ADAPTIVE CONTROL OF VIBRATOR

A DISSERTATION

submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

ELECTRICAL ENGINEERING

(With Specialization in Measurement and Instrumentation)

By

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CANDIDATES DECLARATION

I hereby declare that the work presented in this dessertation entitled "**ADAPTIVE CONTROL OF VIBRATOR**" in partial fulfillment of the requirements for the award of the degree of MASTER OF ENGINEERING in Electrical Engineering with the specialization in MEASUREMENT AND INSTRUMENTATION of the University of Roorkee, Roorkee is an authentic record of my own work carried out during the period from August 1996 to March 1998 under the guidance of Dr. H.K. Verma, Professor Department of Electrical Engg., UOR, Roorkee and Dr. Vinod Kumar, Professor, Department of Electrical Engg., UOR, Roorkee.

The matter presented in this dissertation has not been submitted by me for any other degree.

Dated: 30-3-98

Place: Roorkee

Goyal

(Anup Kumar Goyal)

CERTIFICATE

This is to certify that above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Vibration Test is a part of basic environmental testing of electronic and electerical items and components. Vibration test (IS:9001, Part XIII-1981) determines the ability of electronic and electrical items to withstand specified severities of vibration. The vibration test with an antilogarithmic sweep rate of 1 octave/min and a frequency range of 10-150-10 Hz is developed. The vibration test developed in this work is to test the Energy Meters, hence the severities of vibrations as per IS:13010-1990 are followed. The amplitude of vibrations is controlled and maintained constant at 2mm peak in constant displacement range and 2.2g peak in constant acceleration range.

Vibrator, on which the meter under test is placed has an input-output response characteristics which varies with frequency and weight placed on it. Hence, displacement and acceleration of vibrations generated by vibrator changes for same input excitation with varying frequency & mass.

The purpose of this work is to generate the desired excitation signal i.e. a signal having an antilogarithmic frequency sweep rate of 1 octave/min over a frequency range of 10-150-10 Hz, which produces the required displacement and acceleration amplitudes of vibrations. For this, the parameters of the transfer function of the vibrator system are roughly estimated to cover the frequency and mass dependency. Displacement and acceleration are monitored with the help of accelerometer.

First the open loop control of input excitation is done and the output acceleration is monitored. Then the closed loop PID control is used for controlling the input excitation to get displacement and acceleration to a specified constant value. The developed software is giving satisfactory results and is independent of the characteristics of the vibrator, pay load and frequency range.

CONTENTS

CHAPTER - 1

INTRODUCTION

1.1 VIBRATION TEST

The vibration test requires, that the frequency should increase and then decrease in an antilogarthmic fashion with constant peak to peak displacement for certain lower range of frequencies and with a constant acceeleration in higher range of frequencies. As vibration test is used for testng many different types of electronic and electrical items, hence, different standards specify a different value of frequency range, peak to peak displacement, acceleration and cross over frequency. For the problem in hand, the values have been taken from IS:13010-1990 corresponding to testing to Energy meters and efforts have been made here to achieve these values. The values are as follow:

(a) Range of sweep frequency 10-150-10 Hz

(b) Sweep rate: 1 octave/min.

(c) Constant Amplitude (between 10 Hz & 16.7 Hz) : 2 mm peak.

(d) Constant Acceleration (between 16.7 Hz to 150 Hz) : 2.2 g peak.

The vibration amplitude can be specified in terms of constant displacement or constant velocity or constant acceleration. The term amplitude is used in the wider sense of peak value of an oscillating quantity. Each value of displacement amplitude is associated with the corresponding value of velocity or acceleration amplitude. The relationship is as follows:

$$\text{Acceleration } (m/s^2). = \frac{4\pi^2 f^2}{1000} \text{ Displacement (mm)} \quad (1.1)$$

$$\text{Velocity } (m/s). = \frac{2\pi f}{1000} \text{ Displacement(mm)} \quad (1.2)$$

Where f is frequency in Hz.

For any combination of displacement and acceleration amplitude or displacement and velocity amplitude, a crossover frequency can be calculated from the above releationship, so that the magnitude of vibration is same at this frequency.

1.2 VIBRATION TEST SYSTEM

The vibration table among other uses is used for testing of various electrical and electronic products in the form of vibration test. Vibrator or vibration table is a system on which the unit under test is placed. It's response varies with frequency and weight placed on it.

As the response of the vibrator changes with frequency and mass placed on it, the approximate input excitation vs response relationship is obtained in terms of Transfer Function(TF). The parameters of the T.F. are estimated by studying the input-output characteristics. The excitation is varied with frequency according to the T.F. in the open loop control. Then also, the requirements of peak to peak displacement and acceleration are not met completely. The remaining discrepencies in the achievement of the requirements are nullified by applying the Negative feed back closed loop control. Continious control action consisting of Proportional, Derivative and Integral action is employed for achieving the desired results.

In this work the frequency is changed in steps and 32 samples per cycle are outputted. It is assumed that the wave shape of vibration is sinusoidal. The language used for calculation of non-time critical actions is C language and for time-critical actions is assembly language. Among high level languages, C language has been employed because it can be easily linked with the assembly language procedures.

CHAPTER 2

CONTROL STRATEGY AND SYSTEM SCHEMATIC

The vibration systems input-output response characteristics varies with frequency and mass. The adaptive control strategy is utilized in this work. First the vibration system the gain transfer function is determined. After getting the gain transfer function the open loop control of the input excitation is done to get the desired acceleration output. Finally, the closed loop PID control of excitation is implemented to get the desired displacement and acceleration output.

2.1 ADAPTIVE CONTROL

Adaptive control has been an identifiable topic in instrumentaiton and control engineering for at least a generation. The description adaptive signifies that the controller performs two simultaneous functions; it learns about the controlled process whilst, at the same time, controlling its behaviour[5]. The application of self tuning control strategies started in 1950's with the development of self adaptive system in air-craft for changing flight conditions[6]. These efforts, however were largely unsuccessful because of lack of theory and bad computer hardware.

Renewed interest in adaptive control occured in the 1970's due to significant theoretical developments (Astrom and Wittenmark 1973; Clarke and Gawthrop 1975) and availability of inexpensive microprocessors based hardware. Presently adaptive control systems are used in many processes/systems[6].

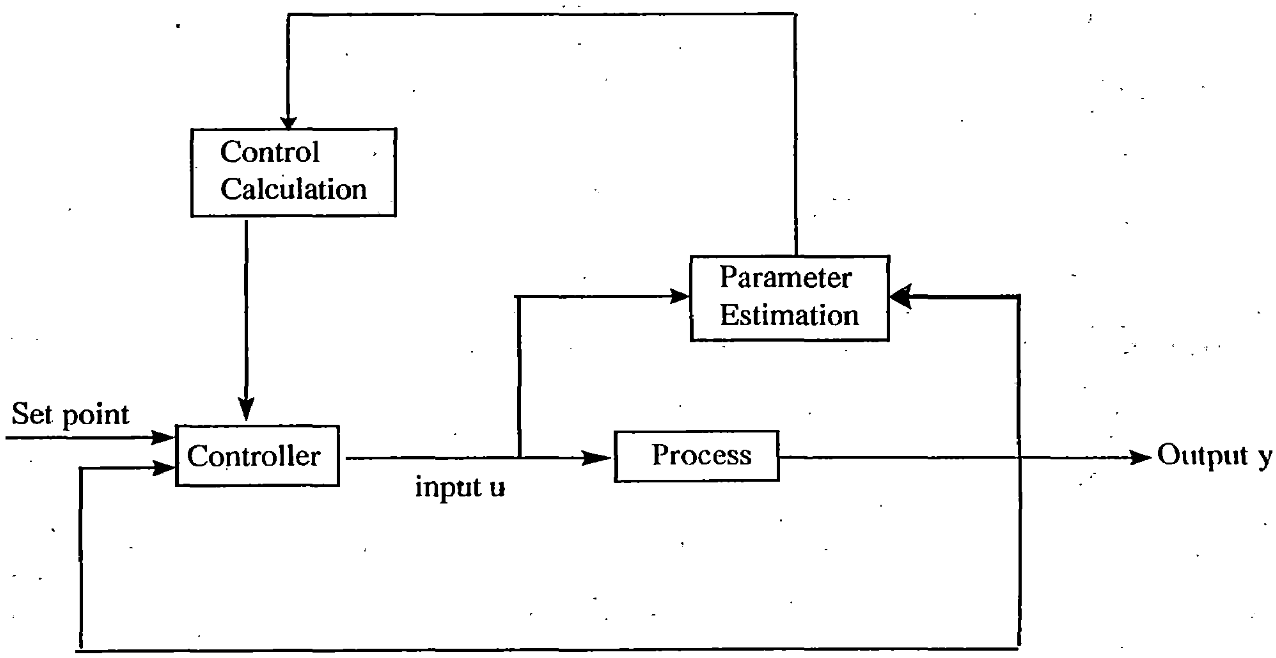


Fig. 2.1 Schematic of Adaptive Controller.

A general approach to the design of an adaptive control strategy is to estimate the parameters in an assumed process model on-line and then adjust the controller settings based on the current model parameter estimates. A block diagram illustrating this approach is shwon in Fig 2.1. At each sampling interval the parameters in the process model are estimated recursively from input-output data of the process and the controller parameters are then updated. This approach is the basis of the self-tuning adaptive controller(Astrom and Wittenmark 1973: Clarke and Gawthrop 1975).

Self Tuning control techniques can be classified into two different methods[6]: explicit method, a process model is used and the control calculations are based on the estimated model parameters. The model parameter do not directly appear in the control law. In the implicit method, the process model is converted to a prediction form that allows the future process output to be predicted from current and past values of the input and output variables by using a predictive model. The control calculations are eliminated because the model parameters are also used as control law parameters. In this case, the control law parameters are directly updated from input-output data.

In this work, as the vibration system input-output response is dependent on frequency and mass of pay load, its gain transfer function was determined. Then for making the system adaptive to the frequency & mass variations, the input excitation was calculated from the gain transfer function for getting desired constant output. In conjunction with the excitation determination from the gain transfer function, PID feed back control was also done.

