RETURN TO INDEX

VIBRATION MEASUREMENTS ON MODULAR CAUSEWAY FERRY (MCF)

Prepared For:

LAKE SHORE, INC.
AN OLDENBURG GROUP COMPANY
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IRON MOUNTAIN, MI 49801

Prepared Under:

LSI PURCHASE ORDER 113667

NKF REPORT NO. 9703-01/1

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TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	1
2.0	OBJECTIVES	1
3.0	MCF CHARACTERISTICS	1
4.0	TECHNICAL APPROACH	1
5.0	PROCEDURE	2
	5.1 INSTALLATION PROCEDURE	2
	5.2 TEST PROCEDURE	3
6.0	CALIBRATION	3
	6.1 LABORATORY CALIBRATION	3
	6.2 FIELD CALIBRATION	4
7.0	DATA REDUCTION	4
8.0	RESULTS	5
	8.1 DISCUSSION OF RESULTS	6
9.0	CONCLUSIONS AND RECOMMENDATIONS	7
	9.1 LINEAR VIBRATION	7
	9.2 TORSIONAL VIBRATION	7
10.0	REFERENCES	12

Appendix A TEST PROCEDURE
Appendix B CALIBRATION DATA
Appendix C VELOCITY WATERFALLS
Appendix D TORSIOGRAPH WATERFALLS AND SWEEPS

LIST OF FIGURES

Figure	Title	Page
1	Outline of Modular Causeway Ferry	8
2	Vibration Sensor Locations	9
3	Instrumentation Block Diagram for Data Recording Mode	10
4	Instrumentation Block Diagram for Accelerometer Calibration Mode	11

LIST OF TABLES

Table	Title	Page
1	Instruments on Starboard Propulsion Unit	3
2	Maximum Velocity Amplitudes	5
3	Maximum Torsional Amplitudes Measured at Front End of Engine	6

1.0 INTRODUCTION

Lake Shore Incorporated (LSI) was the prime contractor to the U.S. Army in the production of the Modular Causeway Ferry (MCF). NKF Engineering, Inc. (NKF) was contracted by LSI under Purchase Order No. 113667 to conduct first article vibration measurements under operational conditions.

Translational and torsional vibration measurements were recorded while underway during trials in Ontonagon, Michigan on Lake Superior. The test was conducted in accordance with the test procedure (Appendix A) and References 1, 2, and 3. This document provides a final report on the survey including: procedure, instrumentation used, calibration method, and a summary of all significant results.

2.0 OBJECTIVES

The objective of this study was to measure and record the vibration characteristics of one MCF propulsion module during full load, full speed sea trials in accordance with References 1, 2, and 3.

3.0 MCF CHARACTERISTICS

General Characteristics: Figure 1 provides a sketch of the MCF which is a modular self-propelled ferry. In the tested configuration, it is 320 feet long x 24 feet wide x 4.5 feet deep. General construction is of ISO compatible steel modules joined by USN standard flexor and shear connectors. Cargo capacity of the MCF in the test configuration is specified as 350 short tons. Maximum speed is specified as 6 knots at full load.

Propulsion modules (40 feet x 8 feet x 4.5 feet) are located aft; one port, one starboard. Propulsion is provided by a Detroit Diesel 8V92TA engine operating through a gearbox to a flush-mounted 360-degree steerable waterjet thruster. A single 4 feet x 6 feet Control Cab (CC) is located on one of the propulsion modules. LSI Drawing No. E26106 provides an outline of the drive train installation.

4.0 TECHNICAL APPROACH

- Determine the longitudinal vibration characteristics of the propulsion system with an accelerometer measuring the longitudinal motion of the waterjet foundation. Vibratory motions of the engine foundation to be measured with an accelerometer mounted in the vertical direction.

- Determine the torsional vibration characteristics of the propulsion system with a rotational velocity transducer, or torsiograph mounted to the free end of the engine. Dynamic angular displacements at the free end of the engine will be used along

with the torsional analysis (Reference 4) to determine maximum dynamic stresses and torque across the gears.

- Measure hull vibrations at the stern of the propulsion module in three principle axes. Vibratory motions will be recorded in acceleration units during trials and converted to velocity or displacement units as necessary. Vibratory motions in the CC in the principle direction of motion will also be measured. Additionally, vibration at any location observed to be excessive or potentially damaging will be measured.

5.0 PROCEDURE

5.1 INSTALLATION PROCEDURE

An adapter shaft to attach the torsiograph to the free end of the propulsion engine crankshaft was provided by LSI. The adapter was designed to interface between the free end of the engine at the crankshaft and the rotational velocity transducer (torsiograph).

Twelve-volt DC power from the propulsion module batteries was used to power the amplifiers and recorder.

The test equipment installed consisted of sensors, signal cable, signal conditioners, calibration equipment, and a recording device. The table below lists the data acquisition system used to complete the test.

QTY	DESCRIPTION	MANUFACTURER	MODEL NO.
6	Accelerometer	Wilcoxon Research	766
2	Accelerometer	PCB Piezotronics	327 A01
1	Rotational Velocity Transducer (Torsiograph)	Knopfle-Stein	s/n 11
1	Variable Reluctance Pickup (Event Marker)	Electro Corporation	3030AN606909
1	12-Channel Amplifier	PCB Piezotronics	483B07
1	21-Channel FM Tape Recorder	TEAC	XR-7000
1	2-Channel Spectrum Analyzer	Ono Sokki	CF-350
1	Accelerometer Calibrator	B&K	4291

Sensors were installed in the locations/orientations shown in Table 1. The orientation of the accelerometer in the control cab was determined by comparison measurements while operating near full power. The location chosen for the extra accelerometer was the top of the water pump because of low frequency displacements noted at this location during operating conditions. An additional accelerometer was mounted on the top of the spicer gearbox in the athwartship direction. Locations of transducers are shown in Figure 2.

Table 1. Instruments on Starboard Propulsion Unit

ITEM NO.	QTY REQUIRED	EQUIPMENT DESCRIPTION	LOCATION	MEASUREMENT DIRECTION
1	1	Accelerometer	Waterjet foundation	Fore/Aft
2	1	Accelerometer	Diesel engine foundation	Vertical
3	3	Accelerometer	Stern of propulsion module	Fore/Aft, Athwartship, Vertical
4	1	Accelerometer	Control cab	Athwartship
5	1	Torsiograph	Free end of diesel engine	Torsional
6	1	Event Marker	Adjacent to main shaft	Shaft Revolutions
7	1	Accelerometer	Top of water pump	Athwartship
8	1	Accelerometer	Top of Z-drive gearbox	Athwartship

The accelerometer mounting blocks were installed using quick set epoxy, taking care to ensure that the threaded holes and/or studs were in the proper orientation for gage attachment.

The torsiograph was attached to the adapter located on the free end of the starboard propulsion engine at the crankshaft centerline.

The event marker target was installed on the propulsion shaft near the z-drive/water pump shaft using strapping tape.

Signal cables were attached to all transducers and connected to an amplifier/power supply, where necessary, and then directly to the tape recorder. Separate cables were used to monitor the tape recorder outputs with a two-channel oscilloscope.

5.2 TEST PROCEDURE

The approved test procedure is included in Appendix A. The test included recording several minutes of data at constant RPM in approximately 75 RPM increments from idle to full speed. In addition, a sweep was recorded in which the RPM was slowly increased over the full operating range.

The logsheets showing equipment gains and settings are also presented in Appendix A. An instrumentation block diagram for data recording is shown in Figure 3.

6.0 CALIBRATION

6.1 LABORATORY CALIBRATION

The accelerometers and accelerometer calibrator were calibrated at an independent laboratory within 6 months prior to the test. These calibrations demonstrated accuracies to within acceptable tolerances, traceable to the National Institute of Standards and Technology (NIST). The

torsiograph was calibrated at NKF's laboratory within 6 months prior to the test. Calibration data and certifications are included in Appendix B.

6.2 FIELD CALIBRATION

A circuit check and physical calibration of the accelerometers were conducted using the accelerometer calibrator to subject the accelerometer to a 1.0 gravity RMS sine motion at a frequency of 80 Hz. The accelerometer output signal passed through all cabling and amplifiers used during the test. The amplifier output was recorded on tape for about 30 seconds. A block diagram of the calibration configuration is shown in Figure 4.

7.0 DATA REDUCTION

The instrumentation used to perform the data reduction/analysis consisted of the following:

QTY	MANUFACTURER	MODEL	DESCRIPTION
1	TEAC	XR-7000	FM Tape Recorder
1	Hewlett-Packard	3566/67A	Spectrum Analyzer
1	Generic	486DX66	Personal Computer (PC)

During data reduction, the conversion from volts to engineering units was calculated using the measured field calibration data from the transducers, signal conditioning gain settings, and recording equipment sensitivity settings.

Using these conversion constants, the constant speed operational data recorded on the tape was then digitized and stored as averaged frequency data by the spectrum analyzer. A flat-top antileakage window was used, and approximately 2 minutes of data was averaged for each constant speed condition. The frequency domain data was acquired and stored in both 50 Hz and 400 Hz full-scale ranges. In the 50 Hz data, frequency resolution was 0.25 Hz. Frequency resolution was 1.0 Hz in the 400 Hz data. These spectra were then transferred to the PC which generated vibratory "waterfall" plots. The data was plotted in velocity units, where the velocity spectra were obtained by frequency domain integration. The torsiograph data was similarly processed and presented in units of degrees (angular displacement).

For the data recorded during the speed sweeps, waterfall-type plots were generated automatically by the spectrum analyzer. The spectra in the sweep waterfalls are instantaneous spectra (from a single time record) and are presented at much closer and uniformly spaced RPM increments than the constant speed runs. These spectra were plotted in units of velocity with the exception of the torsiograph, which was plotted in degrees.

8.0 RESULTS

Appendix C provides "waterfall" analyses for all locations based on the accelerometer measurements at steady speed runs. Table 2 provides a summary of the maximum velocity amplitude extracted from the "waterfall" diagrams.

Table 2. Maximum Velocity Amplitudes

LOCATION	DIRECTION	MAXIMUM VELOCITY (MILS/SEC)				
		FREQ.	ERPM	ENGINE ORDER	PEAK AMPL.	RESONANT OR NONRESONANT
Base of Thruster	Fore/Aft	12.5	1,950	1st Thruster	16	Resonant
		43.0	2,200	1st	14	Nonresonant
		95.0	1,950	3rd	65	Resonant
Base of Engine	Vertical	13.0	2,150	1st Thruster	22	Resonant
		22.0	1,325	1st	180	Sharp Resonant
		42.0	2,200	1st	130	Nonresonant
		145.0	2,150	4th	400	Resonant
Hull Stern	Fore/Aft	13.0	2,075	1st Thruster	16	Resonant
		22.0	1,325	1st	12	Resonant
		41.0	2,200	1st	16	Resonant
		125.0	1,900	4th	20	Resonant
Hull Stern	Athw	12.0	1,950	1st Thruster	11	Resonant
		39.0	2,075	1st	48	Resonant
		32.0	1,700	1st	31	Resonant
		95.0	2,000	3rd	55	Resonant
Hull Stern	Vertical	12.5	1,925	1st Thruster	20	Resonant
		39.0	2,075	1st	65	Resonant
		130.0	2,000	4th	46	Resonant
		140.0	2,150	4th	45	Resonant
Control Cab-Lower Aft Port Corner	Athw	13.0	1,950	1st Thruster	15	Resonant
		41.0	2,150	1st	55	Resonant
		55.0	875	4th	140	Resonant
		105.0	2,000	3rd	70	Resonant
Top Water Pump	Athw	41.0	2,150	1st	280	Resonant
Top Gearbox	Athw	41.0	2,150	1st	3,300	Resonant

Appendix D provides similar "waterfall" analyses for the torsiograph measurements. Table 3 provides a summary of the maximum angular displacements measured by the torsiograph, and the calculated torsional stresses based on the stress per degree values from Reference 4.

Table 3. Maximum Torsional Amplitudes Measured at Front End of Engine

ERPM	FREQUENCY (HZ)	MODE	ORDER	AMPLITUDE* (±DEGREES)	CALC (STRESS/DEG.)	STRESS (PSI)	SECTION OF MAX. STRESS
2,000	13	1	1st Thruster	2.0	2,179	4,358	Coupling to Tr. Gears
2,150	145	3	4th Engine	0.11	0.974E6	107,140	Reduction Gear to 1st Shaft
2,200	147	3	4th Engine	0.091	0.199E5	1,811	Crank Throw No. 4
2,200	183	4	5th Engine	0.120	0.199E5	2,388	Crank Throw No. 4

* Amplitude corrected for analysis ratio of B_4/B_1 for each mode

8.1 DISCUSSION OF RESULTS

Linear Vibrations

Based on the analysis of data in Appendix C and Table 2, the vibration velocity amplitudes are well within limits of acceptability, except for two locations. These two are:

- Base of Engine - Vertical @ 2,150 rpm, vel = 0.40 inch/sec
- Top Gearbox - Athwartship @ 2,150 rpm, vel = 3.30 inch/sec

Although References 2 and 3 were identified as requirements for vibration testing, these references do not identify the limits for vibration severity amplitudes. Therefore, we are suggesting the use of Reference 5 as a guide for acceptability of vibration severity.

Reference 5 is currently being considered by the SNAME HS-7 Committee and the International Standards Organization (ISO) as a recommended guide for shipboard vibration. In general, a velocity level of about 0.3 inch/sec peak is tolerable. Levels higher than this should be investigated.

Thus, based on the summary of measured data (Table 2), it is apparent that vertical vibration at the base of engine is somewhat high, and the athwartship vibration at the top of gearbox is excessively high.

Torsional Vibrations

Table 3 provides the torsional stresses calculated for the 1st, 3rd, and 4th mode maximum torsional amplitudes measured during the test. These stresses are based on the analysis presented by Reference 4 in combination with the measured torsional vibration amplitudes presented herein.

The 13 Hz component agrees with the calculated first mode natural frequency (Reference 4) and is excited by the 1st order of the thruster or misalignment of the universal joint shafts.

The most significant stress of 107,140 psi between Mass 12 and Mass 13 is associated with a 3rd Mode, 4th order vibration at 2,150 ERPM. This value is questionable because of the excessively high value. A quick check of the calculated stress per degree values indicate significant differences between NKF calculations and those provided by Reference 4.

The stresses calculated for the 1st and 4th mode measured amplitudes would be considered acceptable when taken individually. However, since these components all occur in the 2,000 to 2,200 ERPM range, they will periodically be additive and subtractive, depending on their phase relationships. Therefore, it is possible that the torsional vibration stresses at 2,150 ERPM may exceed the MIL-STD-167 limits, even without the questionable stress of the 3rd Mode, 4th order.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 LINEAR VIBRATION

The velocity levels at all stations measured are considered acceptable with the following exceptions:

- **Base of Engine**: The maximum vibration level of 0.40 inch/sec is somewhat higher than desirable. It is recommended that the bolting be checked for adequate holddown torque, and inspections be conducted periodically.

- **Top Gearbox:** The maximum vibration level of 3.30 inch/sec is grossly excessive, indicating the need for corrective action. Suitable stiffening in the athwartship direction may alleviate this problem.

9.2 TORSIONAL VIBRATION

The most serious vibration is the component measured at 2,150 ERPM associated with the 3rd Mode, 4th order. A calculated stress of 107,140 psi would result in rapid fatigue failure. Therefore, we believe the calculated stress per degree provided by Reference 4 is open to question. It is recommended that this be reexamined.

An alternative to this approach would be to measure the torsional stress with strain gages at the shaft section in question.

