	13	10.73	05	11.43		

FIGURE A-2

TABLE OF DAILY POWER GENERATED

APPENDIX B

POWER ESTIMATES (SUMMER MONTHS) FROM HO 700 DATA ON SIGNIFICANT HEIGHT AND PERIOD

WEEK 1	WAVES IN DATA RECORD	$\overline{Ig}$(amps)	$H_{1/3}$(ft)	$T_{1/3}$(sec)	BATT VOLT	$\overline{Power}$ (watts)
1	61	0.004	1.16	8.97	12.68	0.051
2	90	0.061	1.63	4.78	12.68	0.774
3	88	0.001	1.01	5.51	12.65	0.001
4	106	0.029	1.17	3.36	12.65	0.367
5	88	<0.001	1.38	5.45	12.64	

First week average $\overline{P}$ = .0483 watts (average of 6-minute records)

WEEK 2						
1	119	0.129	1.47	3.17	12.64	1.630
2	65	<0.001	0.63	8.26	12.61	---
3	77	<0.001	0.64	7.07	12.61	---
4	82	0.002	0.97	5.36	12.60	0.025
5	80	<0.001	0.75	6.59	12.59	---
6	94	0.003	1.04	5.55	12.59	0.037

Second week average $\overline{P}$ = 0.282 watts (average of 6-minute records)

WEEK 3						
1	106	0.179	1.59	3.91	12.60	2.555
2	101	0.016	1.32	4.61	12.56	0.201
3	86	0.185	2.68	5.18	12.63	2.336
4	NO DATA (instrumentation malfunction)					
5	55	0.033	3.46	9.58	12.59	0.415
6	84	1.070	5.00	5.33	12.89	13.790
7	82	0.606	4.02	4.67	12.78	7.744

Third week average $\overline{P}$ = 4.506 watts (average of 6-minute records)

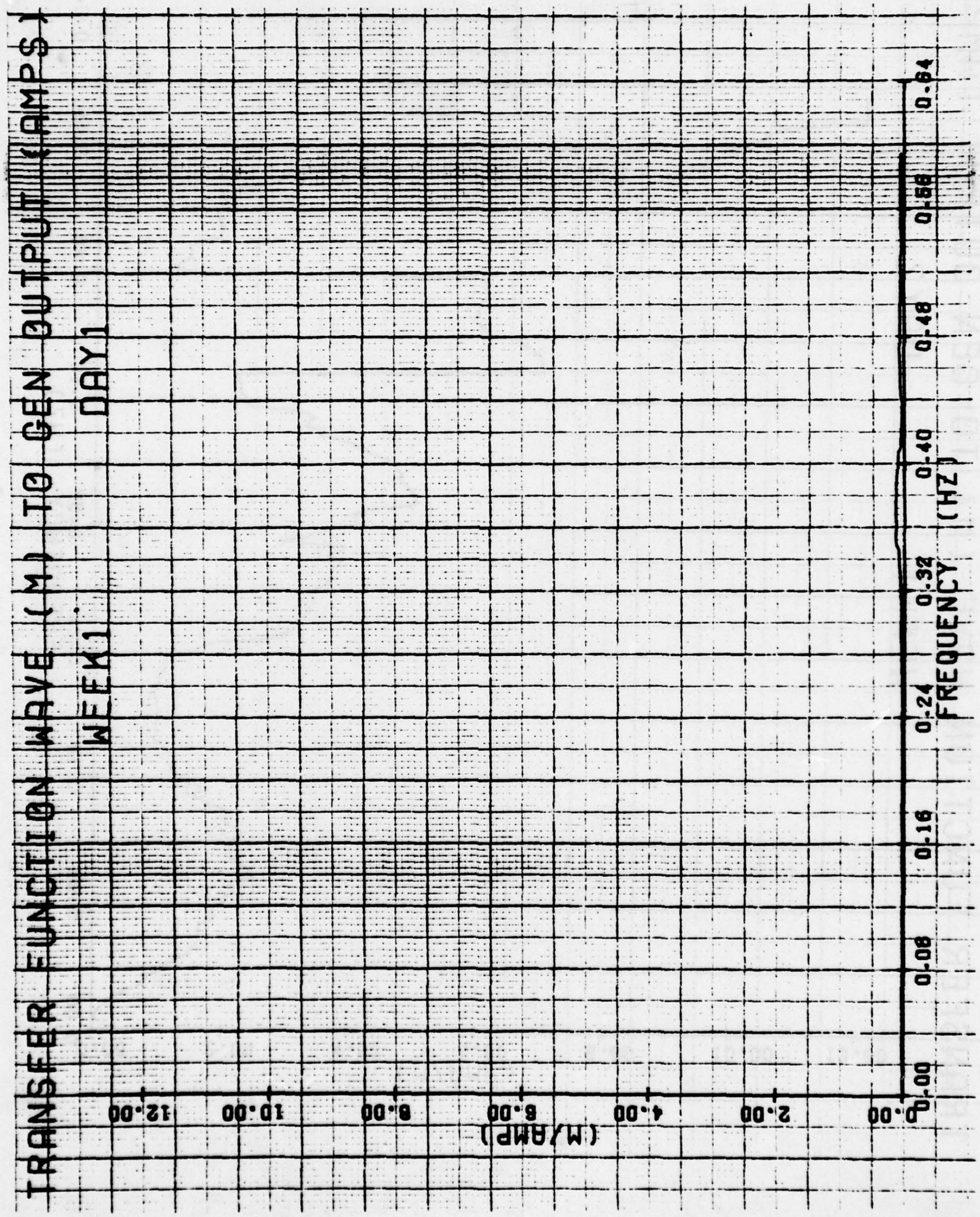
WEEK 4						
1	57	0.001	1.94	8.73	12.54	---
2	73	0.001	1.20	8.35	12.50	---
3	111	0.639	2.63	3.77	12.69	8.019
4	100	0.083	1.68	4.49	12.51	1.038
5	76	0.040	1.98	4.95	12.49	0.500
6	77	0.222	2.65	6.55	12.52	2.779
7	66	0.003	2.15	7.67	12.42	0.037

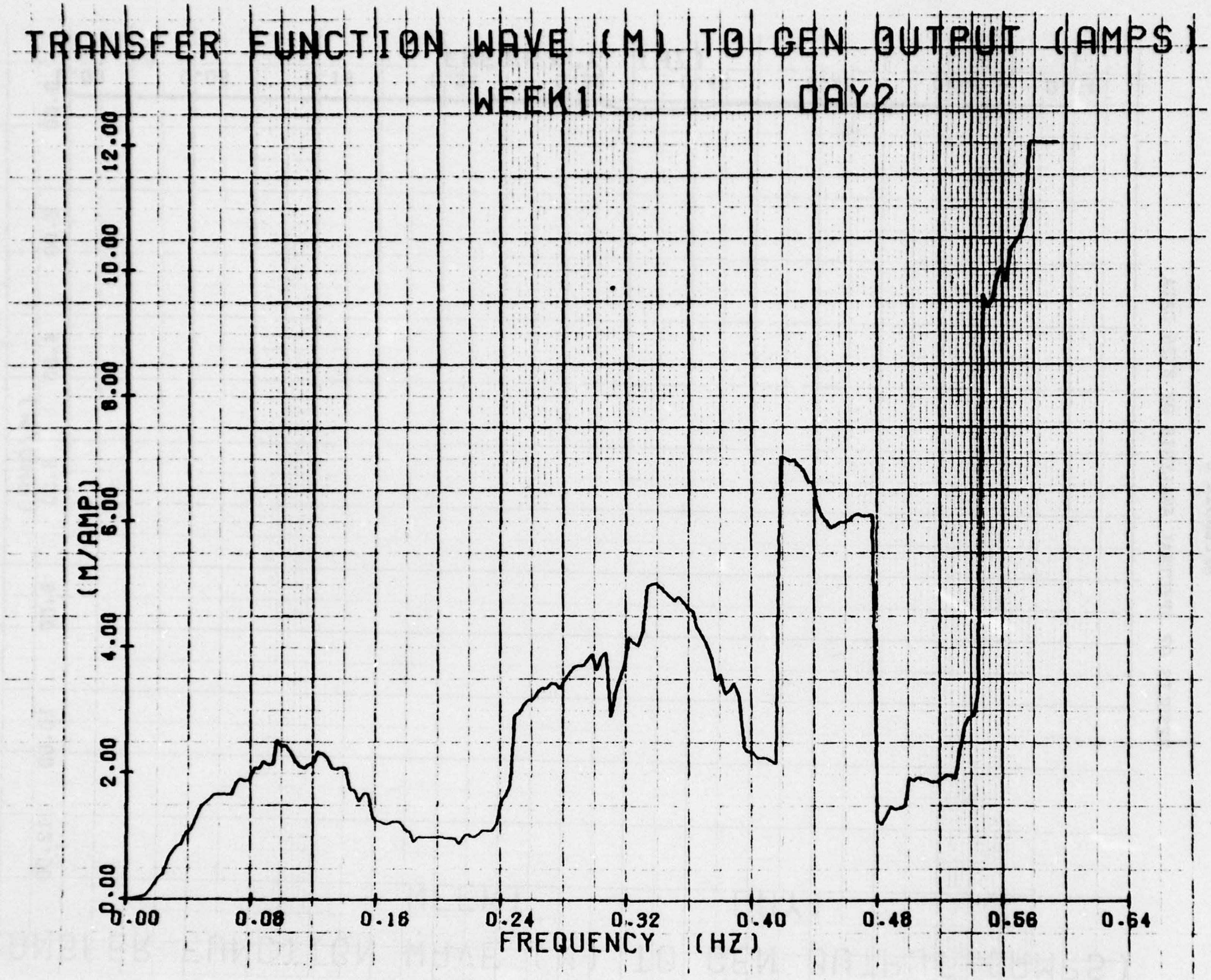
Fourth week average $\overline{P}$ = 1.767 watts (average of 6-minute records)

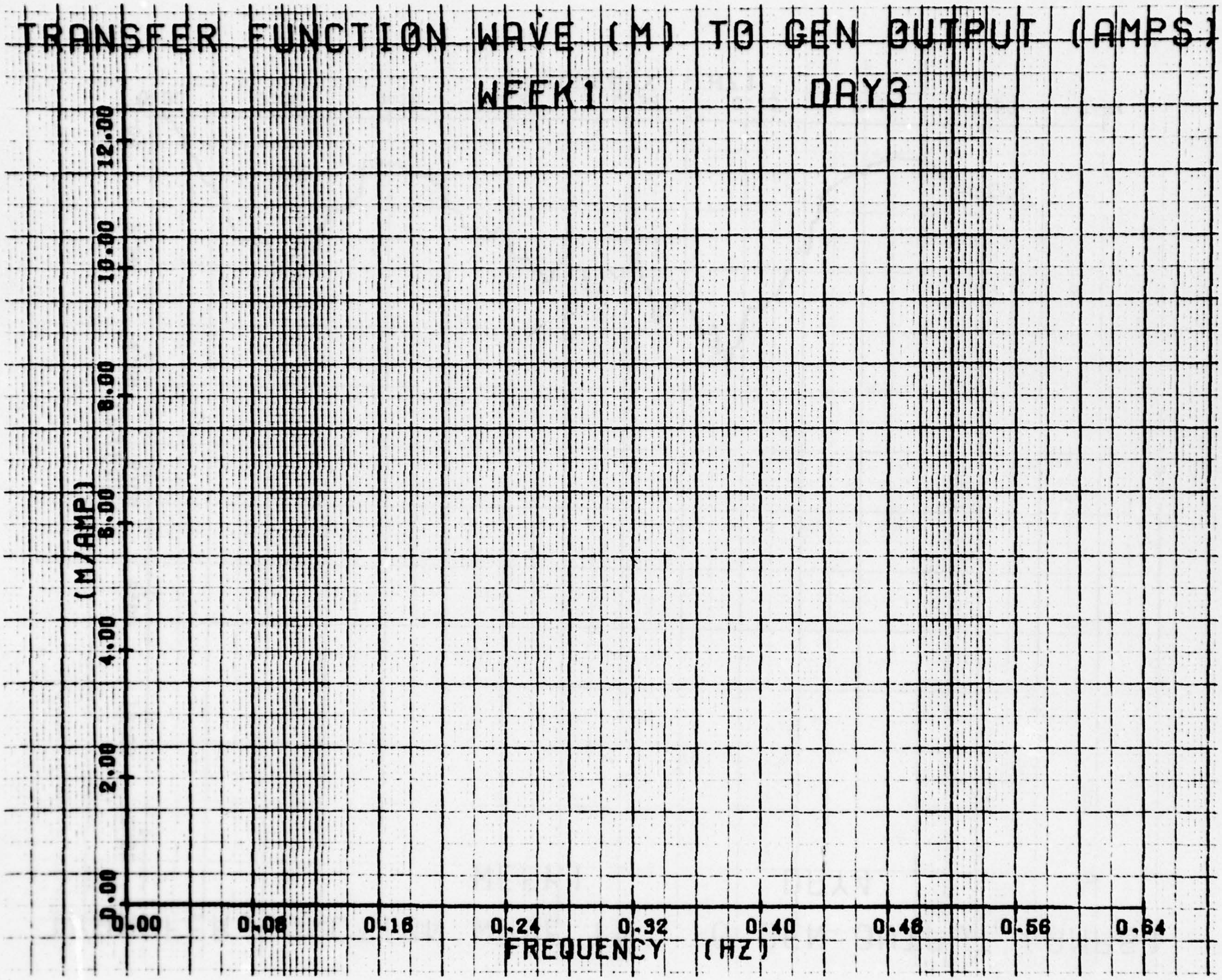
MONTHLY AVERAGE $\overline{P}$ = 1.759 WATTS (AVERAGE OF 6-MINUTE RECORDS)

