Design and Development of Embedded System for DC Motor Speed Characterization using Fast Fourier Transform

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Abstract

This paper describes an automated vibration based DC motor speed characterization system using Frequency Domain Technique (FFT). These sensitive applications require high precision and high speed of response. The system has been programmed on ARM Microcontroller; a constant pulse width modulating (PWM) signal is applied from the microcontroller which accelerates the motor and it attains a steady state speed. The steady state speed increases with increase in PWM duty cycle. The steady state speed is measured with respect to different PWM duty cycles. Samples are taken within a time interval from external accelerometer output at different PWM duty cycles. These samples are fed to the Fast Fourier Transform to check frequency components in real time signal coming due the motor speed up. These frequency components match with the speed of dc motor. At the last moment, characteristics of DC motor is obtained by mathematical equation for dc motor speed with respect to frequency component are determined in MATLAB by using curve fitting tool.

Keywords: DC Motor Speed Characterization; Embedded System; ARM Microcontroller; Fast Fourier Transform; External Accelerometer.

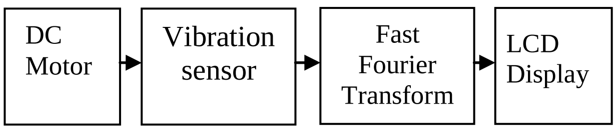
Introduction

For a dc motor, characterization means finding constants of the equation of the motion. Though, data-sheets are provided by manufactures, but the parameters are bound to change for day to day operation, so attempt has been made to determine constants of standard DC motor using an embedded program. These requirements to evaluate parameters are necessary when the motor is to be employed in some operation where minute change in the parameters will affect the performance. The program is employed for time-to-time evaluation of the sensitive parameters.

For DC motor speed characterization, a constant pulse width modulating (PWM) signal is applied from the microcontroller. The duty cycle of this PWM signal is varied and steady state speed of dc motor corresponding to these cycles. Also for the same duty cycles, FFT is taken by capturing vibrations of the motor using vibration sensor and frequency component having maximum amplitude is plotted against PWM duty cycles. Finally, a relation is drawn in between steady state speed and frequency component having maximum amplitude for dc motor which leads to a vibration based dc motor speed characterization system.

A schematic block diagram of Embedded System for DC motor speed characterization is shown in Fig. 1.

Fig. 1: Schematic block diagram of Embedded System for DC motor speed characterization



The vibration sensor is a piezoelectric external accelerometer which is used to sense the vibrations coming from DC motor. The property of external accelerometer is that it senses the vibrations of dc motor and provides an output voltage corresponding to these vibrations. Depending upon the length of Fast Fourier transform (FFT), samples are taken from external accelerometer output within a specified time interval and on these samples FFT is applied so that a frequency response is obtained which is displayed on LCD. With respect to different PWM duty cycle amplitude of these frequency components are plotted. The program for this system and developed hardware for real time signal processing has been verified.

In this paper, section I includes the introduction for dc motor speed characterization, section II describes the dc motor and pulse width modulation, section III describes characterization hardware and software module, section IV gives the result of dc motor characteristics, section V conclusion of the work is presented.

DC Motor and Pulse-Width-Modulation

DC Motor

If a DC motor is connected directly to the voltage supply, the constant power will be supplied to the DC motor all the time. Due to the constant power to motor, the speed of the motor will slow down when the load is heavier and speed up when load is lighter. The speed of dc motor is also directly proportional to the voltage. When voltage increases then speed of motor is alsoincreases and when voltage decreases then speed also decreases.

Pulse-Width-Modulation in Microcontroller

In microcontroller, pulse width modulation is used to control the duty cycle. The supply signal to the motor in square wave with constant voltage but duty cycle is varied. Duty cycle refers to the percentage of one cycle during which the signal remains in high state. Duty cycle also refers to period of one cycle in which system is active. The total period of cycle is held constant while the on-off time is varied; the duty cycle of the PWM is determined by the pulse width. The expression for duty cycle is determined by

$$\text{Duty cycle} = \frac{\text{ton x 100}}{\text{T}} \% \qquad (1)$$

Where T=Total period of one cycle, t_{on}= time for which signal remains high within period T.

DC Motor Characterization System

Hardware Module

For characterizing dc motor, the motor is connected to ARM based microcontroller (NXP LPC 2478) through an interfacing circuit. The Figure below (Figure 2 and 3) depicts the actual Characterization module.