2.2 MODELLING OF VIBRATION SYSTEM

Many Processes are well represented by Transfer Function(T.F.) models upto second order. These TFs may be expressed in continuous or sampled data variables. Also, although most processes are inherently continuous in nature, the system used to control these processes are increasingly based on digital computer and apply a sampled data control algorithm[10]In this work the modelling of the vibration system has been done off-line, so the assumed Gain T.F. was expressed in continuous form. As gain of the system varies inversely with the frequency, so the assumed transfer function was taken as

$$\text{Gain}(G) = \frac{\text{Output acceleration}}{\text{Input Excitation}} \quad (2.1)$$

$$G = \frac{1}{A'F + C} \quad (2.2)$$

Where f is frequency in Hz.

A'&C are Constants

Also, by varying the mass of the pay load, it was observed that the constant A' varies directly with Mass(m), with the relation

$$A' = Am + B \quad (2.3)$$

where A&B are contants.

Hence the assumed Gain T.F. of the vibration system became

$$G = \frac{1}{(Am + B)f + C} \quad (2.4)$$

2.2.1 Study of Response and Parameter Estimation of T.F.

The Input(Exc.) vs Output(Acc.) response was studied for various values of mass(m) viz. 1 Kg, 2.4 Kg. and 4 Kg corresponding to bare table, 1-φ Energy meter and 3-φ Energy meter respectively in the frequency range varying from 20 Hz to 150 Hz. The Gain of the system calculated at various values of mass and frequency are as tabulated in Table 2.1. The plots of gain vs frequency are given in Fig. 2.2, 2.3 & 2.4. After observing the data in Table 2.1 and seeing the trend of the gain vs frequency plots the value of contant C in the assumed T.F was taken as 0.06.

$$C = 0.06 \qquad (2.5)$$

So

$$G = \frac{1}{A'f + 0.06} \qquad (2.6)$$

Then, for same value of frequency (f=100 Hz, say) the value of constant A' was coming to be

$$\begin{aligned} \text{for } m &= 1\text{Kg}, & A' &= 0.000542 \\ m &= 2.4\text{Kg}, & A' &= 0.00107 \\ m &= 4\text{Kg}, & A' &= 0.00162 \end{aligned} \qquad (2.7)$$

So from equations (2.3) and (2.7)

$$\begin{aligned} A+B &= 0.000542 \\ 2.4A+B &= 0.00107 \\ 4A+B &= 0.00162 \end{aligned} \qquad (2.8)$$

TABLE 2.1

Frequency	Measured value of Gain			Gain Calculated from T.F.		
	Mass, m=1 kg	m=2.4 gk	m=4 kg	m=1 kg	m=2.4 kg	m=4 kg
20	14.4	14.4	12.8	14.1	12.36	10.8
25	13.9	14.8	13.1	13.6	11.61	9.95
30	13.4	14.05	12.0	13.1	10.95	9.21
35	12.4	12.26	11.75	12.66	10.35	8.57
40	11.6	12.52	10.87	12.24	9.82	8.01
45	11.5	11.3	9.93	11.85	9.34	7.52
50	11.3	10.47	9.44	11.5	8.9	7.1
55	10.5	8.86	8.0	11.35	8.51	6.71
60	9.9	8.35	7.48	10.81	8.15	6.36
65	11.1	8.29	7.11	10.5	7.82	6.05
70	10.7	8.06	6.86	10.21	7.51	5.8
75	10.2	7.78	6.13	9.93	7.23	5.51
80	9.9	7.39	5.65	9.68	6.96	5.27
85	9.9	6.94	5.65	9.43	6.72	5.06
90	9.8	6.70	5.33	9.2	6.49	4.86
95	9.7	6.33	4.88	8.97	6.28	4.67
100	9.7	6.06	4.84	8.75	6.08	4.5
105	9.5	5.76	4.46	8.55	5.89	4.35
110	9.3	5.54	4.11	8.36	5.72	4.20
115	9.0	5.24	3.58	8.18	5.55	4.06
120	8.7	5.01	3.05	8.0	5.39	3.93
125	8.7	4.88	2.8	7.83	5.25	3.81
130	8.35	4.54	2.89	7.67	5.1	3.7
135	8.1	4.27	2.91	7.51	4.97	3.59
140	7.8	4.14	1.72	7.36	4.85	3.49
145	8.0	3.74	2.25	7.22	4.73	3.39
150	7.7	3.165	2.57	7.1	4.61	3.3

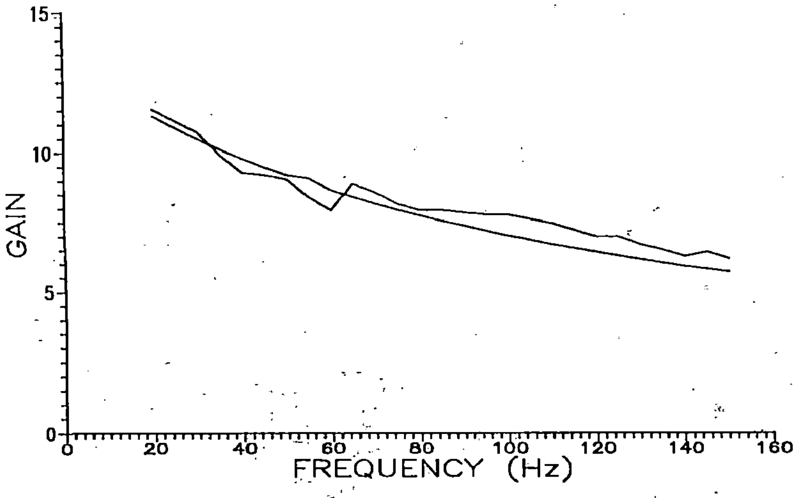


Fig. 2.2 GAIN vs FREQUENCY PLOT (m 1 kg.)

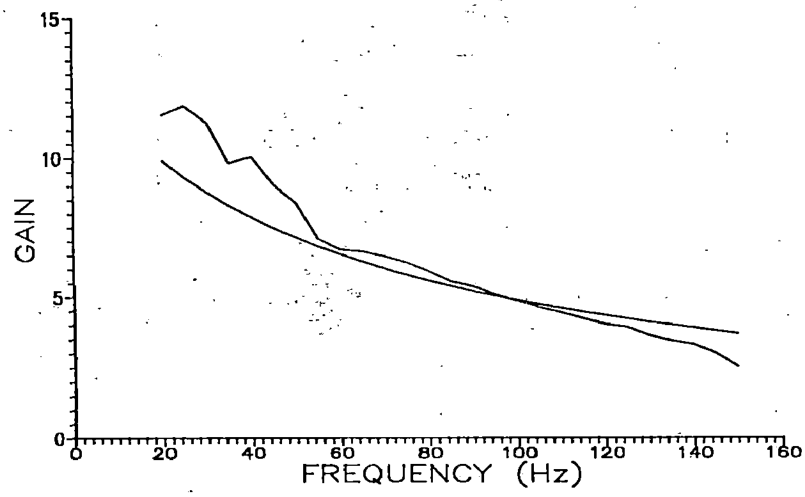


Fig. 2.3 GAIN vs FREQUENCY PLOT (m 2.4 kg.)

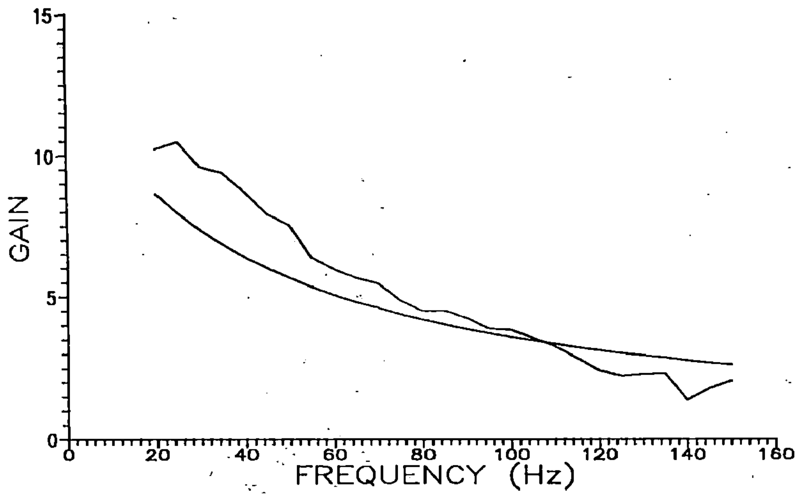


Fig. 2.4 GAIN vs FREQUENCY PLOT (m 4.0kg.)

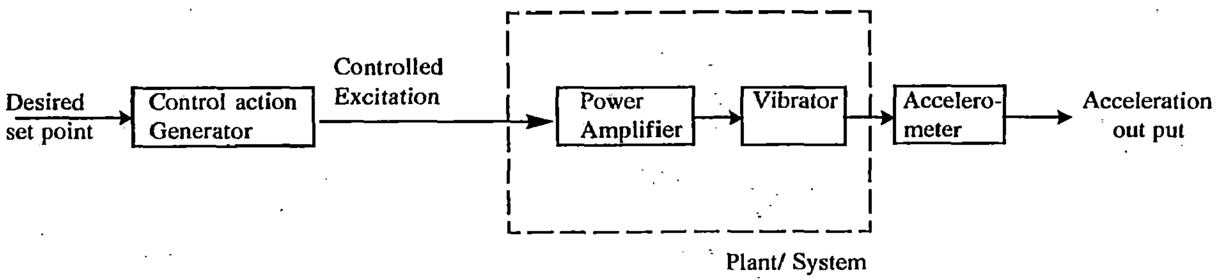


Fig. 2.5 Open loop control system.

By solving equation (2.8) the approximate values of A&B were found as

A= 0.00036 (2.9)

B=0.00018 (2.10)

So the assumed Gain T.F. took the form

$$G = \frac{1}{(0.00036m + 0.00018)f + 0.06} \qquad (2.11)$$

This T.F. is then used for calculating the required input excitation for getting the required output acceleration of 2.2g peak, for the given mass and frequency range.

2.3 OPEN LOOP CONTROL

In the present work, first the open loop control was implemented. The open control system used is shown in fig 2.5. In open loop control the output was changed to any desired value by appropriately changing the input signal. But variations in external conditions or internal paramters of the system may cause the output to vary from the desired value in an uncontrolled fashion[7].