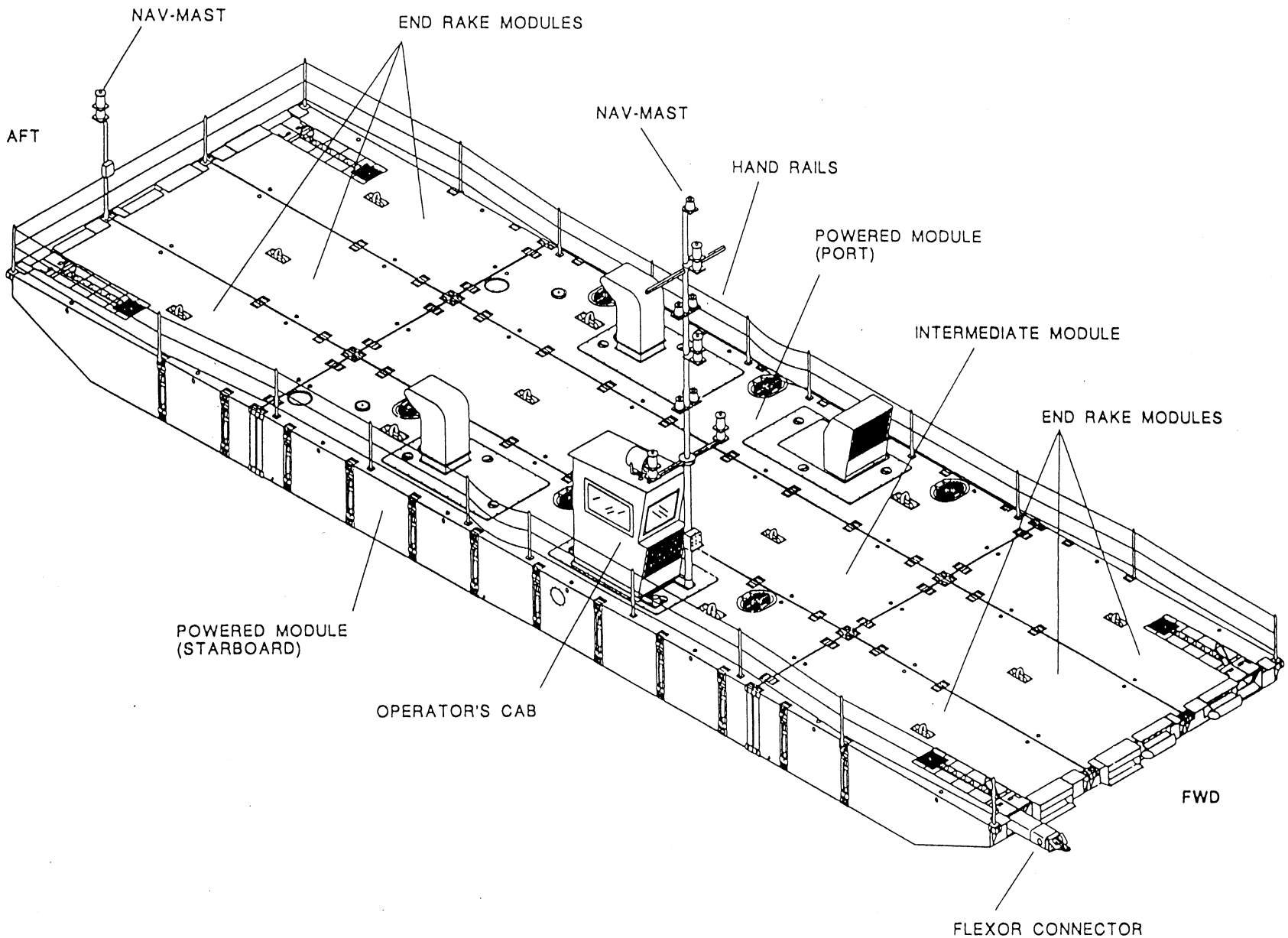


Figure 1. Outline of Modular Causeway Ferry

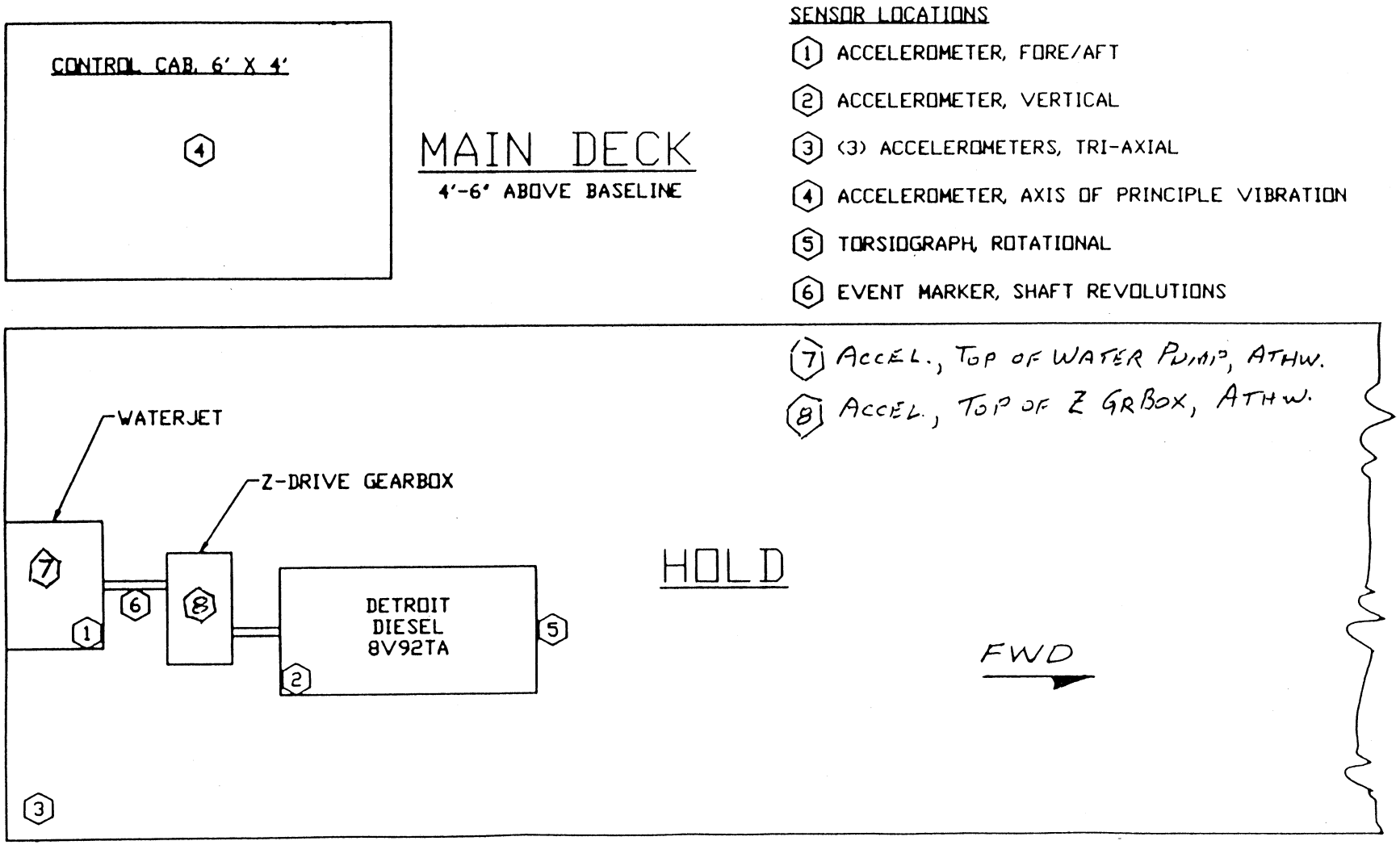


Figure 2. Vibration Sensor Locations

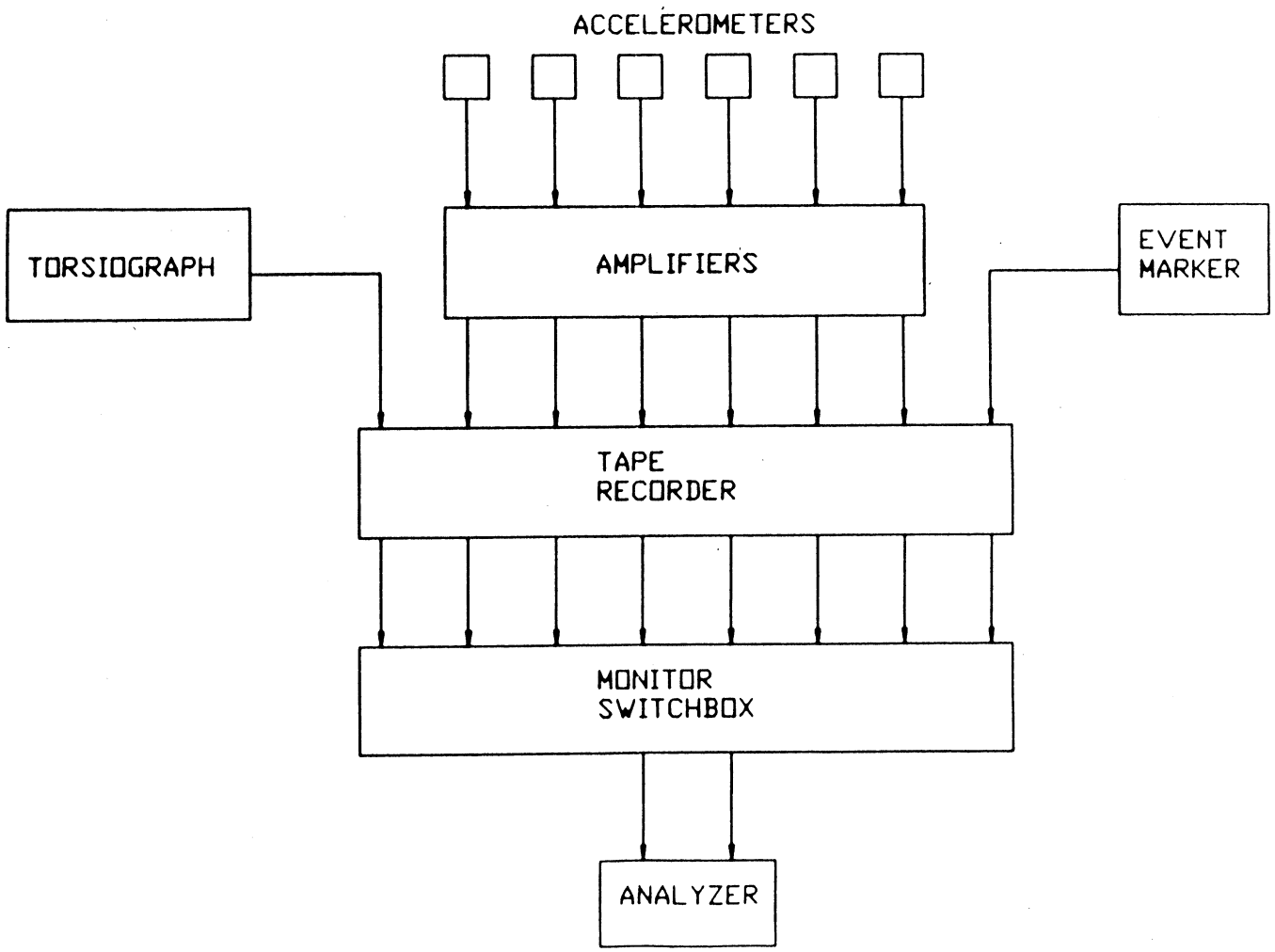


Figure 3. Instrumentation Block Diagram for Data Recording Mode

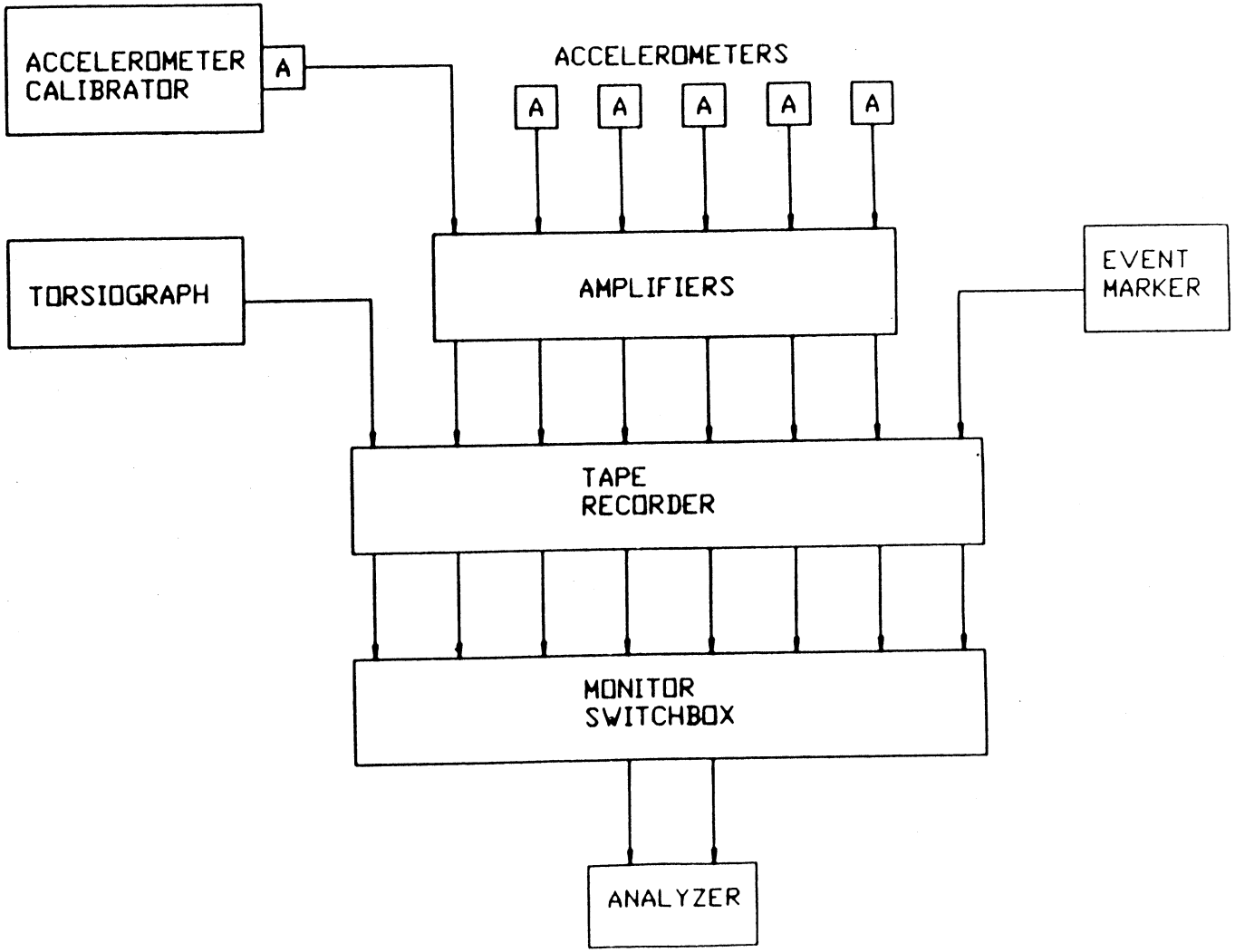


Figure 4. Instrumentation Block Diagram for Accelerometer Calibration Mode

10.0 REFERENCES

1. MIL-STD-167-2, "Mechanical Vibrations of Shipboard Equipment (Reciprocating Machinery and Propulsion System and Shafting), Types III, IV, and V," dated 1 May 1974.

2. SNAME Technical & Research Code C-1, "Code for Shipboard Vibration Measurement," dated January 1975.

3. SNAME Technical & Research Code C-4, "Local Shipboard Structures and Machinery Vibration Measurements," dated December 1976.

4. Detroit Diesel Corporation Engineering Analytical Report I3R-011-11776-00, "Torsional Vibration Analysis of an 8V-92TA Engine Driving a Waterjet Propulsion Thruster through a Twin Disc MG 5111 (1.74:1) Marine Gear with LS 14E-3701 Coupling."

5. International Standard ISO 6954 (1995 proposed).

Appendix A

TEST PROCEDURE

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 1 OF 11
DATE 10/20/94
REVISED 01/31/95

TP-1073-AR-016
CDRL A010

MODULAR CAUSEWAY FERRY VIBRATION MEASUREMENT TEST PROCEDURE

TP-1073-AR-016

CUSTOMER ATCOM

CUSTOMER JOB NO. N/A

CUSTOMER P.O. NO. DAAK01-93-D0007

HULL NOS. First Article

EQUIPMENT Modular Causeway Ferry

EQUIPMENT NO. E03155

EQUIPMENT SERIAL NOS. P40P-0001, P40P-0002 (Powered Modules)

CUSTOMER NOTIFICATION PRIOR TO TESTING 7 DAYS

ENGINEERING NOTIFICATION PRIOR TO TESTING 14 DAYS

LAKE SHORE SALES ORDER NO. 1073AR

DRAWN [signature] DATE Oct 20, 1994

CHECKED [signature] DATE Oct. 21, 1994

APPROVED [signature] DATE Oct 21, 1994

QUALITY Kenneth J. Uesi DATE Oct 21, 1994

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

TP-1073-AR-016
CDRL A010

Rev	Date	Appvl	QA	Description
—	10/21/94	WJK	LSI 1 QA	Initial Issue
A	1/31/95	WJK	LSI 1 QA	Revised for direction of measurement at measurement locations; Added test for determining resonance.

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

TP-1073-AR-016
CDRL A010

VIBRATION MEASUREMENT TEST PROCEDURE

TP-1073-AR-016

1.0 INTRODUCTION

1.1 Objective. The objective of the Vibration Measurement Test is to determine the vibration characteristics of the Propulsion System (including the main engine, reduction gears, thruster, drive shaft, and related equipment) of the Modular Causeway Ferry (MCF) while operating with rated load (350 short tons) at rated speed (6 knots). Testing shall demonstrate that vibration levels of the MCF do not cause severe or damaging vibrations within the Propulsion System or hull as defined by Mil-Std-167-2 for Types III, IV, and V mechanical vibrations.

1.2 Test Item. The test item, described as the MCF, is defined by Lake Shore drawing E03155. The MCF Powered Module is defined by Lake Shore Drawing E02843.

1.3 Test Limitations. Vibration Measurement Testing will be performed in conjunction with Speed Trial Tests, TP-1073-AR-012. Operating conditions are specified in the purchase description as rated load and rated speed. Vibration levels will be measured at intermediate speeds by sweeping through the operating speed range. Measurement locations will be determined by SNAME Codes C-1 and C-4 and through interpretation of Mil-Std-167-2. As specified by Mil-Std-167-2, no testing is required for Type V Lateral Vibration of propulsion shafting.

2.0 REFERENCE DOCUMENTS

2.1	PD 1990-0098	Purchase Description (Para's 4.5.2.7.7, 3.5.8)
2.2	Mil-Std-167-2	Mechanical Vibrations of Shipboard Equipment (Reciprocating Machinery and Propulsion System & Shafting) Types III, IV, & V
2.3	E20001	General Test Requirements
2.4	E20011	Failure Reporting, Analysis, and Corrective Action System (FRACAS)
2.5	SNAME Code C-1	Technical & Research Code, Code for Shipboard Vibration Measurement

2.6	SNAME Code C-4	Technical & Research Code, Code for Local Shipboard Structures and Machinery Vibration Measurements

3.0 TEST PREPARATION

3.1 Approach to Test. The vibration levels of the MCF power train will be determined by measuring and recording the vibration levels in terms of vibration frequency (in Hertz) and vibration amplitude (in inches) and comparing the vibration levels to the forcing function (i.e., the drive train rotational speed) creating the vibration.

Vibration levels will be measured at the hull stern (three axes), and at the machinery foundations of the diesel engine (vertical) and thruster (longitudinal). Vibration levels will be measured at the operator's cab (principle axis). If there is evidence of excessive vibration at any local structure, vibration levels will be measured at that location. Torsional vibration will be measured at the front end of the diesel engine crankshaft.

3.2 General Test Requirements. Refer to the following documents for general test requirements:

E20001	General Test Requirements; location and schedule of test, calibration requirements, safety requirements, and general test documentation.
E20011	Failure Reporting, Analysis, and Corrective Action System (FRACAS).

3.3 Customer Notification. The ATCOM and Government Quality Assurance Representative shall be provided with seven (7) days notification prior to the start of testing.

3.4 Personnel Requirements. The following personnel are required for performance of the Vibration Measurement Test:

3.4.1 Contractor furnished personnel: Test supervisor, MCF operators, MCF crew, test equipment technicians.

3.4.2 Government furnished personnel: Dock side personnel for mooring, fueling, and rigging and handling the MCF load.

3.5 Facilities and Test Equipment. The following facilities, support equipment, and test equipment are required for performance of the Vibration Measurement Test (CFE = Contractor furnished equipment, GFE = Government/Customer furnished equipment):

		CFE	GFE
3.5.1	One (1) complete MCF, outfitted for duty:	X	
3.5.2	A measured course of known distance:	X	
3.5.3	Vibration measurement instrumentation including accelerometers, velocity transducers, integrators, amplifiers, tape recorder, oscillograph, and/or vibration analyzer.	X	
3.5.4	350 short tons of load with rigging for handling the load:		X
3.5.5	Diesel fuel oil, ASTM D975 Grade 2-D or equal:		X
3.5.6	Mooring lines and dockside equipment for mooring the MCF to the pier:		X

3.6 The instrumentation for measuring vibration levels shall be installed to the MCF Powered Module and Operator's Cab at locations indicated in ¶ 4.4.

4.0 TEST PROCEDURE

4.1 Vibration Measurement Testing will be performed in conjunction with the Speed Trial Tests, TP-1073-AR-012. Vibration levels will be measured as the MCF traverses the measured course at full load and full speed. Test documentation shall be recorded on the Test Report TR-1073-AR-016. Unless otherwise defined, testing and test documentation shall be in accordance with SNAME Codes C-1 and C-4.

4.2 Identify all instrumentation used to measure vibration levels (including make, model, serial number) and the calibration procedures and data for the instrumentation.

4.3 Test conditions shall meet the following restrictions.

4.3.1 The test shall be conducted in not less that 20 feet of water.

4.3.2 The test shall be conducted in a quiet sea (Sea State 2 or less).

4.3.3 The test shall determine any resonances of the system by operating the diesel engine through a sweep of the full operating speed range of the engine. If any resonances are found, vibration data shall be taken at the offending engine speed.

4.3.4 The test shall be conducted with the MCF loaded with 350 short tons of cargo and operating at 6 knots.

4.3.5 The test shall be conducted with the MCF being steered in a straight ahead direction with minimum steering action during testing. As test conditions allow, testing may also include vibrations measurements under hard turn conditions.

4.4 Measure and record the vibration data (amplitude of vibration, frequency of vibration, diesel engine speed) for each location identified.

4.4.1 Hull stern location: longitudinal, vertical, athwartship.

4.4.2 Diesel engine foundation: vertical.

4.4.3 Thruster foundation: longitudinal.

4.4.4 Operator's Cab location: Principle axis of vibration.

4.4.5 Local Structure location (identified as having excessive vibration): longitudinal, vertical, athwartship. Identify location of local structure and direction of vibration.

4.4.6 Diesel engine crankshaft: torsional, event marker.

5.0 Acceptance Criteria

5.1 Testing shall demonstrate that vibration levels of the MCF do not cause severe or damaging vibrations within the Propulsion System or hull as defined by Mil-Std-167-2 for Types III, IV, and V mechanical vibrations.

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 7 OF 11
DATE 10/20/94
REVISED January 31, 1995

TP-1073-AR-016
CDRL A010

VIBRATION MEASUREMENT TEST

TEST REPORT

TR-1073-AR-016

CUSTOMER ATCOM

CUSTOMER P.O. NO. DAAK01-93-D-0007

EQUIPMENT MODULAR CAUSEWAY FERRY

POWERED MODULE SERIAL NO. _____

SHOP ORDER _____

TEST COMPLETION DATE _____

Instrumentation and Calibration Data _____

Vibration Measurement Data

Test Data Sheets Attached _____ Acceptable _____ Not Acceptable _____
Accept no excessive or damaging vibration.

Test Witnessed by:

LSI Rep _____ Customer Rep _____ Other _____

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 8 OF 11
DATE 10/20/94
REVISED January 31, 1995

TP-1073-AR-016
CDRL A010

Vibration Measurements:

MODULAR CAUSEWAY FERRY VIBRATION TEST DATA RECORDING SHEET	SEA STATE	DRAFT
	DEPTH	DISPL

TEST CONDUCTOR:	RUN:	RUN:	RUN:	RUN:	RUN:
DATE:	BEG:	BEG:	BEG:	BEG:	BEG:
	END:	END:	END:	END:	END:

	OPERATING CONDITION											
	TAPE CHAN	AMP CHAN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN
Waterjet F/A	1	1										
Engine Vert	2	2										
Hull F/A	3	3										
Hull Aftw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torsiograph	7	N/A										
Rev Marker	8	N/A										

TEST WITNESSED BY:	SHEET NO.
LSI REP.	CUSTOMER REP.

COMMENTS:

Use additional sheets as necessary

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 9 OF 11
DATE 10/20/94
REVISED January 31, 1995

TP-1073-AR-016
CDRL A010

Vibration Measurements:

MODULAR CAUSEWAY FERRY VIBRATION TEST DATA RECORDING SHEET	SEA STATE	DRAFT
	DEPTH	DISPL

TEST CONDUCTOR:	RUN:	RUN:	RUN:	RUN:	RUN:
DATE:	BEG:	BEG:	BEG:	BEG:	BEG:
	END:	END:	END:	END:	END:

	OPERATING CONDITION											
	TAPE CHAN	AMP CHAN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	AMP GAIN	TAPE FS	A. G.
Waterjet F/A	1	1										
Engine Vert	2	2										
Hull F/A	3	3										
Hull Athw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torsiograph	7	N/A										
Rev Marker	8	N/A										

TEST WITNESSED BY:	SHEET NO.
LSI REP.	CUSTOMER REP.

COMMENTS:

Use additional sheets as necessary

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 10 OF 11
DATE 10/20/94
REVISED January 31, 1995

TP-1073-AR-016
CDRL A010

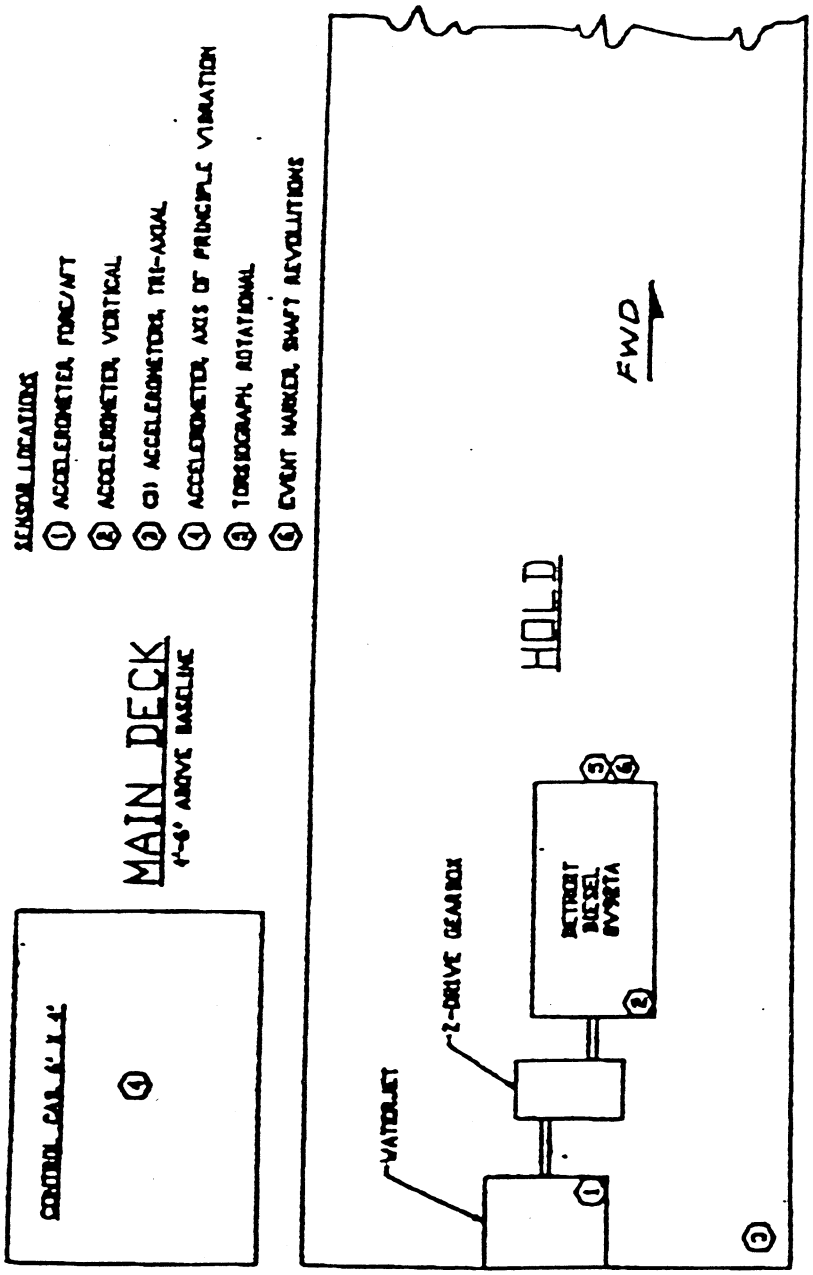


Figure 1. Vibration Sensor Locations

LAKE SHORE INC.
An Oldenburg Group Company
KINGSFORD, MICHIGAN

SHEET 11 OF 11
DATE 10/20/94
REVISED January 31, 1995

TP-1073-AR-016
CDRL A010

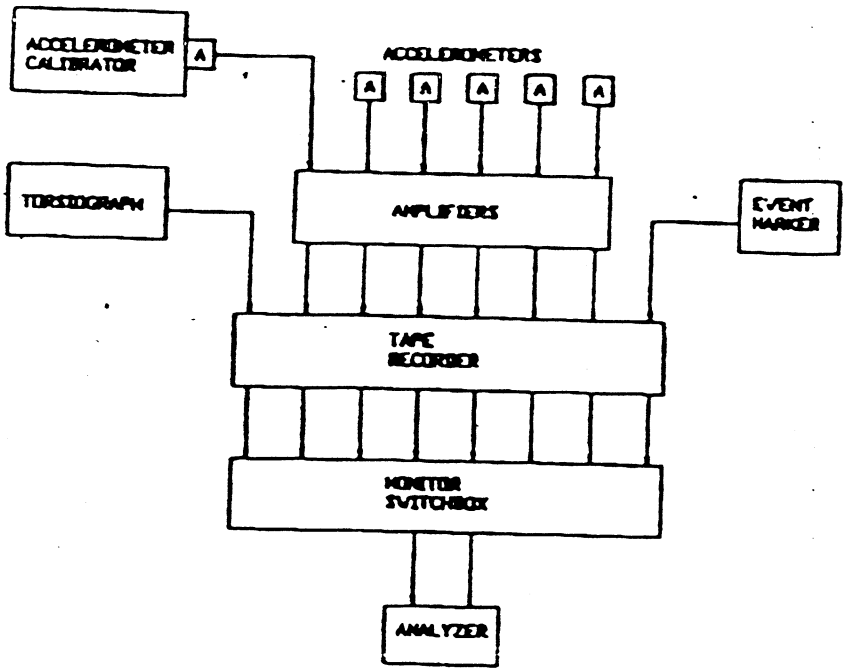


Figure 2. Instrumentation Block Diagram for Accelerometer Calibration Mode

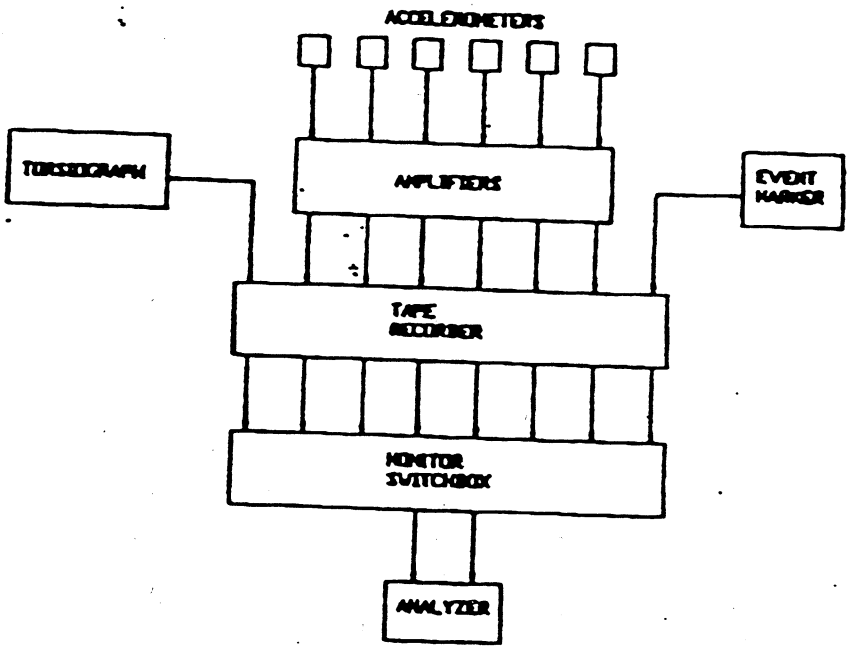


Figure 3. Instrumentation Block Diagram for Data Recording Mode

MODULAR CAUSEWAY FERRY TEST DATA RECORDING SHEET					SEA STATE DEPTH				DRAFT DISPL			
Test Conductor: Bob Guthrie Date: 6/4/96			Run: 1 Beg: 0 End: 25		Run: 2 Beg: 25 End: 36		Run: 3 Beg: 36 End: 45		Run: 4 Beg: 45 End: 56		Run: 5 Beg: 56 End: 66	
TAPE SPEED 4.8 cm/s	Operating Conditions		ELEC. CAL		PHYSICAL CALS #274		CAL #277		CAL #275		CAL #2423	
Gage S/N		Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
276	Waterjet F/A	1	1	1.0	N/A								
263	Engine Vert	2	2										
275	Hull F/A	3	3							1.0	1.0		
277	Hull Athw	4	4					1.0	10				
274	Hull Vert	5	5			1.0	10						
2424	Ctrl Cab *Athw	6	6										
11	Torslograph	7	n/a										
N/A	Rev Marker	8	n/a										
2423	Water Jet Athw	9	7									1.0	10
262	Gearbox Top Athw	10	8										

Test Conductor: Bob Guthrie Date: 6/4/96			Run: 6 Beg: 66 End: 76		Run: 7 Beg: 76 End: 85		Run: 8 Beg: 85 End: 96		Run: 9 Beg: 96 End: 109		Run: 10 Beg: 109 End: 118	
	Operating Conditions		CAL #276		CAL #262		CAL #2424		RE-CAL #2424		CAL #263	
		Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
276	Waterjet F/A	1	1	1.0	10								
263	Engine Vert	2	2									1.0	10
	Hull F/A	3	3										
	Hull Athw	4	4										
	Hull Vert	5	5										
2424	Ctrl Cab *Athw	6	6					1.0	10	1.0	10		
	Torslograph	7	n/a										
	Rev Marker	8	n/a										
	Water Jet Athw	9	7										
262	Gearbox Athw	10	8			1.0	10						

Test Witnessed by: Sheet No. 1 of 4

LSI Rep. [signature] 6-5-96 Customer Rep.

