N91-20036

p. 30

1990 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

LOW FLOW VORTEX SHEDDING FLOWMETER FOR HYPERGOLICS/ALL MEDIA

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DATE:	August 10, 1990
CONTRACT NUMBER:	University of Central Florida NASA-NGT-60002 Supplement: 4

SUMMARY

Current turbine type flowmeters have been used to measure the loading of hypergolics into the Space Shuttle Orbiter. Because of the problems associated with the refurbishment of these meters after each launch, NASA has considered the development of a vortex shedding flowmeter without internal moving parts. The objective of the current project was to test an existing vortex shedding prototype for 1/2" outside diameter pipe and to develop a family of vortex shedding flowmeters for larger line sizes and flow ranges.

In order to test the meter for the flow of Freon 113, which is similar to hypergols, a flow test loop was designed and built. A series of tests were performed on the existing vortex shedding flowmeter to evaluate its output characteristics. Results of the tests indicated a linear relationship between vortex shedding frequencies and flow rates.

A family of vortex shedding flowmeters for larger sizes of 3/4", 1", 1 1/2" and 2" with three different geometries for the shedder bar, were designed and submitted to the prototype shop for fabrication. Test runs on this family of vortex shedding flowmeters are scheduled for next summer.

ACKNOWLEDGEMENTS

I would like to thank all members of the Transducer Section for their help during my tenure of this summer project. I am grateful to **Bob Howard** for his encouraging words which brought me to the Kennedy Space Center and his strong support toward my research endeavour. I also would like to thank **Dr. Loren A. Anderson** and **Dr. Mark A. Beymer**, Directors of the NASA/ASEE Summer Faculty Fellowship Program, for their assistance and hospitality which make my days at KSC very educational and enjoyable.

ABSTRACT

The purpose of this summer project was to further develop a family of vortex shedding flowmeters for flow measurement of hypergols that requires a long term operation without removal from system lines. A family of vortex shedding flowmeters without moving parts have been designed. The test loop to evaluate the meters for the Freon flow which simulates the hypergolic fluids, has been modified and reconstructed. Preliminary results were obtained on the output frequency characteristics of an 1/2" flowmeter as a function of the flow rate.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.1 STATEMENT OF PROJECT NEEDS.

During the loading of hypergolic fuels and oxidizers, flow meters are used to measure the amount of fluid. The current method of metering these fluids involves turbine type meters and shuttle-ball type vortex shedding meters. One of the problems that occurs with these meters is that after each launch the meters have to be taken apart and refurbished then recalibrated. The reason for this process is that there are moving parts of the meters in contact with the flowing fluid. Figure 1.1 shows a typical turbine flowmeter. The bushings and bearings of these meters are susceptible to wear, especially during the purge phase of fuel loading process when severe over speeds of the rotor occur due to gas flow through the lines. The process of refurbishment of the meters is costly due to the techniques required to handle the very toxic hypergols. It is estimated that a saving of about $1000 per flowmeter per launch can be made if the meters do not require this maintenance. There are about 6000 flowmeters of all sorts on the Space Shuttle.

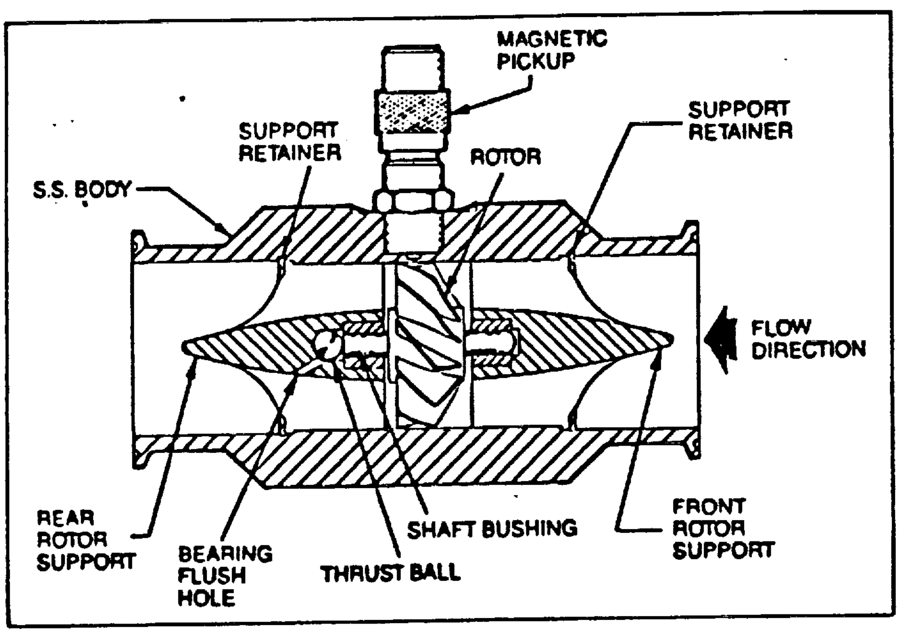


Figure 1.1 EXAMPLE OF A TURBINE FLOWMETER

1.2 OBJECTIVE OF THE PROJECT.

The objective of this project is to develop a family of vortex shedding flowmeters for applications that require long term operation without removal from system lines. This family of vortex shedding flowmeters would have no moving parts. The linearlarity between the frequency and the flow rate would be as close as that of the turbine type. The flowmeters could be installed permanently after the initial calibration and only the signal conditioner would be removed for calibration. This procedure would not affect the totalcalibration accuracy of the meter.

II. VORTEX SHEDDING FLOWMETERS

2.1 BACKGROUND OF VORTEX SHEDDING PHENOMENA.

The phenomenon of vortices being shed from a surface in a flowing fluid is not new, and the application of the vortex shedding to the measurement of flowrate is well established.

For an uniform flow past a circular cylinder, vortices are formed at the two separation points and shed off regularly in an alternating fashion, as shown in figure 2.1. These vortices move downstream in a regular pattern. Von Karman did the initial analysis of the stability of vortex trail behind a cylinder. According to his analysis, a stable vortex pattern must have a geometry such that

$$h/l = 0.281 \qquad (1)$$

where h and l are the linear dimensions.

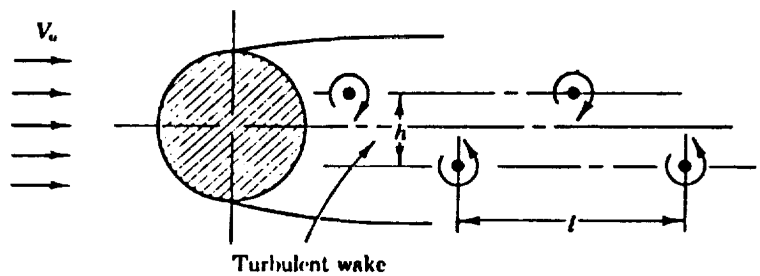


Fig. 2.1. VON KARMAN VORTEX TRAIL

The vortices move downstream with a velocity u which is less than the mainstream velocity U. Von Karman derived the following formula for calculating the drag force per unit length of the cylinder:

F = Rho*U**2*h*(2.83*(u/U)**2-1.12*(u/U)**2) (2)

where U is the velocity of the freestream, h and u are determined from experimental measurements, Rho is the density of the fluid.