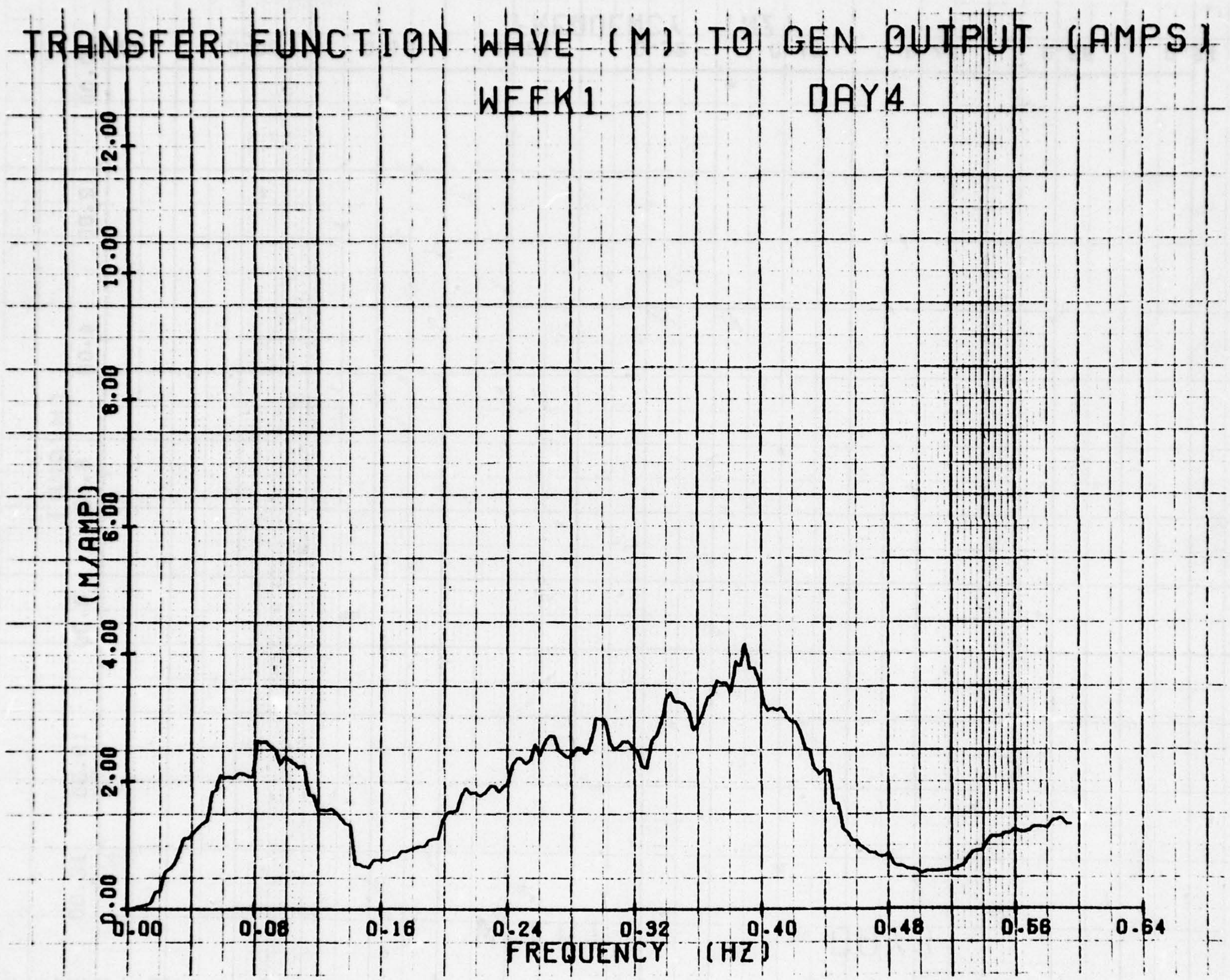
APPENDIX C

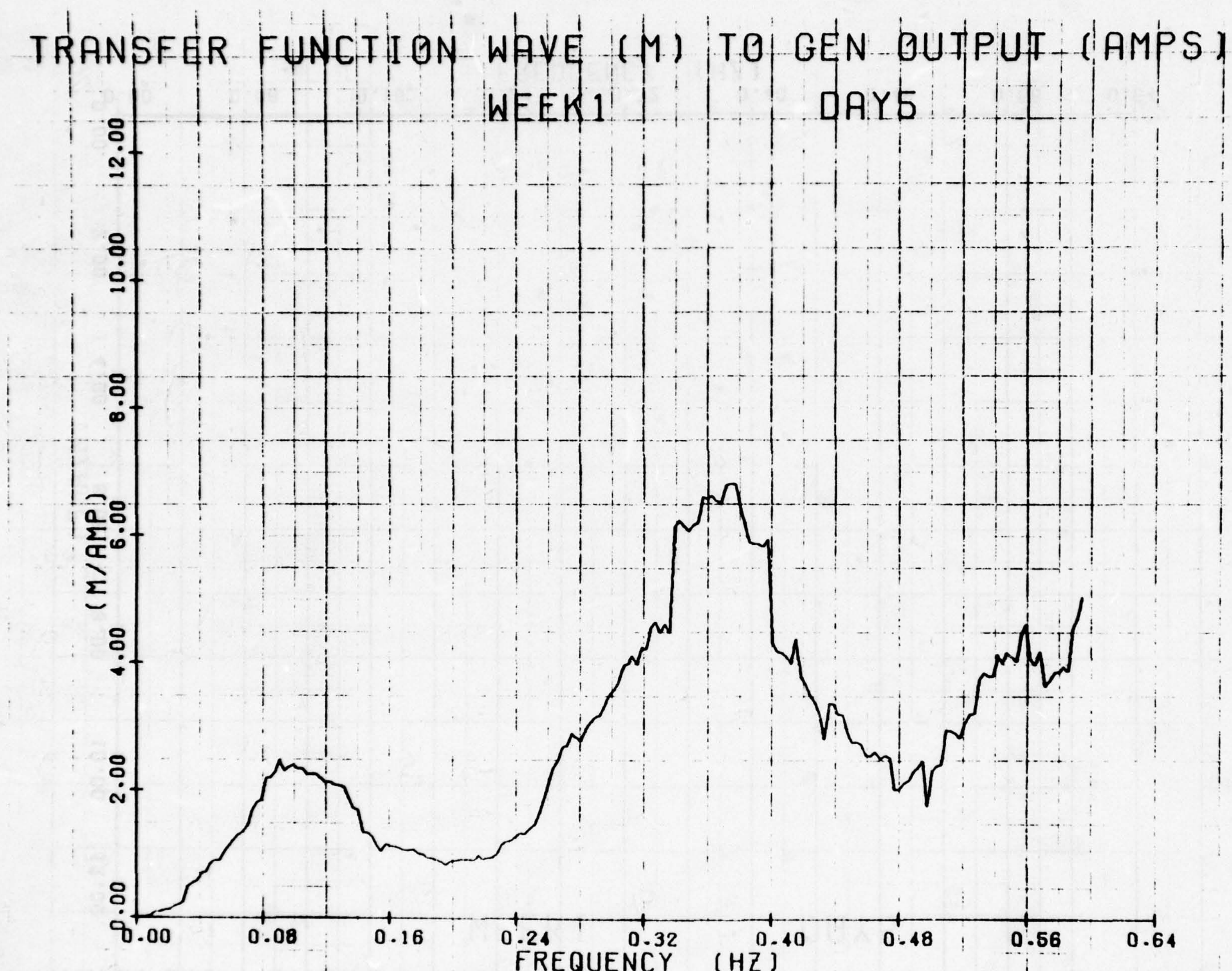
RESULTS OF SPECTRAL ANALYSIS OF 8X26 DATA