Comments:

Figure 4. Test Data Recording Sheet

MODULAR CAUSEWAY FERRY TEST DATA RECORDING SHEET					SEA STATE 0 (calm) DEPTH 20 ft +				DRAFT (FWD) 37" DISPL			
Test Conductor: Bob Guthrie Date: 6/5/96			Run: 11 Beg: 118 End: 202		Run: 12 Beg: 202 End: 285		Run: 13 Beg: 285 End: 386		Run: 14 Beg: 386 End: 474		Run: 15 Beg: 475 End: 565	
	Operating Conditions		SPEED SWEEP		800 RPM		875 RPM		950 RPM		1025 RPM	
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1	1.0	5								
Engine Vert	2	2		.5								
Hull F/A	3	3		5								
Hull Athw	4	4		5								
Hull Vert	5	5		5								
Ctrl Cab *	6	6		10								
Torsiograph	7	n/a	1.0			—		—		—		—
Rev Marker	8	n/a	10			—		—		—		—
WJ Athw	9	7	1.0	5								
GB Athw	10	8	1.0	.5								

Test Conductor: Bob Guthrie Date: 6/5/96			Run: 16 Beg: 565 End: 655		Run: 17 Beg: 655 End: 745		Run: 18 Beg: 745 End: 836		Run: 19 Beg: 836 End: 925		Run: 20 Beg: 925 End: 1015	
	Operating Conditions		1100 RPM		1175 RPM		1250 RPM		1325 RPM		1400 RPM	
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1										
Engine Vert	2	2										
Hull F/A	3	3										
Hull Athw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torsiograph	7	n/a		—		—		—		—		—
Rev Marker	8	n/a		—		—		—		—		—
WJ Athw	9	7										
GB Athw	10	8										

Test Witnessed by: Sheet No. 2 of 4

LSI Rep. [signature] 6-5-96 Customer Rep.

Comments: Run #13, slow turn @ end of run

Figure 4. Test Data Recording Sheet

MODULAR CAUSEWAY FERRY TEST DATA RECORDING SHEET			SEA STATE 0						DRAFT 37"			
			DEPTH 20 ft						DISPL			
Test Conductor: Bob Guthrie			Run: 21		Run: 22		Run: 23		Run: 24		Run: 25	
			Beg: 1015		Beg: 1115		Beg: 1205		Beg: 1295		Beg: 1385	
Date: 6/5/96			End: 1115		End: 1205		End: 1295		End: 1385		End: 1475	
	Operating Conditions		1475 RPM		1550 RPM		1625 RPM		1700 RPM		1775 RPM	
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1	1.0									
Engine Vert	2	2										
Hull F/A	3	3										
Hull Athw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torsiograph	7	n/a		–		–		–		–		–
Rev Marker	8	n/a	10	–		–		–		–		–
WJ Athw	9	7	1.0									
GB Athw	10	8	1.0									

↓ * START @ 1690

Test Conductor: Bob Guthrie			Run: 26		Run: 27		Run: 28		Run: 29		Run: 30	
			Beg: 1475		Beg: 1565		Beg: 1655		Beg: 1780		Beg: 1875	
Date: 6/5/96			End: 1565		End: 1655		End: 1780		End: 1875		End: 1966	
	Operating Conditions		1850 RPM		1925 RPM		2000 RPM		2075 RPM		2150 RPM	
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1										
Engine Vert	2	2										
Hull F/A	3	3										
Hull Athw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torsiograph	7	n/a										
Rev Marker	8	n/a										
WJ Athw	9	7										
GB Athw	10	8										

Test Witnessed by:	Sheet No. 3 of 4
LSI Rep. [signature] 6-5-96	Customer Rep.

Comments:

Figure 4. Test Data Recording Sheet

MODULAR CAUSEWAY FERRY TEST DATA RECORDING SHEET					SEA STATE C DEPTH 26 ft +				DRAFT 37" DISPL			
Test Conductor: Bob Guthrie Date: 6/5/96			Run: 31 Beg: 1966 End: 2055		Run: 32 Beg: 2055 End: 2098		Run: 33 Beg: 2098 End: 2147		Run: 34 Beg: 2147 End: 2307		Run: 35 Beg: 2307 End: 2331	
	Operating Conditions		2200 RPM (FULL)		CRASH ASTERN		CRASH AHEAD		HARD TURN TO PORT		UNDERWAY ELEC. CAL	
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1	1.0	5	1.0		1.0		1.0		1.0	
Engine Vert	2	2		.5								
Hull F/A	3	3		5								
Hull Athw	4	4		5								
Hull Vert	5	5		5								
Ctrl Cab *	6	6		10								
Torslograph	7	n/a		—	2.0	—	2.0	—	2.0	—	2.0	—
Rev Marker	8	n/a	10	—	10	—	10	—	10	—	10	—
WJ Athw	9	7	1.0	5	1.0		1.0		1.0		1.0	
GB Athw	10	8	1.0	.5	1.0		1.0		1.0		1.0	

Test Conductor: Bob Guthrie Date: 6/5/96			Run: 36 Beg: 2331 End: 2420		Run: ____ Beg: ____ End: ____		Run: ____ Beg: ____ End: ____		Run: ____ Beg: ____ End: ____		Run: ____ Beg: ____ End: ____	
	Operating Conditions		** SEE BELOW									
	Tape Chan	Amp Chan	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain	Tape FS	Amp Gain
Waterjet F/A	1	1	1.0									
Engine Vert	2	2										
Hull F/A	3	3										
Hull Athw	4	4										
Hull Vert	5	5										
Ctrl Cab *	6	6										
Torslograph	7	n/a	2									
Rev Marker	8	n/a	10									
WJ Athw	9	7	1.0									
GB Athw	10	8	1.0									

Test Witnessed by: Sheet No. 4 of 4

LSI Rep. [signature] 6-5-96 Customer Rep.

Comments:

Reverse @ 5.3 knots before run 33

** 2200 RPM, moved ch 6 to upper aft port corner

Figure 4. Test Data Recording Sheet

Appendix B

CALIBRATION DATA

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER CALIBRATOR
Manufactured By: BRUEL & KJAER
Model No: 4291 Serial No: 619378
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 4291 B & K

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 7

Felix A. Christopher

uncompromised calibration
West Caldwell Calibration Laboratories, Inc.
1086 Bloomfield Avenue
West Caldwell
New Jersey
07006
Telephone
(201) 882-4900
Fax
(201) 808-9297

uncompromised calibration
West Caldwell Calibration Laboratories, Inc.

1086 Bloomfield Avenue
West Caldwell
New Jersey
07006

Telephone
(201) 882-4900
Fax
(201) 808-9297

REPORT OF CALIBRATION

for

BRUEL & KJAER — ACCELEROMETER CALIBRATOR

Model 4291 — Serial No. 619378

Submitted by:

Customer: **NKF ENGINEERING INC.**

The above listed instrument was checked using calibration procedure documented in West Caldwell Calibration Laboratories Inc. procedure : **4291 B & K** Revision **Jul-95**

Calibration results:

The vibration level measured was 10.0 ms-2, Peak , specification 10 ms-2 peak + - 2 %

Frequency: 79.4 Hz, spec. 79.6 Hz + - 0.5 %

This Calibration is traceable through NIST test number: 822/253333-94

Uncertainty:

The absolute uncertainty of calibration: 2.0% at 99% confidence level.

Unless otherwise noted, the reported value is both the "as found" and "as left" data.

Calibration was performed by West Caldwell Calibration Laboratories Inc. under Operating Procedures intended to implement the requirements of ANSI/NCSL Z540-1,(MIL-STD-45662A), and ISO 9002

Certified References:		Date of Cal.	Due Date	NIST Test No.
Bruel & Kjaer 8305	S/N1739345	13 July 95	13 July 96	822/253333-94
Hewlett Packard 3458A	S/N2823A00324	17 Oct. 95	17 Oct. 96	2452J2416

Laboratory Environment:

Ambient Temperature:	22	°C
Ambient Humidity:	38	% RH
Ambient Pressure:	1011	hPa (mbar)
Calibration Date:	5/17/96	
Calibration Due:	11/17/96	
Report Number:	3075 - 7	
Control Number:	3075	

Measurements performed by:

Felix A Christopher

Form Exit920423-5

This document may be reproduced in whole

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 277
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 6

Felix A. Christopher

uncompromised calibration West Caldwell Calibration Laboratories, Inc.

1086 Bloomfield Avenue
West Caldwell
New Jersey
07006

Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -6

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

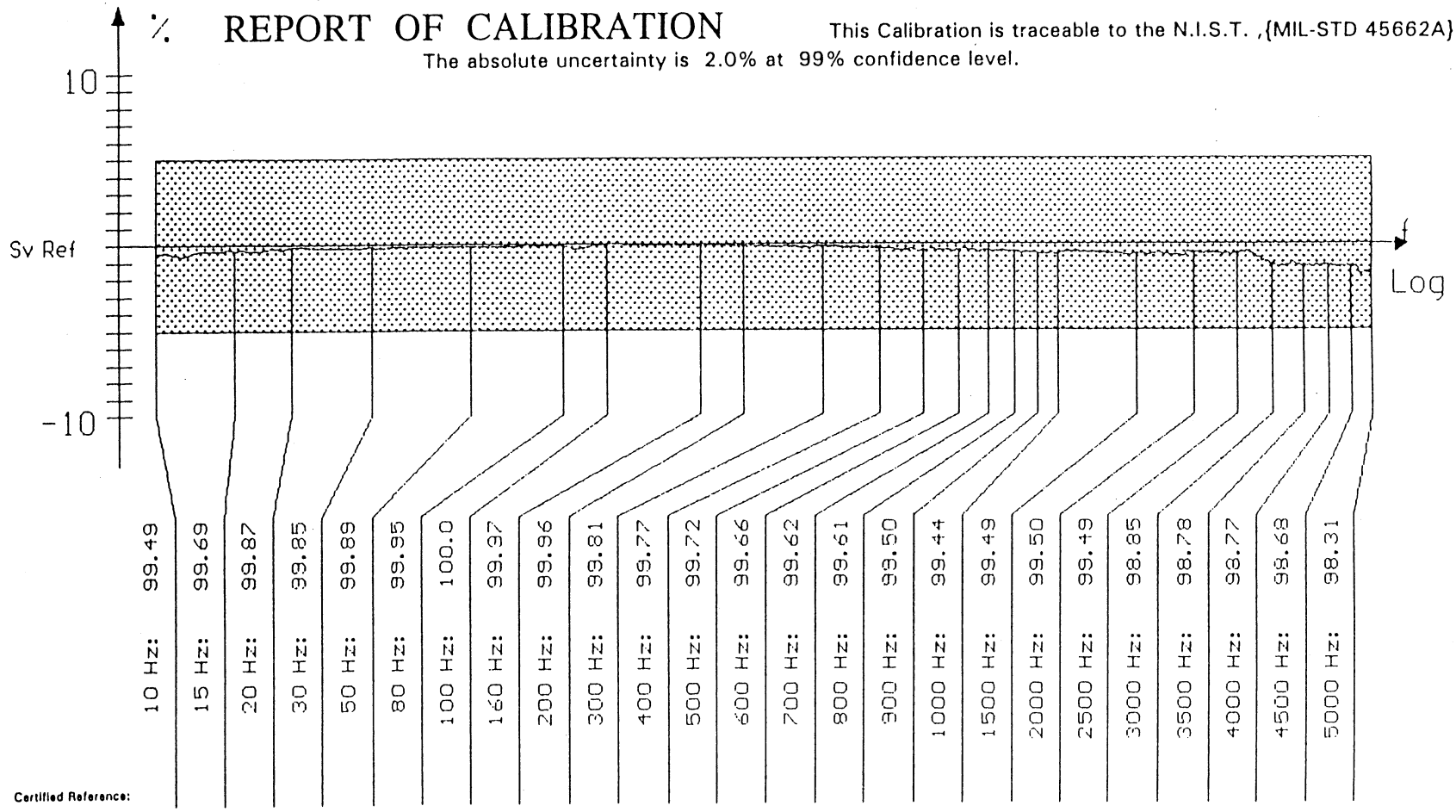
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 14:05
Serial No.	: 277	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:44
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 100.0 mV/g 10.197 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 276
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 5

Felix A. Christopher

uncompromised calibration **West Caldwell Calibration Laboratories, Inc.**

1086 Bloomfield Avenue
West Caldwell
New Jersey
07006

Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -5

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

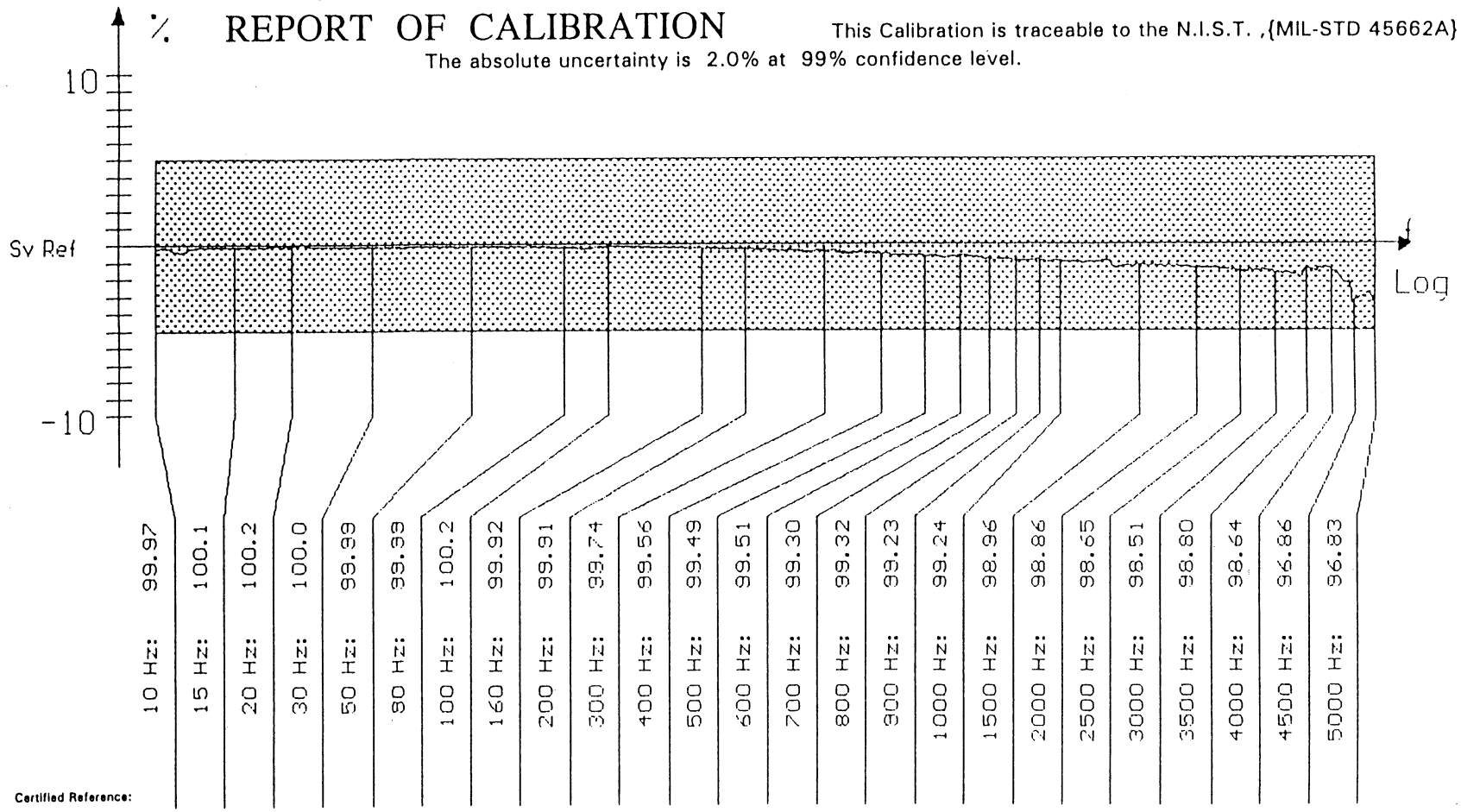
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 13:58
Serial No.	: 276	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:38
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,(MIL-STD 45662A)

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 100.2 mV/g 10.217 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

Page 1 of 1 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 275
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 4

Felix A. Christopher

West Caldwell Calibration Laboratories, Inc.
uncompromised calibration

1086 Bloomfield Avenue
West Caldwell
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Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -4

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

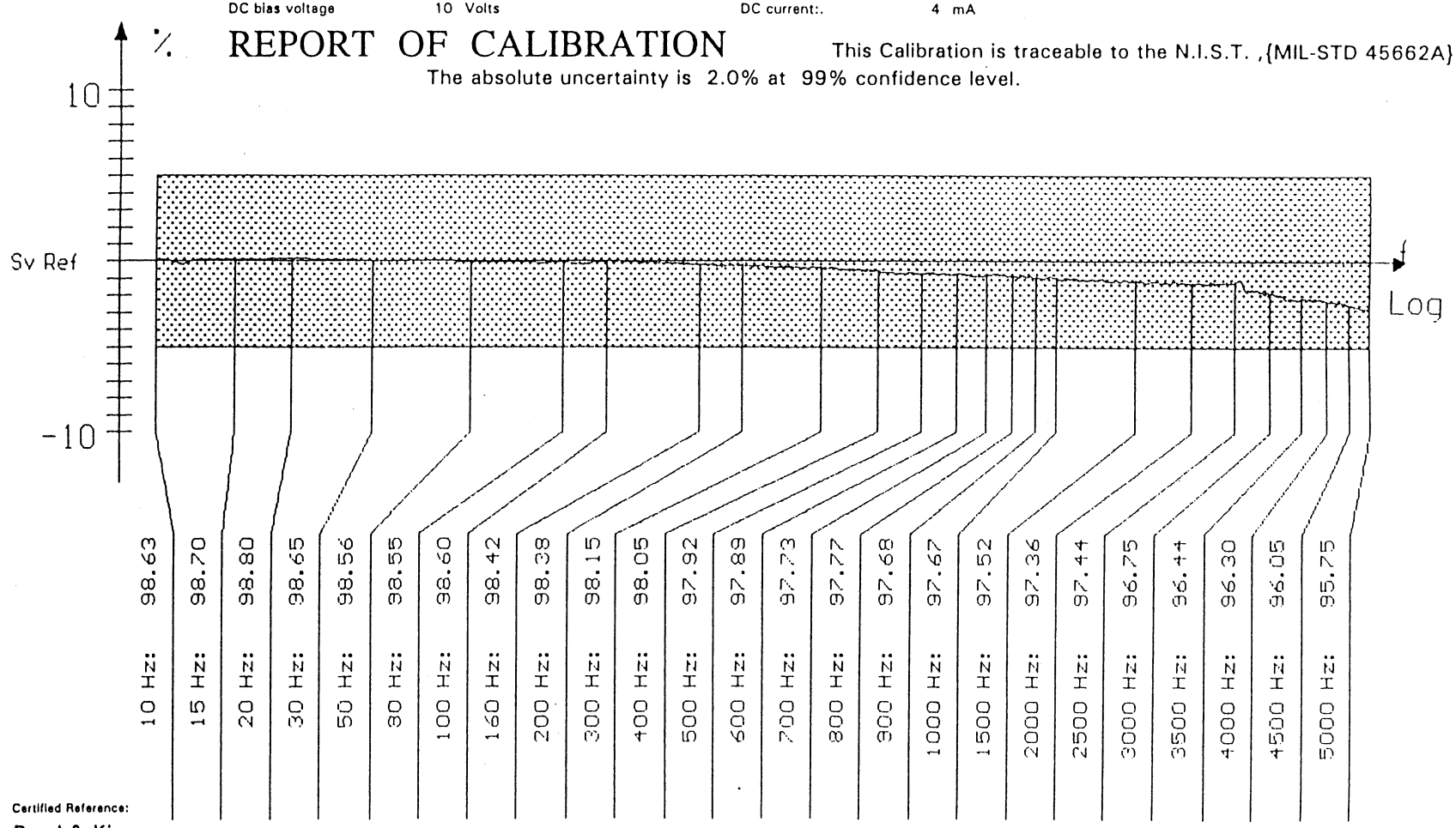
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 13:41
Serial No.	: 275	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:32
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 98.60 mV/g 10.054 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 274
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 3