The system transfer function was obtained as discussed in section 2.2. The control action generator calculates the controlled excitation from the system T.F. From equation(2.1).

$$\text{Input Exc.} = \frac{\text{Output acc.}}{G} \qquad (2.12)$$

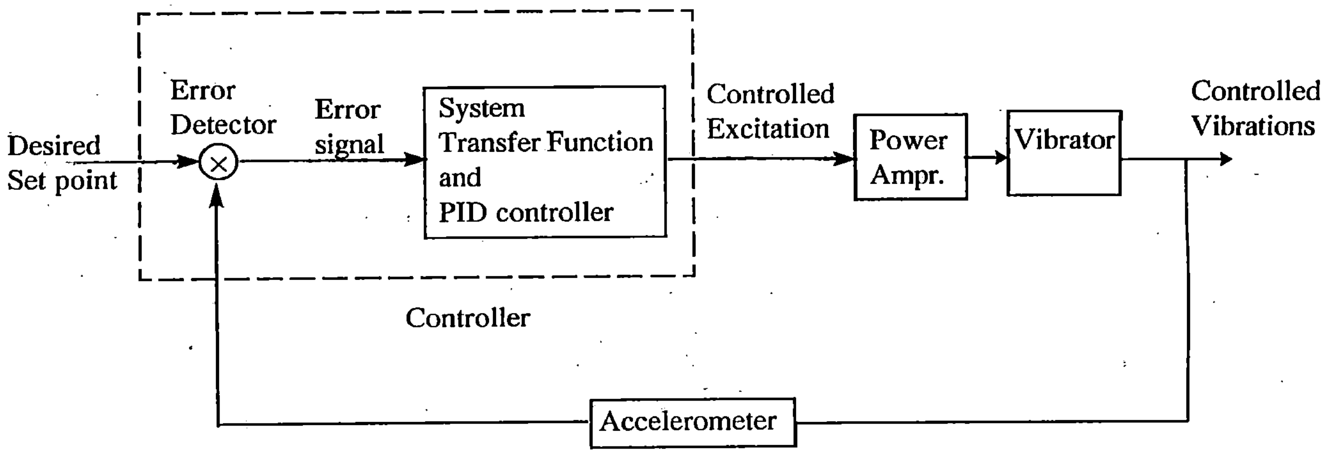


Fig. 2.6 Closed loop control system

Substituting value of G from eqn. (2.11).

Input Exc. = output acc x [(0.00036m+0.00018)f+0.06]   (2.13)

The controlled excitation was given to vibrator through Power Amplifier for producing vibrations. The acceleration of the vibrations was monitored for the desired values.

2.4 COLSED LOOP PID CONTROL

After monitoring the open-loop controlled output, to improve the vibration test system further, closed loop PID controller has been implemented. The closed loop control system used is shown in fig. 2.6.

In this system the excitation is updated with the change in the signal frequency based on the system transfer function and also corrected with the help of PID controller based on the error signal.

2.4.1 PID Control

The PC provides proportional, integral and derivative control action through software. The general analog equation for the PID controller output is

$$m(t) = K_p' e(t) + K_i' \int e(t)\,dt + K_d' \frac{d}{dt} e(t) + M_o \qquad (2.14)$$

In discrete form, the equation is

$$m_n = K_p' e_n + (K_i' \Delta t)\sum_{j=1}^{n} e_j + \left(\frac{K_d'}{\Delta t}\right)(e_n - e_{n-1}) + M_o \qquad (2.15)$$

$$m_n = K_p e_n + K_i \sum_{j=1}^{n} e_j + K_d (e_n - e_{n-1}) + M_o \qquad (2.16)$$

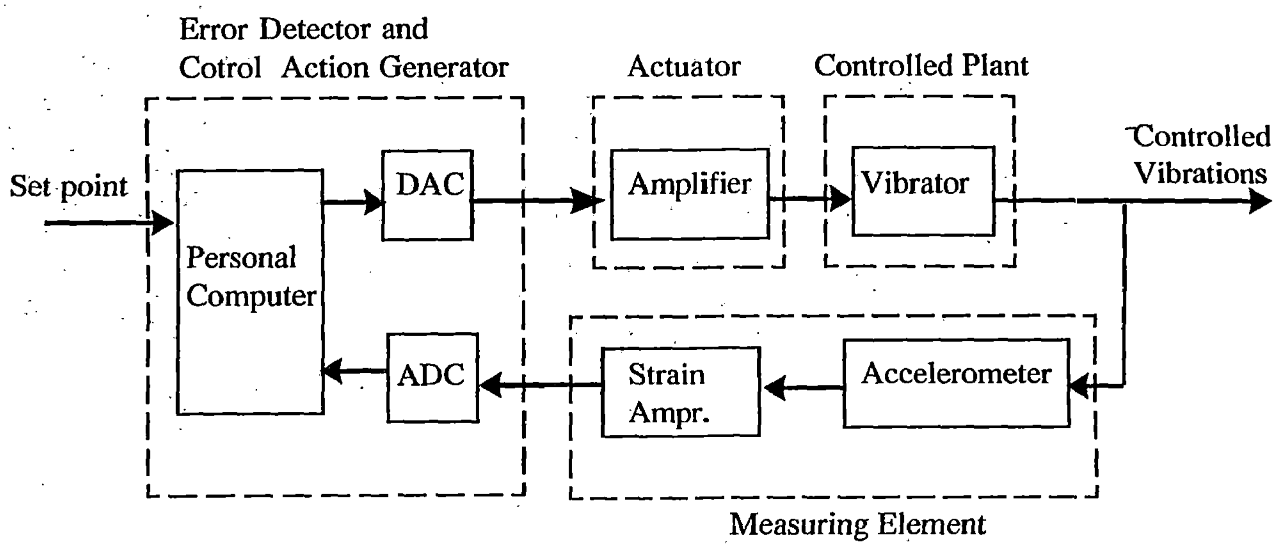


Fig. 2.7 System Schematic

where $m(t)$ = Controller input signal.

$e(t)$ = Error signal

M_o = Constant

K_p = Proportional gain constant

K_i = Integral action constant

K_d = Derivative action constant

The controlled input m_n is given to the vibrator through the DAC and power amplifier.

2.5 SYSTEM SCHEMATIC

The major blocks of the vibration test system developed are shown in fig. 2.7.

Here, comparing with the general closed loop system.

(a) Personal computer (PC), Digital to Analog Converter (DAC) and Analog to Digital Converter (ADC) corresponds to error detector and control action generator.

(b) Power Amplifier correspond to actuator.

(c) Vibration table corresponds to controlled plant.

(d) Accelerometer along with Strain Amplifier corresponds to measuring element.

The control action has been provided through software techniques.

2.5.1 Signal Flow

Before starting the real-time problem, the necessary data for antilogarithmic sweep rate of frequency are calculated as explained in chapter 4 and stored in arrays and file (for inspection later on) in the PC. This data is used in time-critical segments of program, where because of time constraints, it would not be possible to calculate these data.

In the time-critical segments of program, the PC, initially increases the excitation count in steps of 10 starting from initial value taken as 10, to reach the vibrations upto the set point. Then onwards, the acceleration count is inputted from the ADC and calculates the error that is present from the desired set point value. Then after applying control action, new excitation is found by adding the previous count to the control action count and is outputted to the DAC.
As the signal from the DAC can not be directly used as excitation signal to the vibration table because of its low voltage and current, so it needs amplification . An a.c. power amplifier is employed for this purpose. The amplified signal is given to the vibrator whose peak to peak displacement and acceleration of vibrations are required to be controlled.

For the measurement of the acceleration and displacement accelerometer is employed. The set point count for constant acceleration mode is calculated corresponding to 2.2 g peak. The set point count corresponding to constant displacement mode is calculated from the set point count for constant accelaration mode by multipling it by the squares of the ratio of frequency to the crossover frequency. The determination of setpoint values are discussed in detail in section 4.6.

A calibrated accelerometer is mounted on the vibration table. With the change in acceleration the output voltage of the accelerometer changes. The voltage output of accelerometer being very small has to be amplified. For amplification, strain amplifier is used. Strain amplifier measures the difference between the voltages existing at the two input terminals, amplifies it by a precisely set gain and causes the output to apperar between a pair of terminals in the output circuit. The output of the amplifier goes to the peak detector and the signal then goes to one of the channels of the ADC.

CHAPTER -3

SYSTEM HARDWARE

Vibration Test system for testing of the Energy Meters was developed. Referring to the system schematic shown in fig 2.7, the vibrator is used for producing the vibrations, which require excitation. The controlled excitation is given by Personal computer (PC) through DAC and amplifier. For measuring the amplitude of vibrations, accelerometer and strain amplifier are used.

The measured acceleration signal is given to the data acquisition system consisted of ADC and Personal Computer for control purposes. Hence, the system hardware designed for the vibration test system includes the following:

1. Accelerometer and Signal Processing.
2. Vibration System.
3. Data Acquisition System and Controller.

3.1 ACCELEROMETER AND SIGNAL PROCESSING

The accelerometer used is of strain gage type. With the change in acceleration, the resistance of the strain gauge inside the accelerometer changes and hence the output voltage of the accelecometer changes. The details about accelerometer are given in Appendix A.

The output of accelerometer is given to strain amplifier which is used as a signal processing device. The gain of the amplifier is set at 5000. The signal after strain amplifier is given to peak detector, used for detecting the peak value of acceleration. The peak signal is given to the controller through ADC.

3.2 VIBRATION SYSTEM

The signal outputted by Controller through DAC is discrete in nature. So, it has to be passed through a low pass filter before power amplification to convert it into uniform wave. The power amplifier has an inbuilt low pass filter. The power amplifier can give a maximum current of 25A (rms) and a maximum voltage of 25V (rms). Its operating frequency range is 10-1000Hz.

The product to be tested for vibration test is mounted on the vibration table and it is the excitation of this table which has to be controlled by which the peak to peak displacement and acceleration of its vibrations can be held constant in lower and higher frequency ranges. The vibration table consists of a vibration generator which converts the electrical signal into the mechanical vibrations.

3.3 DATA ACQUISITION SYSTEM AND CONTROLLER

The Personal Computer (PC) and the data acquisition card PCL-208 are used for this purpose.The PC used is AT 386 having a clock frequency of 33 MHz. It has a processor type 80386. It has 2 MB RAM. It has got 8 input/output (I/O) slots, into one of which the data acquisition card is fitted. The PC was also used as software control action generator.

The card used is Dynalog Micro-system PCL-208 high performance data acquisition card. It has switch selectable 16 single-ended or 8 differential analog input channels. Out of these only one-single ended channel in bipolar mode is used for feedbacking of acceleration information in this work. It has a 12-bit successive approximation converter (ADC 674). The card has a switch selectable versatile analog input range in bipolar and unipolar modes.