The alternating shedding of vortices from the separation points on the surface of a circular cylinder produces transverse forces on the cylinder and causes the cylinder to oscillate. Such effects were first studied in the laboratory about 1878 by Strouhal, who showed that the vibrations would cause the sound to transverse to the fluid. He also showed that the frequency f of the vibration was related to the air speed U and the cylinder diameter d by the approximate equation:

$$f = U/6d \qquad (3)$$

Vortex shedding flowmeters work on the principle that the frequency of the vortex shedding behind a bluff body is proportional to the fluid velocity past that body as shown in Figure 2.2.

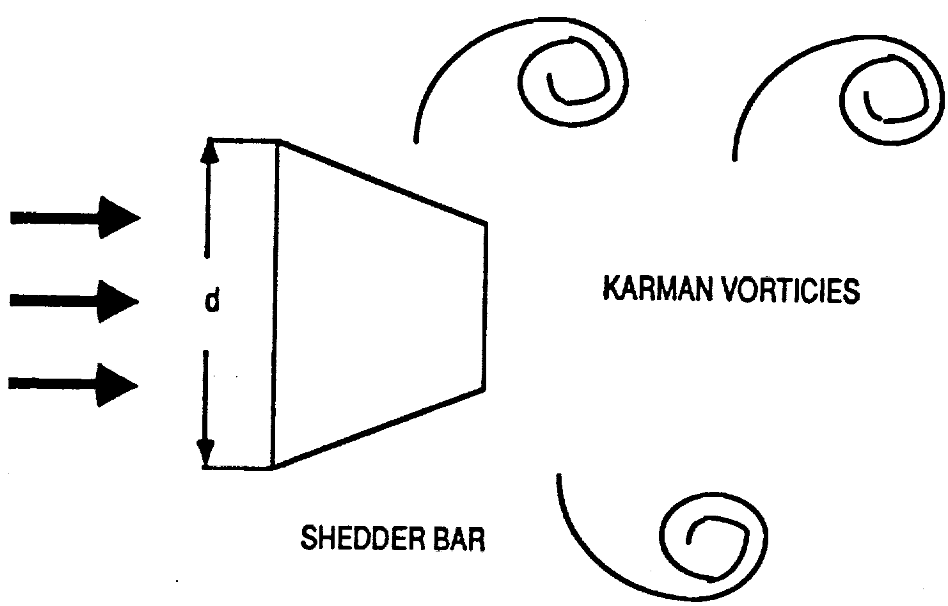


Figure 2.2 VORTEX SHEDDING PHENOMENON

The proportionality constant or the relationship between the vortex shedding frequency and velocity of the uniform flow is called the Strouhal number which is related to the vortex shedding frequency in the following equation:

$$f = St^{*}U/d^{*}(1\text{-}20/Re) \qquad (4)$$

where:

f Vortex shedding frequency, Hz
St Strouhal number
U Fluid flow velocity, ft/sec
d Characteristic dimension of bluff body, ft
Re Reynolds number of pipe flow

Equation (4) can be simplified if the ratio 20/Re is assumed negligible:

$$f = St^{*}U/d \qquad (5)$$

or

$$St = f^{*}d/U \qquad (6)$$

2.2 DESIGN OF THE PROTOTYPES.

Figure 2.3 shows the design for an one-inch vortex shedding flowmeter with a rectangular shedder bar. The meter was scaled down to 1/2", 3/4" and up to 1 1/2" and 2" models. The prototypes were designed to use the same pressure transducer type to simplify the testing procedures. With 3 different types of shedder bar which will be mentioned in the next section, there will be 15 different flowmeter models to study experimentally.

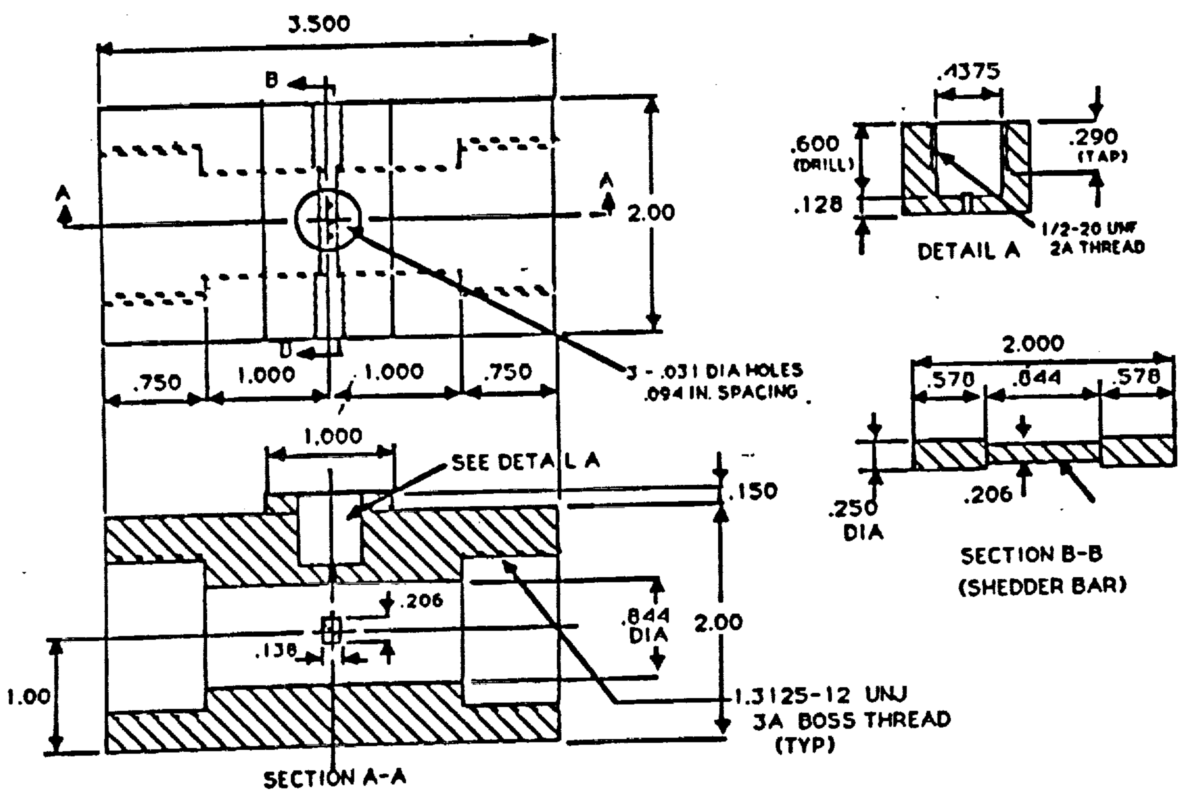


Figure 2.3 ONE-INCH VORTEX SHEDDING FLOWMETER

The geometry of the shedder bar determines the characteristic of the frequency of vortices. Three shapes for the shedder bar were selected for this study. They are circle, rectangular, and reversed wedge as shown in following figure 2.4.

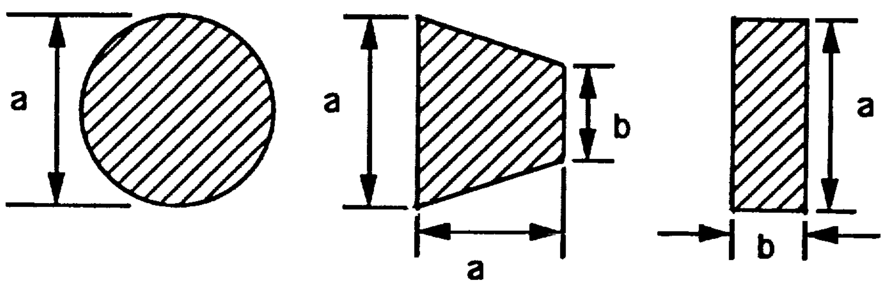


Figure 2.4 SHEDDER BAR GEOMETRY

Table 2.1 shows the geometrical dimensions of the flow meter components related to the flow field as well as the shedder bar dimensions.