Felix A. Christopher

uncompromised calibration **West Caldwell Calibration Laboratories, Inc.**

1086 Bloomfield Avenue
West Caldwell
New Jersey
07006

Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -3

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

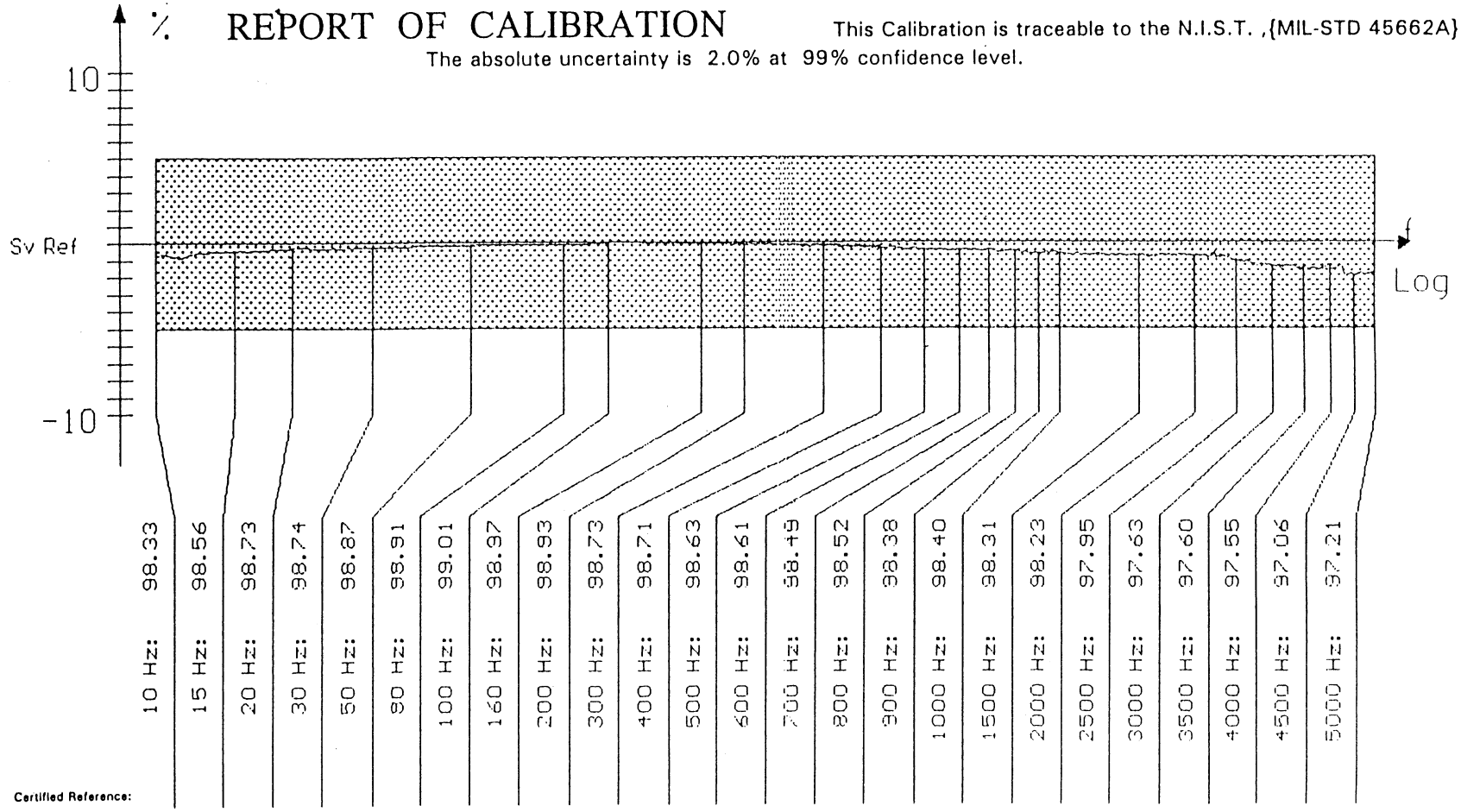
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 13:51
Serial No.	: 274	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:27
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 99.01 mV/g 10.096 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 263
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 2

Felix A. Christopher

uncompromised calibration **West Caldwell Calibration Laboratories, Inc.**

1086 Bloomfield Avenue
West Caldwell
New Jersey
07006

Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -2

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

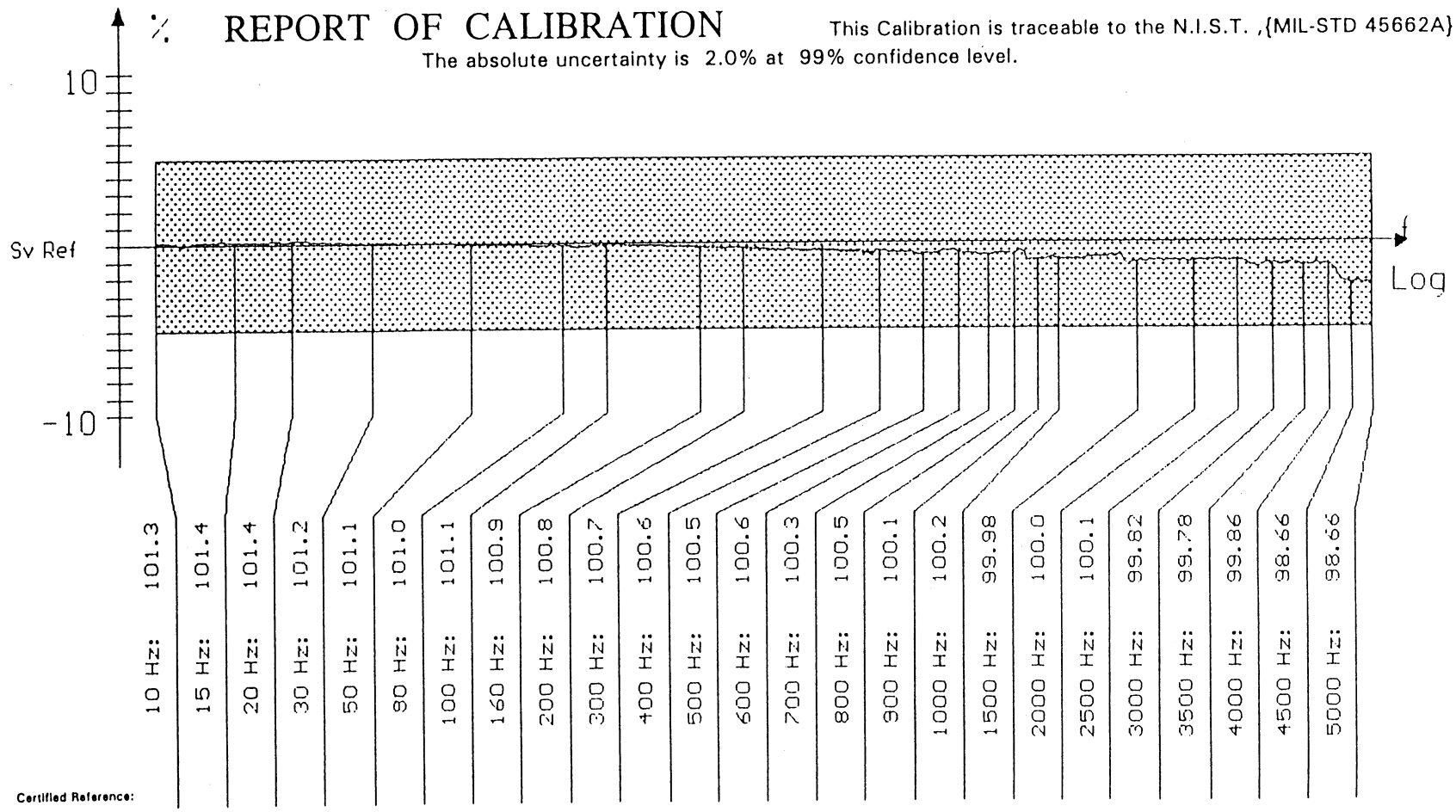
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 13:22
Serial No.	: 263	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:17
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

% REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 101.1 mV/g 10.309 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

Page 1 of 1 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: WILCOXON RESEARCH
Model No: M766 Serial No: 262
Calibration Recall No: 3075

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. M766 W R

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: May 17 , 1996
Calibration Due: Nov. 17 , 1996
Certificate No: 3075 - 1

Felix A. Christopher

uncompromised calibration
West Caldwell Calibration Laboratories, Inc.
1086 Bloomfield Avenue
West Caldwell
New Jersey
07006
Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 3075 -1

Control no: 3075 Customer: NKF ENGINEERING INC. Temp. 22 °C RH: 38%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1011 hPa

Felix A. Christophe

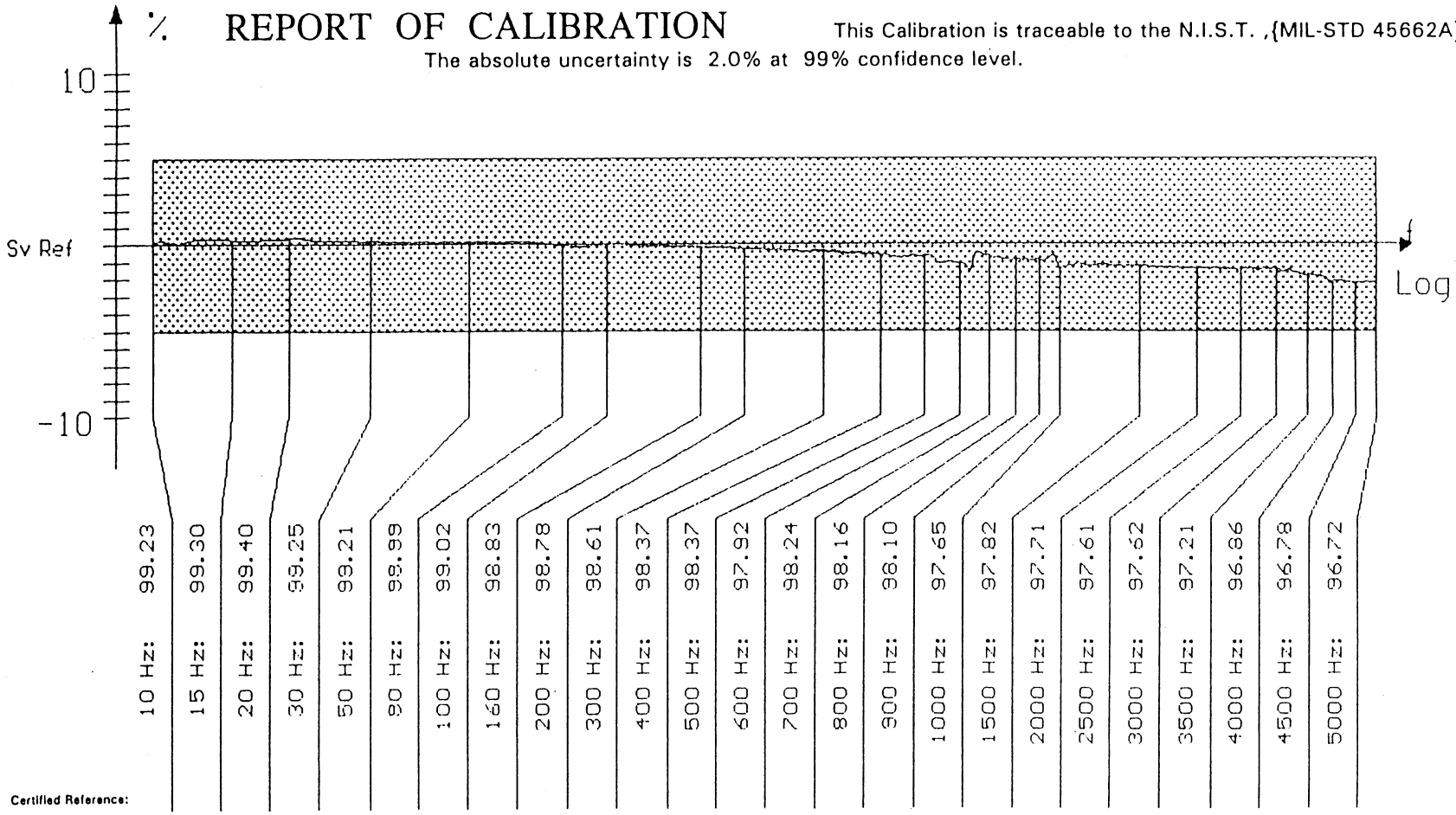
Manufacturer	: Wilcoxon Resea.	Work Unit Code	: M766WR	Operator ID	: CHRIS
Part No.	: M766	Measurement Angle	: 0 °	Calibration Date	: 17 May 1996, 13:32
Serial No.	: 262	Ref. Sensitivity	: Passed	Last Cal. Date	: 12 Jan 1995, 12:12
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 99.02 mV/g 10.097 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

 FormA920515

Calibrated on Brüel & Kjær system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: PIEZOTRONICS
Model No: 327A01 Serial No: 2423
Calibration Recall No: 2531

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 327A01 PCB

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: Oct. 13, 1995
Calibration Due: Apr. 13, 1996
Certificate No: 2531 - 17

Felix A. Christopher

uncompromised calibration
West Caldwell Calibration Laboratories, Inc.
1086 Bloomfield Avenue
West Caldwell
New Jersey
07006
Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 2531 -17

Control no: 2531 Customer: NKF ENGINEERING INC. Temp. 23 °C RH: 42%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1005 hPa

Felix A. Christopher

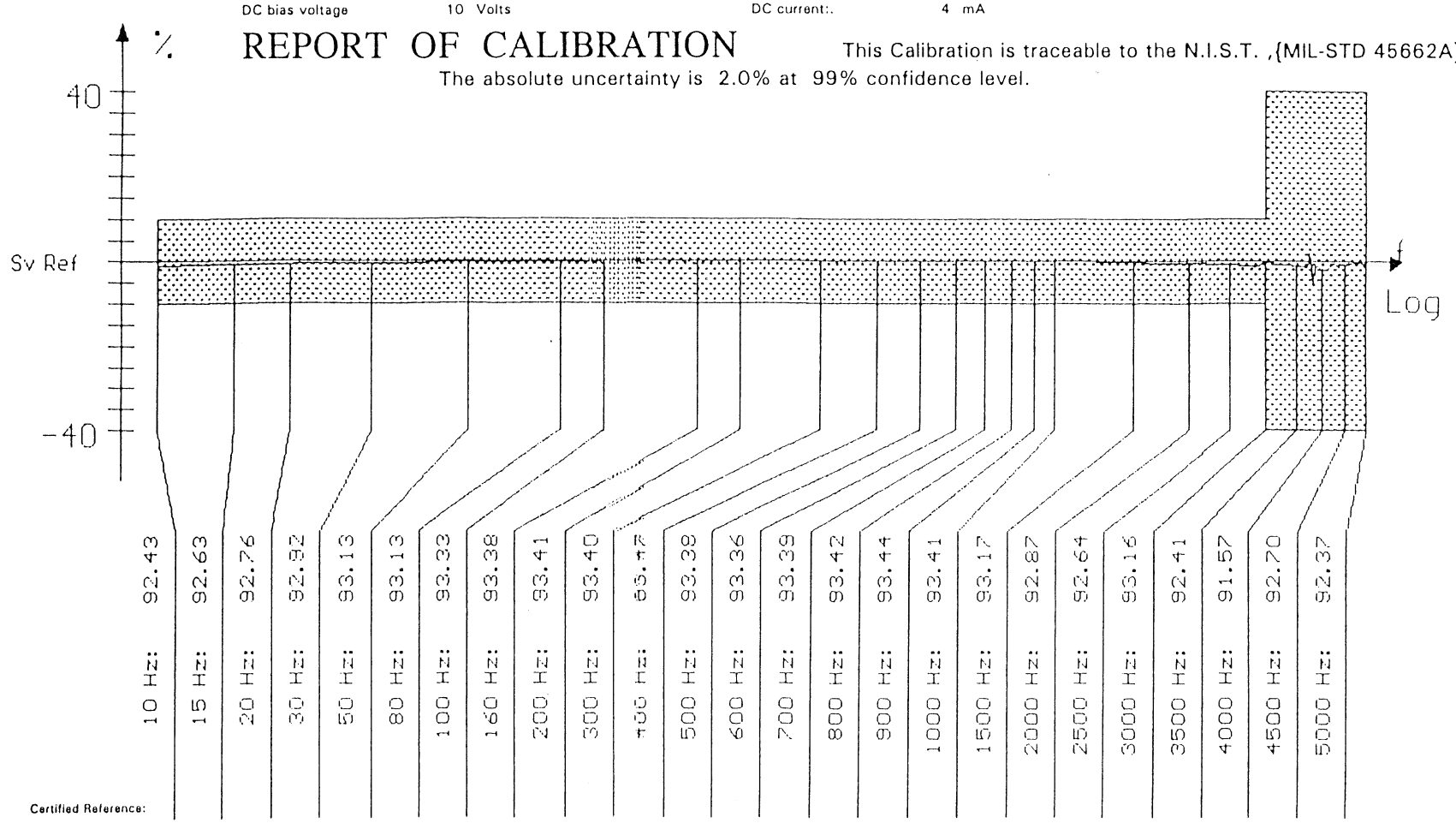
Manufacturer	: PCB	Work Unit Code	: 327A01PCB	Operator ID	: CHRIS
Part No.	: 327A01	Measurement Angle	: 0 °	Calibration Date	: 13 Oct 1995, 3:19
Serial No.	: 2423	Ref. Sensitivity	: Passed	Last Cal. Date	:
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 93.33 mV/g 9.52 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

Calibrated on Brüel & Kjaer system type 9610

West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER
Manufactured By: PIEZOTRONICS
Model No: 327A01 Serial No: 2424
Calibration Recall No: 2531

Submitted by:
Customer: BOB GUTHRIE
Company: NKF ENGINEERING INC.

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 327A01 PCB

Upon receipt for calibration, the instrument was found to be:

Within (x)
Outside ( ) see attached data

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements of MIL-STD-45662A.

Measurement performed by:

Calibration Date: Oct. 13, 1995
Calibration Due: Apr. 13, 1996
Certificate No: 2531 - 18

Felix A. Christopher

uncompromised calibration
West Caldwell Calibration Laboratories, Inc.
1086 Bloomfield Avenue
West Caldwell
New Jersey
07006
Telephone
(201) 882-4900
Fax
(201) 808-9297

West Caldwell Calibration Laboratories Inc.

1086 Bloomfield Ave. West Caldwell NJ 07006

Accelerometer Voltage Sensitivity (Sv)

Report no: 2531 -18

Control no: 2531 Customer: NKF ENGINEERING INC. Temp. 23 °C RH: 42%

The listed instrument was checked on B&K 9610 system using work unit code listed below. Revision 7/95 Barometric Pressure: 1005 hPa

Felix A. Christopher

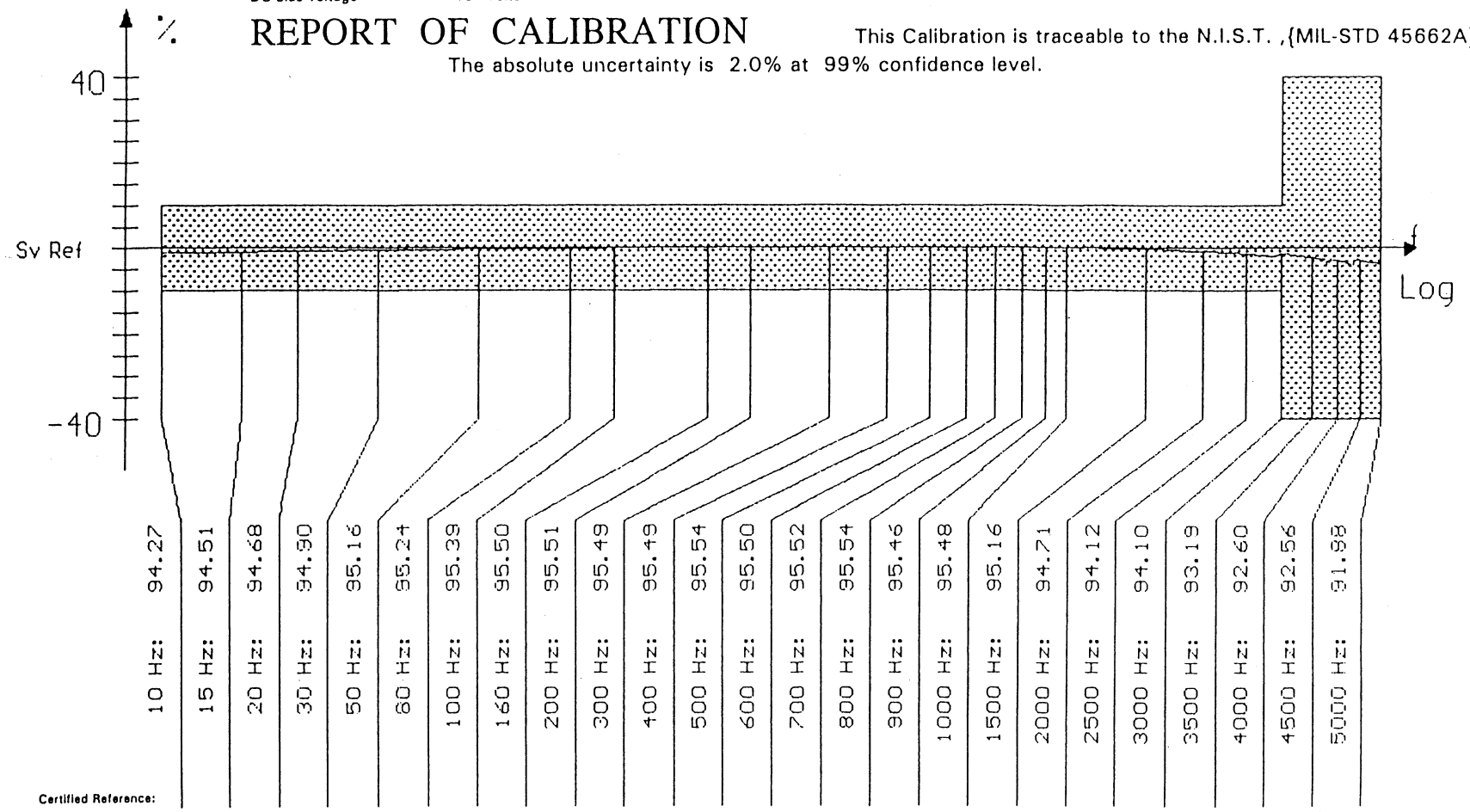
Manufacturer	: PCB	Work Unit Code	: 327A01PCB	Operator ID	: CHRIS
Part No.	: 327A01	Measurement Angle	: 0 °	Calibration Date	: 13 Oct 1995, 3:12
Serial No.	: 2424	Ref. Sensitivity	: Passed	Last Cal. Date	:
Freq. range	: 10-5000 Hz	Generator range	: As freq. range		

DC bias voltage 10 Volts DC current:. 4 mA

REPORT OF CALIBRATION

This Calibration is traceable to the N.I.S.T. ,{MIL-STD 45662A}

The absolute uncertainty is 2.0% at 99% confidence level.