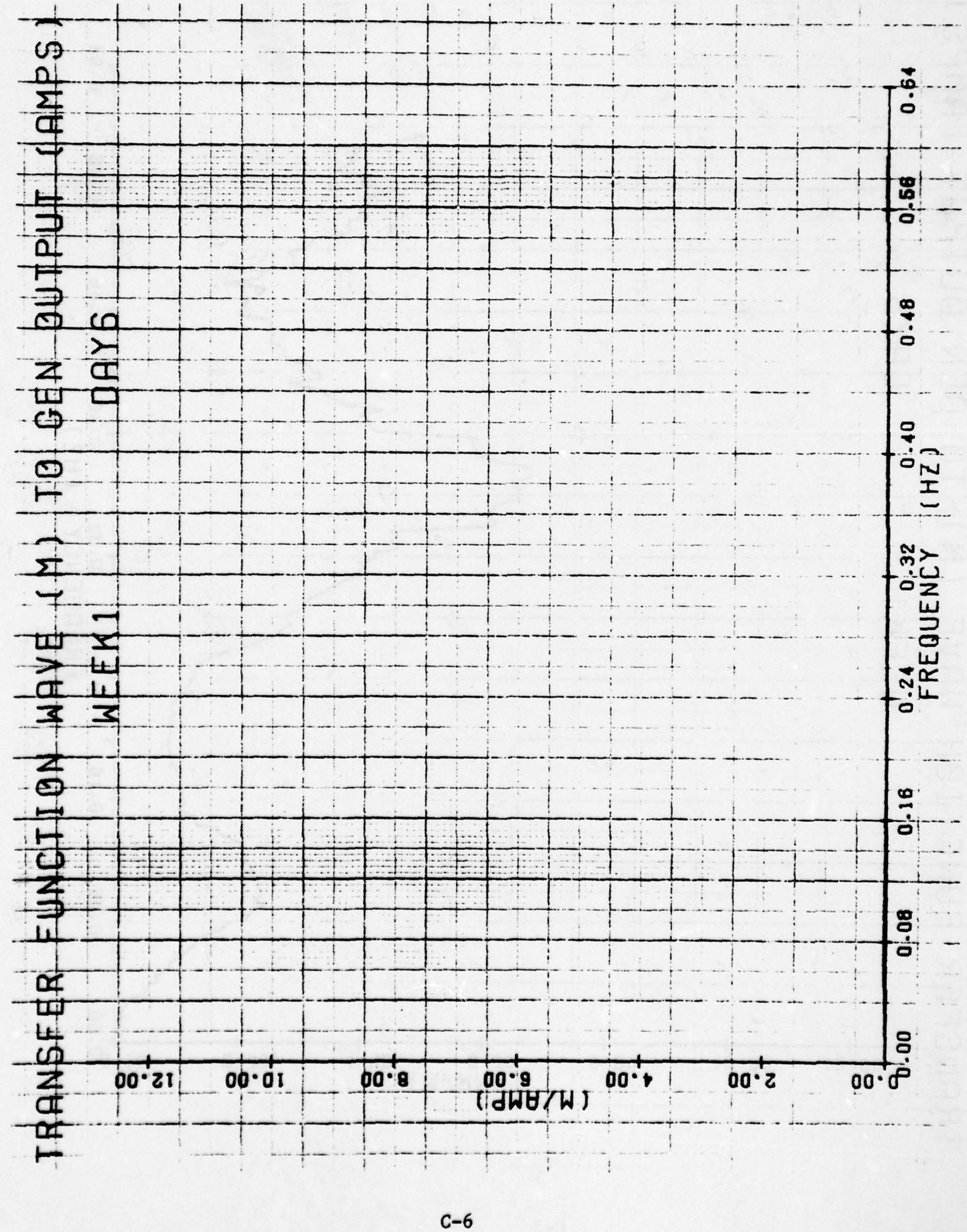



TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK1 DAY2
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK1
DAY3
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK1
DAY4
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK1 DAY5
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)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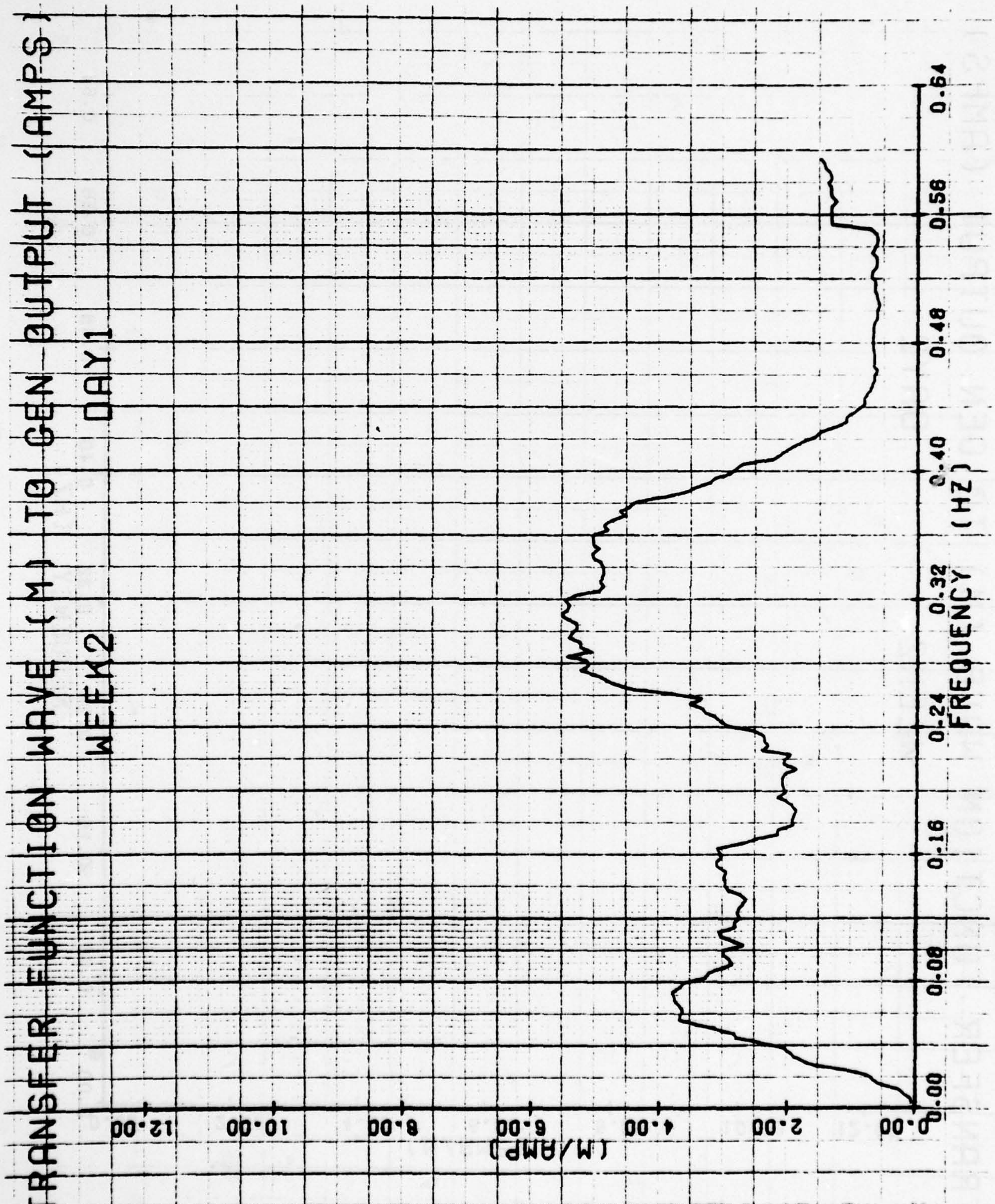
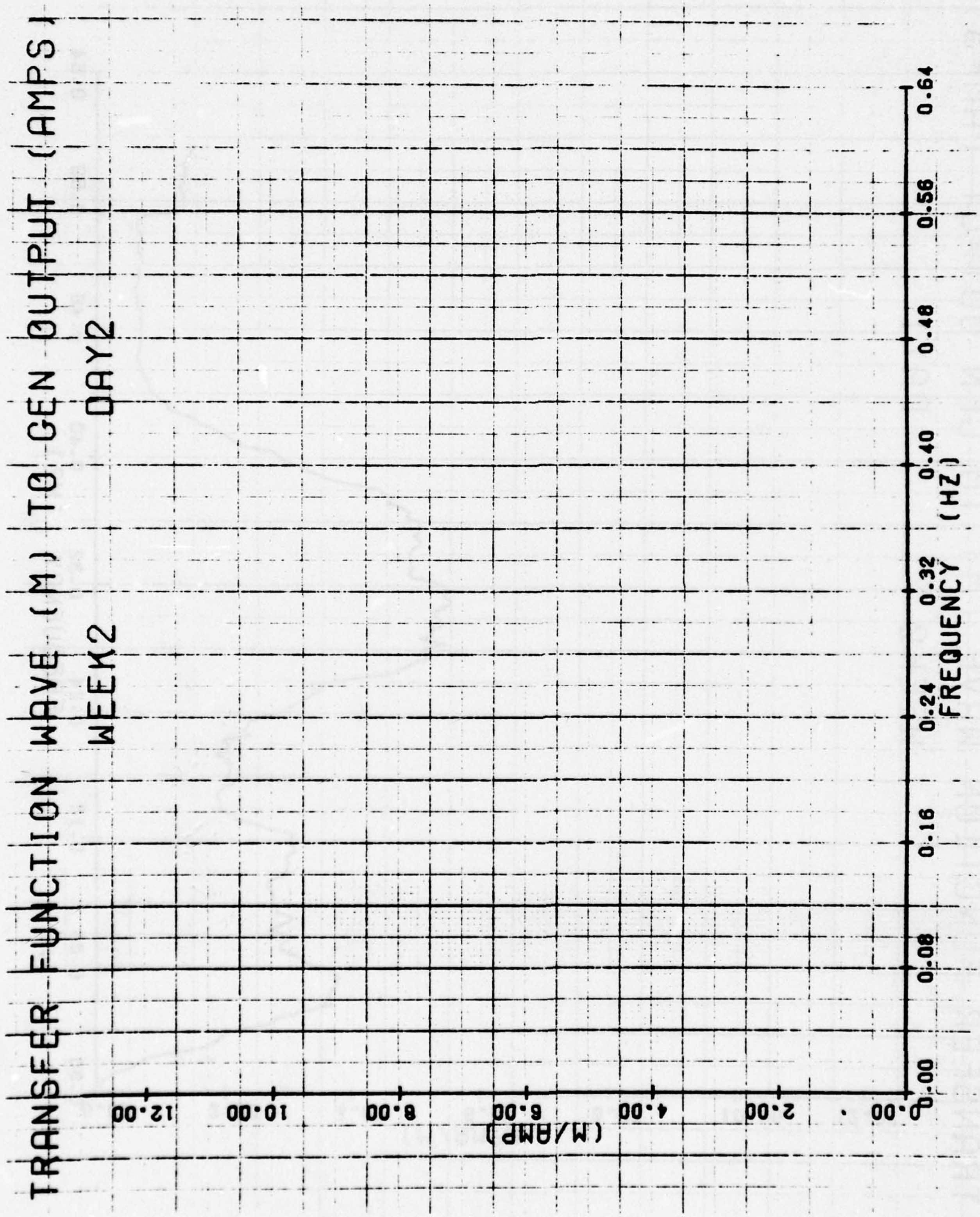
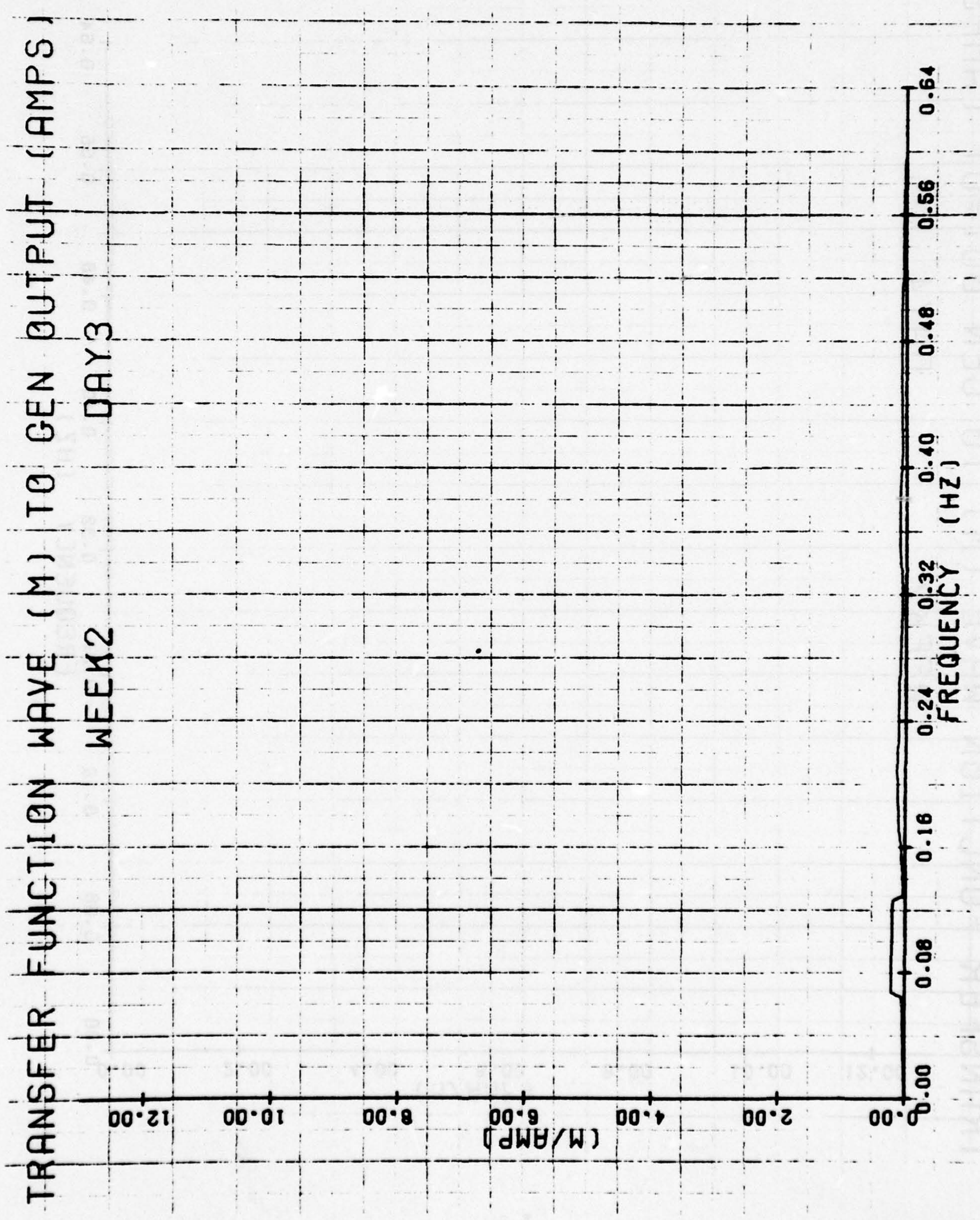
WEEK1 DAY6
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