Fig. 2: Interfacing Circuit

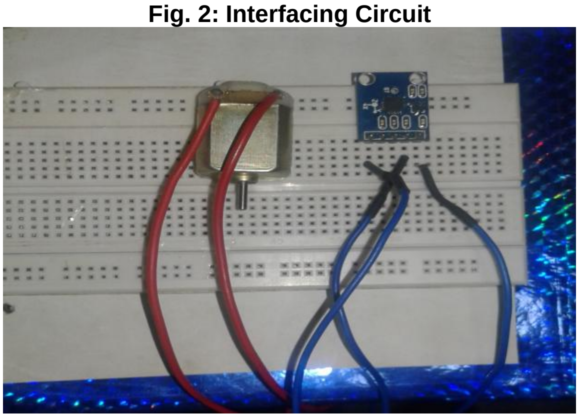
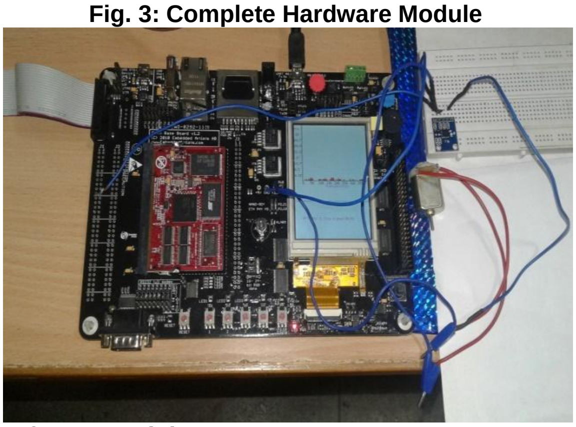


Fig. 3: Complete Hardware Module



Software Module

1. Keil
2. Embedded C
3. MATLAB

By varying the PWM duty cycles from 10% to 90% vibrations of the system is obtained on which DC motor is situated. The vibrations are picked up external accelerometer sensor mounted don breadboard. So, there will be change in output voltage of the external accelerometer sensor. By using analog to digital converter, this output analog voltage is converted into digital form and ARM7 (LPC2478) contains 10 bits successive approximation analog to digital converter. From the external accelerometer output samples are taken within a time interval of one millisecond. A software code is written to compute Fast Fourier transform. Then this code is applied to samples from the external accelerometer output and finally the result is taken from the LCD. This gives a relation between the frequency component and PWM duty cycle for dc motor.

After obtaining the relation between frequency component and PWM duty cycle of the system, the model is simulated in MATLAB using curve fitting tool.

Characterization Results and Discussion

The signals coming from the motor vibrations are in real-time domain. The external accelerometer picked up these vibrations and fed to the fast fourier transform. The real-time signal and its FFT display at different PWM duty cycle is shown in Fig.4 and Fig. 5.

Fig. 4: FFT Display at 40% PWM

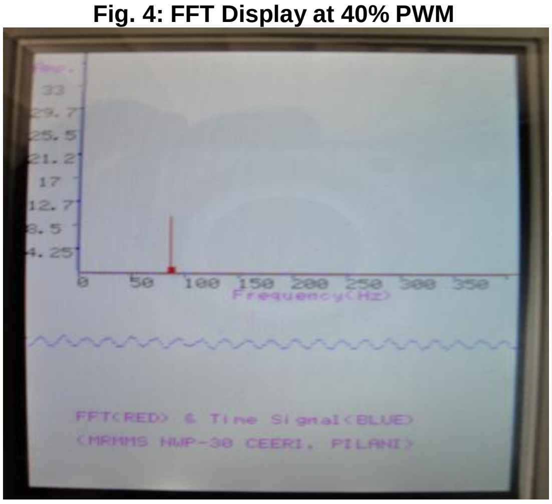


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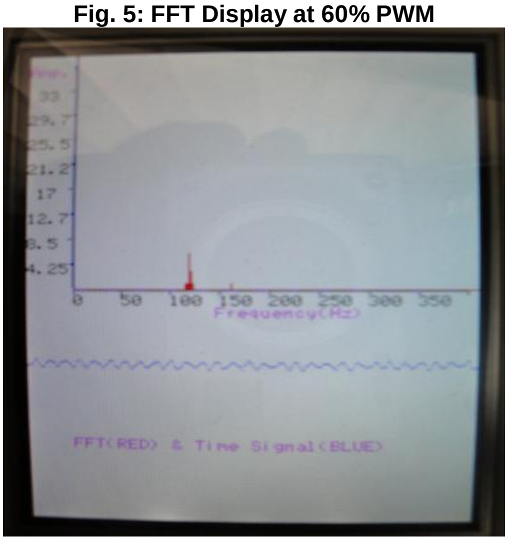
Fig. 5: FFT Display at 60% PWM