Certified Reference:
Bruel & Kjaer
8305
S/N 1739345

Ref. Sensitivity @ 100Hz: 95.39 mV/g 9.73 mV/ms-2

Date of Cal. July 13,95 Due Date July 13,96 NIST Test No. 822/253333-94

 FormA920515

Calibrated on Brüel & Kjær system type 9610

TORSIOGRAPH CALIBRATION

Jan 17, 1995 - NKF Torsiograph S/N 11

Raw Data: Poi

	0	0
		.00015
	3	.0010
	4.5	.0032
	5.5	.00442
	7	.00330
	9	.00255
	15	.00201
	20	.00184
TG1 =	25	.00178
	30	.00176
	50	.0017
	70	.00165
	90	.00168
	110	.00168
	140	.001695
	170	.001695
	200	.001695
	400	.001695

UNITS: Volt-Sec/Deg

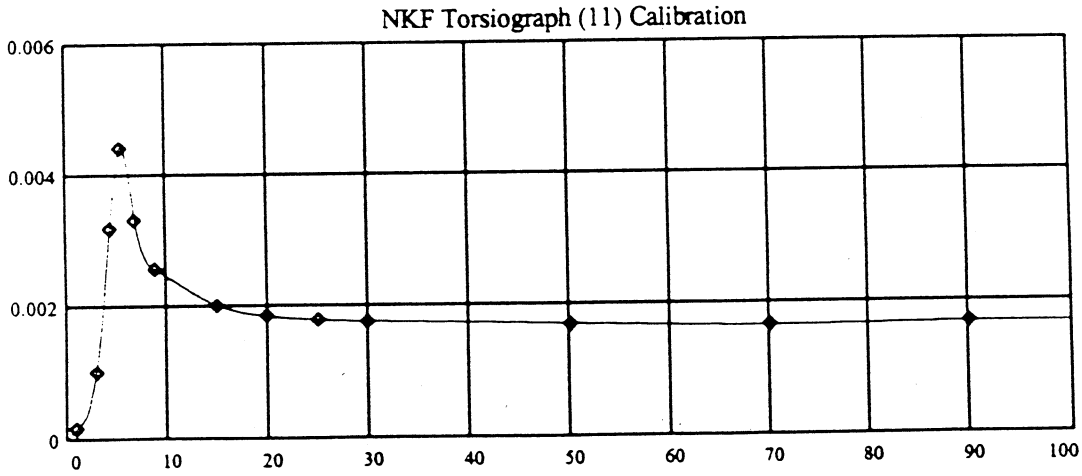
$nrow := rows(TG1) - 1 \quad j := 1..nrow$

Generate a spline fit to data:

$npt := 400 \quad i := 1..npt \qquad f_{max} := 100 \qquad f_i := \frac{i}{npt} \cdot f_{max}$

$vs1 := lspline(TG1^{<0>}, TG1^{<1>})$

$H1_i := interp(vs1, TG1^{<0>}, TG1^{<1>}, f_i)$



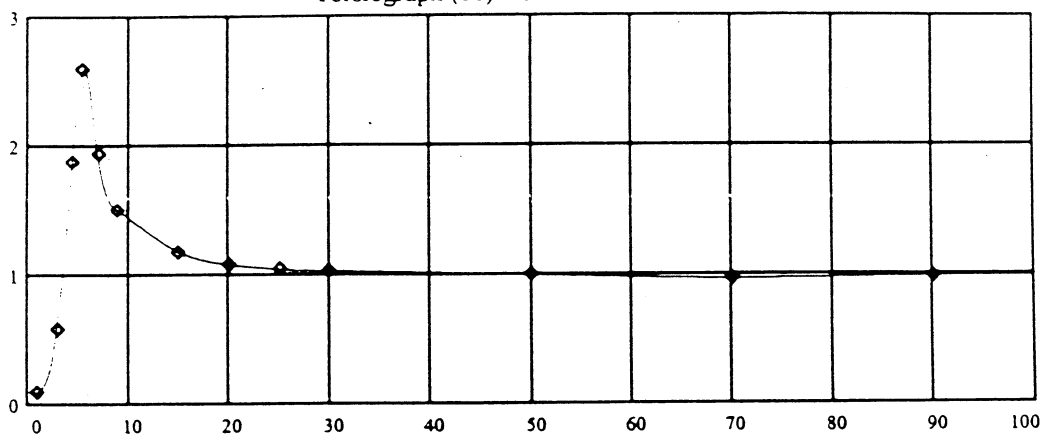
Normalize Curve to Average above 20 Hz:

$$avg := \frac{\sum_{i=9}^{14} TG1_{i,1}}{6} \qquad avg = 0.001708 \qquad TG1_{j,1} := \frac{TG1_{j,1}}{avg} \qquad TG1_{0,1} := 0.1$$

$$vs1 := lspline(TG1^{<0>}, TG1^{<1>})$$

$$H1_i := interp(vs1, TG1^{<0>}, TG1^{<1>}, f_i)$$

Torsiograph (11) Normalised Calibration



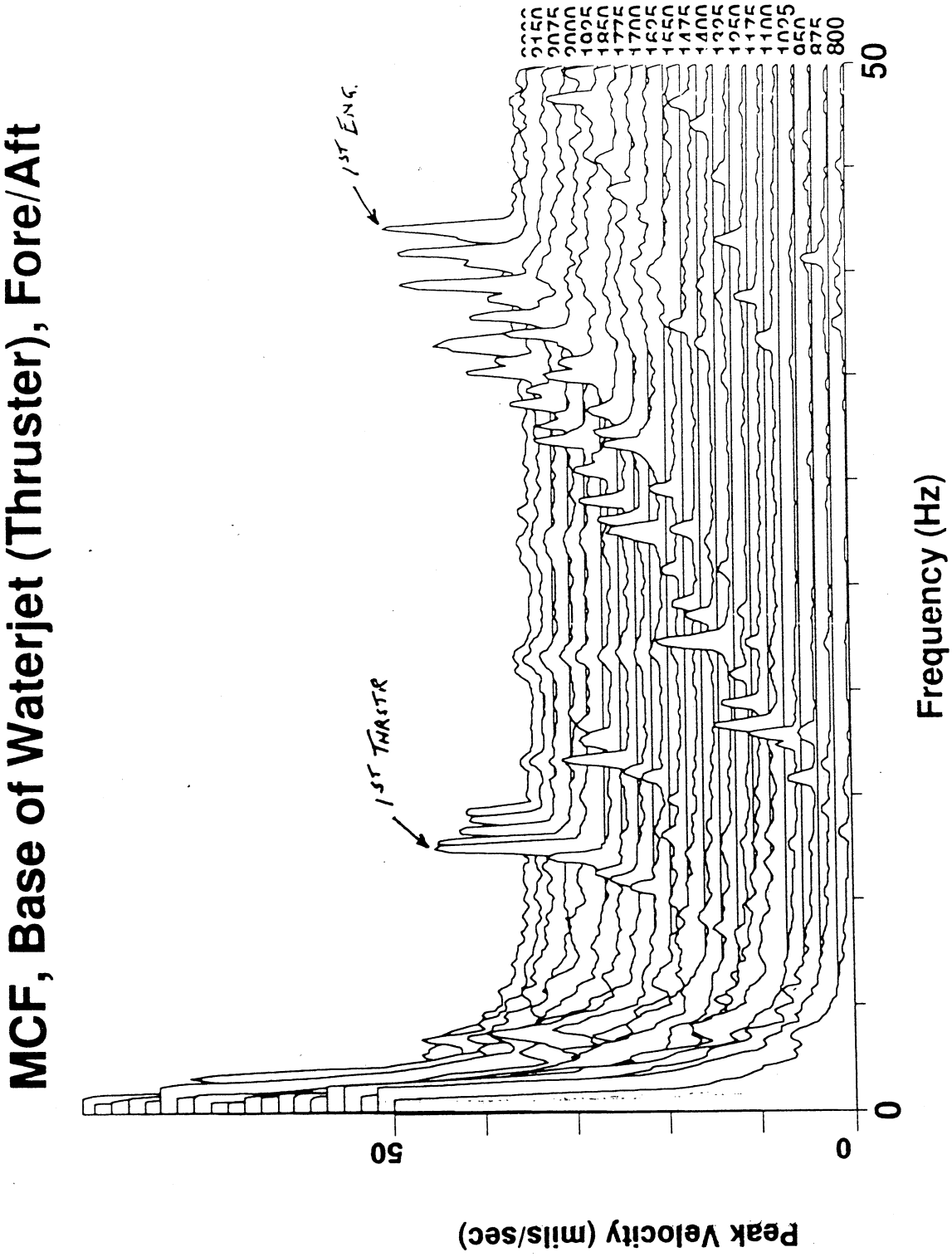
$$f50_i := \frac{i}{npt} \cdot 50 \qquad H1\_50_i := interp(vs1, TG1^{<0>}, TG1^{<1>}, f50_i) \qquad j := 1..npt \qquad Cor\_50_j := \frac{1}{H1\_50_j}$$

$$f200_i := \frac{i}{npt} \cdot 200 \qquad H1\_200_i := interp(vs1, TG1^{<0>}, TG1^{<1>}, f200_i) \qquad Cor\_100_j := \frac{1}{H1_j} \qquad Cor\_200_j := \frac{1}{H1\_200_j}$$

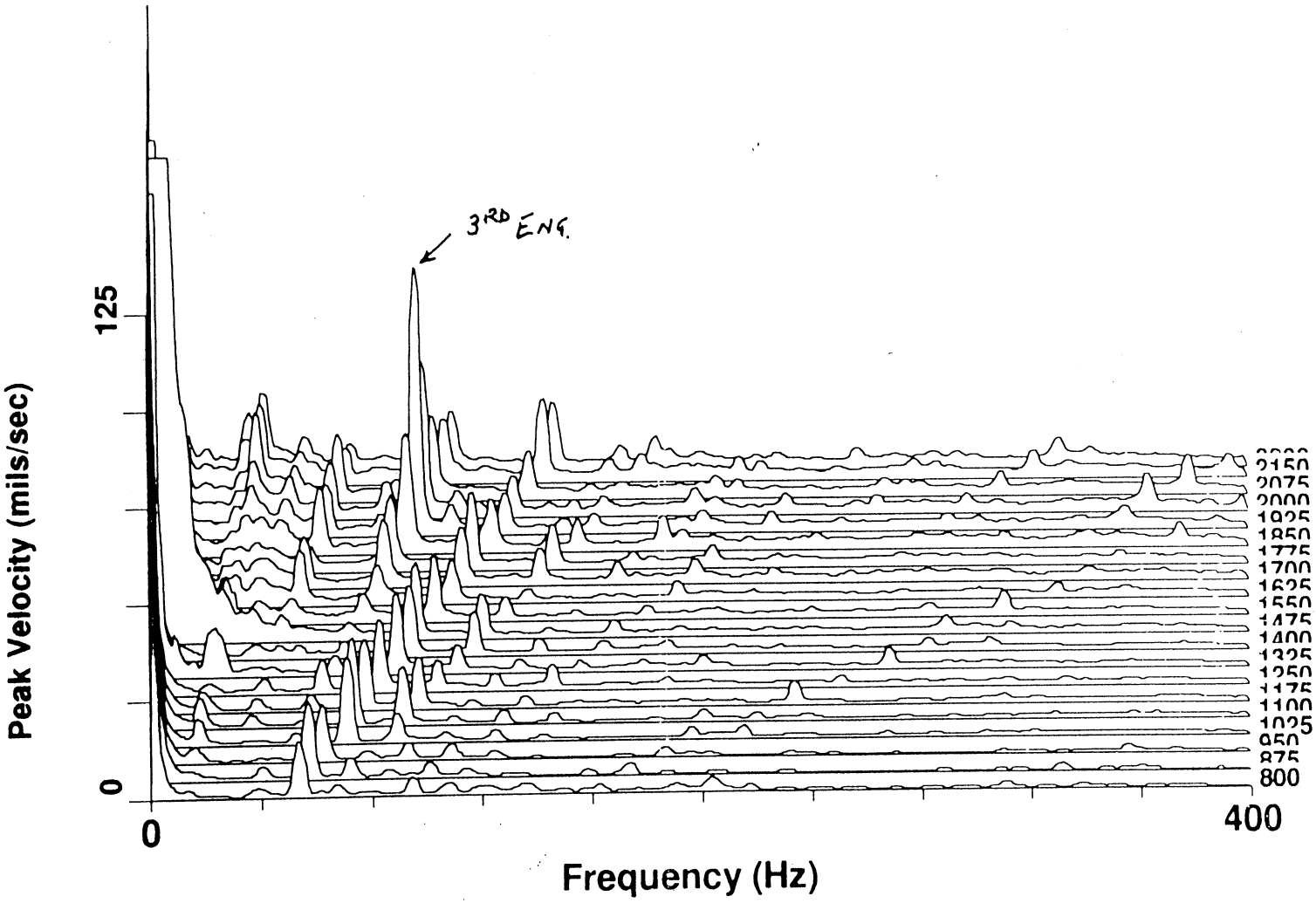
$$f400_i := \frac{i}{npt} \cdot 400 \qquad H1\_400_i := interp(vs1, TG1^{<0>}, TG1^{<1>}, f400_i) \qquad Cor\_400_j := \frac{1}{H1\_400_j}$$

Appendix C

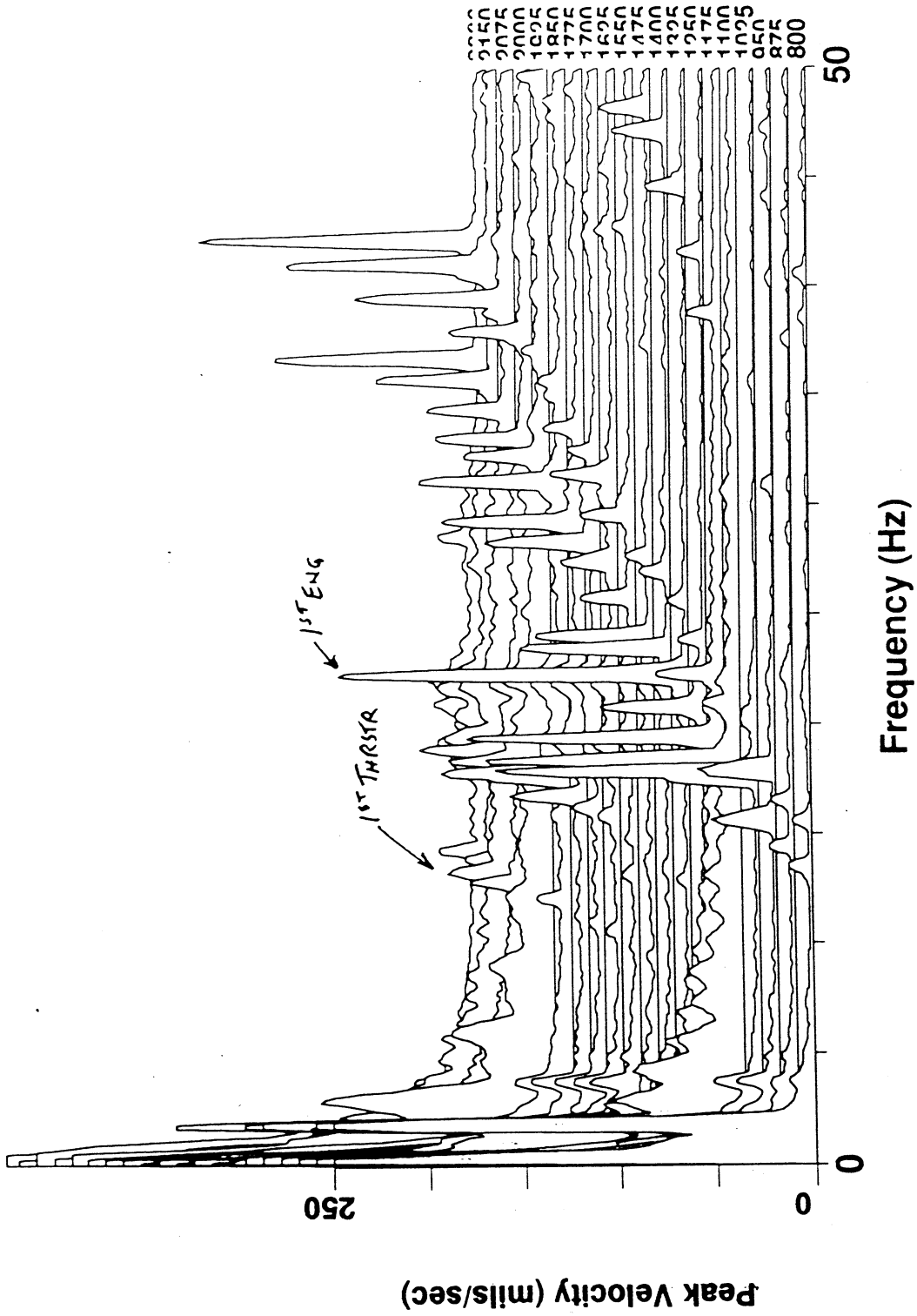
VELOCITY WATERFALLS


MCF, Base of Waterjet (Thruster), Fore/Aft
1ST ENG.
1ST THRSTR
Peak Velocity (mils/sec)
50
0
0
50
Frequency (Hz)

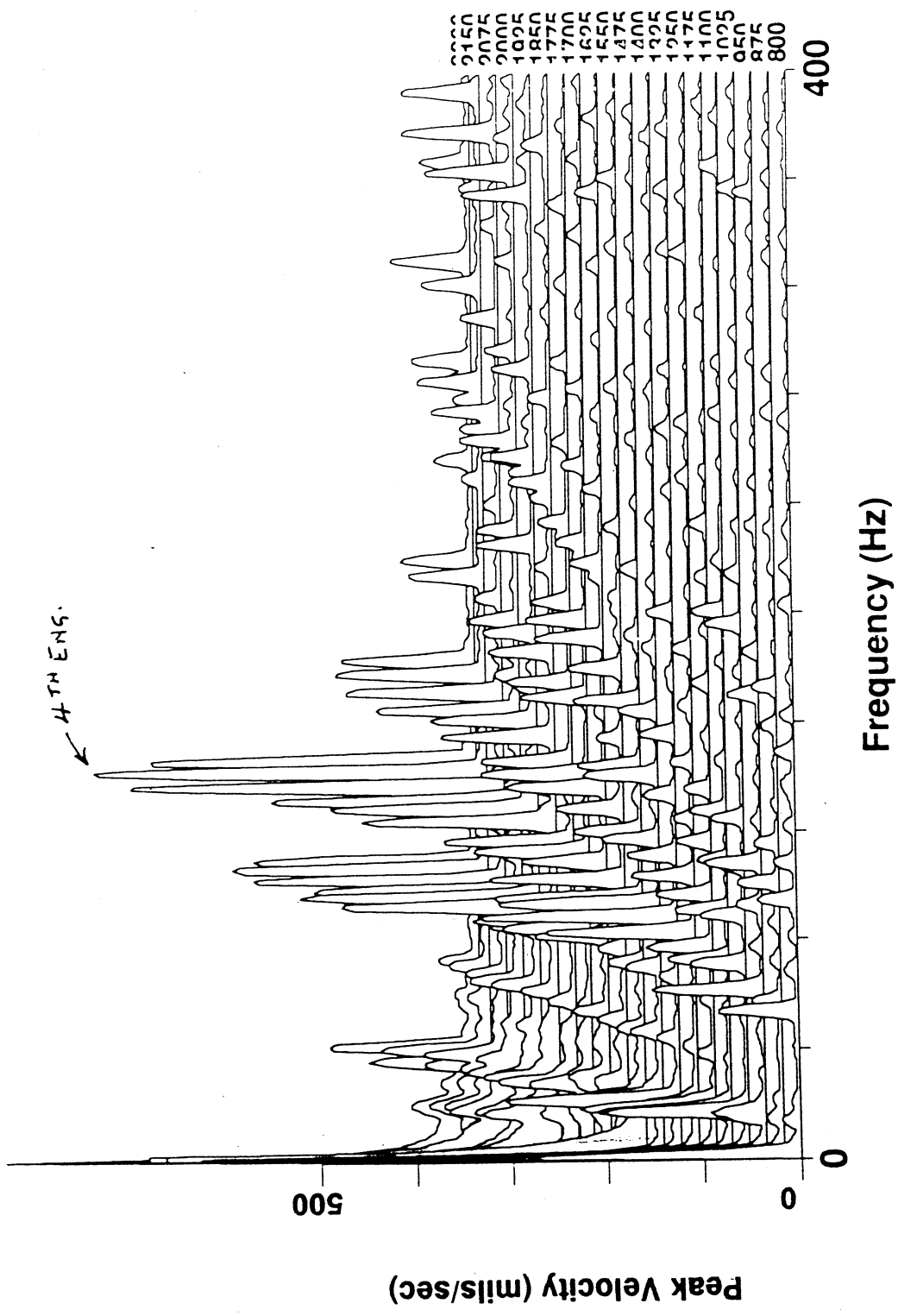
MCF, Base of Waterjet (Thruster), Fore/Aft