TABLE 2.1

SHEDDER BAR DIMENSIONS

FLOWMETER (O.D)	1/2"	3/4"	1"	1 1/2"	2"
I.D (in.)	.410	.609	.844	1.312	1.781
a (in.)	.110	.170	.235	.367	.500
b (in.)	.075	.115	.155	.245	.335

III. EXPERIMENTAL STUDY

3.1 INTRODUCTION

The basic goal of the project were to design and construct a flow bench to test a family of vortex shedding flowmeters. The prototype flowmeters have been designed and the development stage will follow. The test considered in this section is on an existing KSC modified prototype for 1/2" O.D. pipe. Freon 113 (Trichlorotrifluoroethane) is the working fluid. Freon was chosen because it has similar properties to the hypergolic fluids which will be metered by the flowmeter considered in this project.

3.2 FLOW BENCH DESIGN

The flow bench to test the family of vortex shedding flowmeters has been designed using the existing set up to measure the 1/2" KSC prototype flowmeter.

The existing flow loop is shown schematically in figure 3.1. The test section in which the flowmeters are located have been modified to accommodate all the pipe sizes of the flowmeters. Two 50-gallon dewars were used as containers for the freon fluid. Dewar #1 was located inside the laboratory and was placed on a load platform used to measure the mass flow rate of Freon 113. Dewar #2 was located outside of the laboratory window and was connected to the flow loop through the window. By proper adjustment of the valve system Freon 113 could flow through the loop from either dewar. High pressurized nitrogen gas was used to vent Freon from one dewar through the test section into another dewar. The quantities measured in the loop include the output signals from the turbine flowmeter used as a reference, from the vortex shedding flowmeter under test, from the pressure transducers at various locations in the test loop, and from the load cell transducers installed under Dewar #1. The vortex flowmeter output signals were detected by a Kistler transducer (model 206). The Kistler transducer was a piezoelectric type of device and came with a Kistler signal coupler (model 5116) which could produce an AC coupled

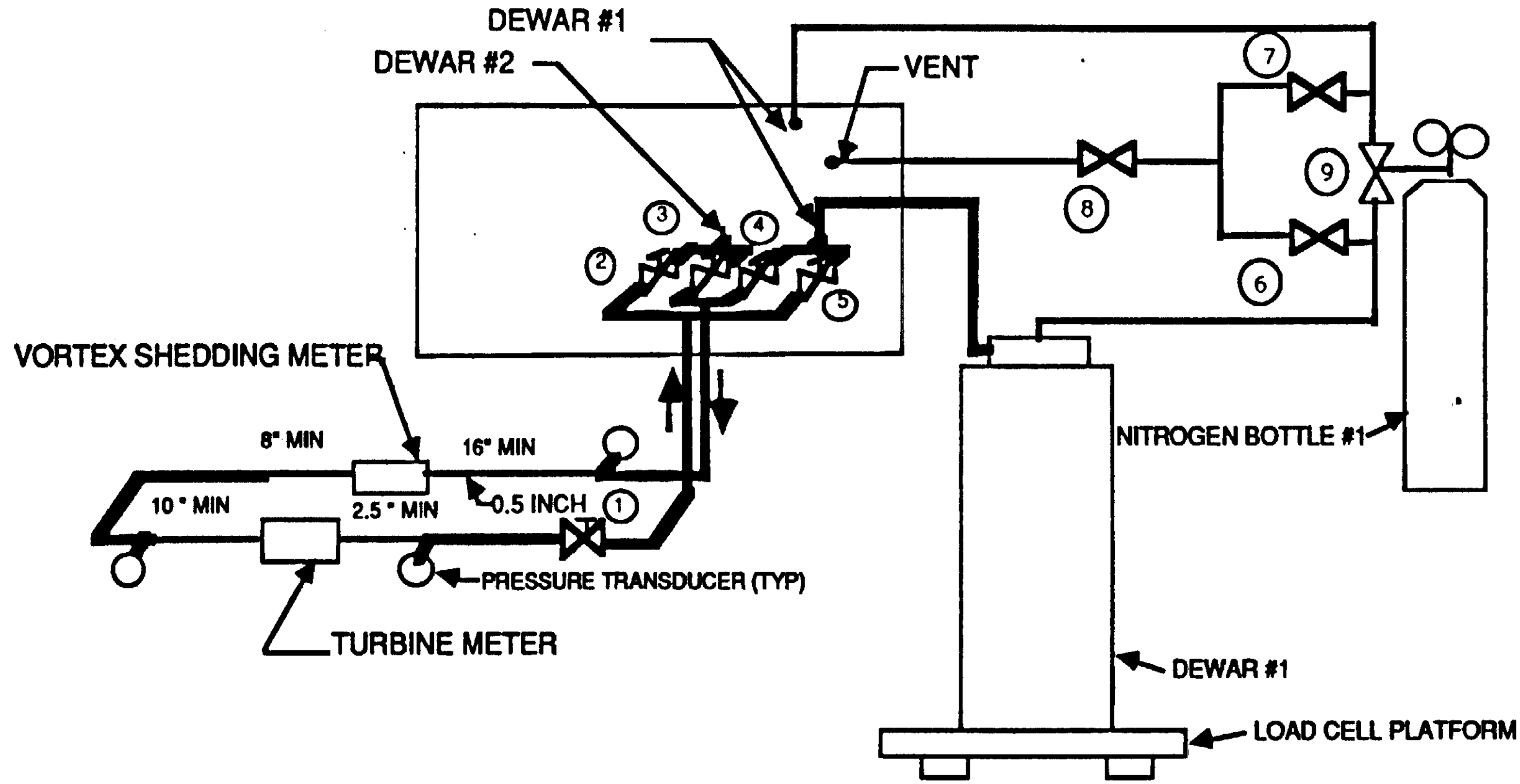


Figure 3.1 FLOW TEST SCHEMATIC

millivolt output proportional to pressure fluctuations. A Philips oscilloscope PM3320A was used to analyze the pressure fluctuations. The frequency of the vortex shedding was then obtained.

3.3 1/2" FLOWMETER TEST

One of the goals for this summer project was to study experimentally the existing 1/2" vortex shedding flowmeter to obtain some characteristic data using the turbine meter as a reference. To vary the flow rate, more or less pressure was applied to the Freon dewar using the three-way valve connected to Nitrogen Bottle #1. Steady flow was indicated by a steady output reading from the calibrated turbine meter in series with the vortex meter. The turbine meter output consists of a voltage from the signal conditioner which is linearly proportional to the flow rate. The calibration curve relating gallons per minute (GPM) and frequency in Hz to output voltage are shown in Figure 3.2, 3.3 and Appendix A.

The output from the vortex shedding flowmeter was analyzed using the Philips oscilloscope PM33204. The output signal from the Kistler pressure transducer was clearly picked up on the oscilloscope and the frequency results were easily obtained. The oscilloscope used had a storage capability which permitted a freeze on the trace for easy pulse counting and frequency determination.

The measurement of pressures and temperatures at various locations in the flow loop were also needed. However, only one pressure reading at the inlet of the flowmeter was obtained at this time. A thermocouple will be used to determine the temperature Freon in the flowmeter.