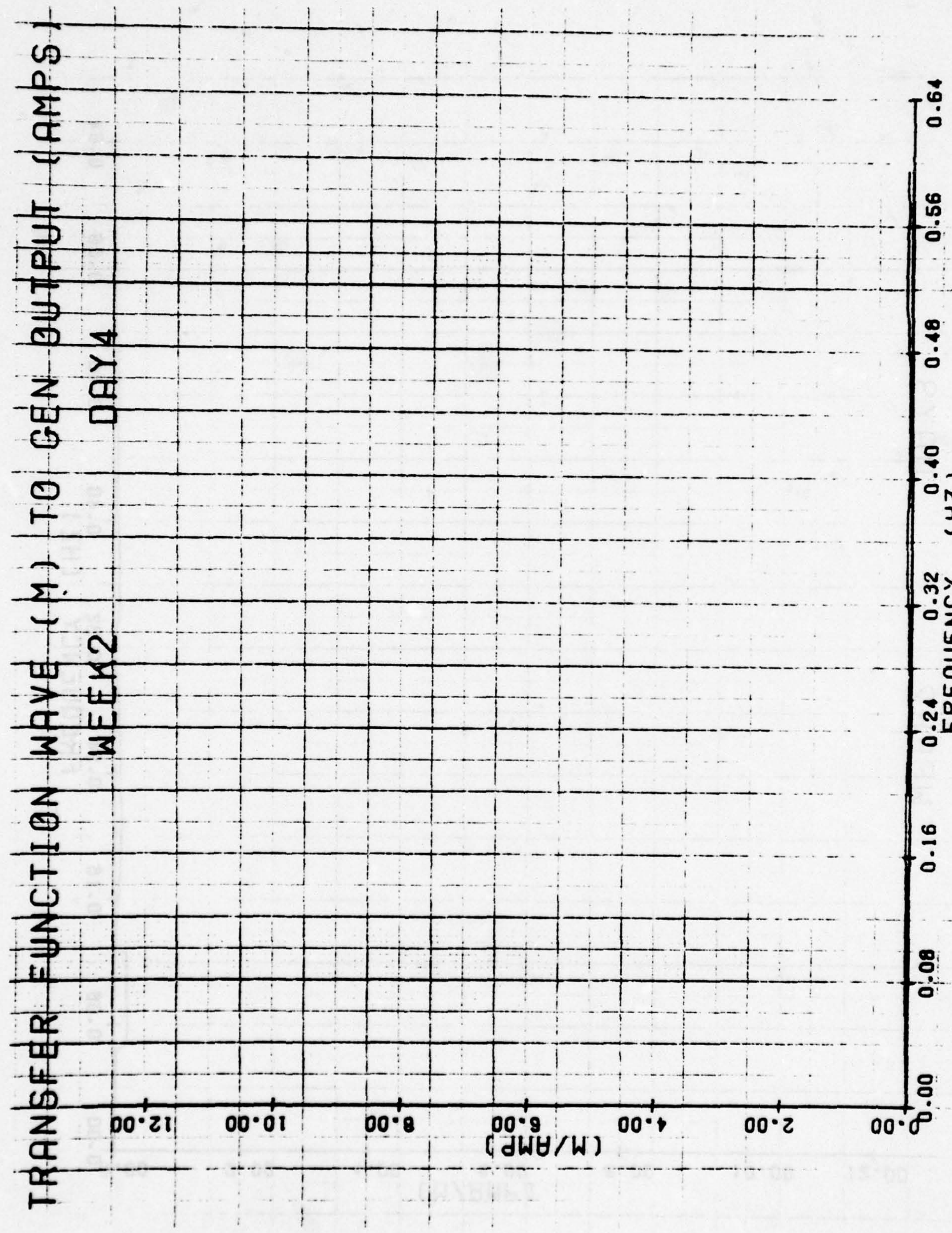


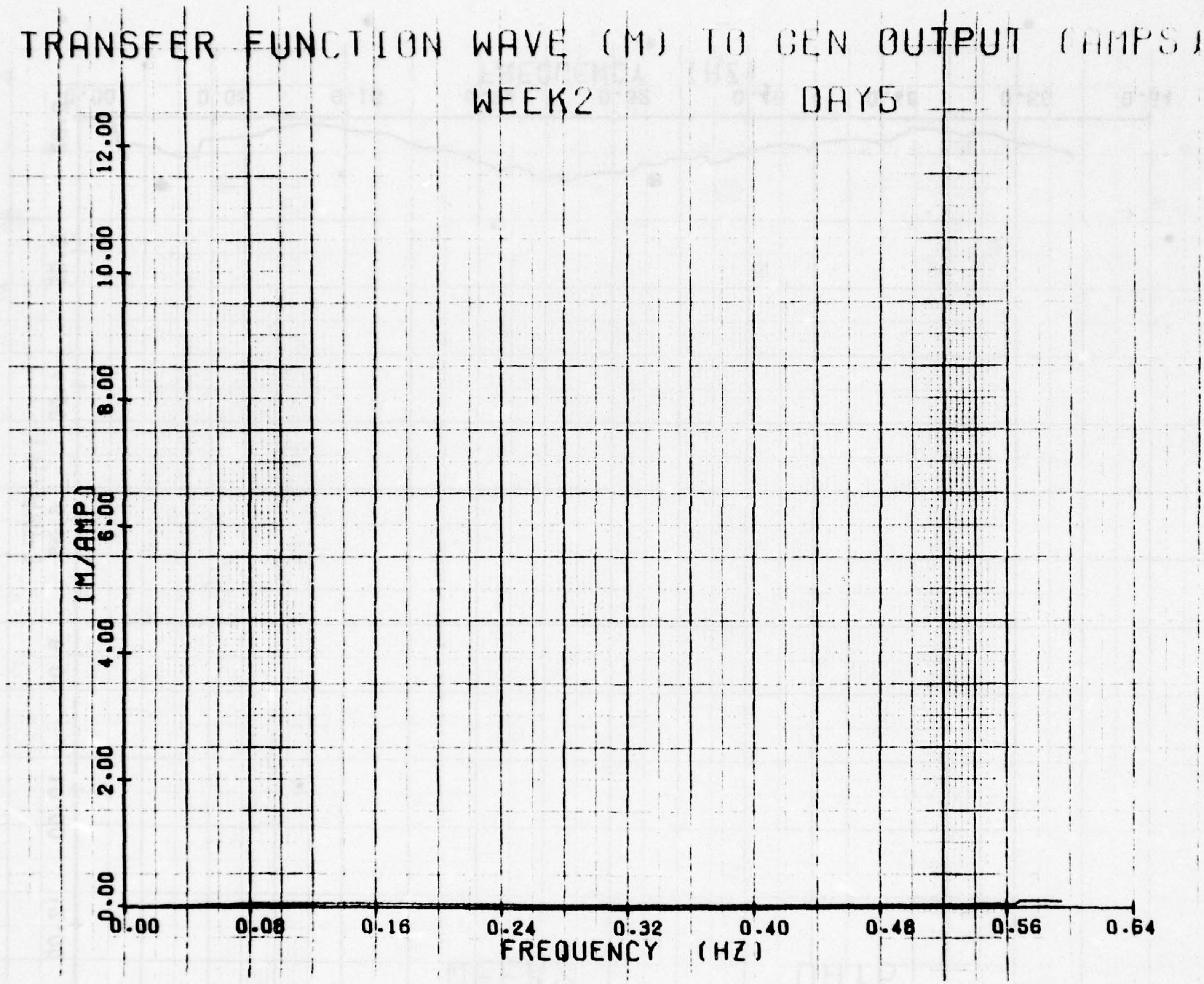
TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2 DAY1
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

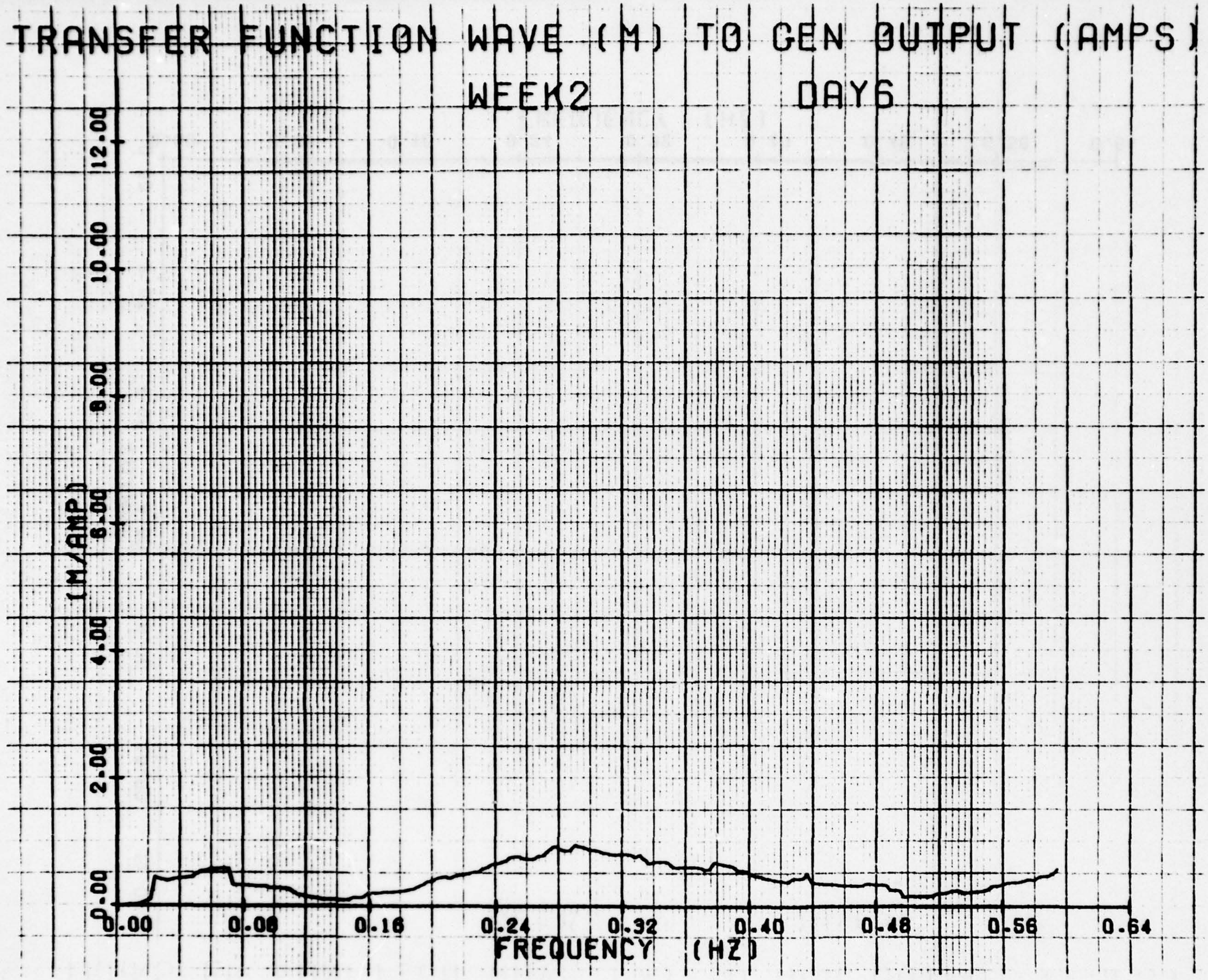


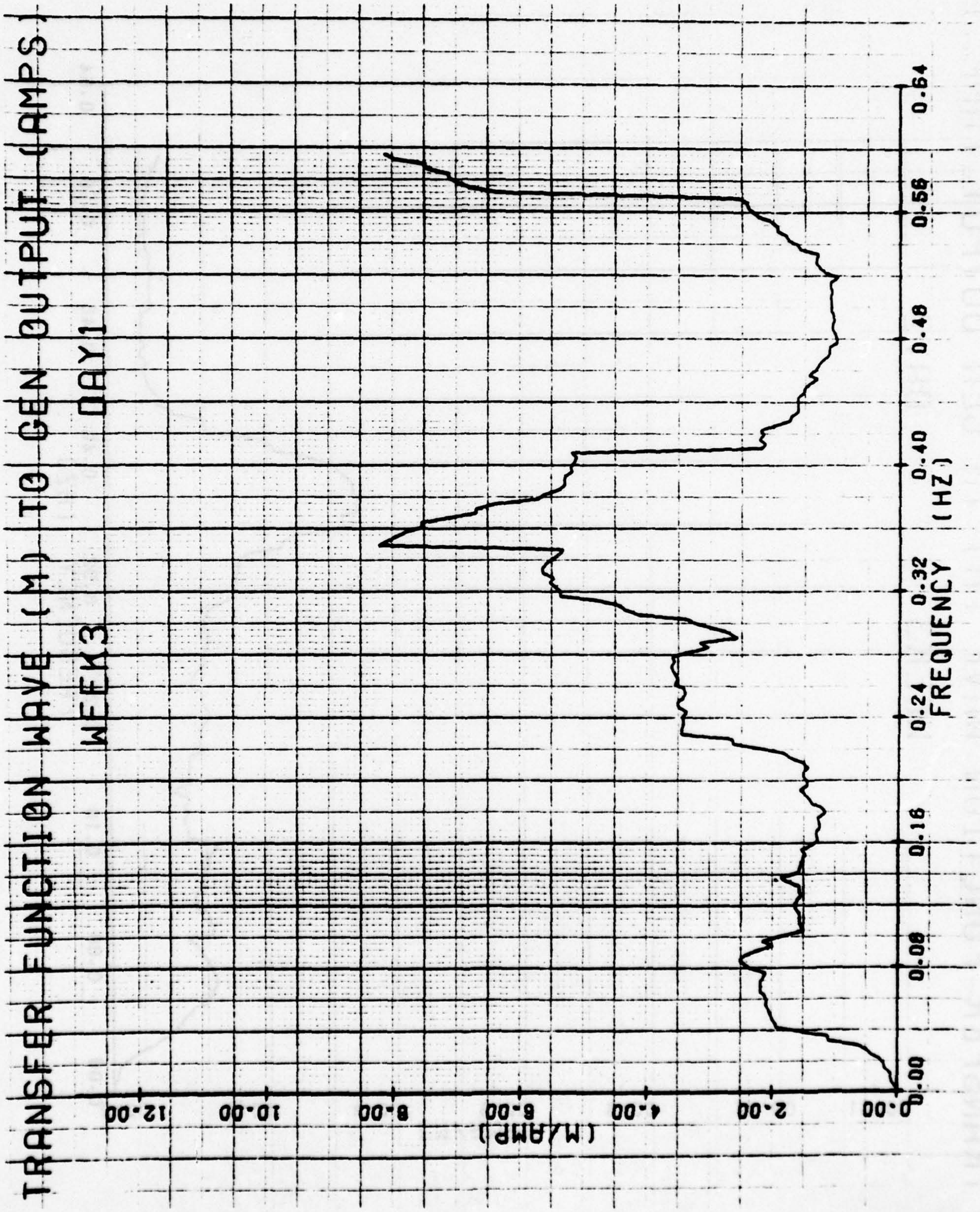
TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2
DAY2
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00