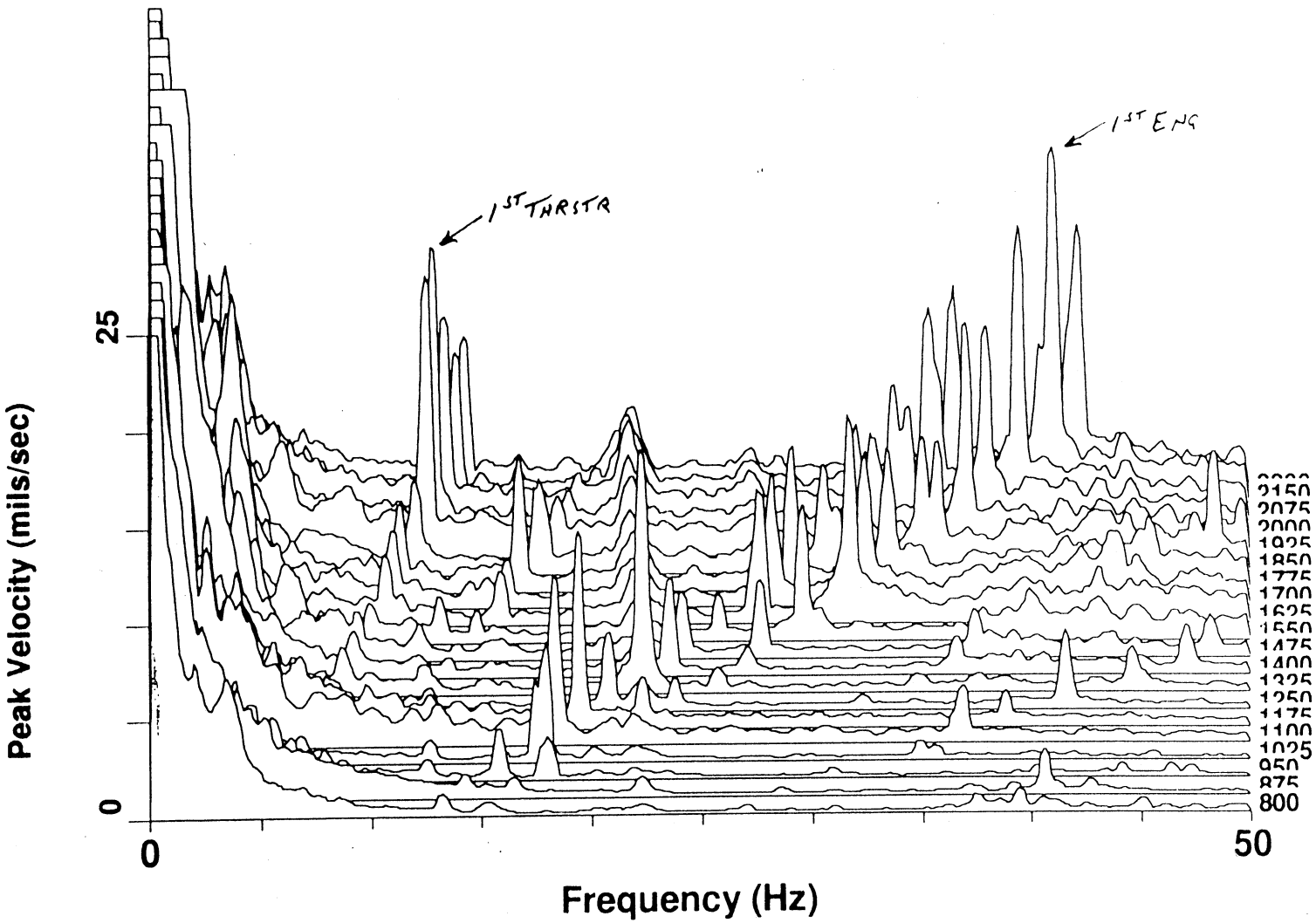
MCF, Base of Engine, Vertical



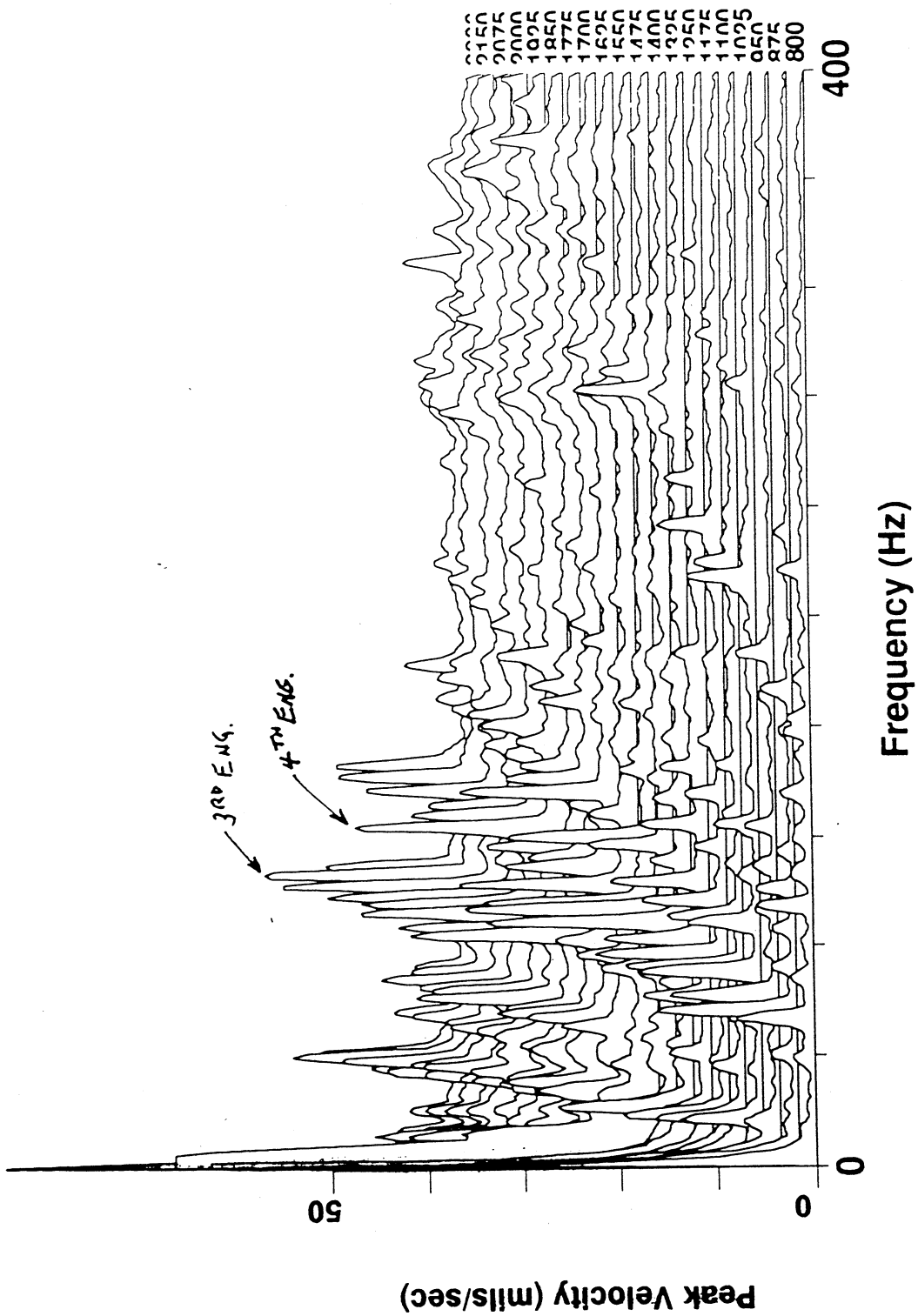
MCF, Base of Engine, Vertical

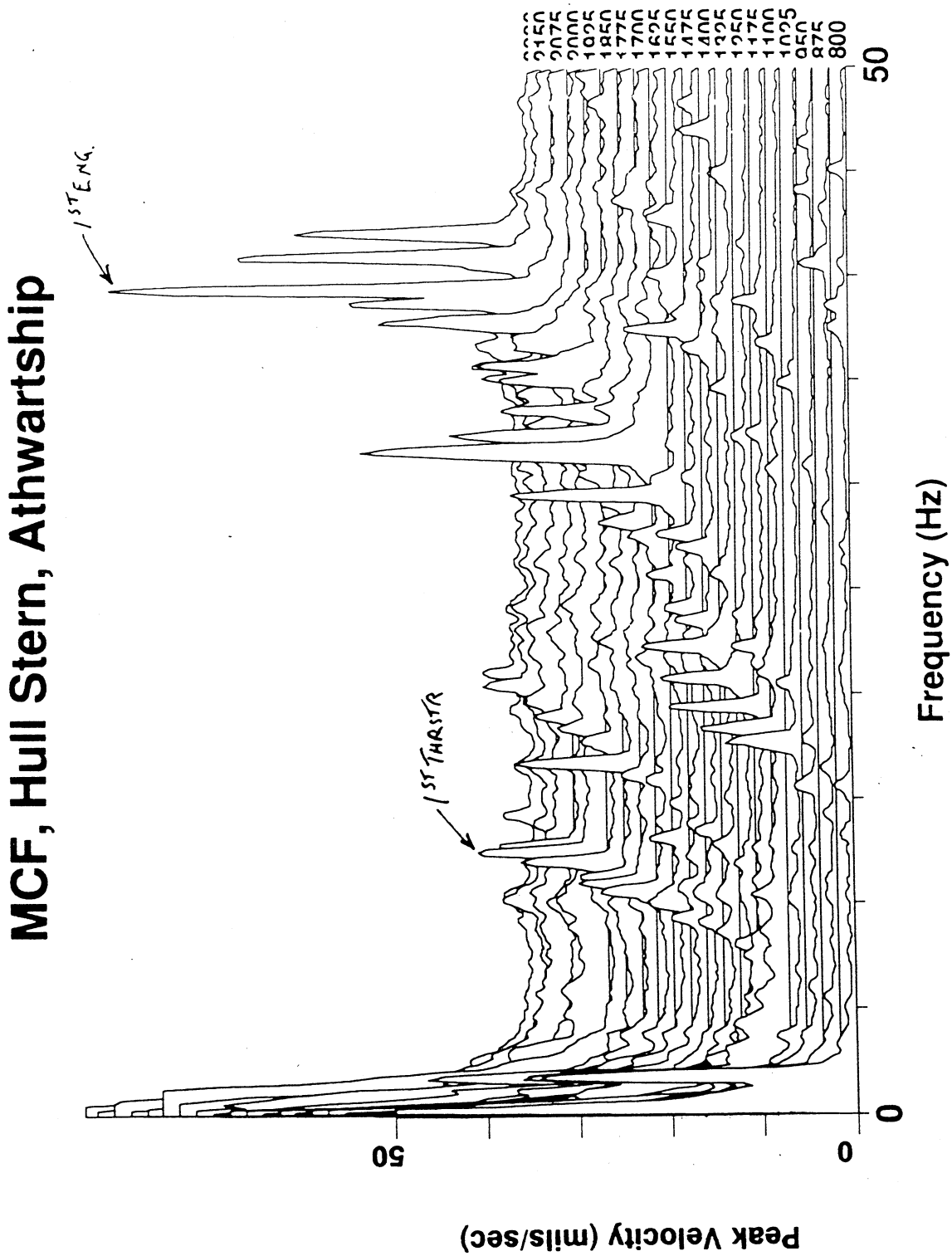


MCF, Hull Stern, Fore/Aft

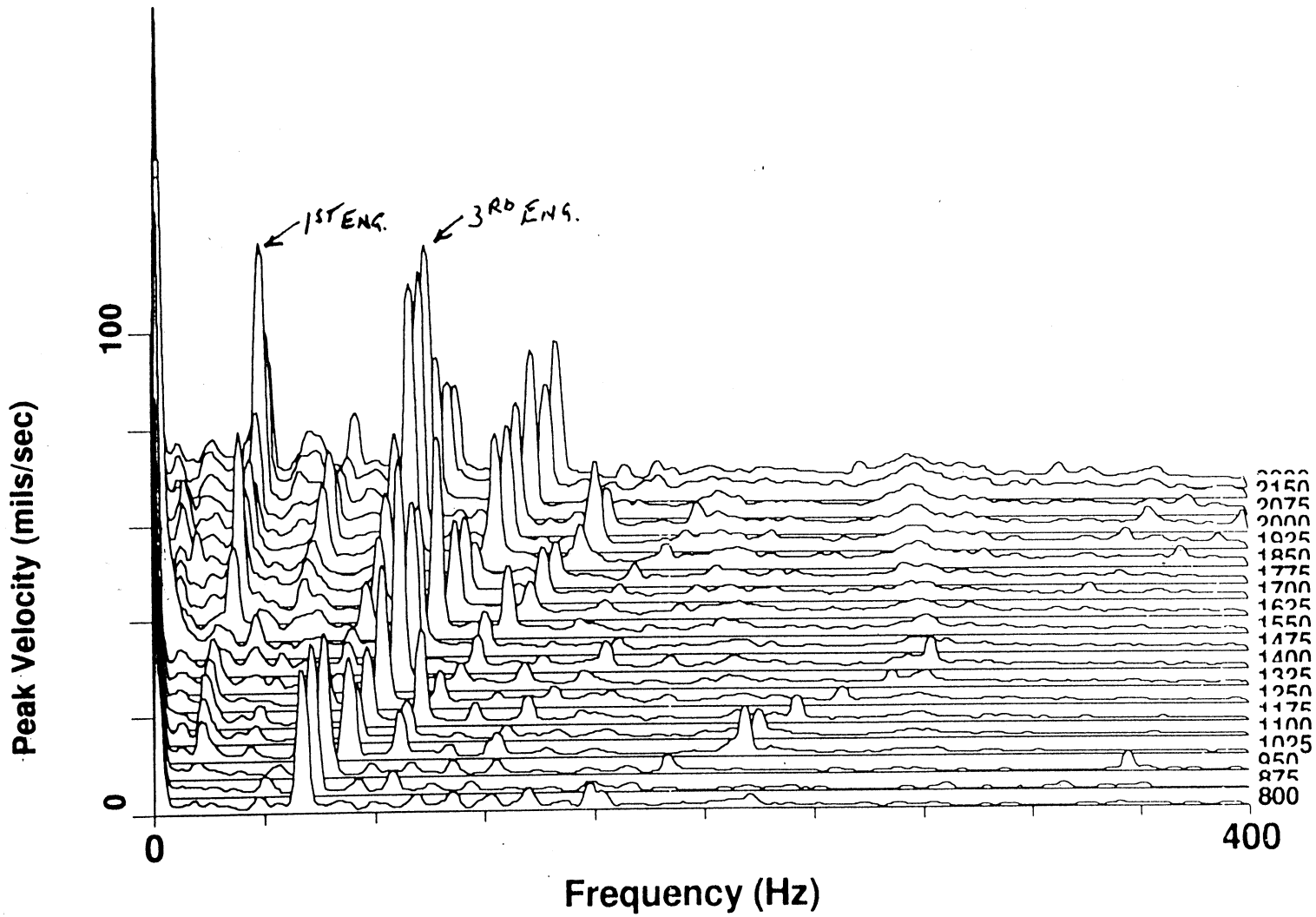


MCF, Hull Stern, Fore/Aft

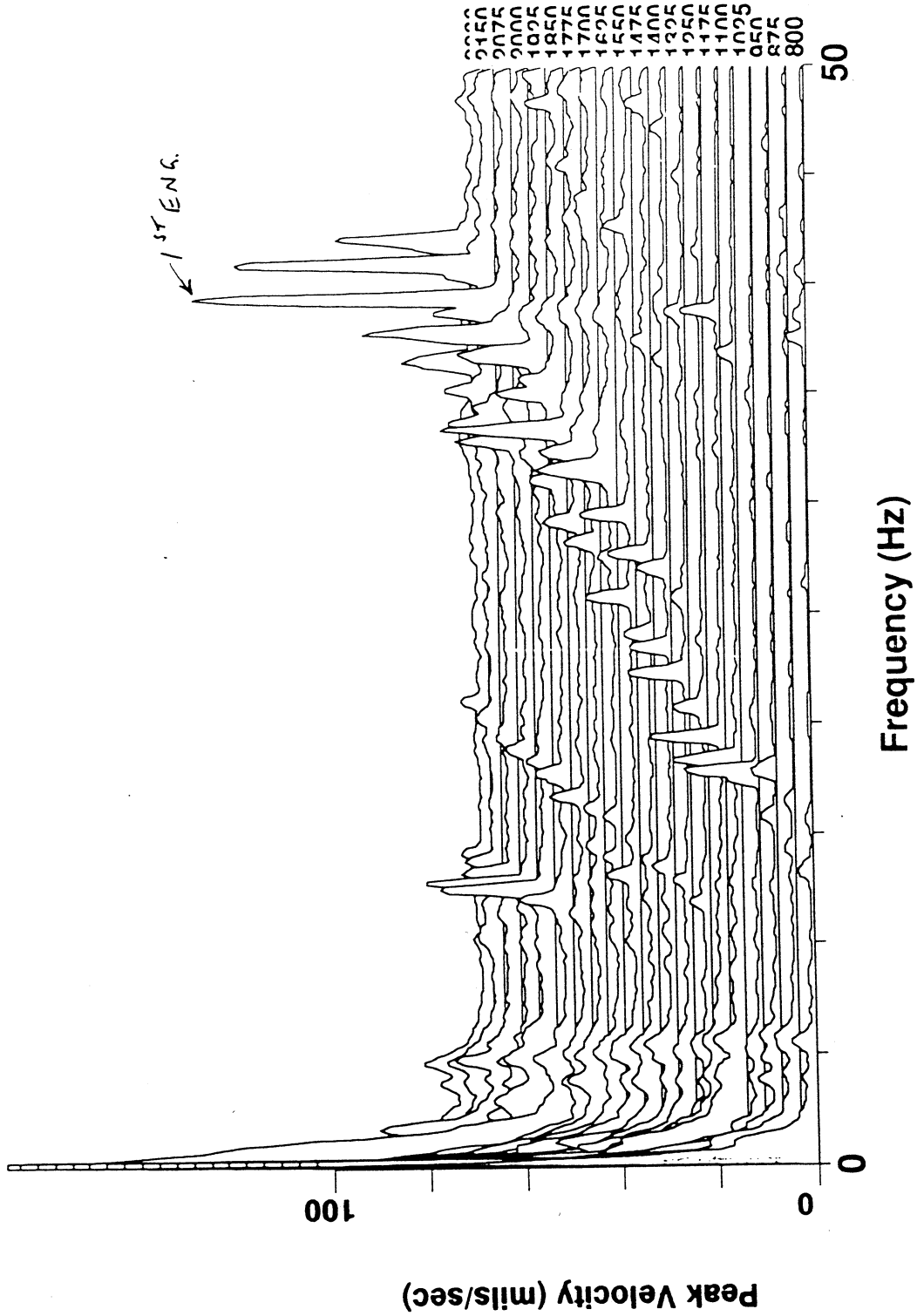



MCF, Hull Stern, Athwartship
1ST ENG.
1ST THRUSTR
Peak Velocity (mils/sec)
50
0
0
50
Frequency (Hz)
2250
2075
2000
1925
1850
1775
1700
1625
1550
1475
1400
1325
1250
1175
1100
1025
950
875
800