Mass flow rate measurements were also taken for three conditions. The output data was read from three Dynasco pressure transducers which were connected to three Lebow load cells. The Freon dewar #1 was placed on a load platform which in turn was placed on the three Lebow load cells. Results of the mass flow rate measurement were tabulated and shown in Appendix B.

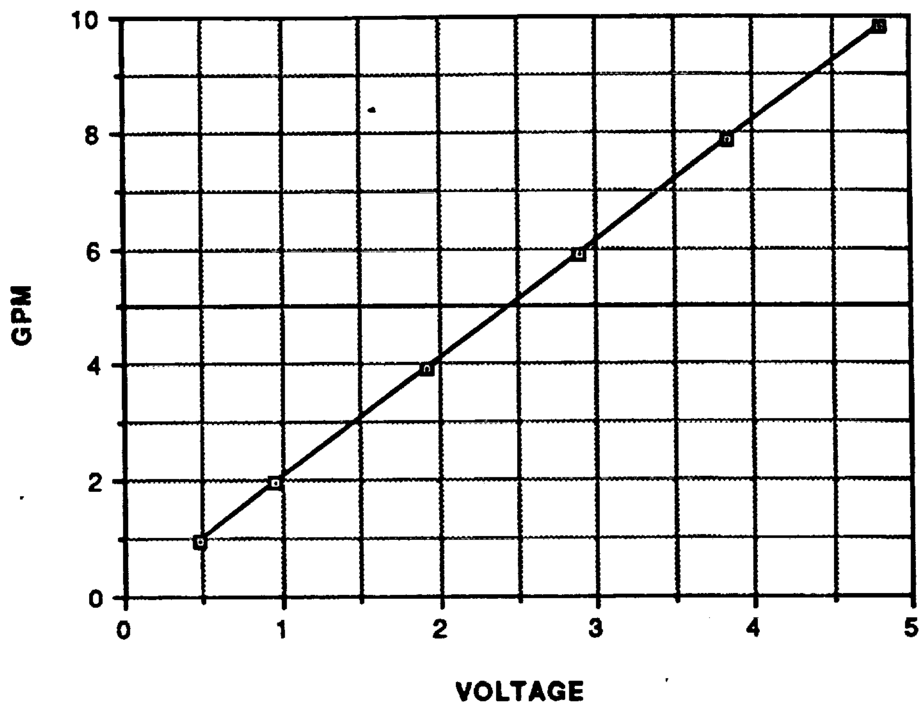


Figure 3.2 TURBINE FLOWMETER CALIBRATION, V vs Q

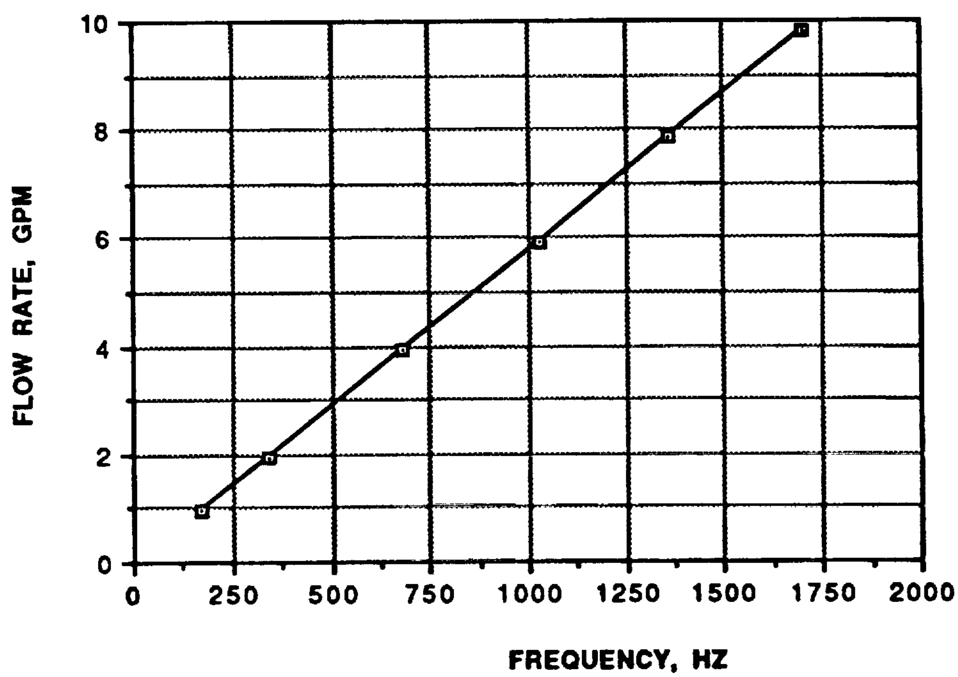


Figure 3.3 TURBINE FLOWMETER CALIBRATION, Q vs FREQ.

3.4 RESULTS AND DISCUSSION

The experimental results consist of a determination of the vortex shedding frequency versus flow rate which was interpreted from the calibration curve of the turbine flow meter. Test results for the 1/2" KSC flowmeter are shown in Appendix C. As can be seen from Figure 3.4, the relationship between vortex frequency and flow rate is linear. The Kistler pressure transducer and the Philips oscilloscope produced excellent output signals which help make the analysis simple. Appendix D shows the pressure pulses recorded on the oscilloscope screen and plotted with an HP ThinkJet printer. The frequency of the vortex shedding was analyzed and appeared on the output screen.

Table 3.1 shows the average frequency from 2 test cases and the corresponding mass flow rate interpolated from the turbine flowmeter calibration. The Reynolds number and the Strouhal numbers as well as the velocity of the Freon flow were also calculated.

The calculated mass flow rate of Freon 113 compared well with measured results (Appendix C) within a 5% discrepancy. This discrepancy would be less if one Dynasco transducer was connected to read the total mass from the three separate readings.

TABLE 3.1

TEST CASE RESULTS

Freq. (Hz)	Q (gpm)	Q (ft3/s)	m (lbm/s)	u (ft/s)	St	Re	Turb/Ref Voltage
164	2.032	.004526	.440	4.941	.277	360	1.0
241	3.058	.006811	.663	7.436	.270	540	1.5
332	4.083	.009094	.885	9.928	.279	725	2.0
387	5.104	.011367	1.106	12.409	.260	900	2.5
440	6.125	.013641	1.327	14.892	.246	1085	3.0
509	7.146	.015915	1.549	17.374	.244	1265	3.5

Density = 97.31 Lbm/ft3, Viscosity = .00142 Lbf-sec/ft2

Results shown on Figure 3.5 and 3.5 also indicate a linear relationship between the vortex shedding frequency and the Reynolds & Strouhal numbers.