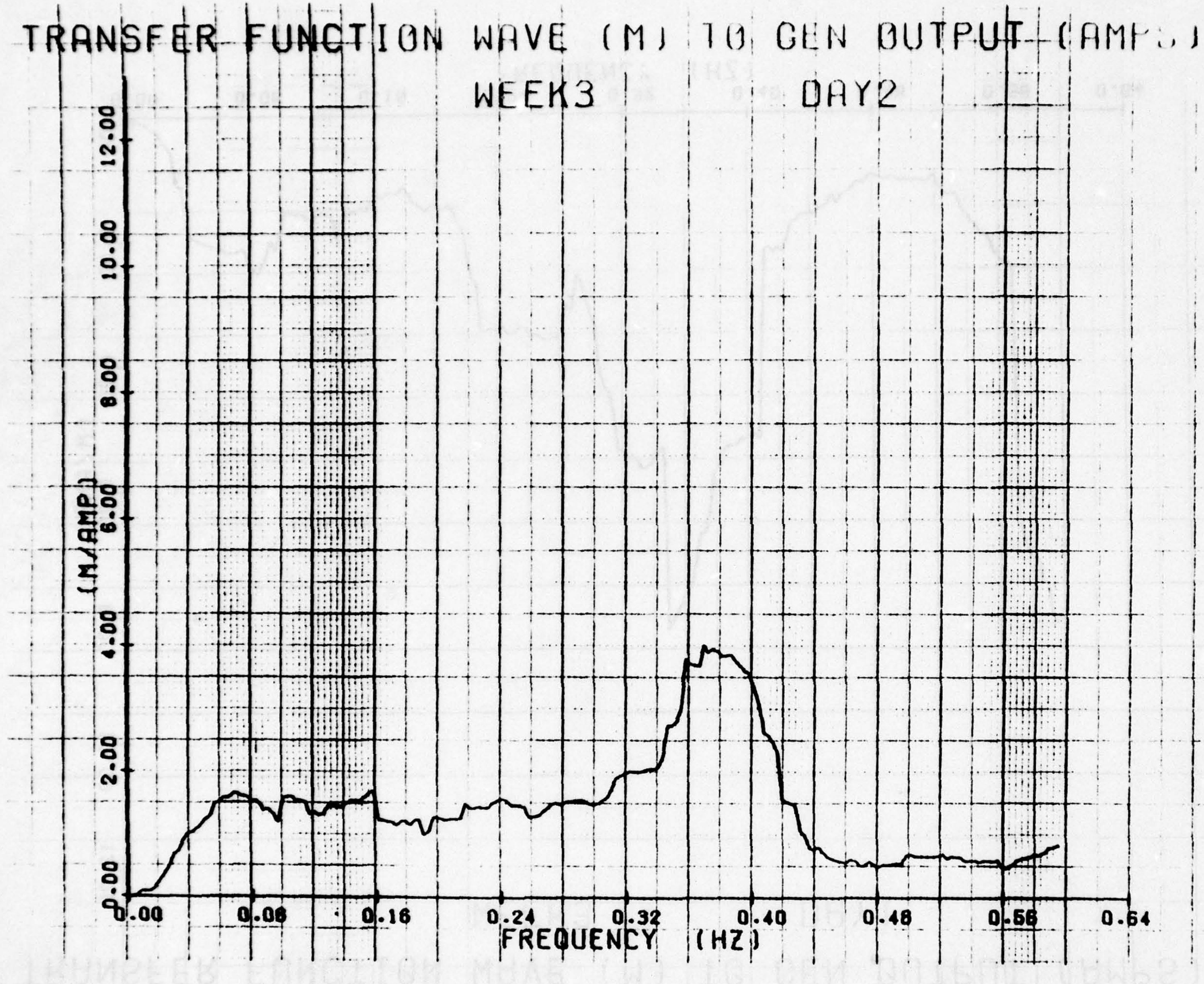

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2 DAY3
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2 DAY4
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

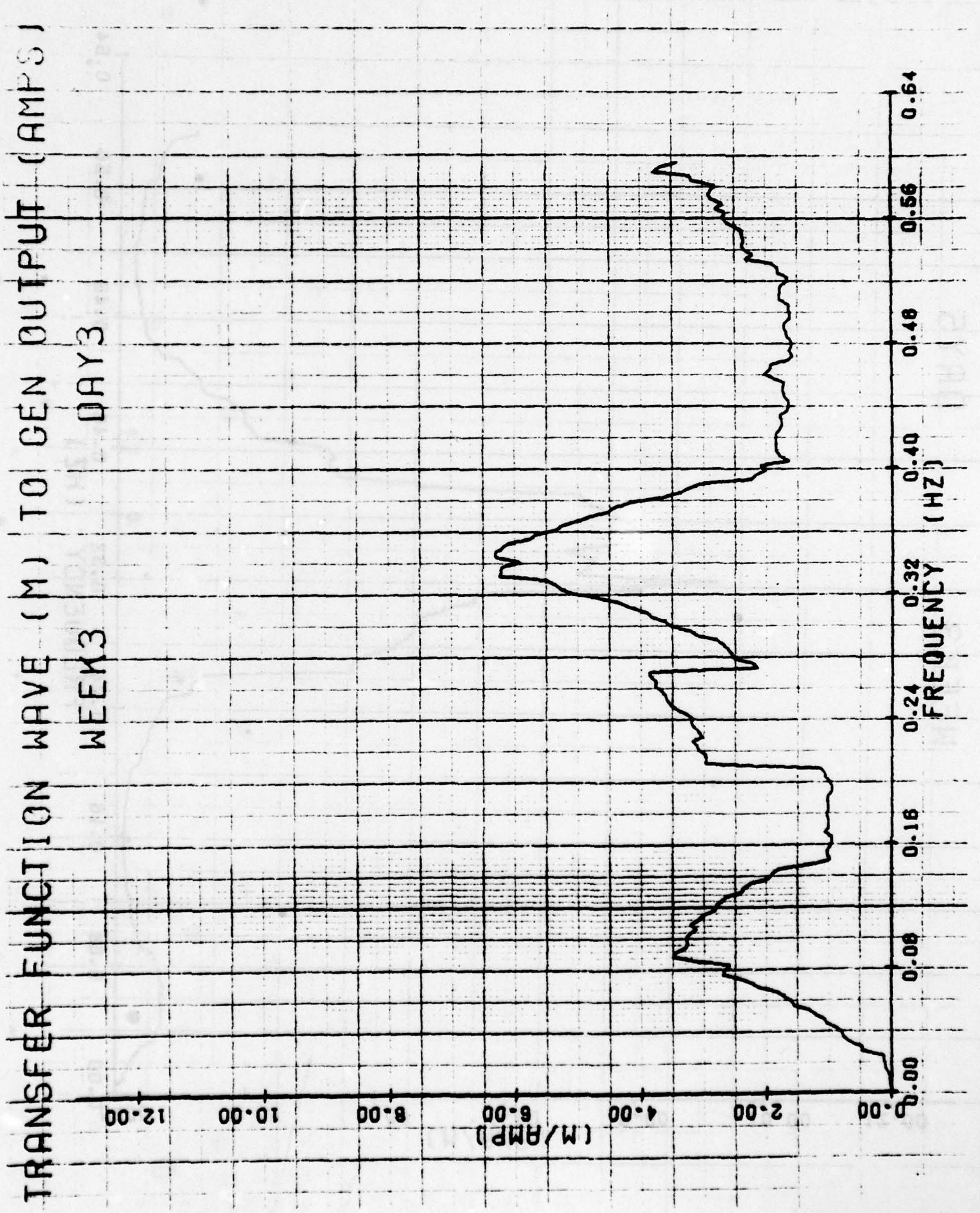

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2 DAY5
12.00
10.00
8.00
6.00
4.00
2.00
0.00
(M/AMP)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

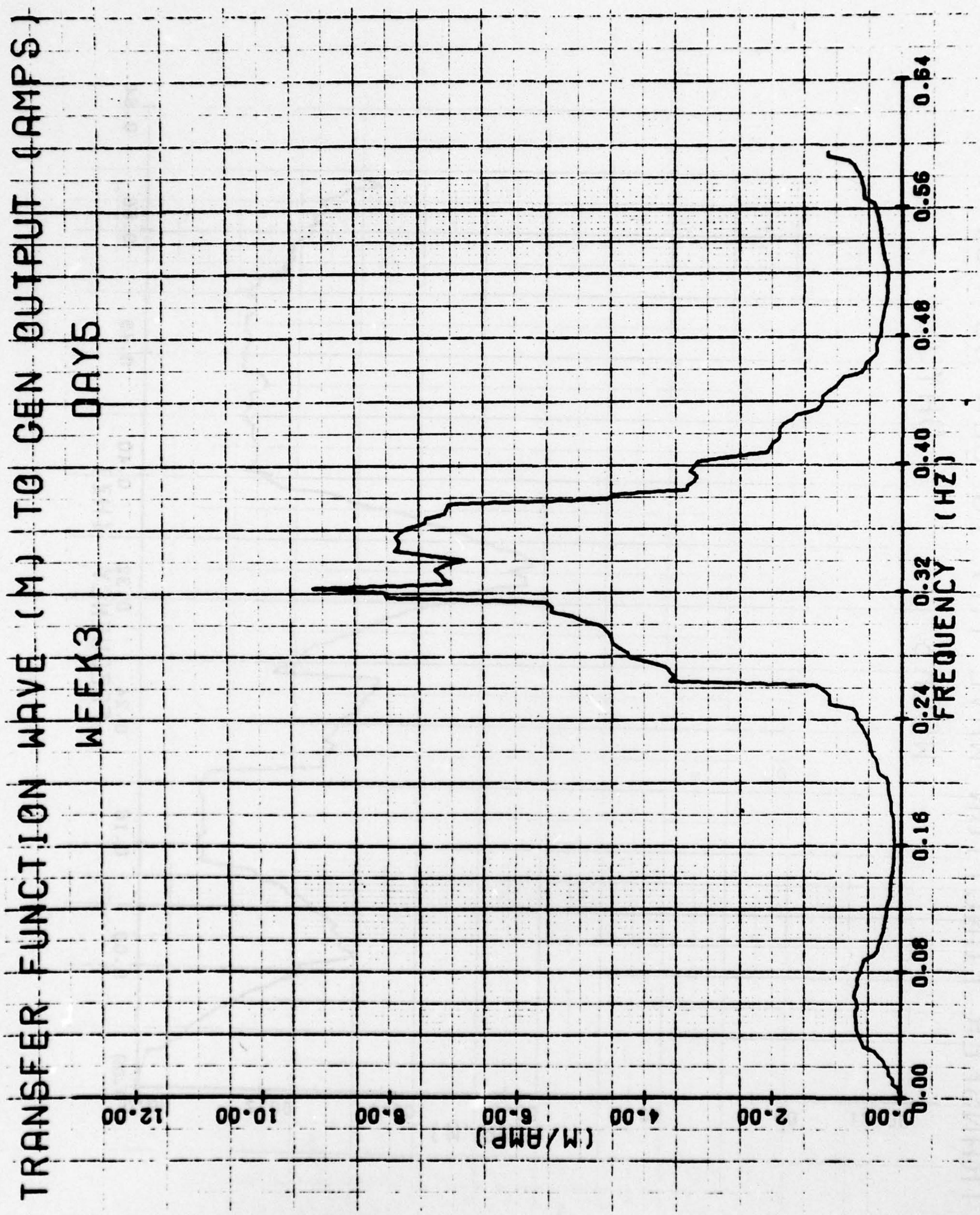

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK2 DAY6
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY1
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