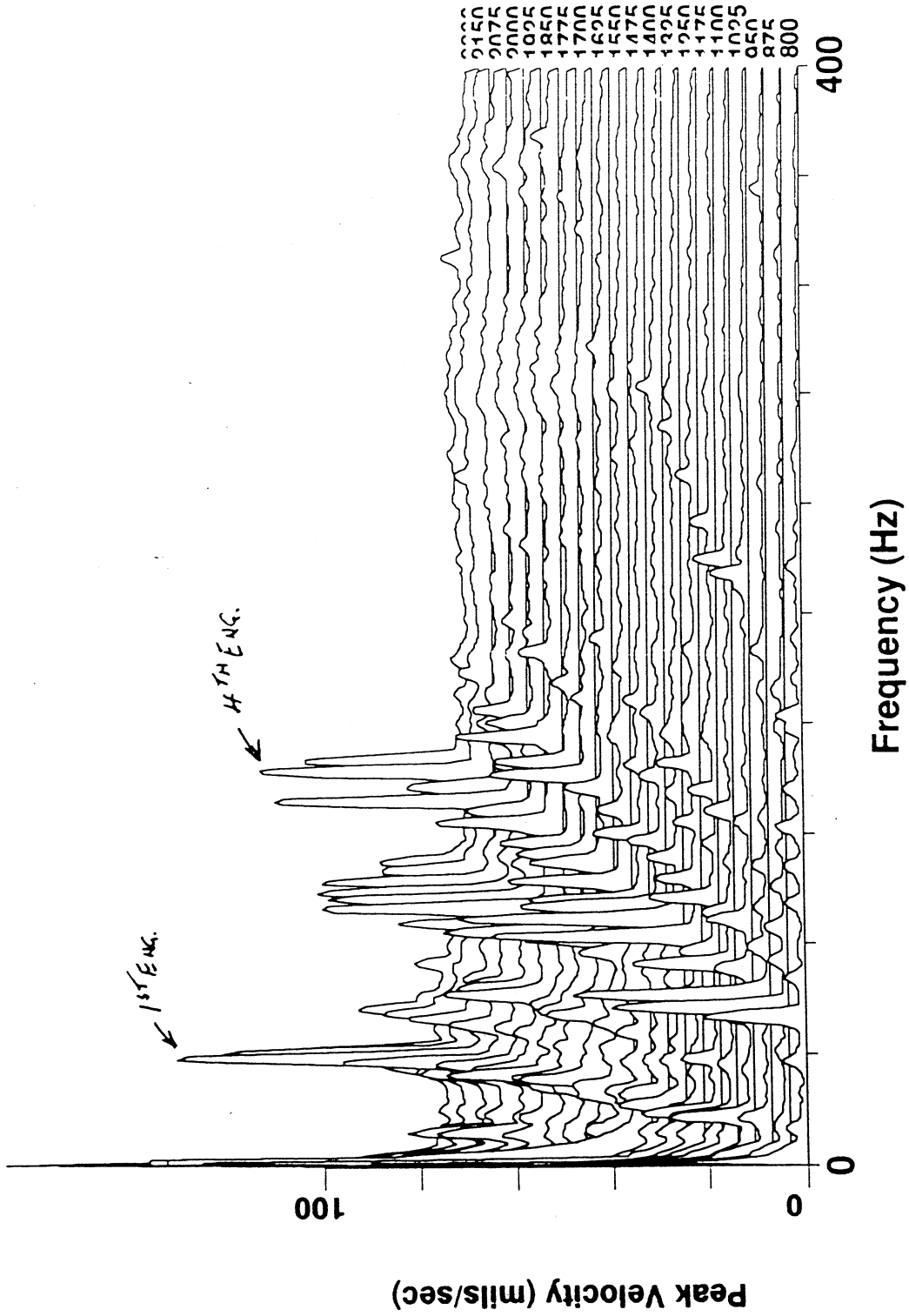
MCF, Hull Stern, Athwartship



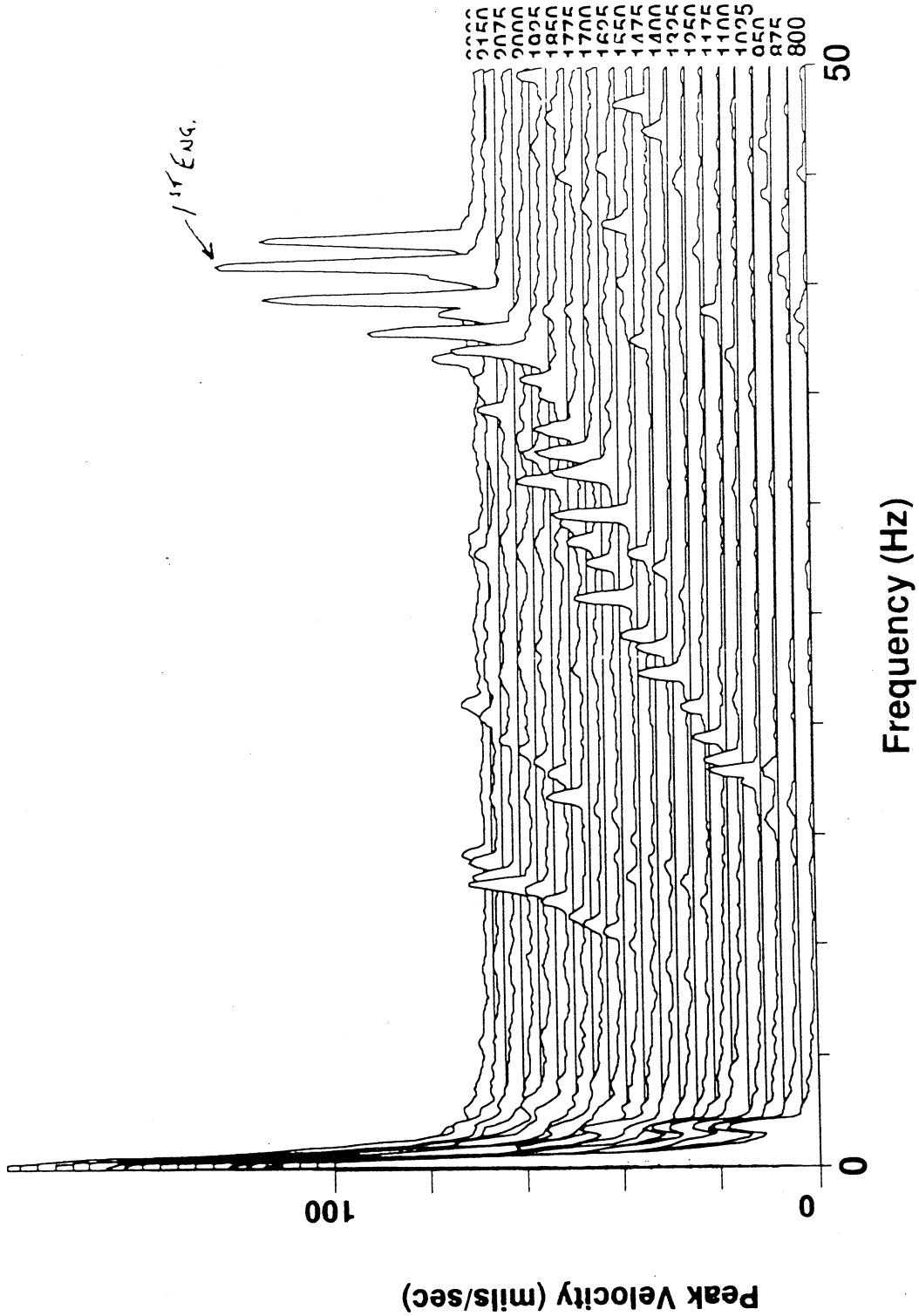
MCF, Hull Stern, Vertical



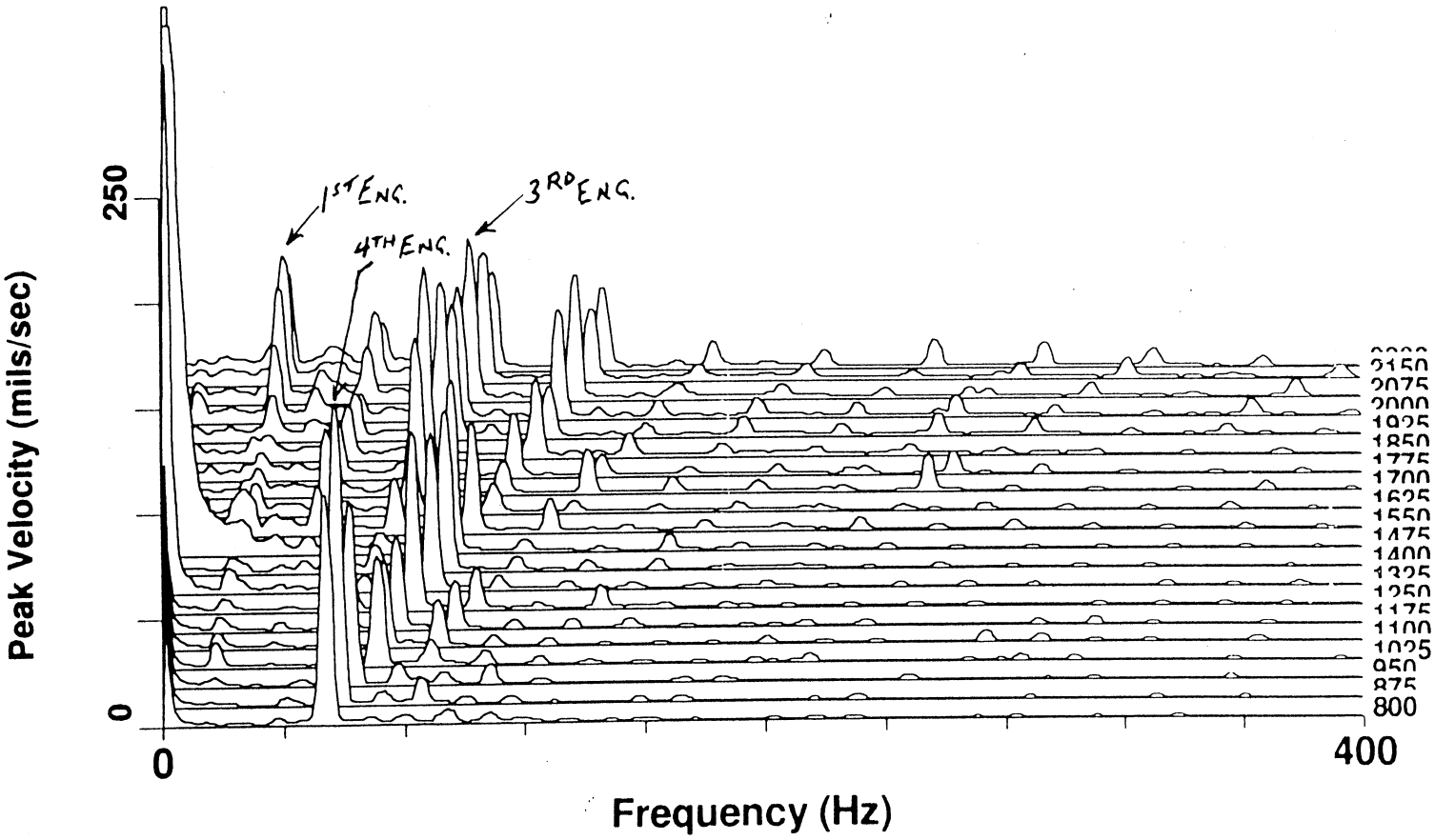
MCF, Hull Stern, Vertical



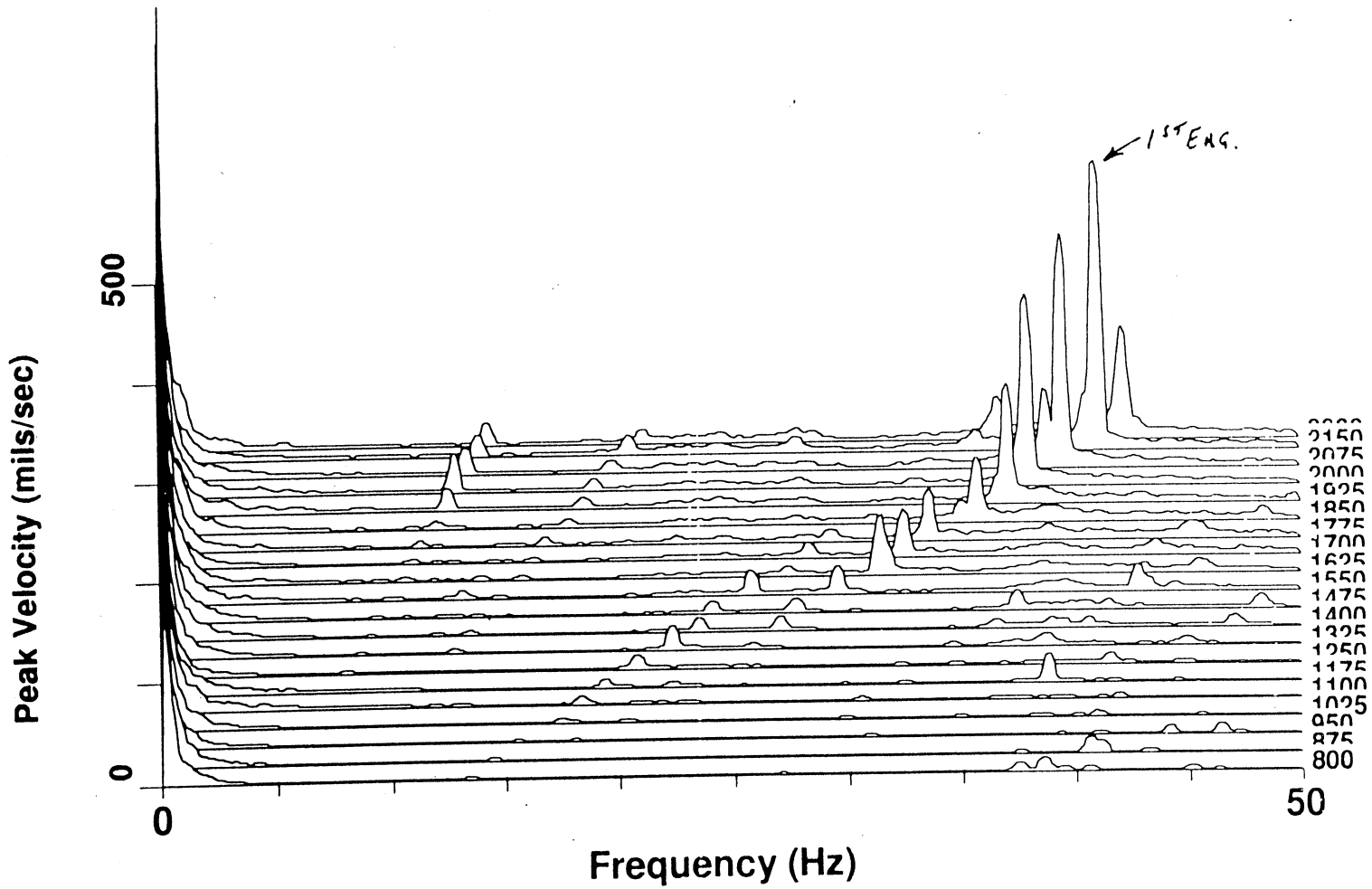
MCF, Control Cab, Lower Aft Port Corner, Athwartship



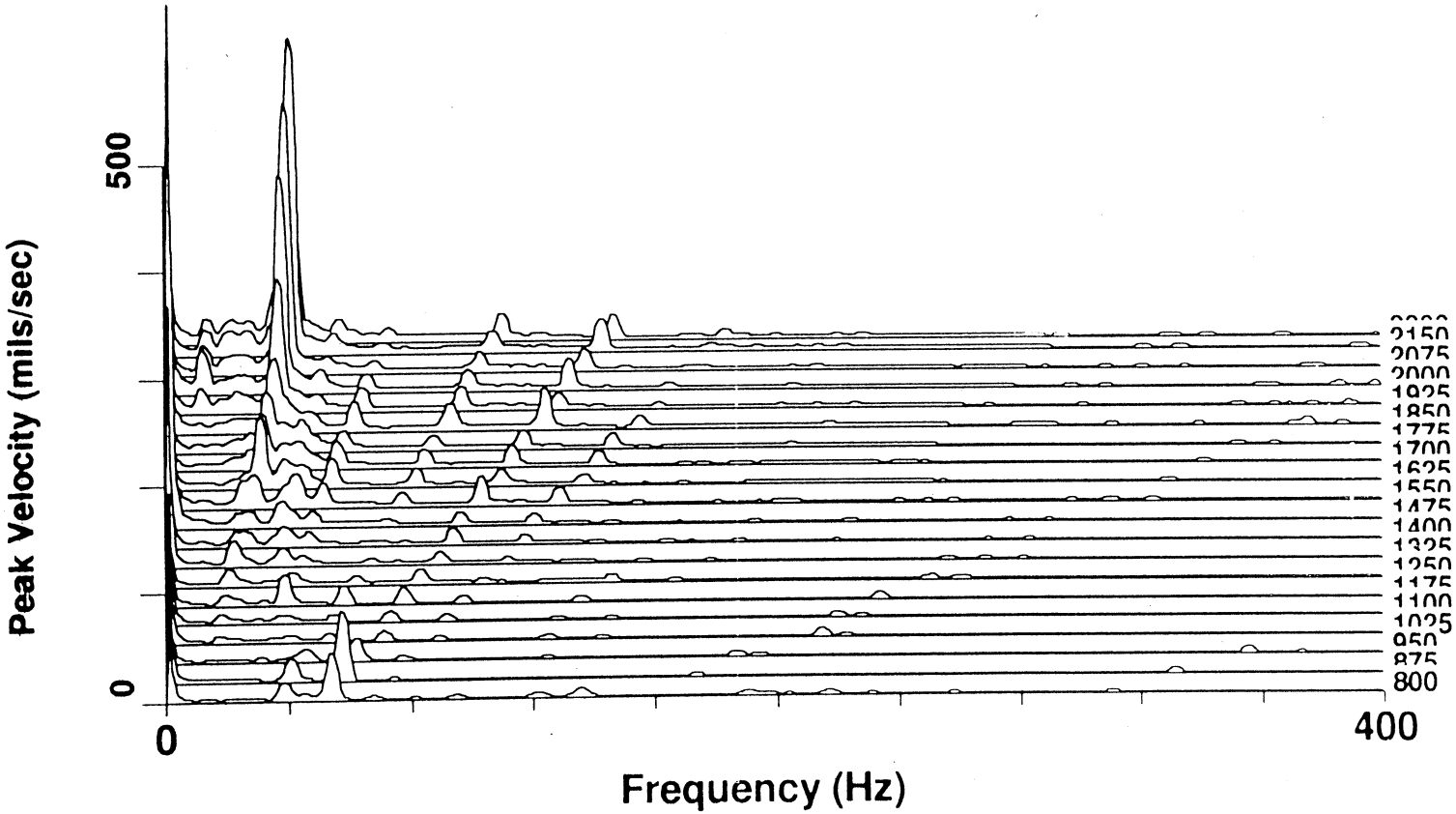
MCF, Control Cab, Lower Aft Port Corner, Athwartship