It provides three A/D trigger modes

Software trigger

Programmable pacer trigger

External trigger pulse trigger

In this work programmable pacer trigger mode is used for generating the desired frequency excitation signal.

An INTEL 8254 programmable Timer/counter provides pacer output (trigger pulse) at the rate of 2.5 MHz to 71 minutes/pulse to the A/D. The timer time base is switch selectable 10 MHz or 1 MHz. In this work timer time base of 1 MHz is used.

The card has two 12-bit monolithic multiplying D/A output channels. Both the D/A outputs are put to use in this work because of time critical limitations. D/A channel 0 is used as the master unit giving its output to the reference input terminal of the D/A channel 1. So, by adjusting the output of channel 0, the amplitude of whole cycle data sample values which are to be outputted through the D/A channel 1 can be controlled.

The hardware settings of the card are as follows:

1.	Base address selection	- 0300 H
2.	Channel Configuration	- 16 channel
3.	Unipolar/Bipolar selection	- Bipolar
4.	Input range selection	- ± 5V
5.	Timer clock selection	- 1 MHz
6.	External voltage selection	- D/A channel 0 to Internal reference (-5V).
		- D/A channel 1 to external reference (connected to channel 0 output).

The details of Data Acquisition Card are given in Appendix-B.

CHAPTER 4

SYSTEM SOFTWARE

4.1 INTRODUCTION

In this work the excitation to the vibration table is controlled to get desired values of peak to peak displacement and acceleration. The control is done through software techniques. The transducer used is accelerometer for measuring the acceleration. Both open loop and closed loop controls are designed. In this work, 32 samples are transmitted every cycle and the frequency is changed in steps of 0.5Hz, 1Hz, 2Hz & 5Hz antilogarithmically with time.

The programming language used is C language[3] for non-time critical segments and assembly language[4] for time critical segments of the programme. The software complier used is C^{++}

4.2 FREQUENCY & INTEGER NUMBER OF CYCLES CALCULATION

The signal frequency should change at a sweep rate of 1 octave per minute i.e. frequency doubles every minute, so the equation at the time of rise of frequency from 10 Hz to 150 Hz can be taken as

$$f=10[2]^{T}=10[2]^{t/60} \qquad (4.1)$$

where f is in Hz, T in minutes, t in seconds.

The freq. is increased in steps of 0.5 Hz, 1 Hz, ~~1 Hz~~, 2 Hz & 5 Hz and the starting time ts, finish time tf & the integer no. of cycles are calculated as below:

Let f 0 = f1 = 10 Hz.

```
Repeat  :  freq[i] = f1
           If (f1<25) f2 = f1 + 0.5
           If (25 ≤ f1< 40) f2 = f1+1
           If(40 ≤f1<100) f2 =f1+2
           If(100≤ f1<150) f2=f1+5
           ts= 60 x log (f2/f0)/log(2)
           int-cy[i]=(ts-t0) x f1
           tf=int-cy[i]/f1
           t0 = t0+tf
           f1 = f2
           i = i+1
           If (ts < t150)
           Go to Repeat
```

From 150 Hz to 10 Hz the same data of 10 to 150 Hz comes but in reverse order.

4.3 CALCULATION OF PACER TRIGGER TIME COUNT

The A/D pacer trigger rate is set by specifying the divisor of counter 1 and counter 2. The pacer trigger rate is calculated as:

Pacer Rate = Input clock rate/(c2 x c1)   (4.2)

where c2 = counter 2 divisor

c1 = counter 1 divisor

The values chosen in this work are

input clock rate = 1 MHz----------(Selected by the slide switch SW1)

$$c1 = 4 \quad (4.3)$$

$$c2 = 1000,000/\{Freq(i) \times 32 \times 4\} = \text{time count } [i] \quad (4.4)$$

Therefore

$$\text{Pacer Rate} = 1000,000 \times freq\,[i] \times 32 \times 4/\,(4 \times 1000,000)$$

$$= freq[i] \times 32 \quad (4.5)$$

4.4 SAMPLE DATA CALCULATION

In this work 32 samples are transmitted in a cycle to output the sine wave. The samples are outputed through a 12-bit DAC. The value of any sample is found from the following formula assuming amplitude of wave to be unity

$$a = \sin(2 \times \pi \times i/32) \quad (4.6)$$

As the maximum value that 12-bits can have is 4095 and lowest value is 0, so the value, in terms of count, of the samples is found by

$$cy\text{-}dat[i] = a \times 2048 + 2048 \quad (4.7)$$

If the simple count value Cy-dat[i] comes greater than 4095, then the sample count value Cy-dat[i] is reloaded by 4095.

4.5 CALCULATION OF EXCITATION

The system response is obtained in terms of the transfer function by studying the input-output characteristics with different mass and frequency combinations. The excitation Exi[0] for 10 Hz obtained by increasing the excitation to a point where the displacement is equal to the set point. For other frequencies the excitation count is calculated as below.

$$Exi[i] = Exi[0] \times Exc[i]]/[Exc[0] \quad (4.8)$$

Where

$$Exc\ [i] = Output\ Acc.\ [((0.00036m)+0.00018)\ freq\{i\}+0.06] \quad (4.9)$$

The count thus obtained in Exi[i] is outputted at D/A channel#0. The term Exc[i]/Exc[0] is termed as gain[i]. For closed loop PID control the gain[i]=Exc[i]/Exc[i-1].

4.6 CALCULATION OF SET POINTS

Accelerometer is used as transducer for measuring the acceleration and displacement. Accelerometer is used with strain amplifier and peak detector. The calibration of accelerometer is done first as given below.

Reading corresponding to +1g = 1.30V

Reading corresponding to - 1g = -1.38V

∴ 2g corresponds to 2.68 Volts.

∴ 2.2g peak corresponds to 2.948 Volts

Now as the 12-bit A/D converter is configured in the range ±5V. So 5 Volts corresponds to a count of 2048.

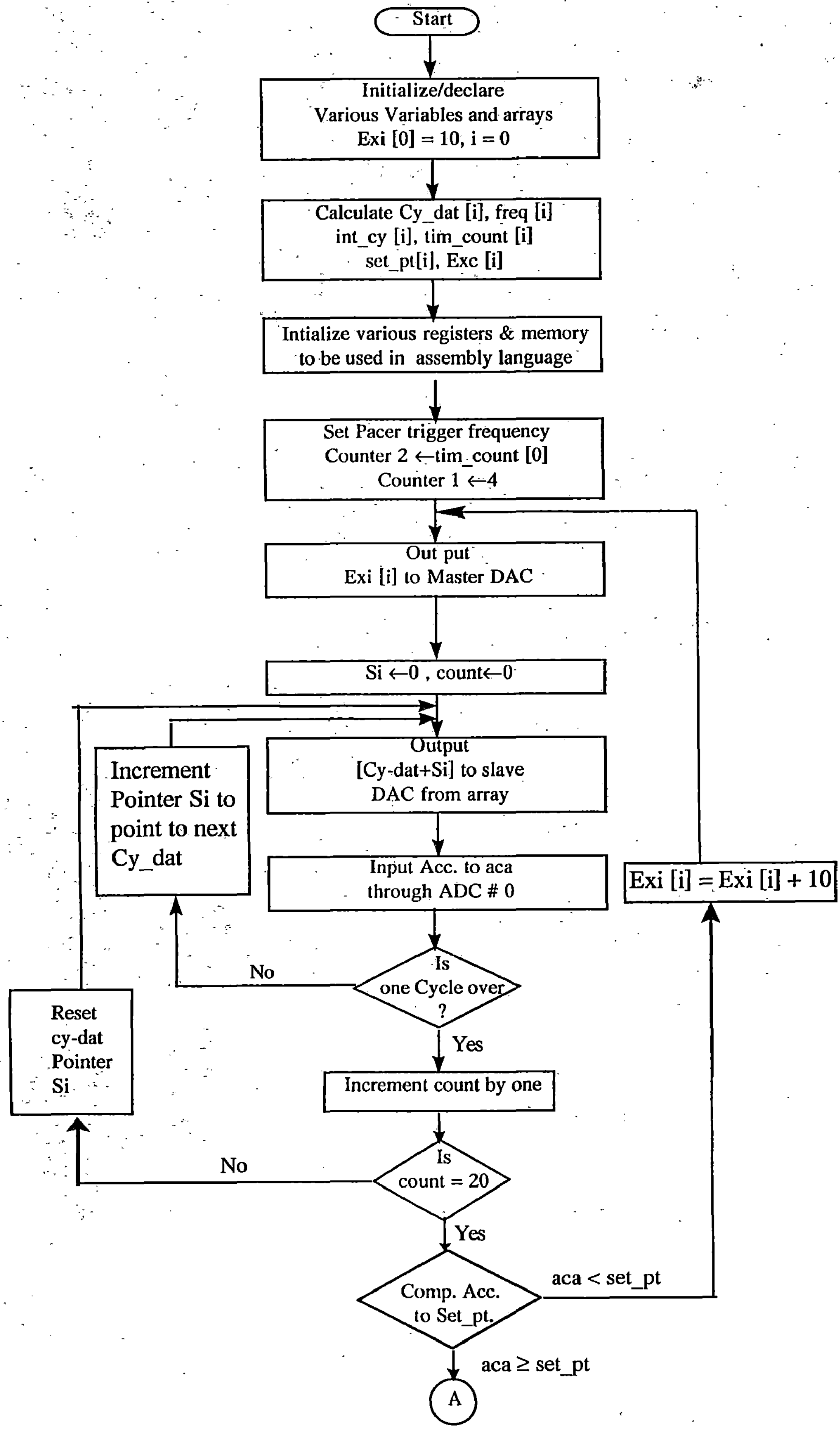
Hence, the set point count corresponding to 2.948 Volts comes out to be Set point count ≐ 2.948 x 2048/ 5.0 = 1200 (Approx.)

The set point 1200 is for constant acceleration range, i.e. if frequency is greater than or equal to 16.7 Hz then the set point is 1200. But in constant displacement range, i.e. when the freq. is less than 16.7 Hz, the set point is given by

$$\text{set point} = 600 \times \text{freq}[i] \times \text{freq}[i]/(16.7 \times 16.7)$$

4.7 FLOW CHART

The flow chart of the software developed for the open loop control and the closed loop adaptive PID control are given in fig 4.1 and fig 4.2. The flow charts are self explainatory.