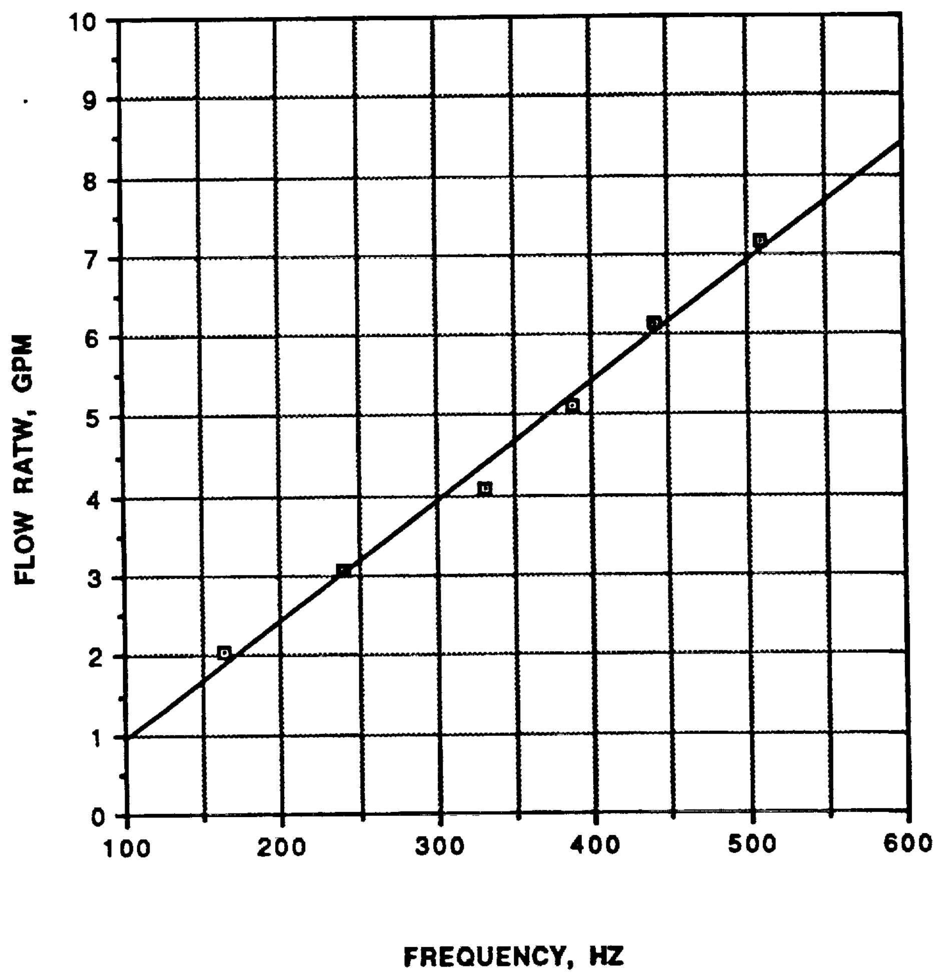


Figure 3.4 TEST RESULTS FOR THE 1/2" KSC MODEL

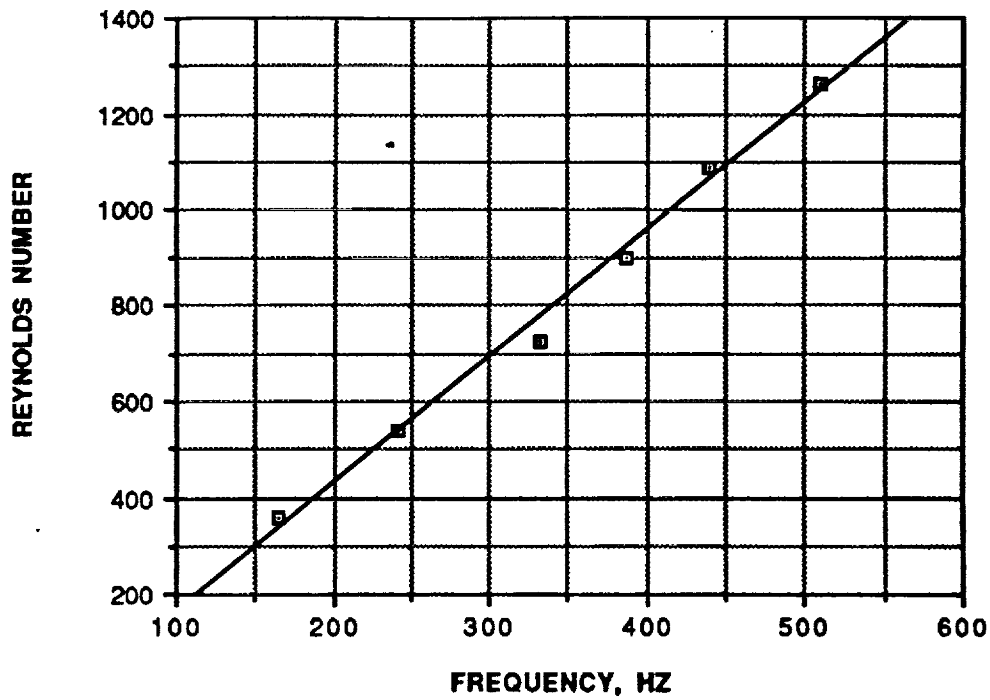


Figure 3.5 TEST RESULTS FOR THE 1/2" KSC MODEL RE vs FREQ.

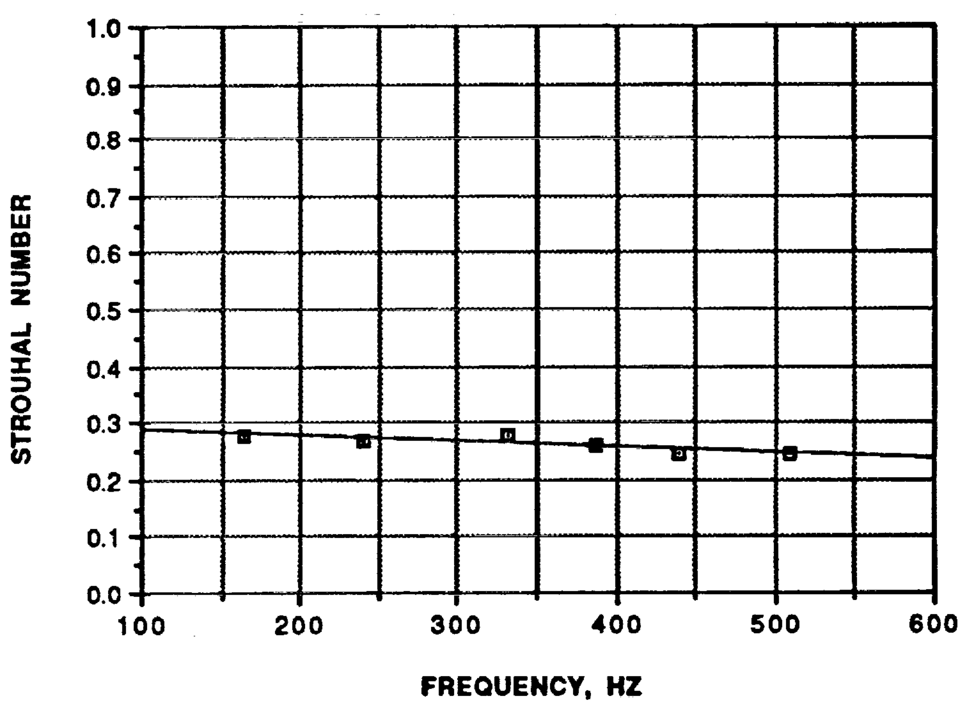


Figure 3.6 TEST RESULTS FOR THE 1/2" KSC MODEL ST vs FREQ.

IV. CONCLUSION AND RECOMMENDATION

Preliminary test results on the 1/2" model suggested that the vortex shedding flowmeter is a possible replacement for the turbine flowmeter which has been used to measure the loading of hypergols into the space shuttle. A family of vortex shedding flowmeters with various shedder bar shapes have been designed and fabricated. More experimental work have been scheduled for next summer.

The existing flow bench is adequate for the models with 1/2", 3/4" O.D.; however for the models with 1", 1 1/2" and 2" O.D. where more mass flow rate is needed, a new flow bench design will be required. It is suggested that a system which consists of a pump to circulate the Freon flow, be utilized for all models.