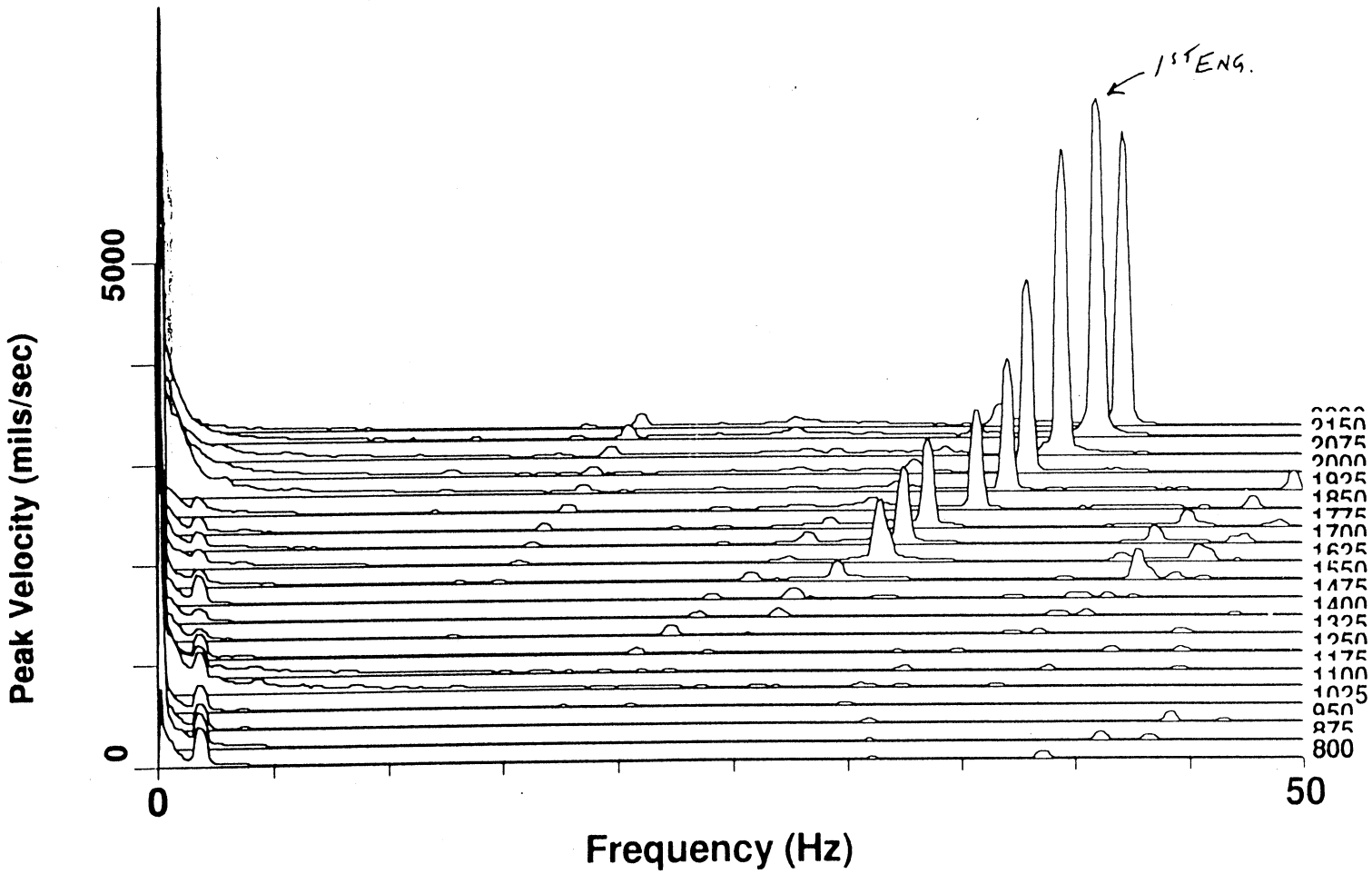
MCF, Top of Water Pump, Athwartship



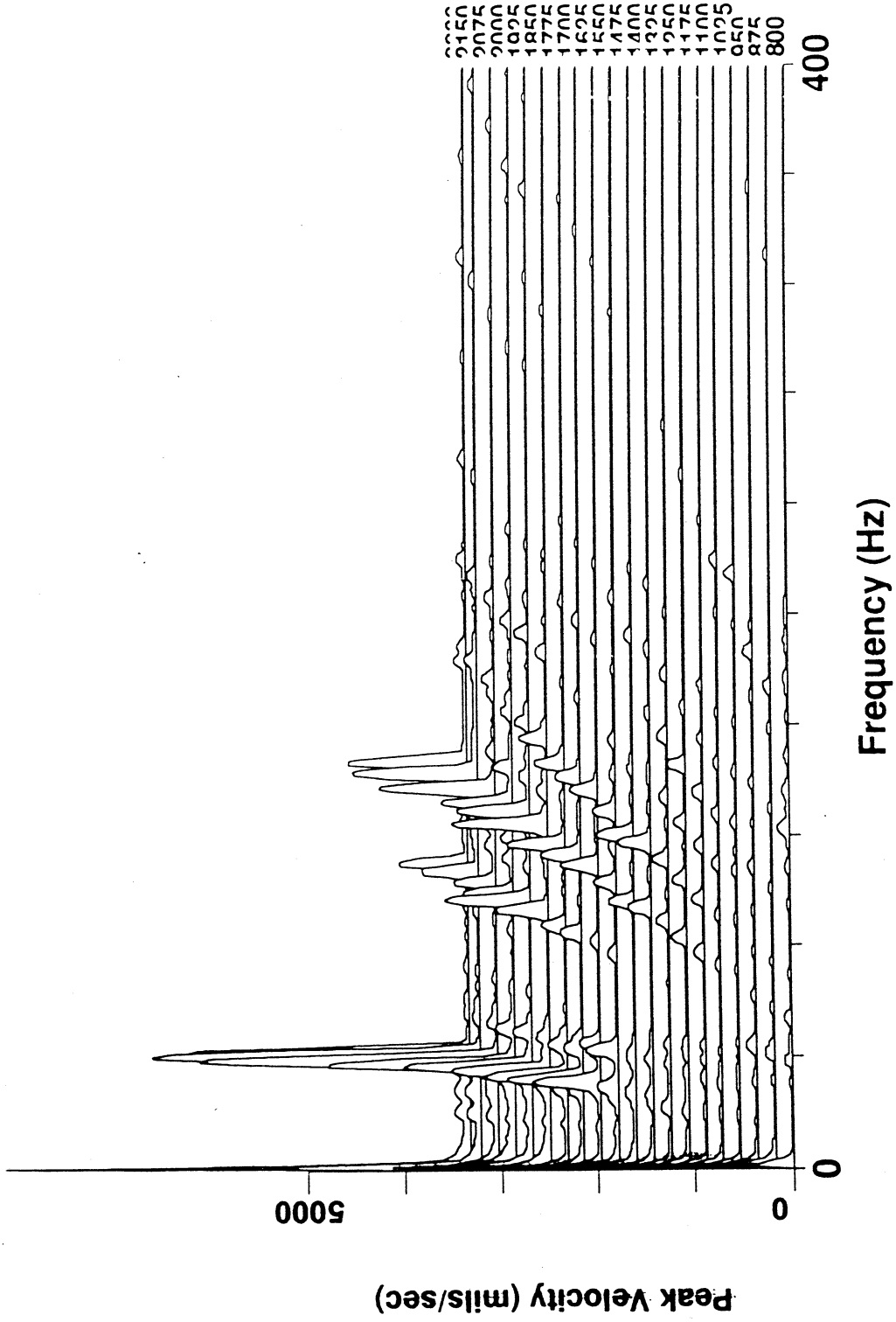
MCF, Top of Water Pump, Athwartship



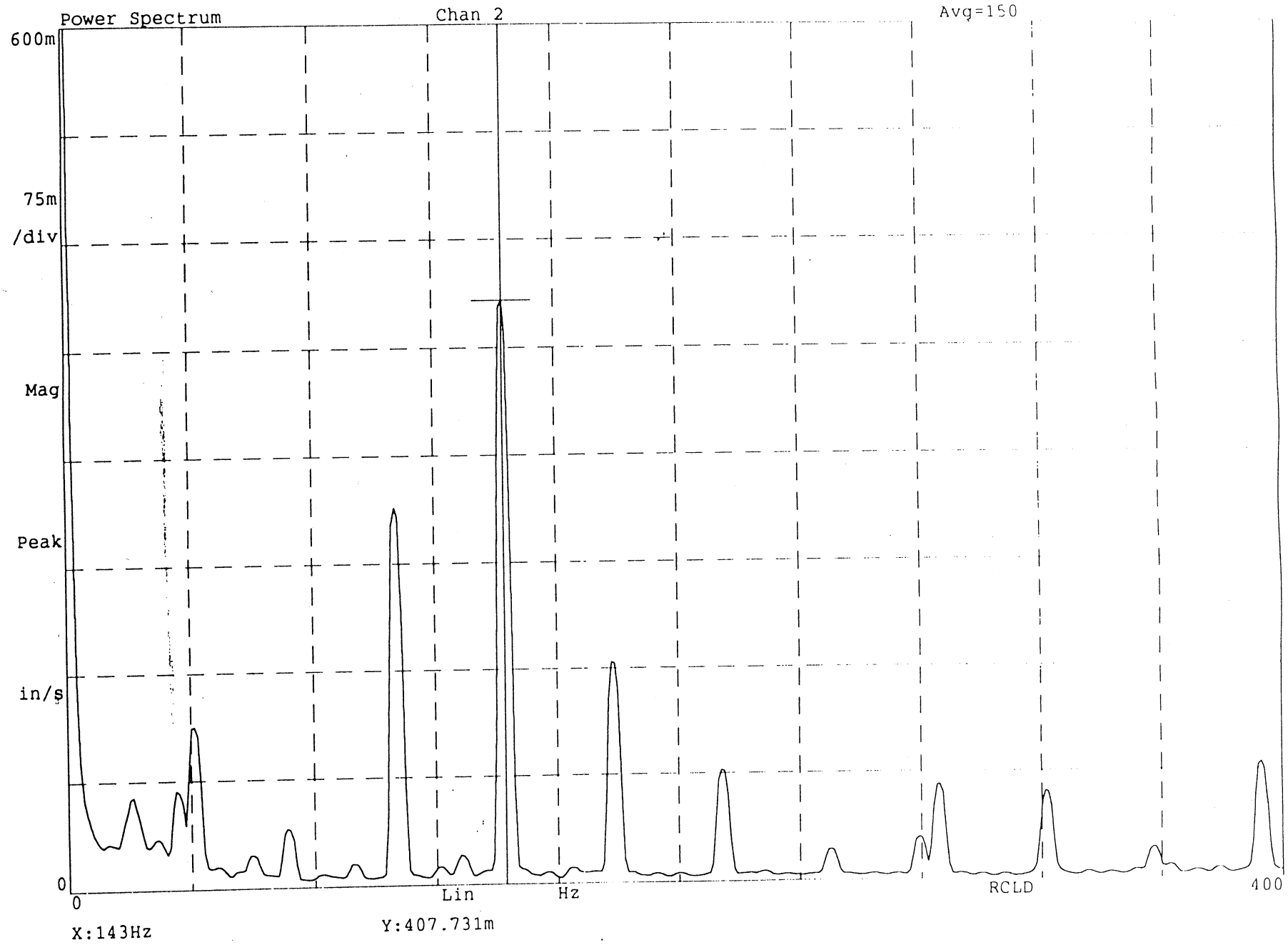
MCF, Top of Gear Box, Athwartship



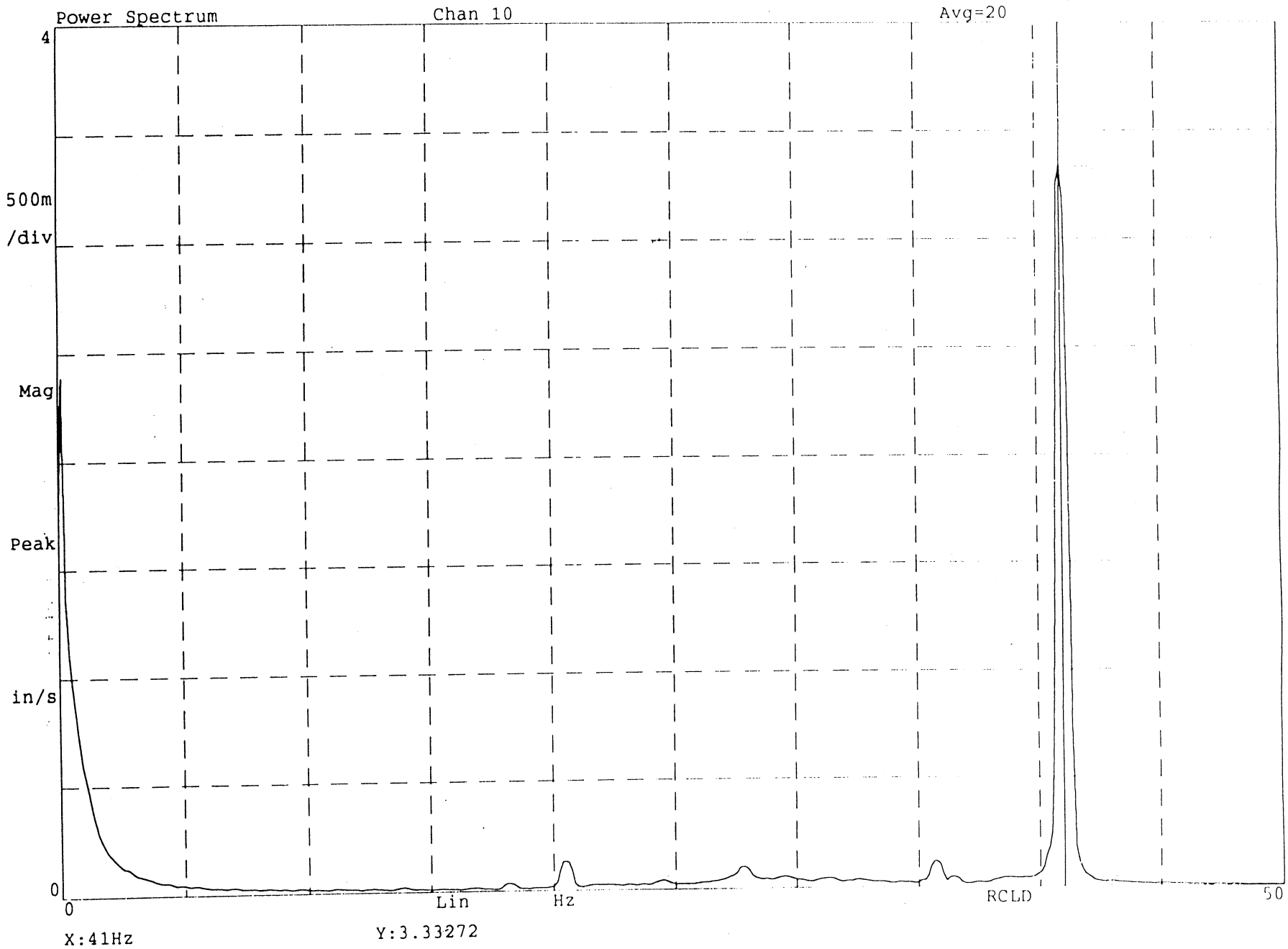
MCF, Top of Gear Box, Athwartship



MCF, 2150 RPM, Base of Engine, Vertical



MCF, 2150 RPM, Top of Gear Box, Athwartship

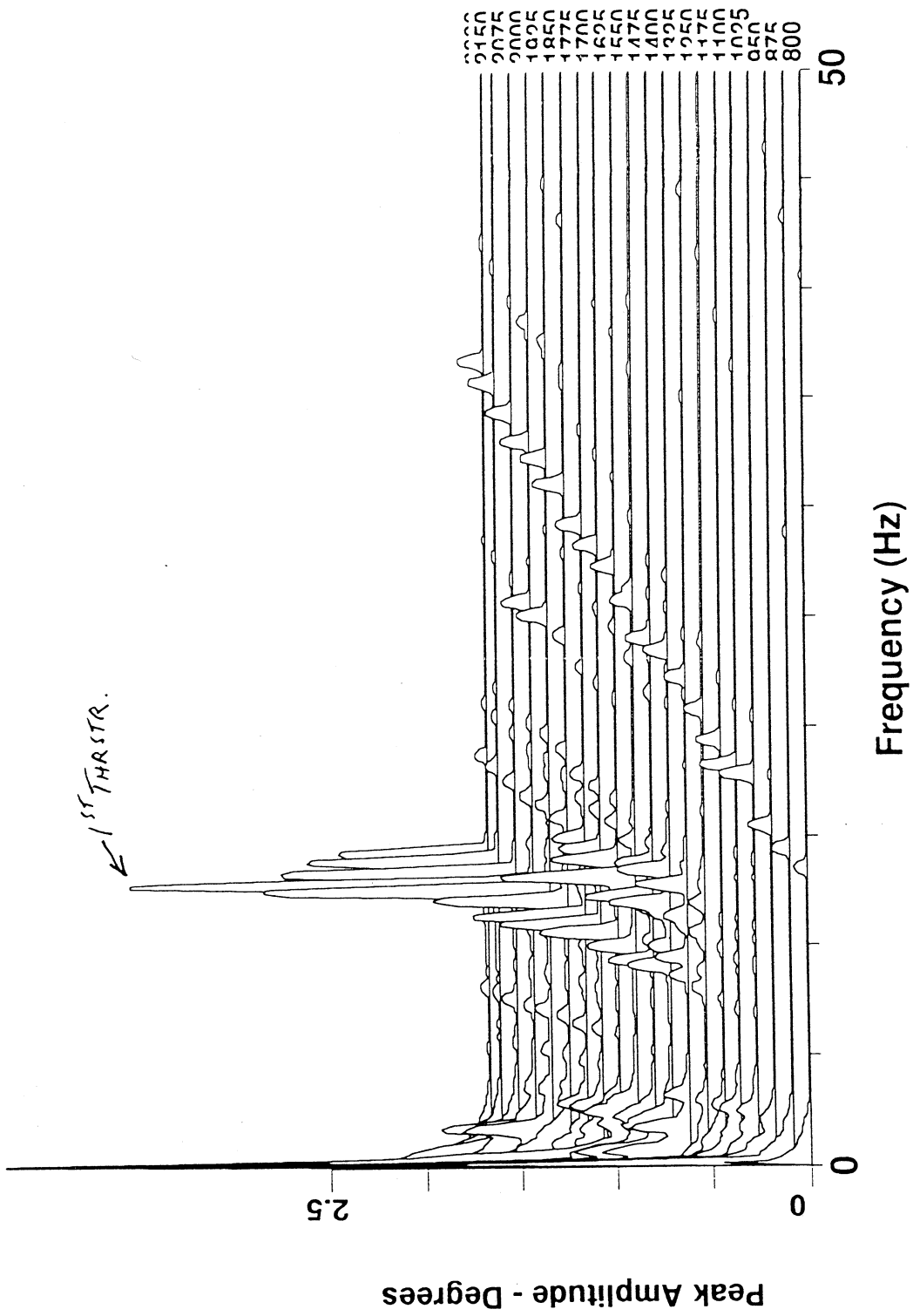


Appendix D

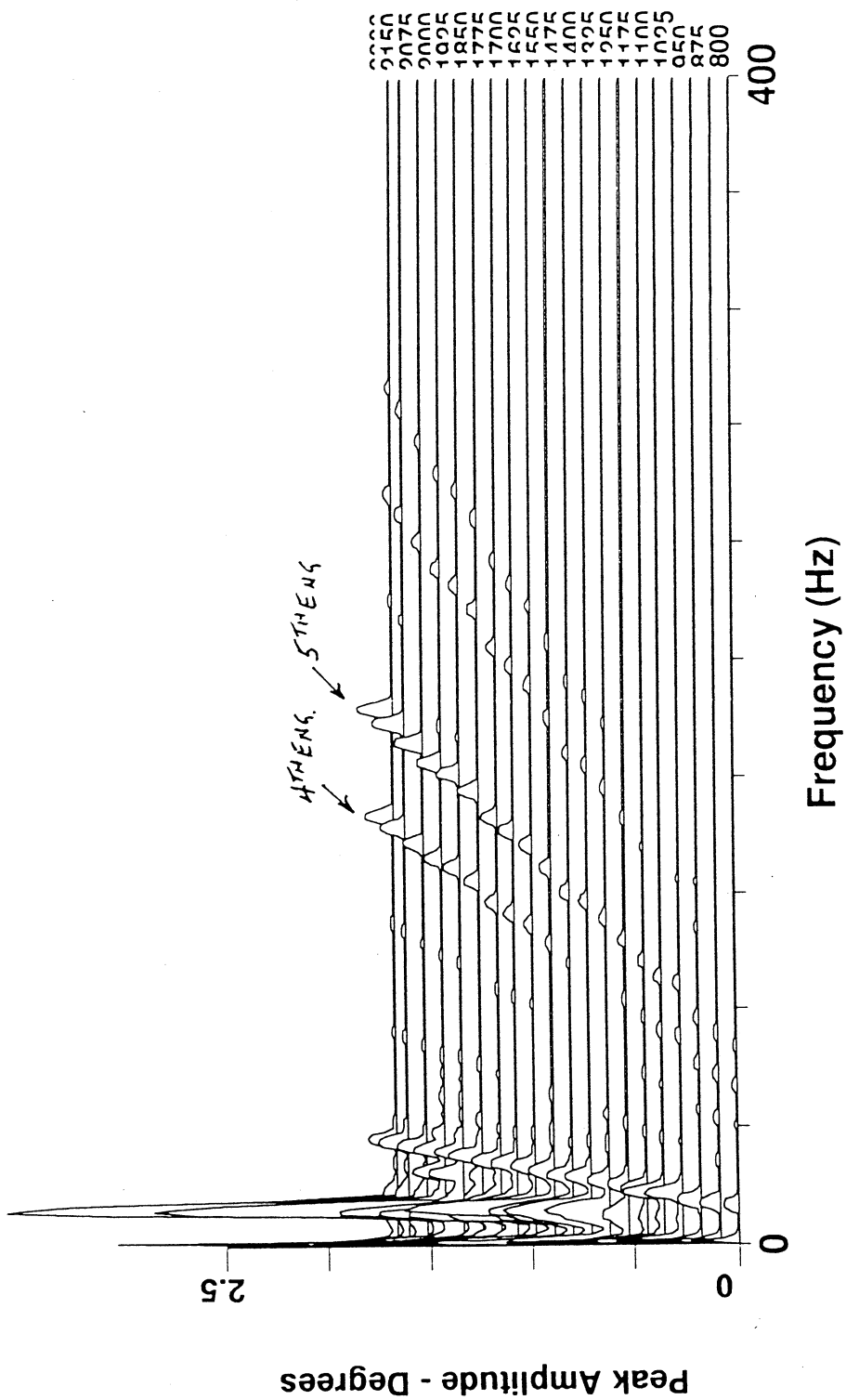
TORSIOGRAPH WATERFALLS AND SWEEPS

B960604

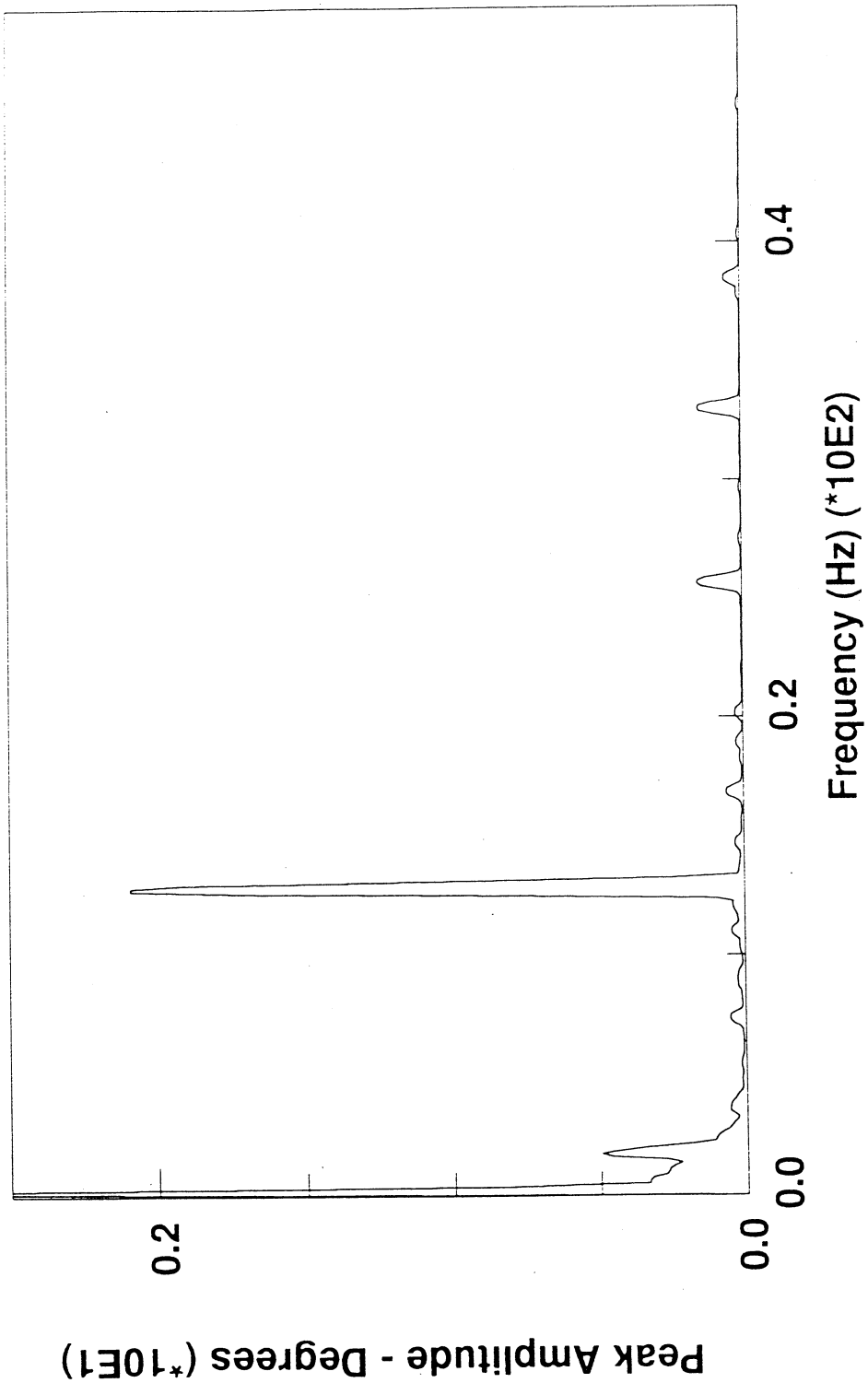
MCF, Main Engine Torsiograph(Corr, Int=1, Scale=57.2958)



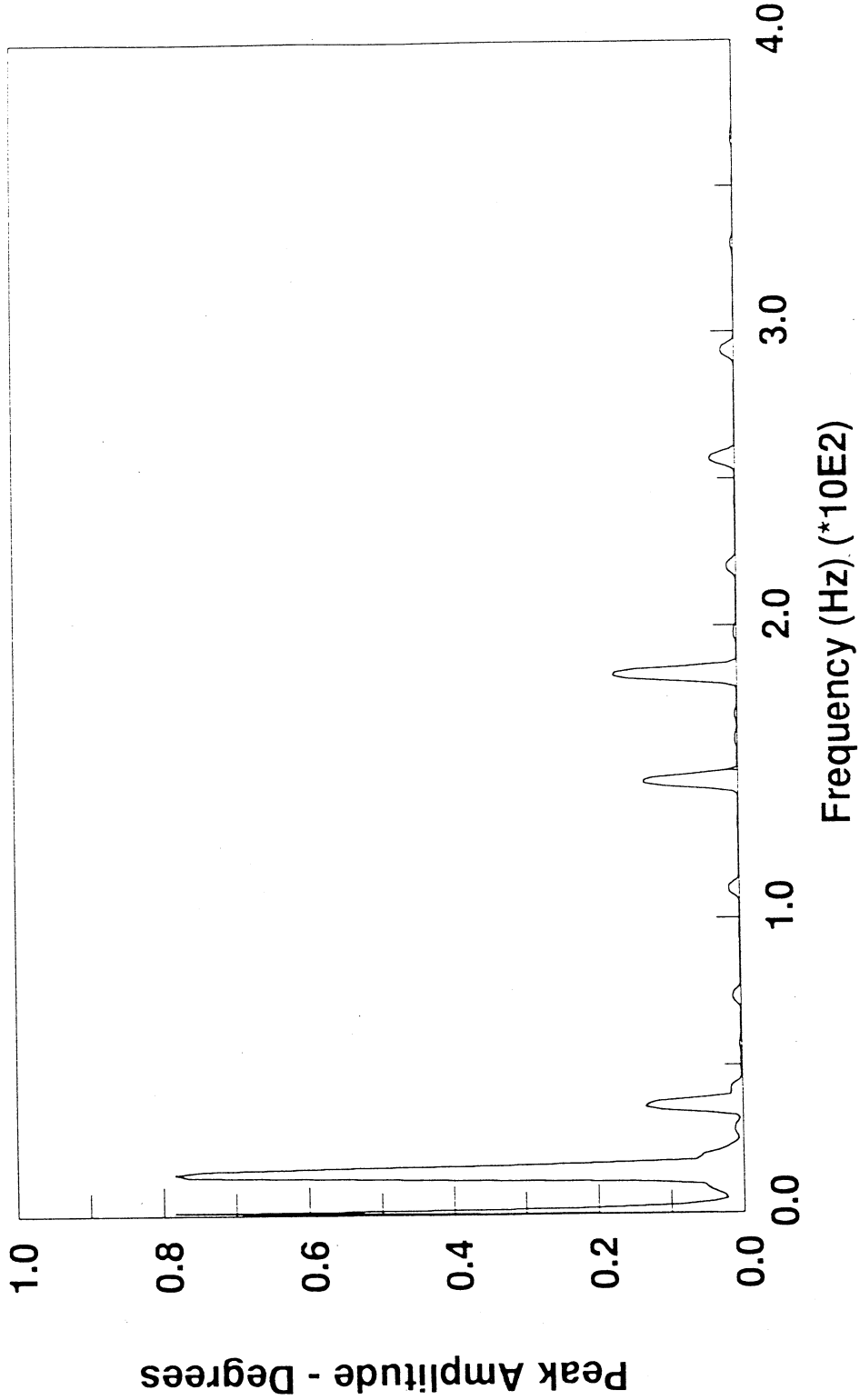
MCF, Main Engine Torsiograph(Corr, Int=1, Scale=57.2958)



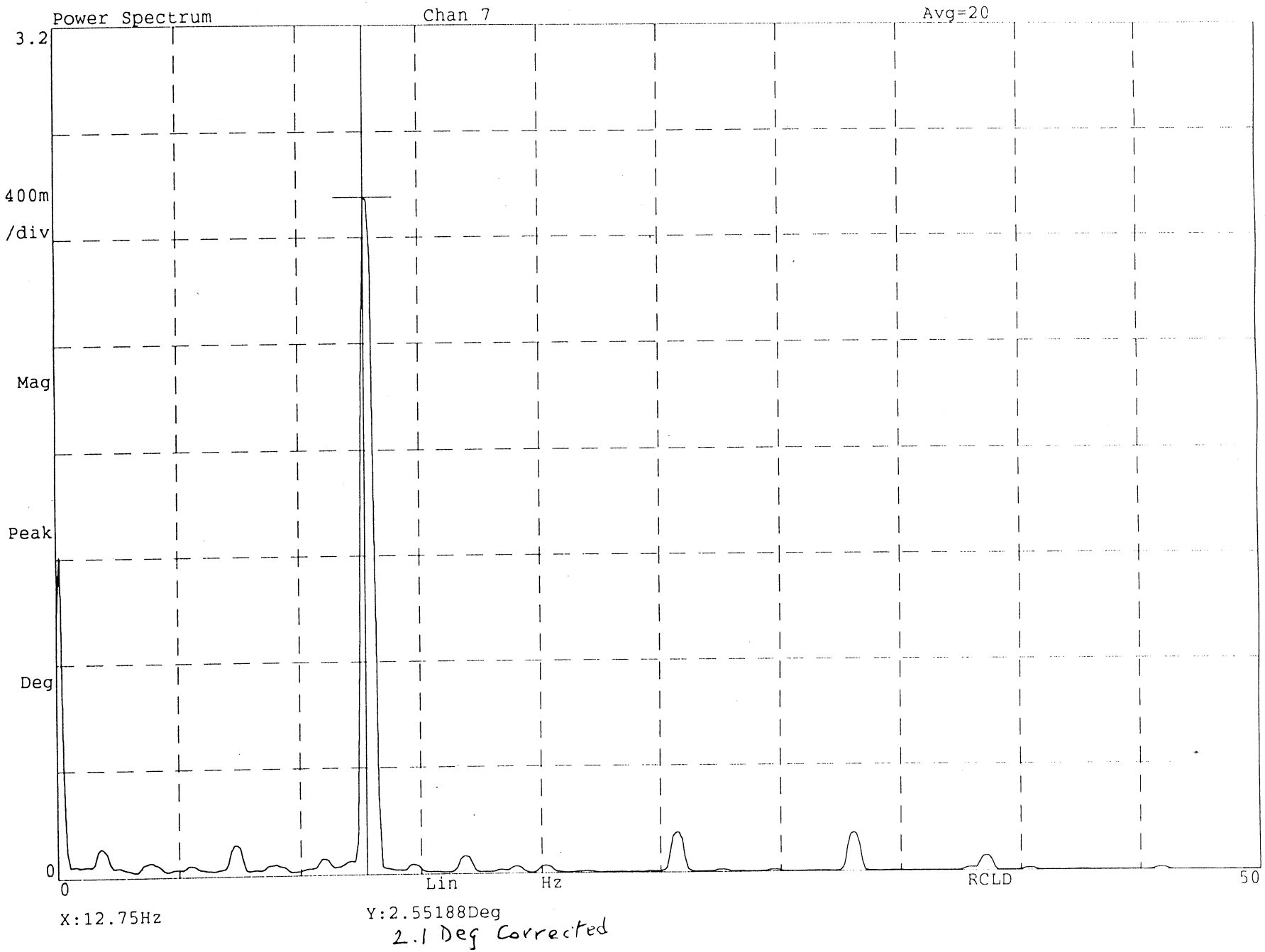
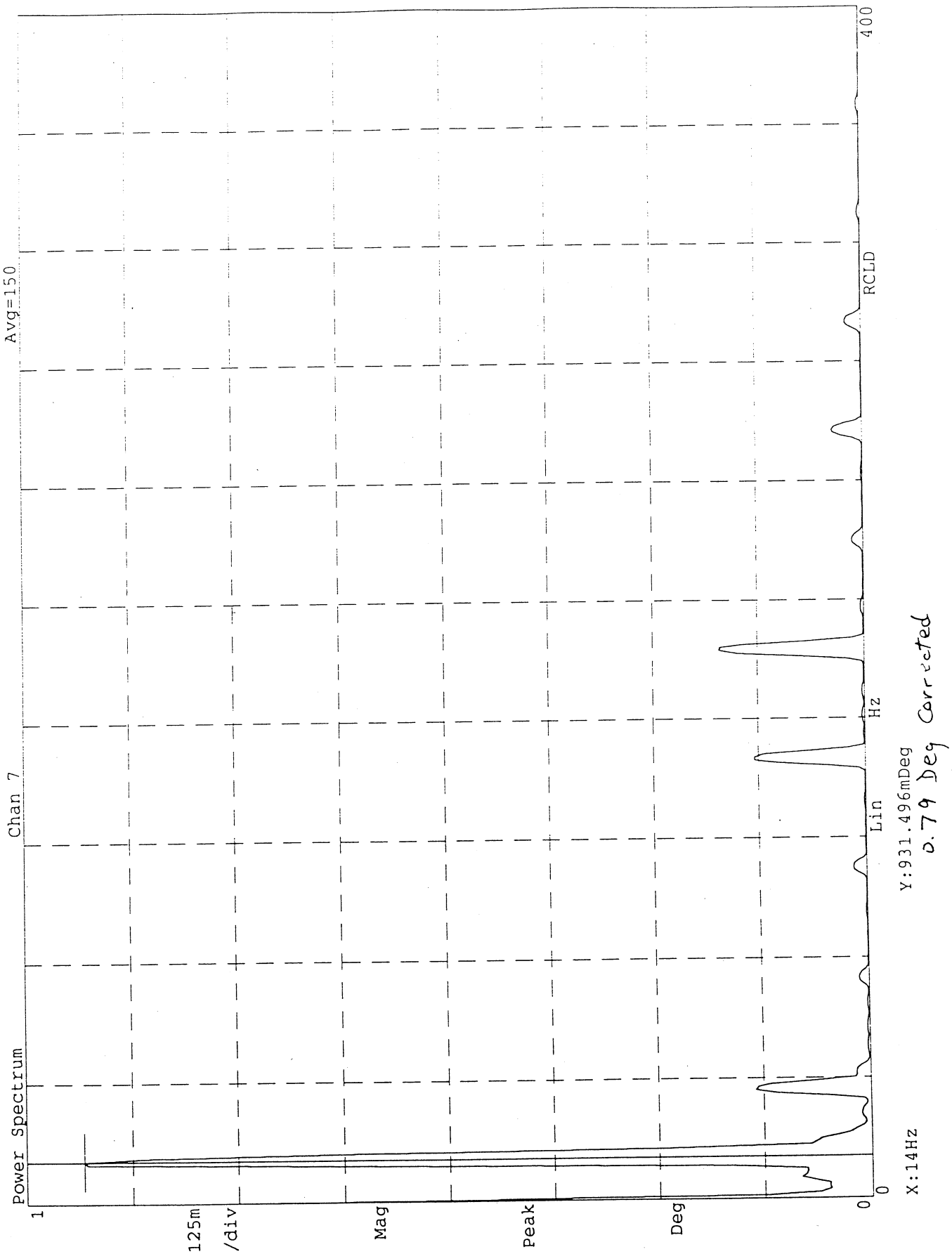
MCF, Main Eng Torsiograph
2000 RPM



MCF, Main Eng Torsiograph
2200 RPM



MCF, 2000 RPM, Main Engine Torsiograph (uncorrected)



MCF, 2200 RPM, Main Engine Torsiograph (uncorrected)