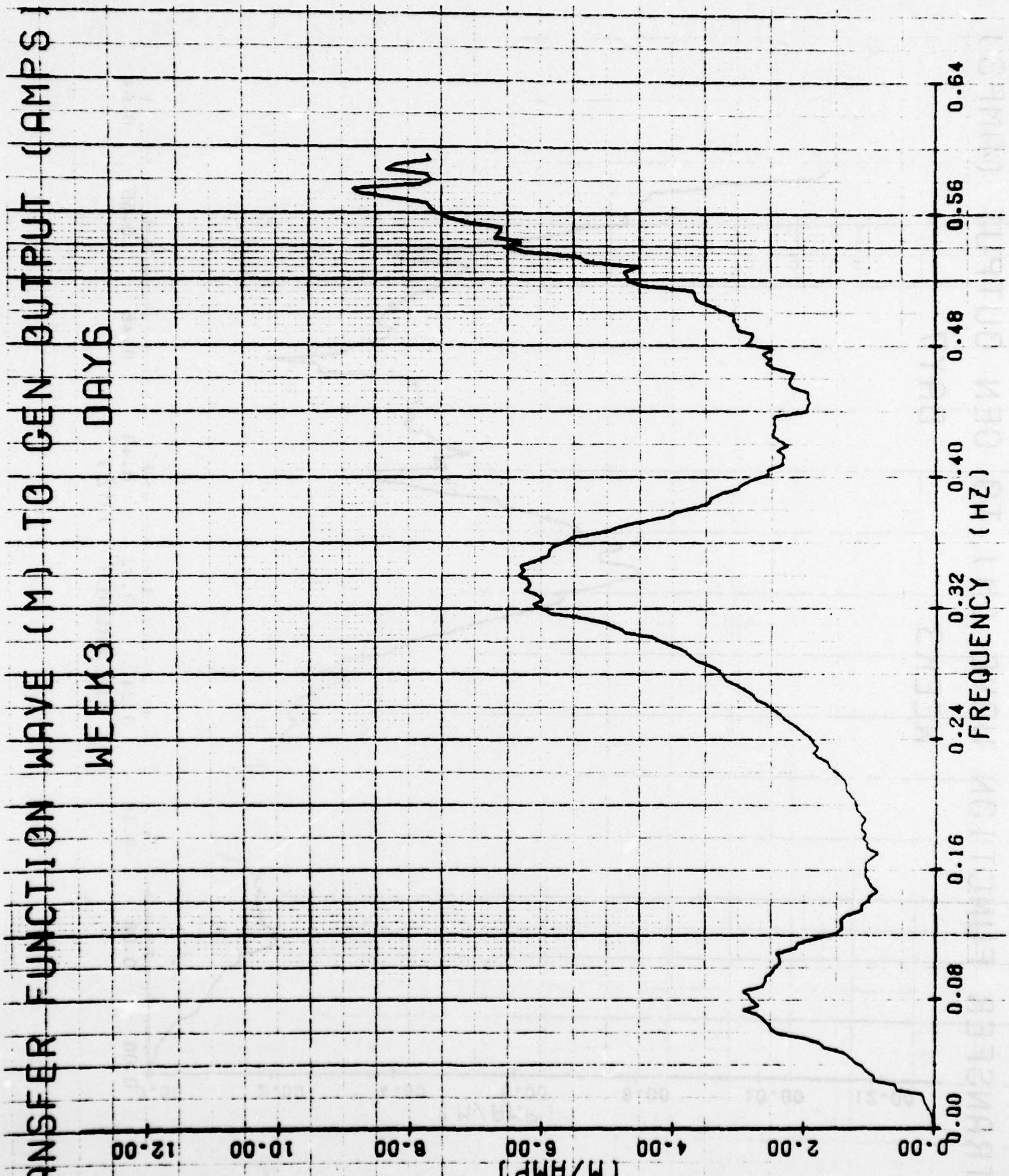


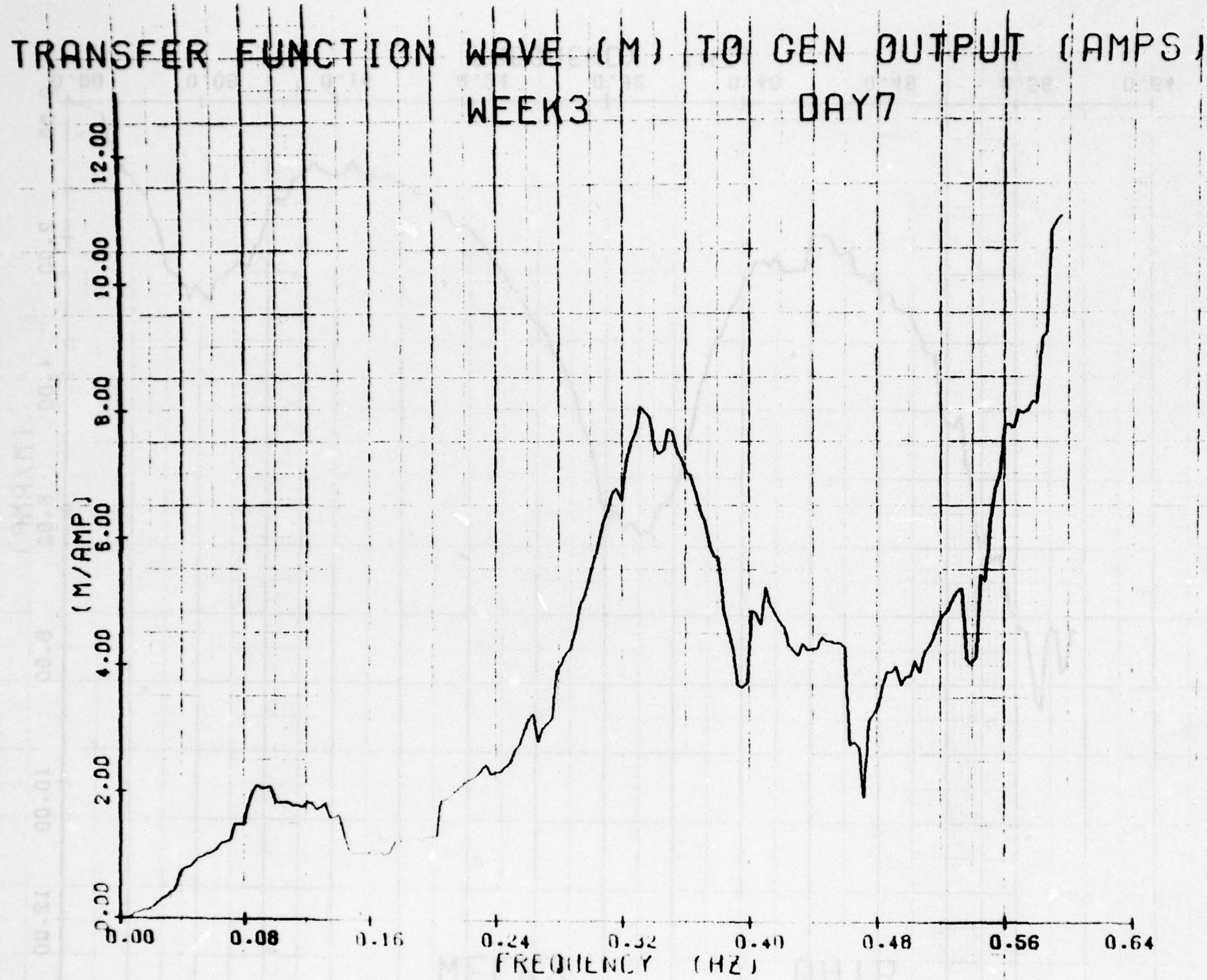
TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY2
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY3
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64

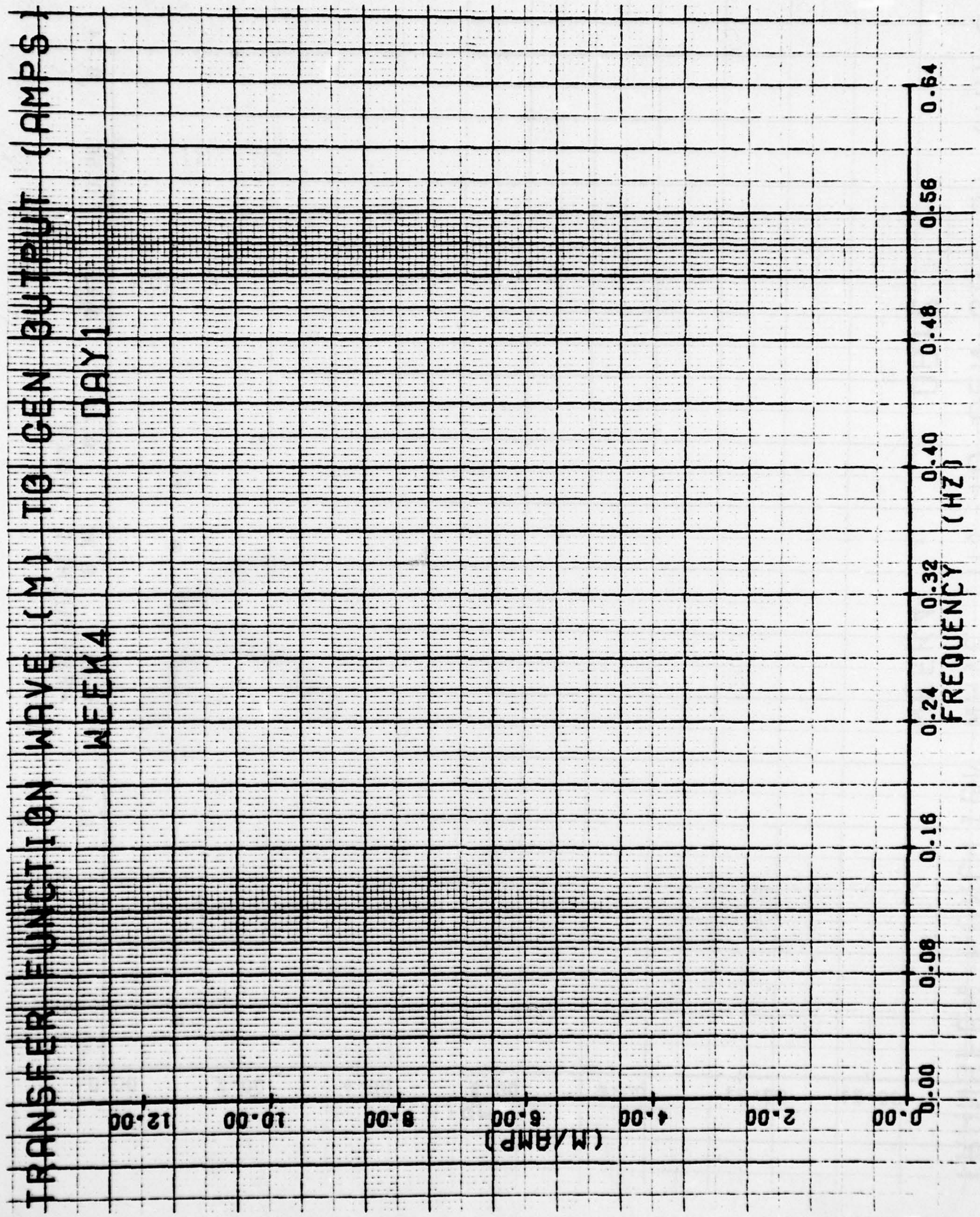


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY5
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64

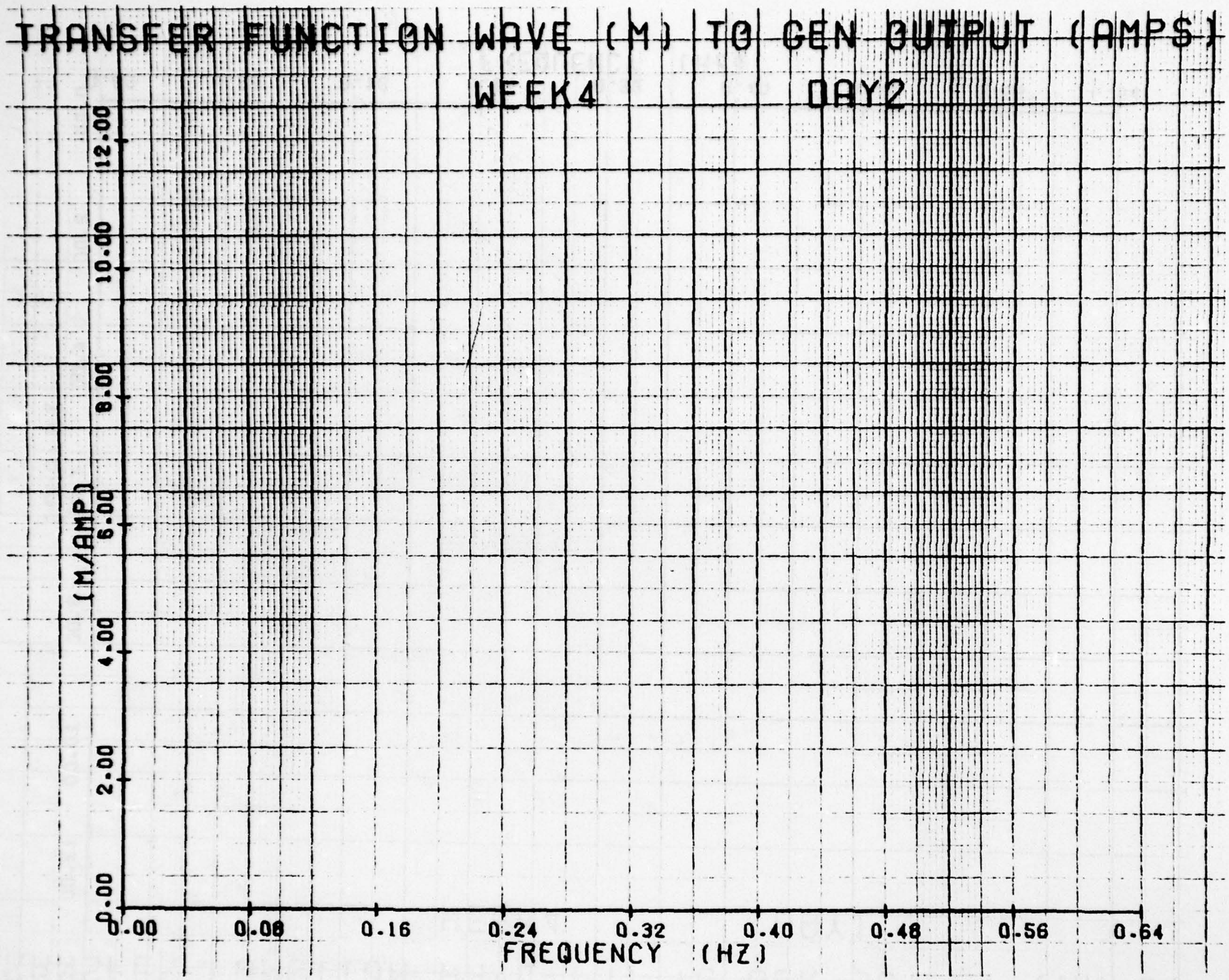

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY6
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)