Start
Initialize/declare
Various Variables and arrays
Exi [0] = 10, i = 0
Calculate Cy_dat [i], freq [i]
int_cy [i], tim_count [i]
set_pt[i], Exc [i]
Intialize various registers & memory
to be used in assembly language
Set Pacer trigger frequency
Counter 2 ←tim_count [0]
Counter 1 ←4
Out put
Exi [i] to Master DAC
Si ←0 , count←0
Output
[Cy-dat+Si] to slave
DAC from array
Increment
Pointer Si to
point to next
Cy_dat
Input Acc. to aca
through ADC # 0
Exi [i] = Exi [i] + 10
No
Is
one Cycle over
?
Yes
Reset
cy-dat
Pointer
Si
Increment count by one
No
Is
count = 20
Yes
Comp. Acc.
to Set_pt.
aca < set_pt
aca ≥ set_pt
A

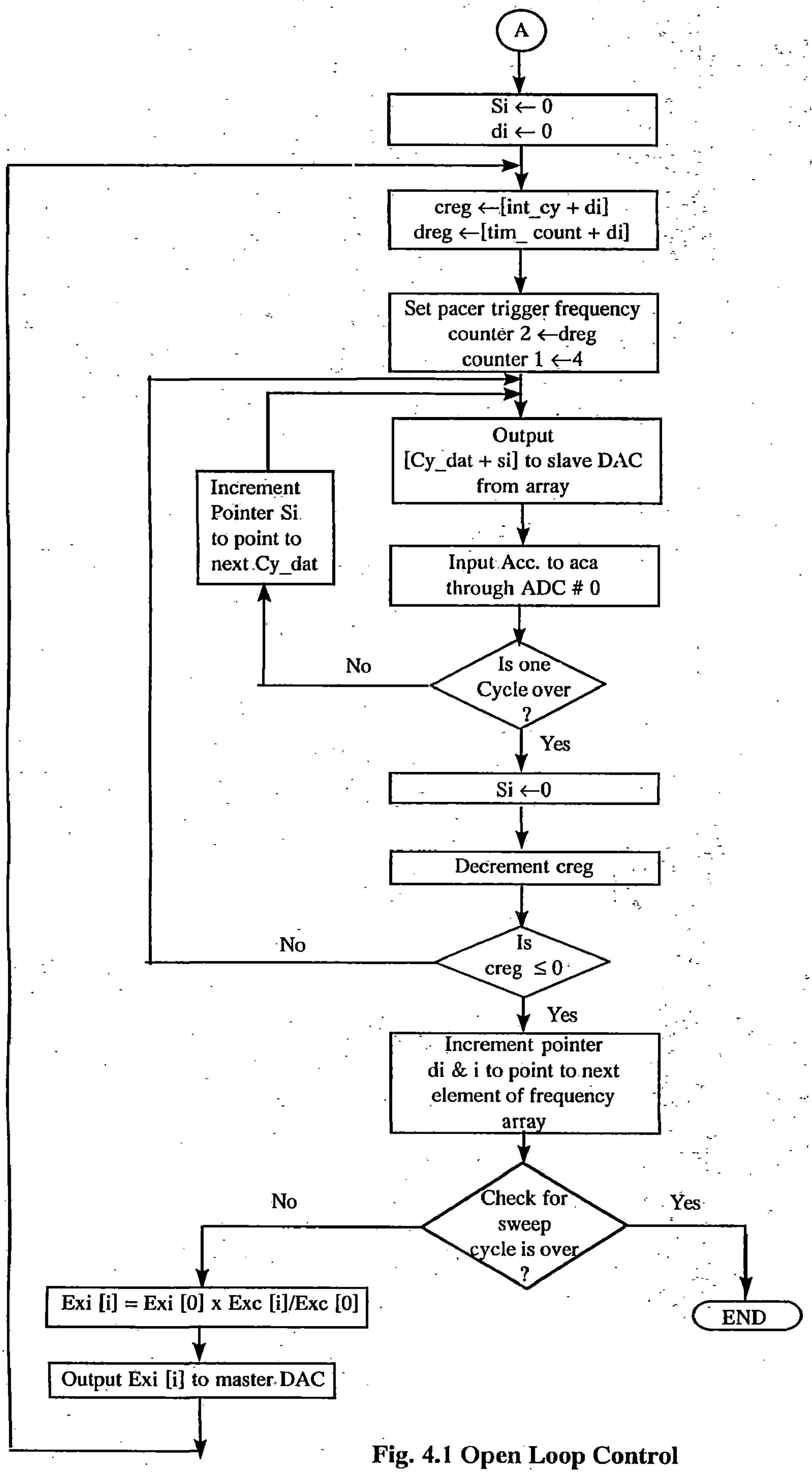
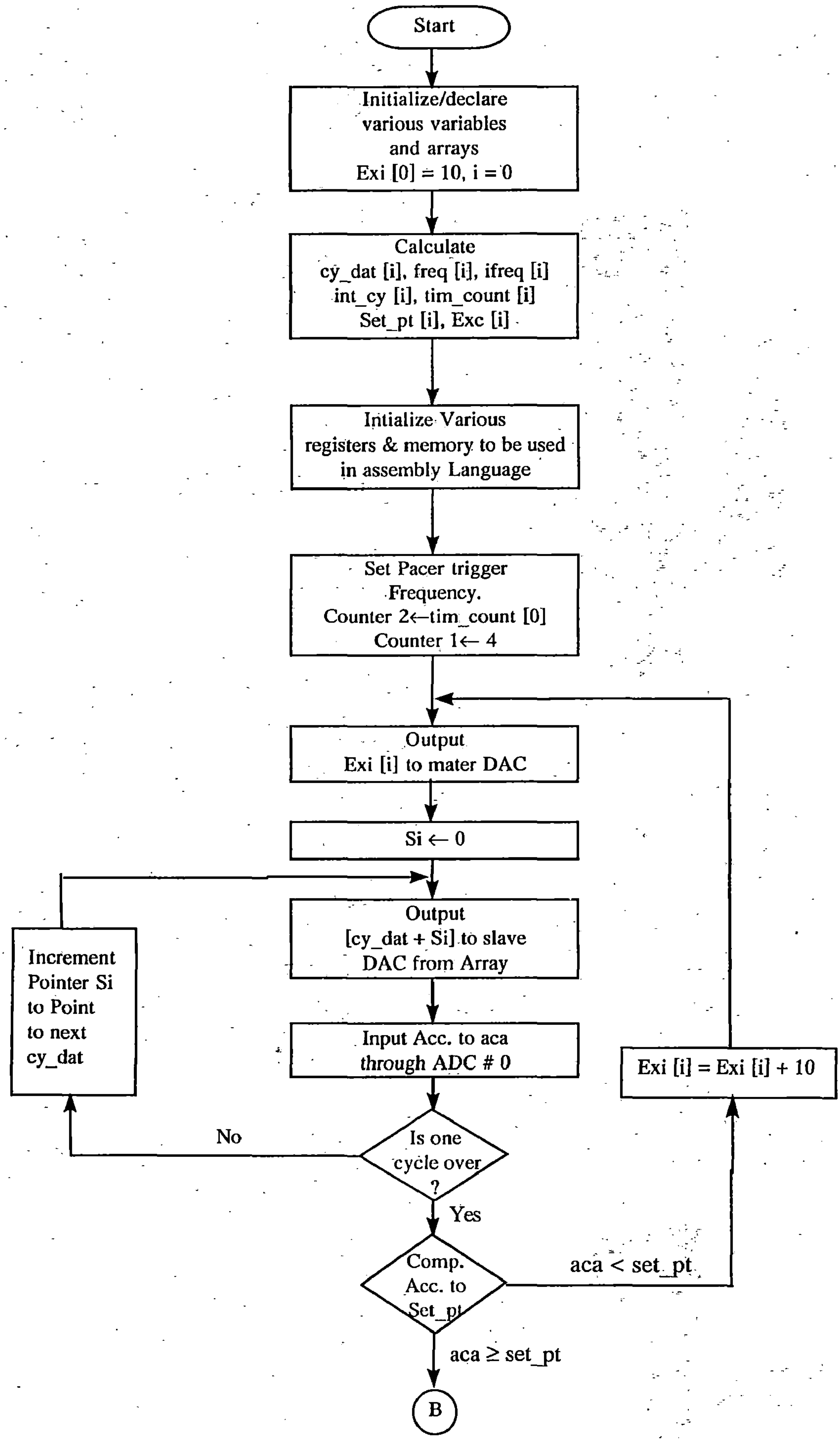


Fig. 4.1 Open Loop Control


Start
Initialize/declare various variables and arrays Exi [0] = 10, i = 0
Calculate cy_dat [i], freq [i], ifreq [i] int_cy [i], tim_count [i] Set_pt [i], Exc [i]
Intialize Various registers & memory to be used in assembly Language
Set Pacer trigger Frequency. Counter 2←tim_count [0] Counter 1← 4
Output Exi [i] to mater DAC
Si ← 0
Output [cy_dat + Si] to slave DAC from Array
Input Acc. to aca through ADC # 0
Is one cycle over ?
No
Increment Pointer Si to Point to next cy_dat
Yes
Comp. Acc. to Set_pt
aca < set_pt
Exi [i] = Exi [i] + 10
aca ≥ set_pt
B