APPENDIX A

TURBINE FLOWMETER CALIBRATION

Nominal %F.S.	Flowrate GPM	Frequency Hz	K Factor Observed	Endpoint Line GPM
10	0.95	166.67	10571.036	0.95
20	1.95	340.48	10503.239	1.95
40	3.92	681.83	10436.173	3.92
60	5.90	1024.80	10430.534	5.90
80	7.84	1359.70	10412.508	7.84
100	9.82	1703.00	10402.117	9.82

APPENDIX B

MASS FLOW RATE MEASUREMENT

Turbine Flowmeter Voltage	2.0	3.0	3.8
#1 Pres. Gage	206.-167.	250.-190.	164.-145.
#2 Pres. Gage	198.-160.	238.-180.	154.-136.
#3 Pres. Gage	185.-151.	217.-166.	143.-127.
Time	120 sec.	120 sec.	30. sec.
Mass Flow Rate	.925 Lbm/s	1.409 lbm/s	1.767 lbm/s

APPENDIX C

TEST DATA FOR THE KSC 1/2" MODEL

TEST RUN 1

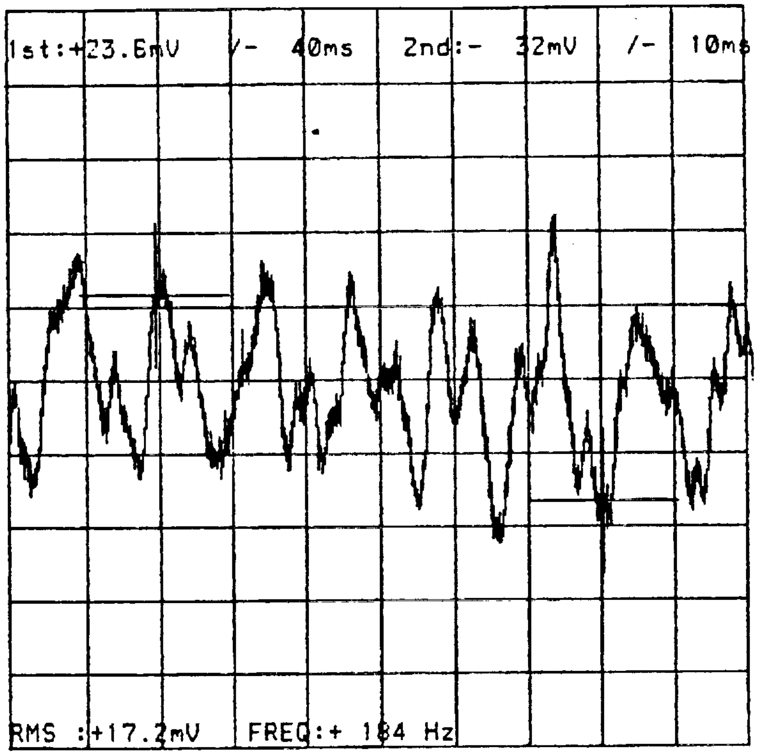
Turbine flowmeter as Reference Voltage (Volts)	Vortex Shedding flowmeter Voltage (Volts)	Vortex Shedding flowmeter Frequency (Hz)
1.00	.55	184
1.50	.70	230
2.00	.91	318
2.50	1.13	372
3.00	1.35	439
3.50	1.56	539

TEST RUN 2

Turbine Flowmeter	Tank	Vortex Shedding Flowmeter		
Voltage (Volts)	Pressure (psi)	Voltage (Volts)	Freq. (Hz)	Inlet Pressure (psi)
1.00	60	.60	144	55.70
1.50	65	.70	211	58.50
2.00	75	.85	345	60.00
2.50	85	1.08	402	58.60
3.00	90	1.15	441	58.40
3.50	120	1.50	478	66.00

APPENDIX D

PRESSURE PULSES RECORDED



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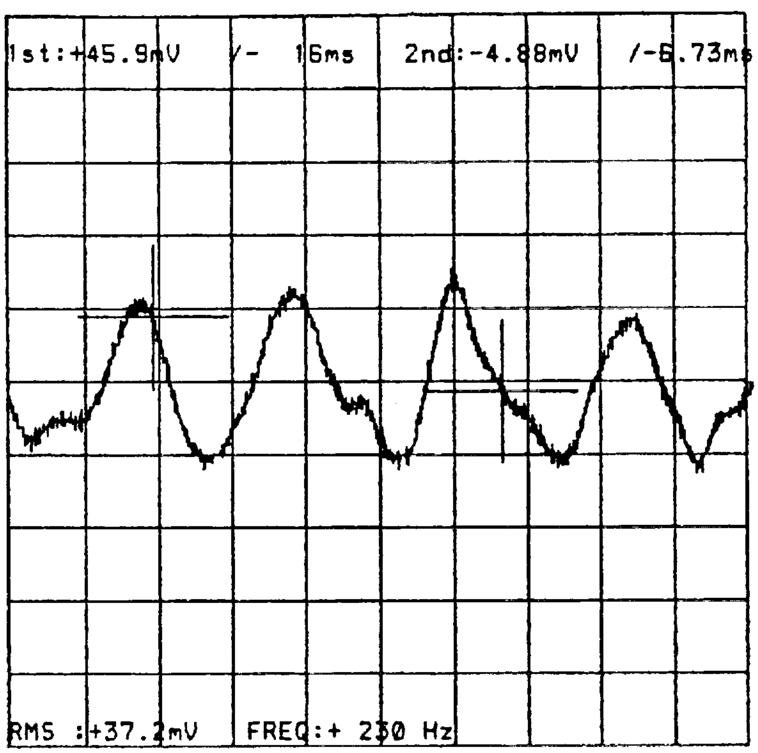

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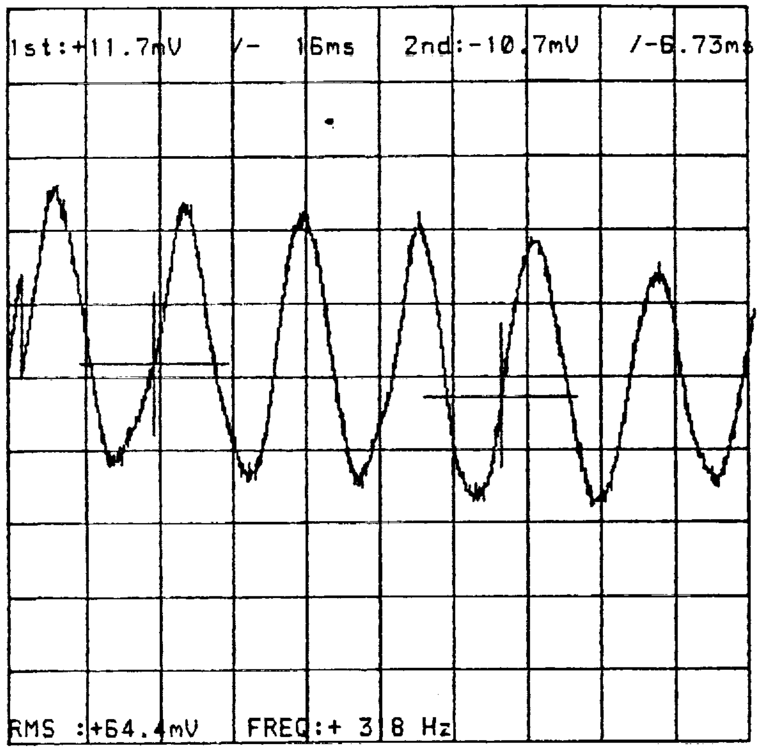