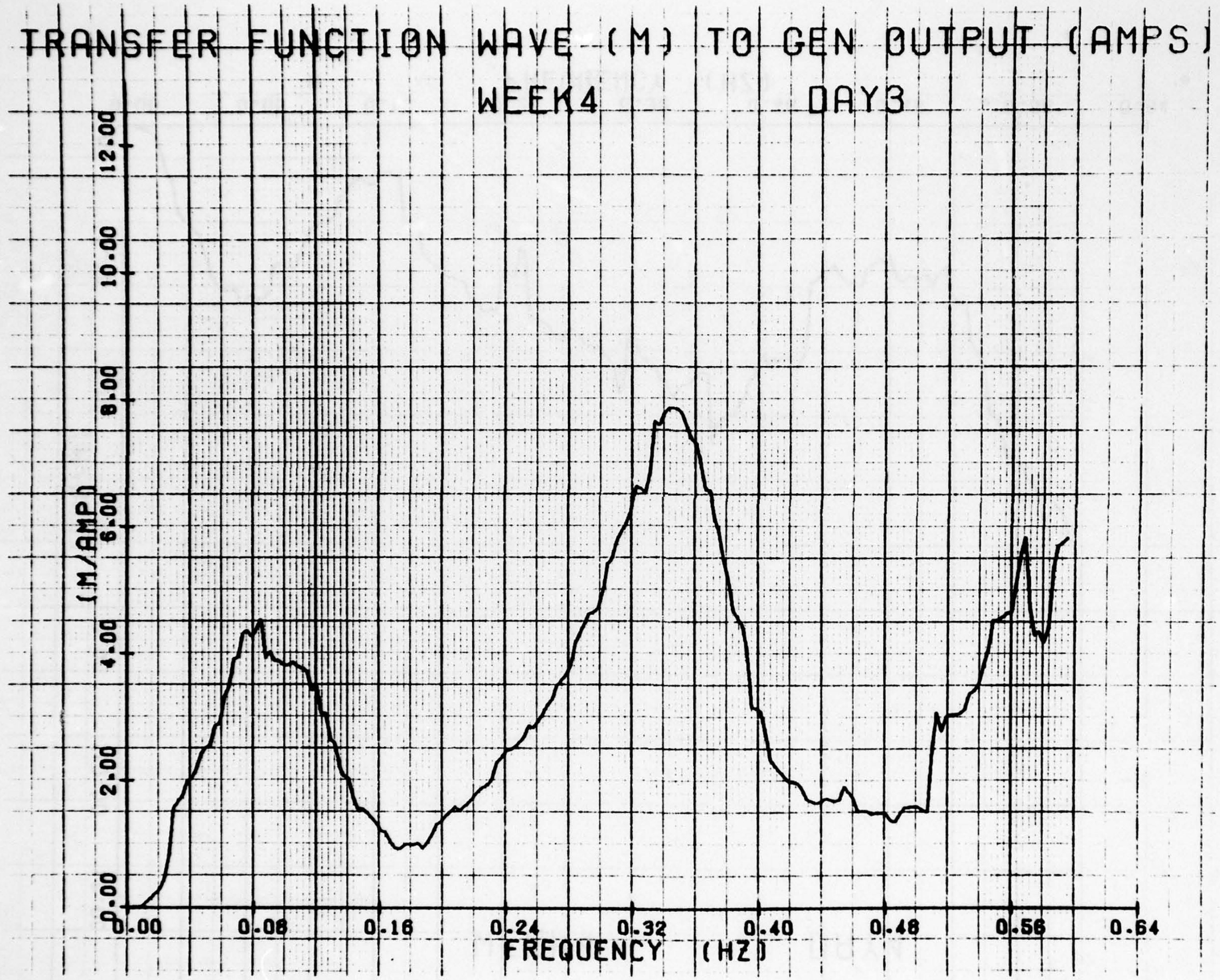
TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK3 DAY7
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

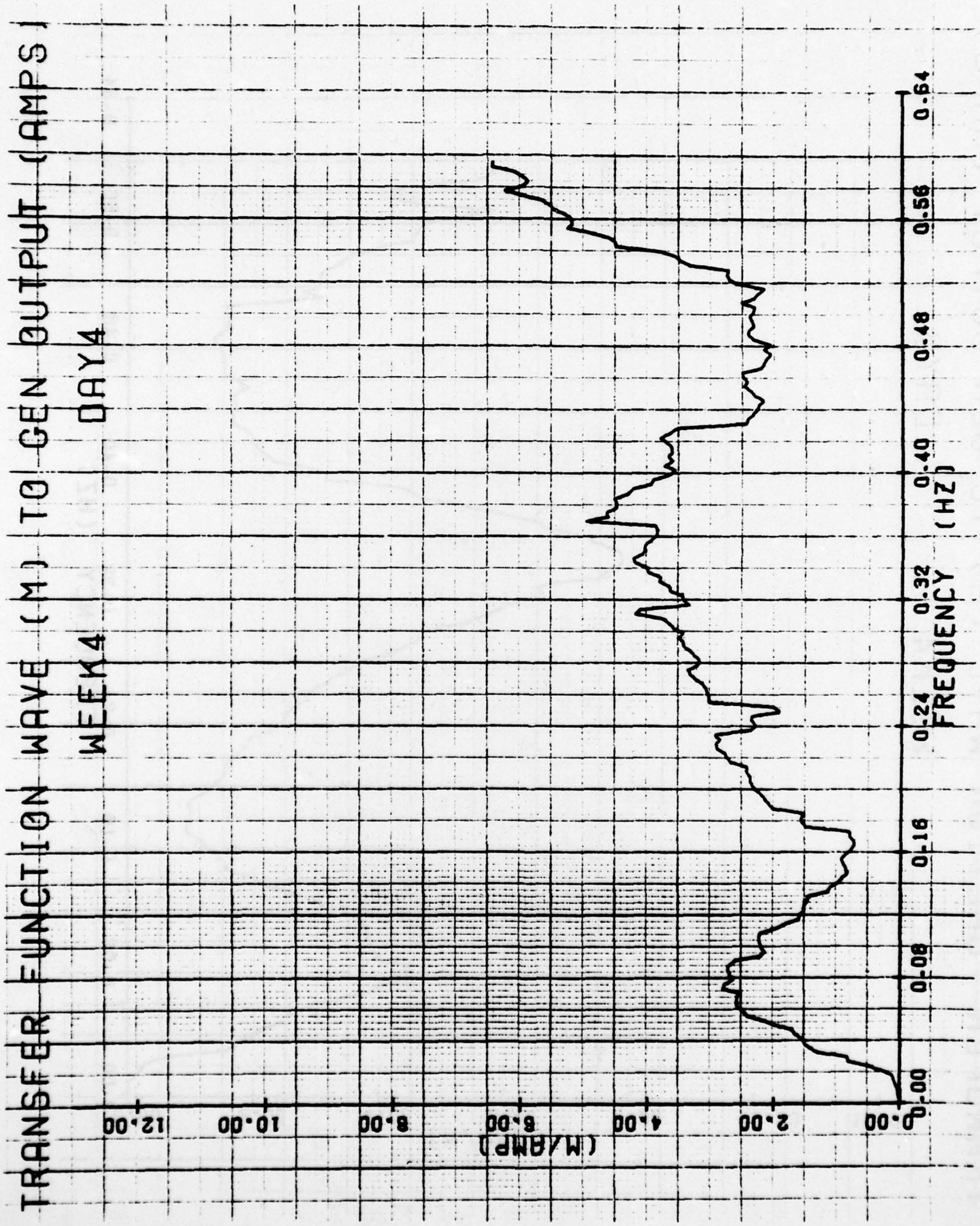


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4
DAY1
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00

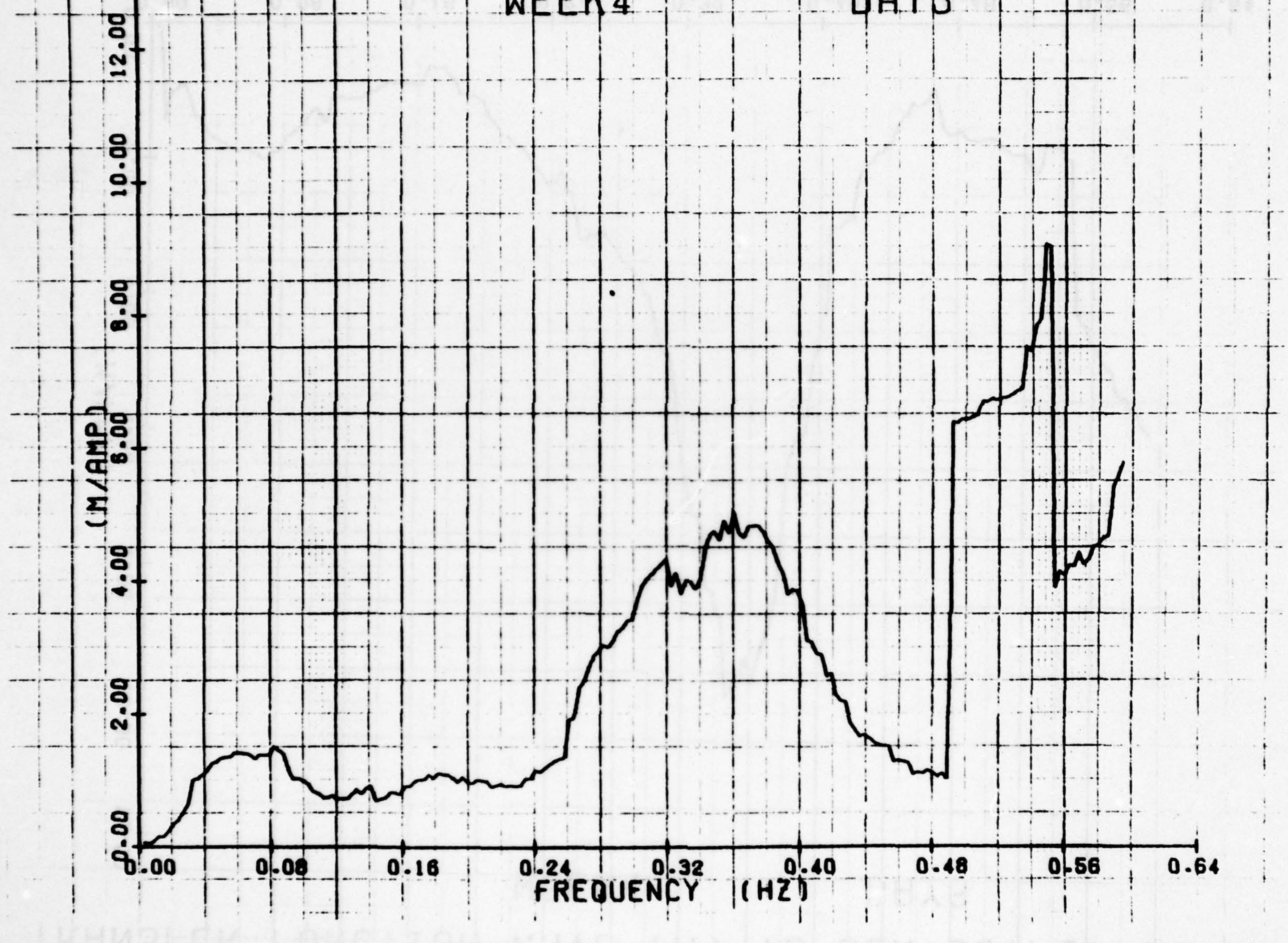


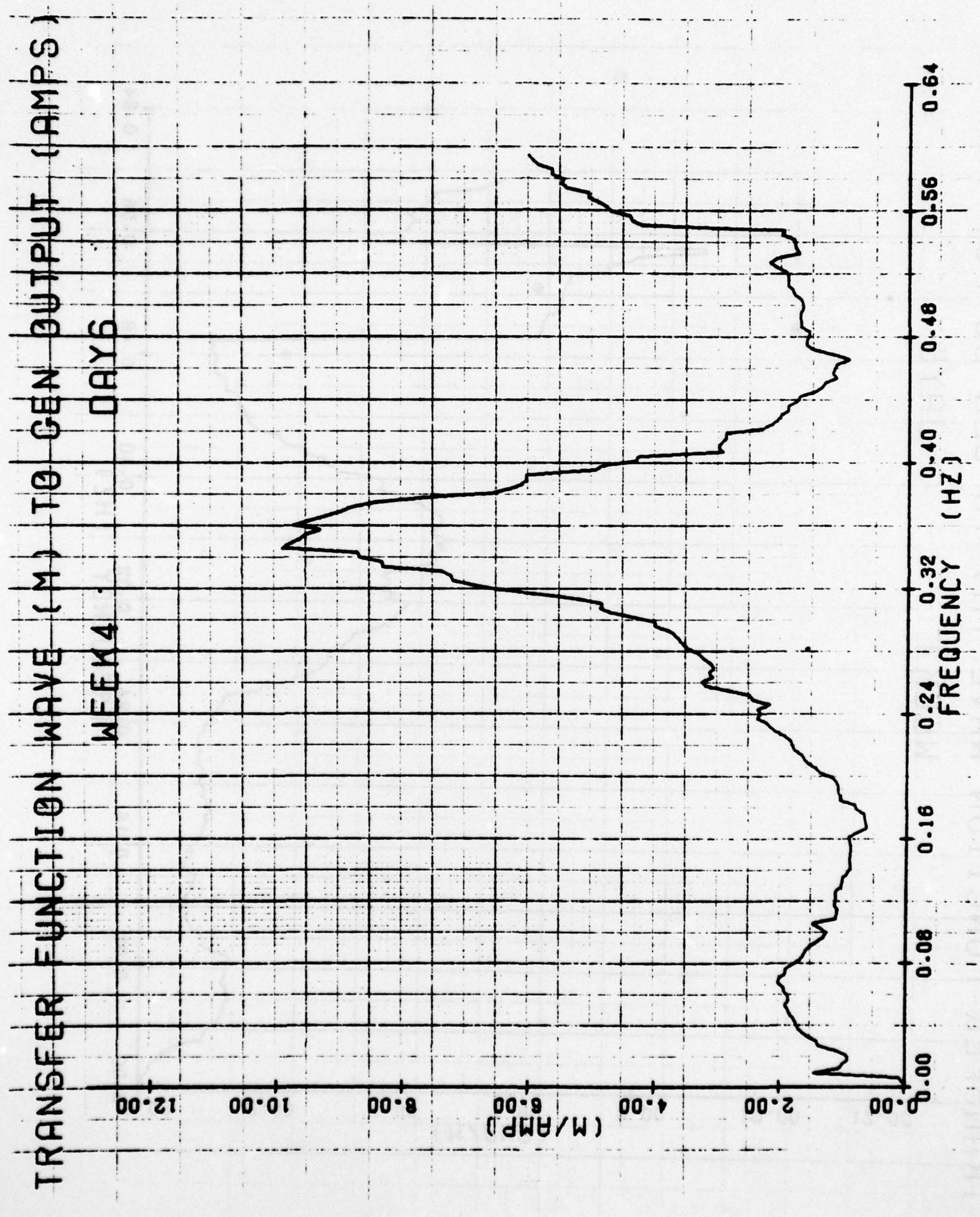
TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY2
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY3
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