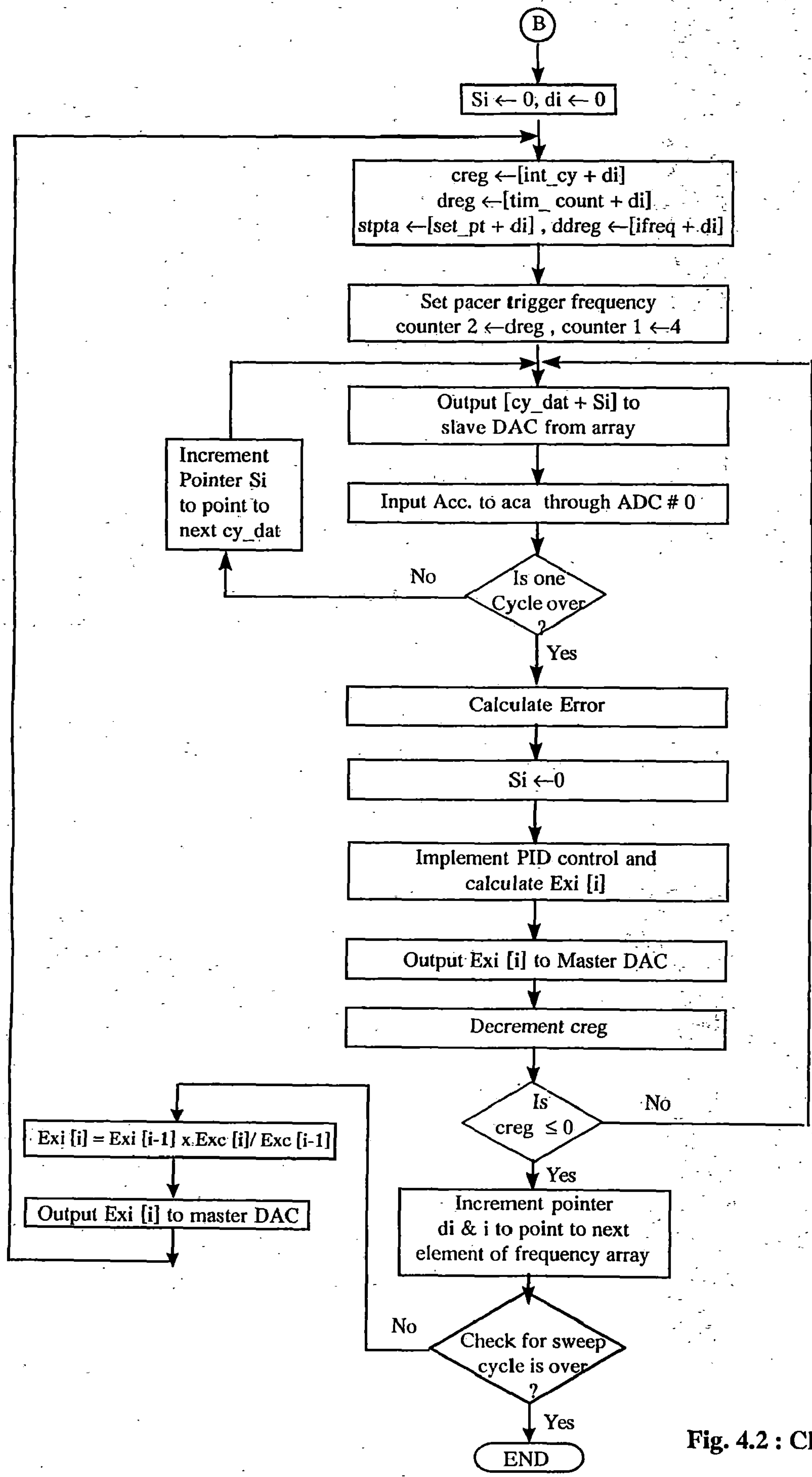


Fig. 4.2 : Closed Loop Control

CHAPTER 5

RESULTS AND CONCLUSION

The software was developed in various modules. The calibration of the accelerometer and the strain amplifier was done to get the output in the desired range. The input-output response of the vibration table system was obtained for different pay load setting viz 1Kg, 2.4 Kg and 4 Kg and frequency range 20 Hz to 150 Hz. The gain ~~transfer function~~ of the system calculated at various values of mass and frequency are given in Table 2.1. The Gain Transfer Function (G) of the system was determined as discussed in section 2.2 and it came out to be.

$$G = \frac{\text{Output acceleration}}{\text{Input excitation}}$$

$$= \frac{1}{(0.00036m + 0.00018)f + 0.06}$$

Where m = Mass of payload in Kg

f = Frequency in Hz.

It is further used for calculating the input excitation for desired output.

5.1 RESULTS

The Open Loop Control of the excitation has been implemented through the above Transfer Function in the constant aceleration range of frequency. The graphs for Open Loop control are shown in fig 5.1, 5.2 and 5.3 for m=1Kg, m=2.4 Kg and m=4 Kg respectively. The graphs are plotted with a frequency sweep rate of 1 octave/ min in terms of output count vs frequency. The number of cycles for every frequency are very high. The number of cycles even reaches to many hundreds and recording all the cycles would require a large memory space. In this work for each frequency,

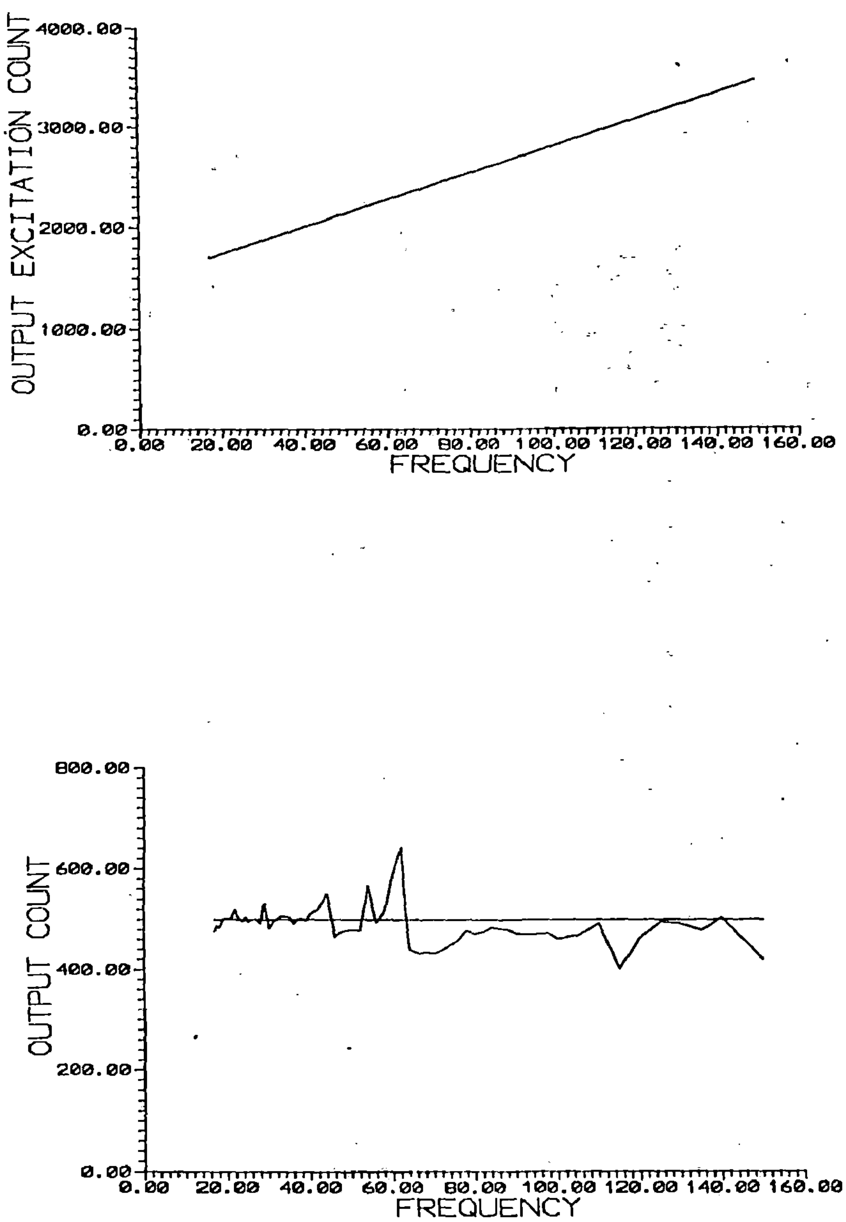
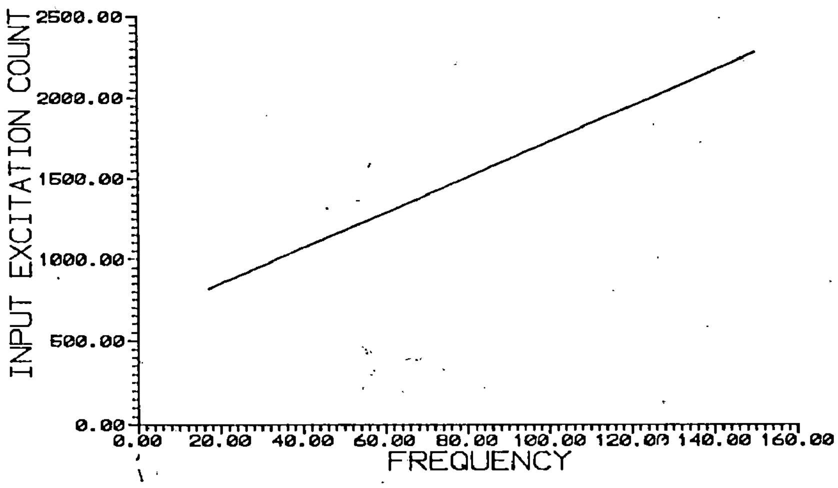


Fig. 5.1 : Open Loop Control, m = 1kg (Bare Table)



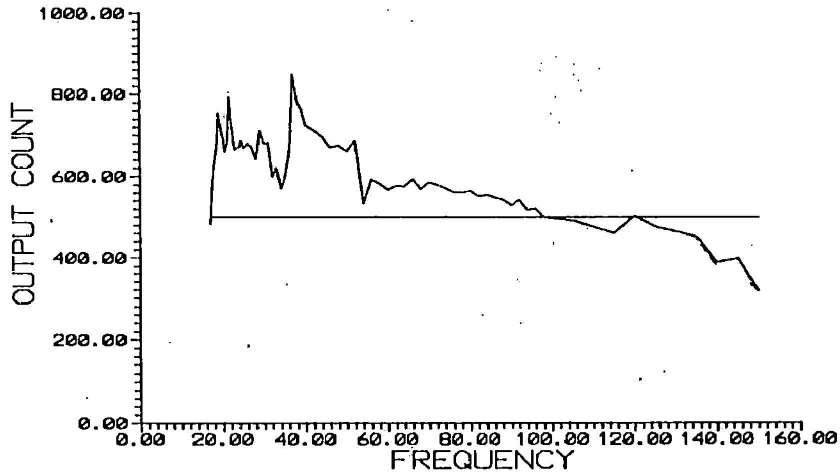


Fig 5.2 : Open Loop Control m = 2.4 kg (with 1-φ Energy Meter)