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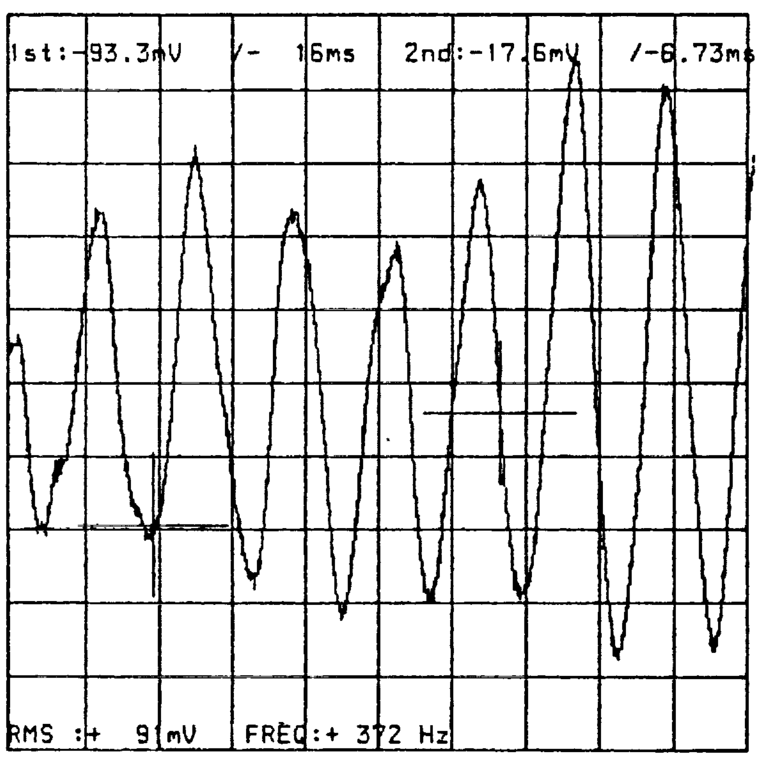

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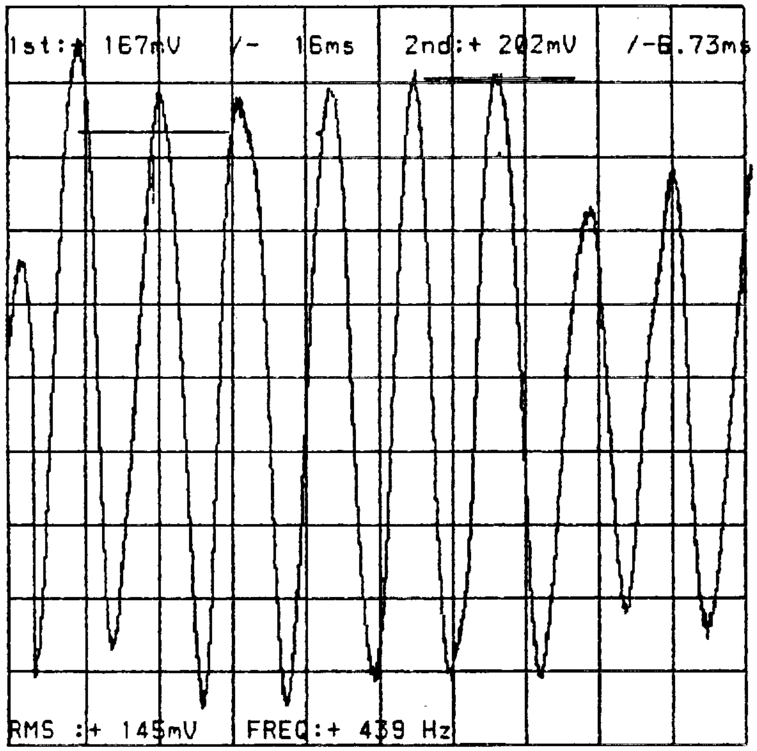

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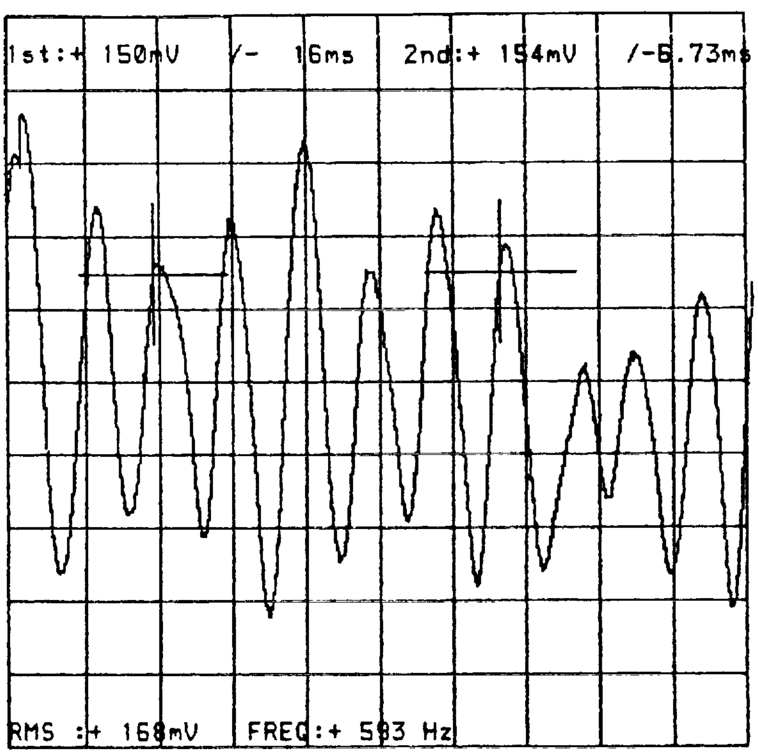

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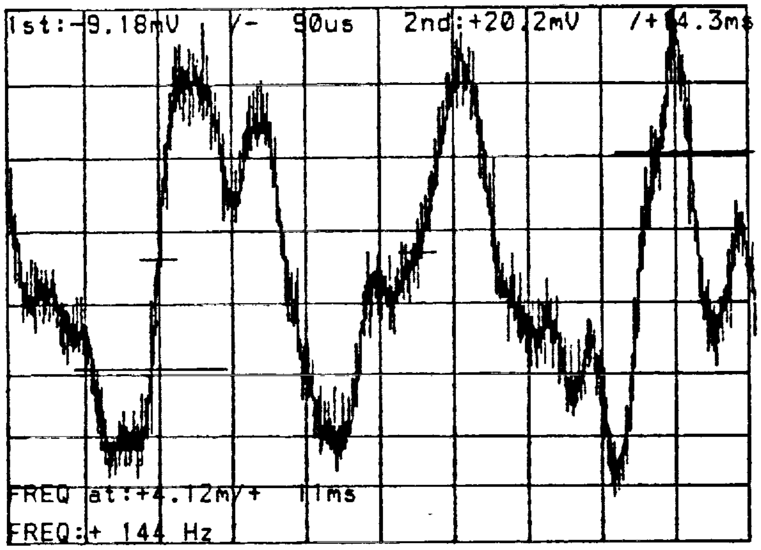