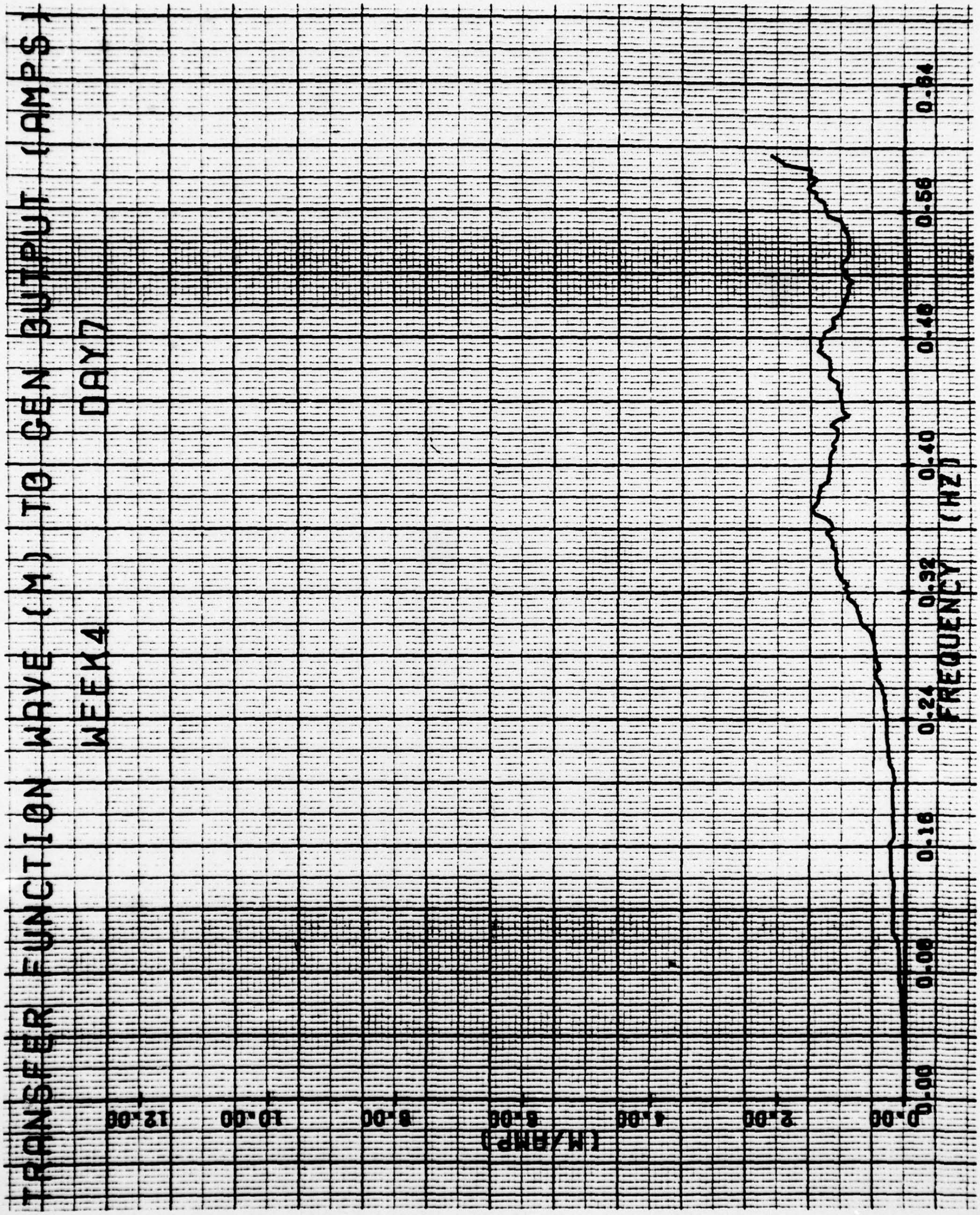

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY4
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)

TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY5





TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY6
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
FREQUENCY (HZ)


TRANSFER FUNCTION WAVE (M) TO GEN OUTPUT (AMPS)
WEEK4 DAY7
FREQUENCY (HZ)
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
(M/AMP)
0.00
2.00
4.00
6.00
8.00
10.00
12.00

APPENDIX D

COST ANALYSIS CALCULATIONS

BATTERY DISPOSAL COSTS

BATTERY SIZE	NUMBER OF BUOYS	NUMBER OF BATTERIES/BUOY	NUMBER OF BATTERIES
1000 Ah	2725	5	13,625
2000 Ah	584	10	5,840
3000 Ah	584	10	5,840
TOTAL	3893		25,305

Total disposal cost at \$2.50/battery =

$$25{,}305 \times \$2.50 = \$63{,}262.50$$

$$\text{Average disposal cost/buoy} = \frac{\$63{,}262.50}{3893} = \$16.25/\text{buoy}$$

NOTE: Based on a two-year life expectancy, these figures may be halved when figuring annual costs.

CALCULATION OF ANNUAL BATTERY REPLACEMENT COSTS

1000 amp-hr batteries

\$270.11 x 0.70 = \$189.08

2000 amp-hr batteries

\$540.22 x 0.15 = \$ 81.03

3000 amp-hr batteries

\$657.90 x 0.15 = \$ 98.69

Weighted total cost per buoy = \$368.80

NOTE: Calculated by multiplying cost per rack times percentage that rack is used.

At a 21 percent failure rate

\$368.80 x 0.21 = \$ 77.45

APPENDIX E

OUTLINE OF DATA PROCESSING

E.1 PREPROCESSING

The Metrodata cassette recorded on the buoy is read by a PDP-8/S at the CG R&DC and transferred to a 7-track Kennedy tape (non-standard format). The remainder of the preprocessing was done on a Univac 1108 at NUSC.

The 7-track Kennedy tape, containing the 24-channel serial order data, is used as input to METROREAD, a program which produces a data file, a listing, and a Univac formatted 7-track tape. The data is still in scans of 24 channels.

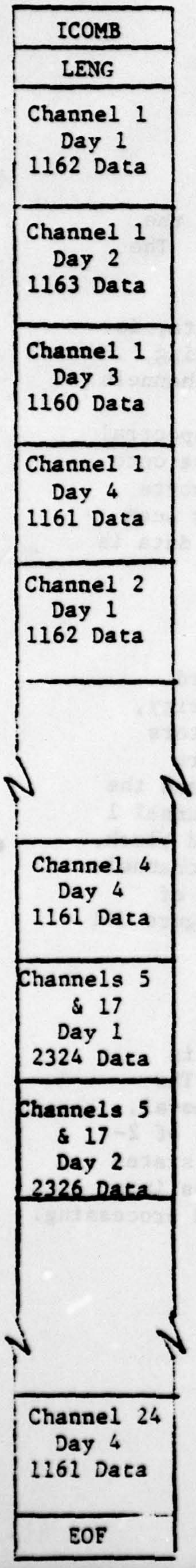
This output is further preprocessed by KENSH, which separates the spectral (3 Hz) scans from the single (1 every 15 minutes) scans, and writes these onto two tapes, SPECO and HISTO, respectively. Before writing these, KENSH sorts the data by channel and merges those channels which were taken twice per scan to achieve a 6 Hz sample rate (SPECO). This is the format in which the data is stored.

E.2 FORMAT OF STORED DATA

SPECO and HISTO have identical formats except that each day's record contains about 80 or 1160 scans respectively. Both are 800 BPI, odd parity, Binary code, 7-track tapes. Each file on the tape is headed by two vectors ICOMB (21,2) and LENG (15). The former specifies the channels which were merged and the latter specifies the number of days of data in the file and the number of scans per day. Immediately after the two heading vectors, Channel 1 Day 1 data occupies the first block, Channel 1 Day 2 occupies the second block, and so forth until all days of each channel have been written. Merged channels are written in the same block and the file is terminated by an EOF (End of File) mark. Each succeeding week of data forms a file on the tape. Figure E-1 is a typical data tape.

E.3 PROCESSING

Program MAIN 100 does the actual processing. MAIN 100 is written in structured FORTRAN (SFTRAN) and requires 40,000 36-bit words of core. The sequence of operations to be performed (calibration, mean and trend removal, integration, fourier transform, etc.) are input to MAIN 100 as a series of 2-digit numbers. MAIN 100 assembles the necessary subroutines dimension statements and control statements into an absolute element which it then maps into core and executes. Figure E-2 is a flow chart of the preprocessing and processing.



For example, a week of 4 days having 1162, 1163, 1160, and 1161 scans respectively.

Channels 5 through 11 are merged with 17 through 23.

ICOMB =	1	2	3	4	5	6	7	8	9	10	11	12
	0	0	0	0	17	18	19	20	21	22	23	0

LENG = 1162 1163 1160 1161 0 0 4

FIGURE E-1

DATA STORAGE FORMAT

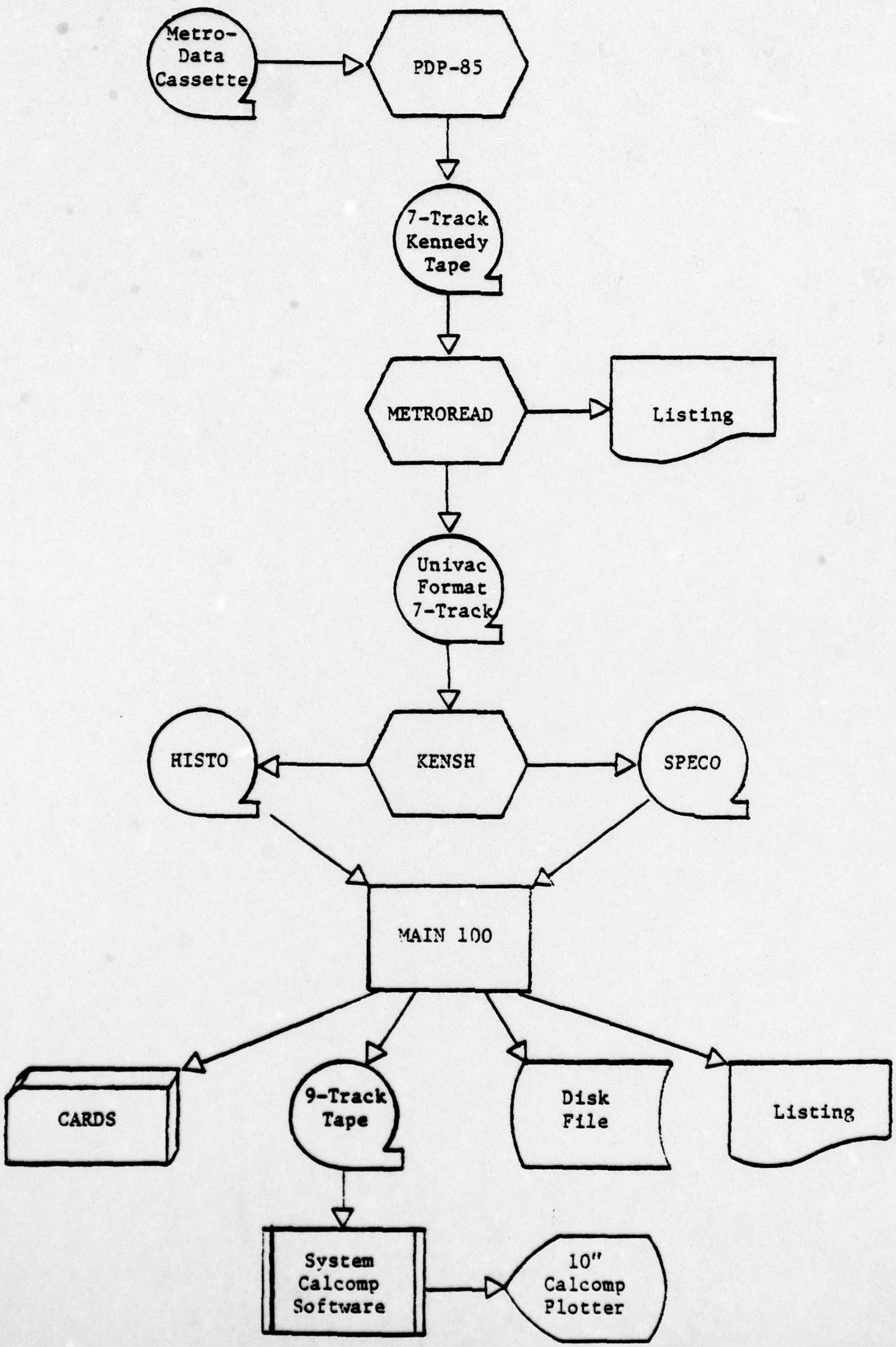


Figure E-2. Processing Flow Chart