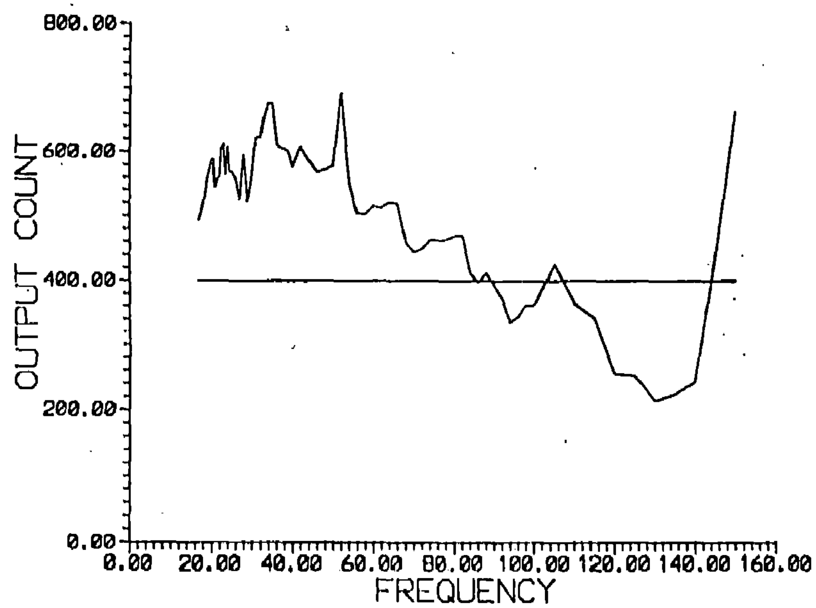
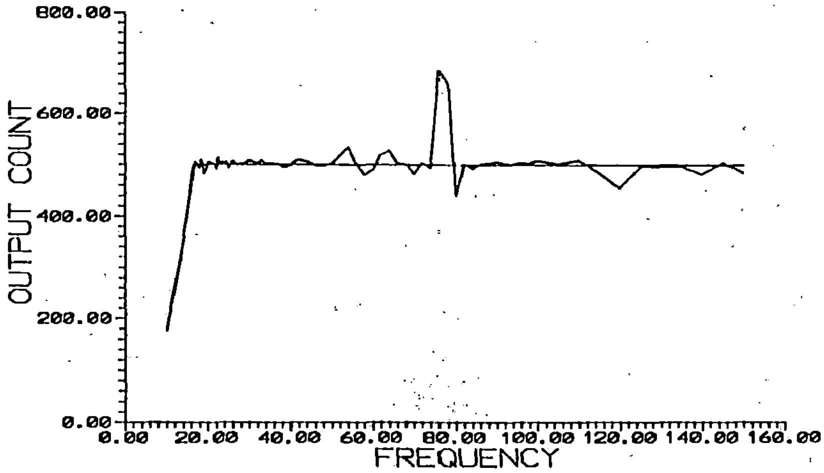
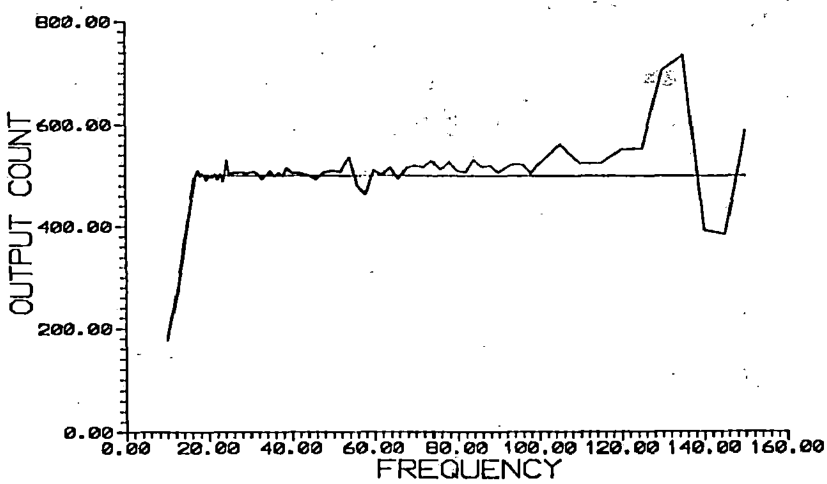


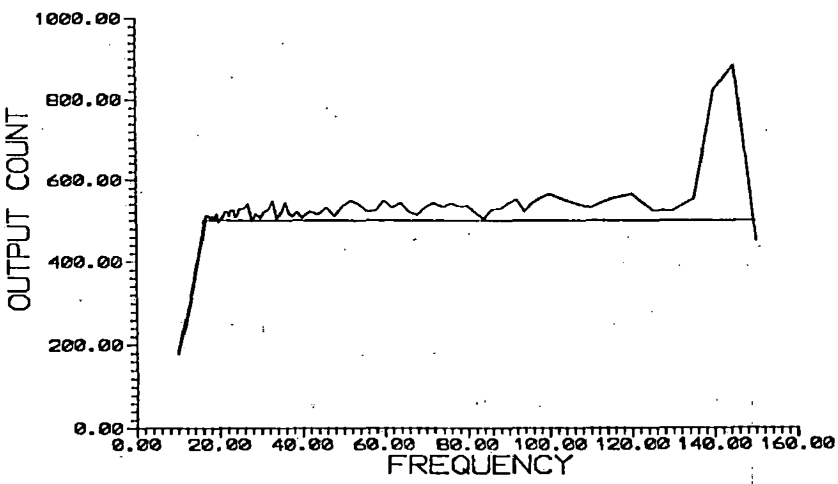
Fig 5.3 : Open Loop Control m = 4 kg (with 3-ϕ Energy Meter)



(a) $K_p = 1$; $K_I = 3$; $K_d = 10$

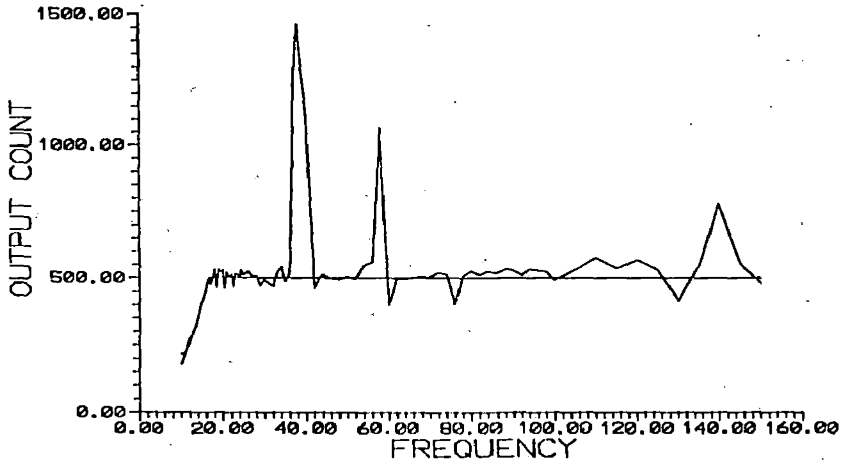


(b) $K_p = 1$; $K_I = 3$; $K_d = 5$

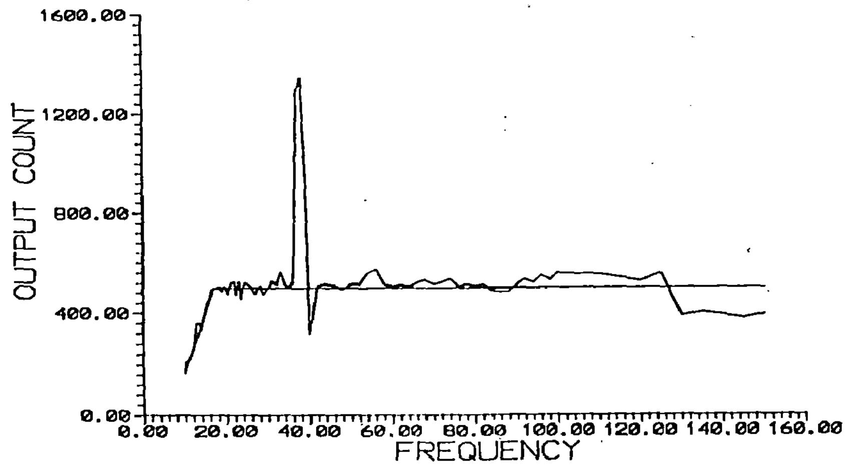


(c) $K_p = 1$; $K_I = 5$; $K_d = 4$

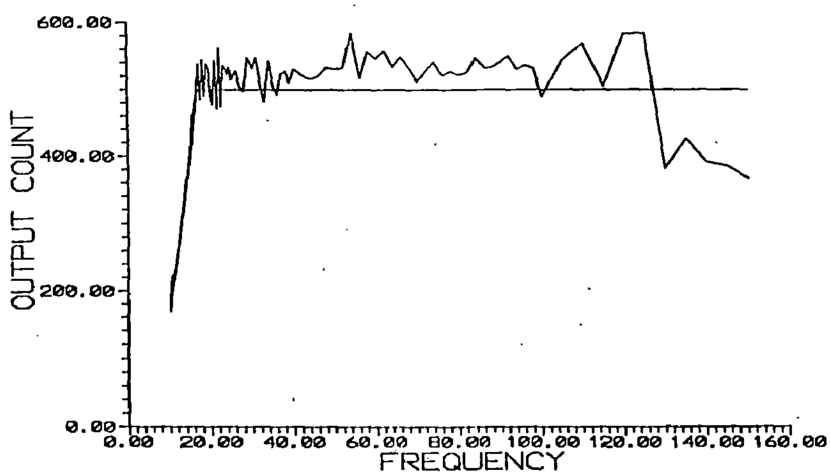
Fig 5.4 : Closed Loop PID Control, m = 1 kg (Bare Table)