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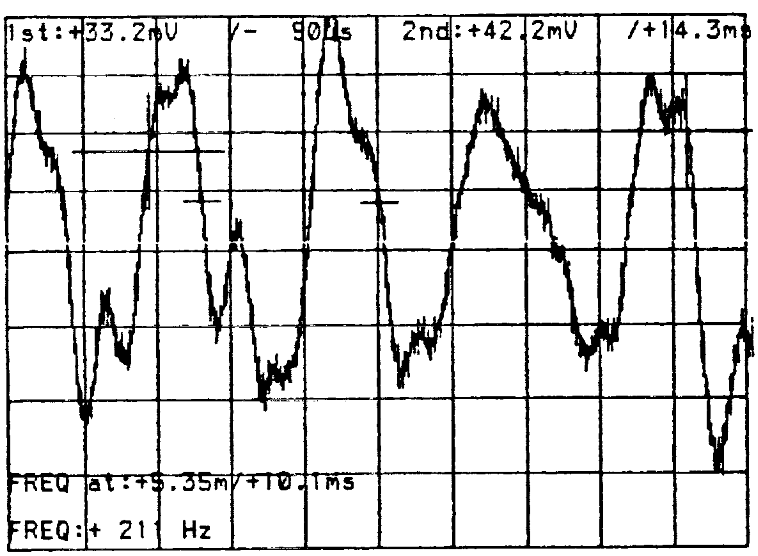

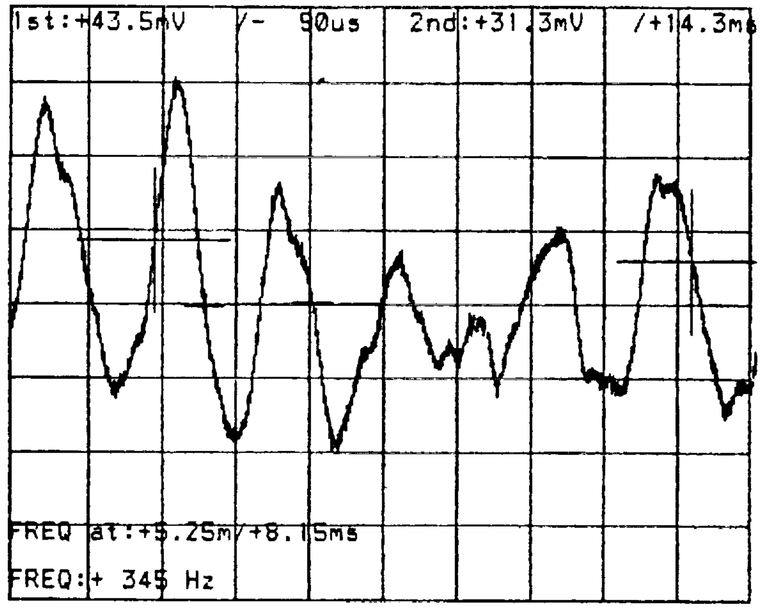

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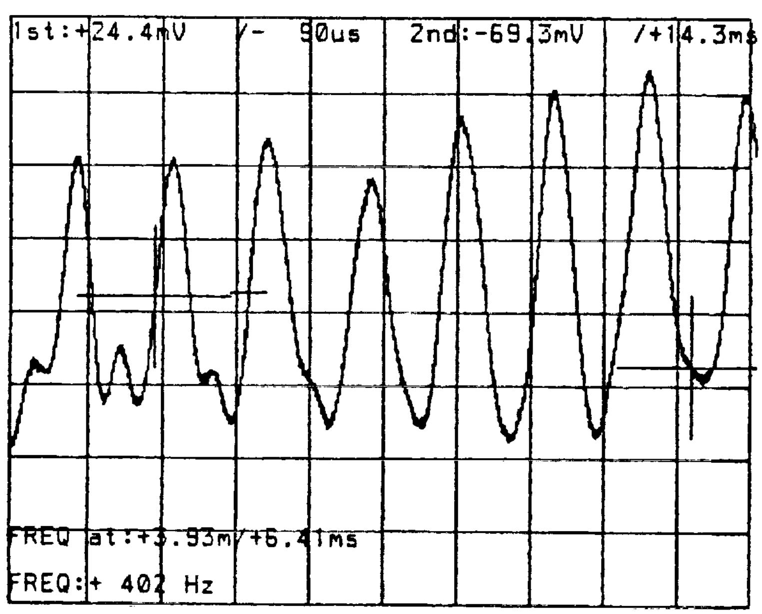

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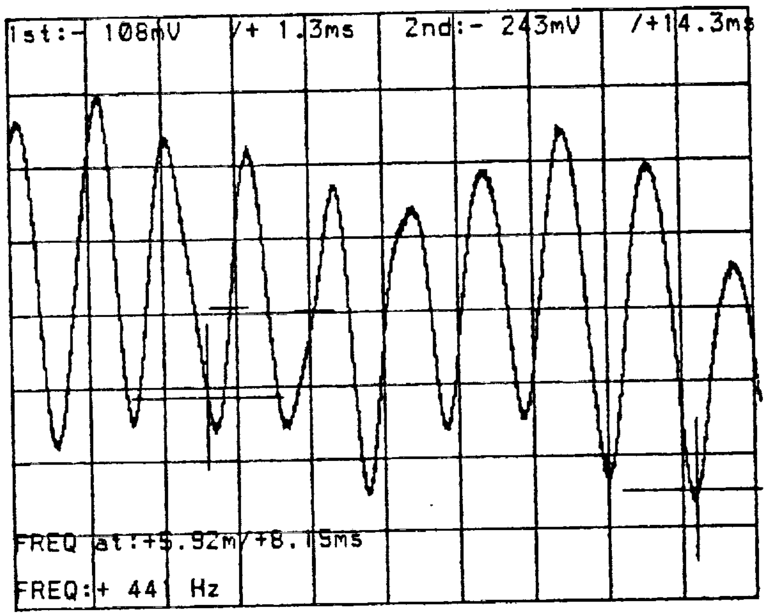

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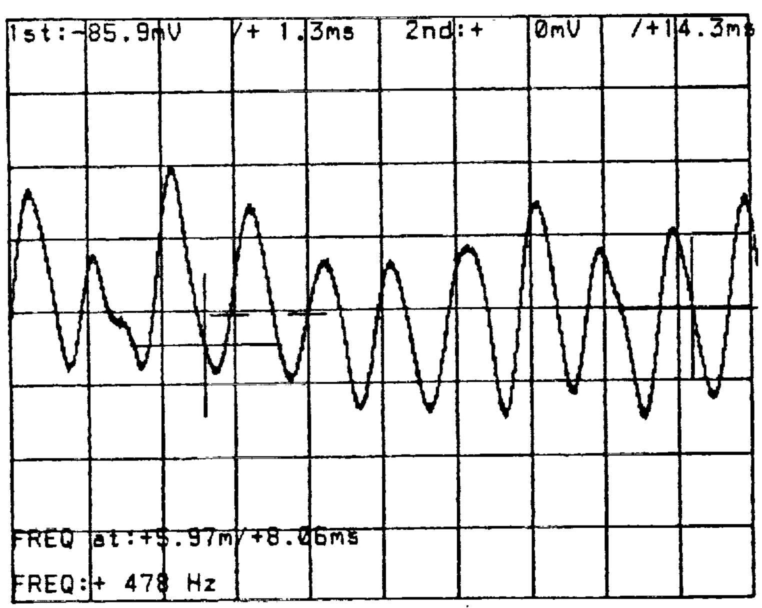

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