(a) $K_p = 1 ; K_i = 3 ; K_d = 10$

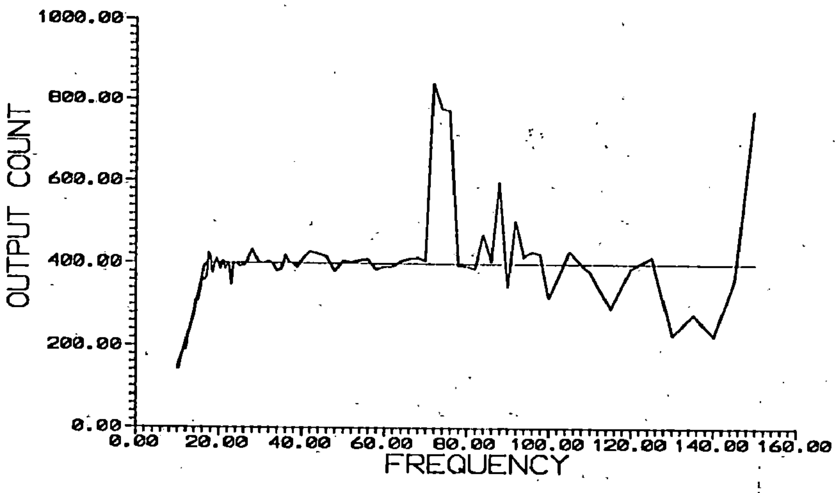


(b) $K_p = 1 ; K_i = 3 ; K_d = 5$

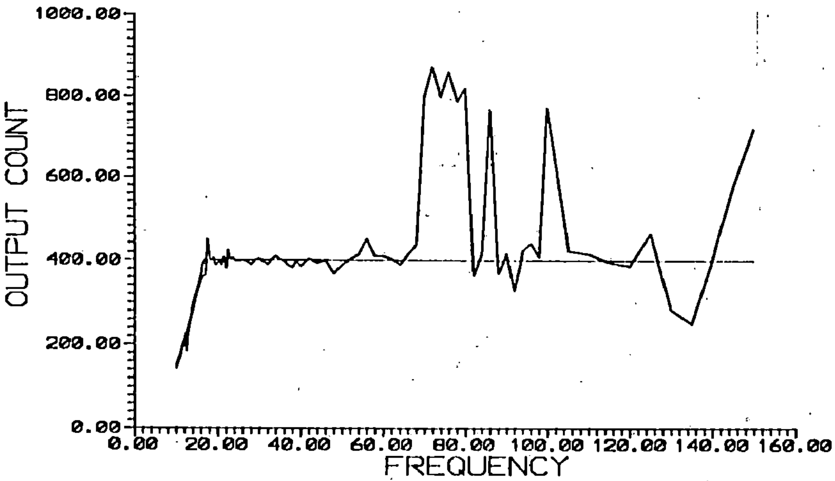


(c) $K_p = 1 ; K_i = 5 ; K_d = 4$

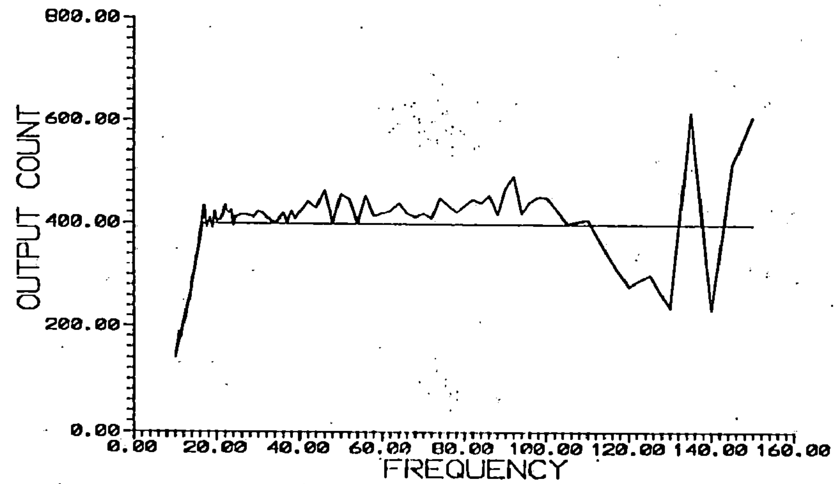
Fig 5.5 : Closed Loop PID Control, m = 2.4 kg (with 1-ϕ Energy Meter)



(a) $K_p = 1$; $K_I = 3$; $K_d = 10$



(b) $K_p = 1$; $K_I = 3$; $K_d = 5$



(c) $K_p = 1$; $K_I = 5$; $K_d = 4$

Fig 5.6 : Closed Loop PID Control, m = 4 kg (with 3-ϕ Energy Meter) one value of output corresponding to 20th Cycle is recorded and is ploltted in graph. The Open Loop Control are satisfactory but the deviation from the set point is much higher. So the closed loop PID control was also implemented for both the constant displacement and constant acceleration ranges of the frequency. The graphs for closed loop PID control are shown in fig 5.4, 5.5 and 5.6 for m=1Kg, m=2.4Kg and m=4Kg respectively. The PID controller gains K_p, K_i and K_d are optimized experimentally. The results for three combinations of PID gains (K_p=1, K_i=3, K_d=10), (K_p=1, K_i=3, K_d=5) and (K_p=1, K_i=5, K_d=4) are obtained and given in graphs for each value of mass(m). The value of gains K_p, K_i and K_d as given above are implemented in the PID controller software with a gain value equal to $1/(2)^{Kp}$,$1/(2)^{Ki}$ and $1/(2)^{Kd}$ respectively.

The results are good in the constant displacement range and are quite satisfactory for initial frequencies in constant acceleration range. The output acceleration count was close to the set point count except the frequencies where resonance occured.

5.2 CONCLUSION

The PID controller gains K_p=1, K_i=5 and K_d=4 are giving good results. The resutls are good in the constant displacement range of frequency. In the constant acceleration range of frequency also the results are good, but in this range as the resonance frequency of the system comes, so the amplitude of vibrations deviates from the setpoint by large amounts.

The modelling of the system has been done by taking first order system and studying the system input-outpot response in the range of mass variation from 1kg to 5kg and frequency variation from 10Hz to 150Hz. For future work, the modelling of the system can be done more precisely, may be by taking second order system.

APPENDIX-A

ACCELEROMETER TEST DATA

Type	AR-5[illegible]F
Capacity	5[illegible] g
Rated Output Strain	1146×10^{-6}
Calibration Coefficient	0.00436g/μV
Frequency response range	0 -120 Hz
Non-Linearity	1 % R.O.
Input Resistance	122.8 Ω
Output Resistance	122.4 Ω
Safe overload Rating	300 % R.O.
Safe temperature range	0 to +50⁰C
Safe Excitation	5V

Note: If measured by strain meter

Acceleration = Calibration Coefficient x Readout Strain.

APPENDIX - B

Data Acquisition Card PCL - 208

Product Specifications

Analog Input (A/D Converter)

Channels	:	16 Single-ended or 8 Differential, switch selectable.
Resolution	:	12 bits.
Input Range	:	Unipolar: + 10 V, + 5 V, + 2 V, + 1 V. Bipolar: +/- 10 V, +/- 5 V, +/- 2.5 V, +/- 1 V, +/- 0.5 V. All input ranges are switch selectable.
Overvoltage	:	Continuous +/- 30 V Max.
Conversion Type	:	Successive Approximation.
Conversion Speed	:	60 KHz max. (PCL-208 Standard) 100 KHz max. (PCL-208 A).
Accuracy	:	0.01 % of reading +/- 1 bit.
Linearity	:	+/- 1 bit.
Trigger Mode	:	Software trigger, on board programmable timer or external trigger (TTL compatible, load 0.4 mA max. at 0.5 V (low) or 0.05 mA max. at 2.7 V (high)).
Data Transfer	:	Program control, Interrupt control or DMA.

Analog Output (D/A Converter)

Channels	:	2 channels.
Resolution	:	12 bits.
Output Range	:	0 to + 5 V with fixed - 5 V reference. +/- 10 V with external DC or AC reference.
Reference Voltage	:	Internal : - 5 V (+/- 0.05 V). External : DC or AC, +/- 10 V max.

Conversion Type	:	12 bit monolithic multiplying (DAC 7541).
Linearity	:	+/- 1/2 bit.
Output Drive	:	+/- 5 mA max.
Settling Time	:	5 microseconds.

Digital Input

Channel	:	16 bits.
Level	:	TTL compatible.
Input Voltage	:	Low - 0.8 V max. High - 2.0 V min.
Input load	:	Low - 0.4 mA max at 0.5 V. High - 0.05 mA max. at 2.7 V.

Digital Output

Channel	:	16 bits.
Level	:	TTL compatible.
Output Voltage	:	Low - Sink 8 mA at 0.5 V max. High - Source -0.4 mA at 2.4 V min.

Programmable Timer/ Counter

Device	:	INTEL 8254.
Counters	:	3 channels, 16 bit. 2 channels permanently connected to 1 MHz/10 MHz clock as prog·

		rammable pacer, 1 channel free for user application.
Input Gate	:	TTL/ DTL/ CMOS compatible.
Time Base	:	10 MHz or 1 MHz, switch selectable.
Pacer Output	:	71 minutes/ pulse to 2.5 MHz.

Interrupt Channel

Level	:	IRQ 2 to 7, software selectable.
Enable	:	Via INTE of CONTROL register.

DMA Channel

Level	:	1 or 3, switch selectable.
Enable	:	Via DMAE of CONTROL register.

General

Power Consumption	:	+ 5 V : typ. 700 mA, max. 1 A. + 12 V : typ. 140 mA, max. 200 mA. - 12 V : typ. 14 mA, max. 20 mA.
I/O Connector	:	20 pin flat cable connector for all Analog/ Digital I/O ports.
I/O Base Address	:	Requires 16 consecutive address locations. Base address is definable by the DIP switches for address lines A9-A4. (Factory setting is &H300).

REFERENCES

1. Indian Standards IS 13010:1990, IS 9000(Part VIII): 1981 and IS 9001 (Part XIII):1981.
2. Owner's Manual, PCL-208 High Performance Data Acquisition Card, Dynalog Micro Systems Pvt. Ltd.
3. Balagurusamy, E., "Programming in ANSI C", Tata McGraw Hill Publishing Company Limited, 1992.
4. Hall, D.V., "Microprocessors & Interfacing: Programming and Hardware", Tata McGraw Hill Publishing Company Limited, 1991.
5. C.J. Harris and S.A. Billings, "Self Tuning and Adaptive Control: Theory and Applications", IEE Control Engineering Series 15, 1981.
6. Brain Roffel, Peter J. Vermeer and Patrick A. Chin, "Simulation and Implementation of Self-Tuning Controllers", Prentice-Hall, Inc., 1989.
7. I.J. Nagrath and M.Gopal. "Control Systems Engineering", Wiley Eastern Limited, 1993.
8. Astrom, K.J., and B. Wittenmark. 1973. "On Self-Tuning Regulators," Automatica, 9, 185.
9. Clarke, D.W., and P.J. Gawthrop. 1975. "Self-Tuning Controller," Proc. IEEE, 122 (September), 929-934.
10. Rolf. Isermann, "Digital Control Systems", Springer - Verlag, 1991.