Several experiments have been done to evaluate steady-state-speed and FFT with different PWM values. Table 1 shows the averaged value of steady state speed (Hz) and frequency component (F_{max} in Hz) for different PWM values.

Table 1: Steady State Speed, FFT With Different PWM Duty Cycles

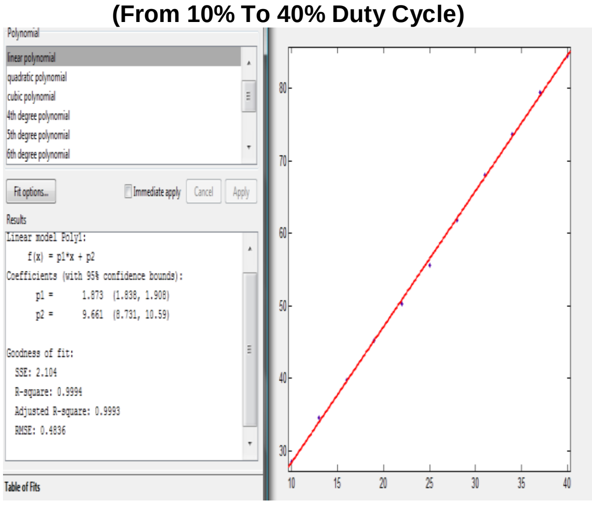
PWM Duty Cycle (%)	Steady State Speed (Hz)	Frequency Component (F_{max}) in Hz
10	28.5	-
13	34.625	-
16	39.75	-
19	45.25	-
22	50.25	-
25	55.625	54.975
28	61.75	60.172
31	68	65.493
34	73.625	71.022
37	84.5	76.011
40	84.5	80.887
43	90.25	85.735
46	94.25	90.257
49	97.775	94.898
52	101.25	99.628
55	105.375	103.72
58	109.125	107.52
61	112.875	112.2
64	116.875	116.398
67	119.375	120.114
70	122.875	124.289
73	126.25	127.939
76	129.25	131.687
79	132	134.734
82	134.5	138.099
85	137.5	140.997
88	140.625	144.511

Speed vs. PWM

By using table 1, the mathematical equations for steady-state-speed with respect to PWM duty cycle are determined in MATLAB by using Curve Fitting Tool.

For PWM duty cycle ranging in between 10% to 40%, the steady state speed vs. PWM is plotted in Fig. 6.

Fig. 6: Speed vs. PWM
(From 10% To 40% Duty Cycle)



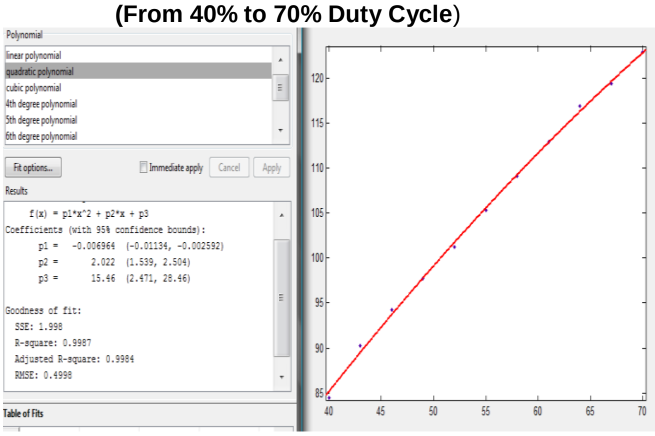
The response is linear and equation for measuring speed with respect to PWM is

$$f(x) = 1.873x + 9.661$$
$$R\text{-square} = 0.9994$$

Here R-square is the coefficient of Determination; it represents the Goodness of fit in curve fitting polynomials.

For PWM duty cycle ranging in between 40% to 70%, the steady state speed vs. PWM is plotted in Fig. 7.

Fig. 7: Speed vs. PWM
(From 40% to 70% Duty Cycle)

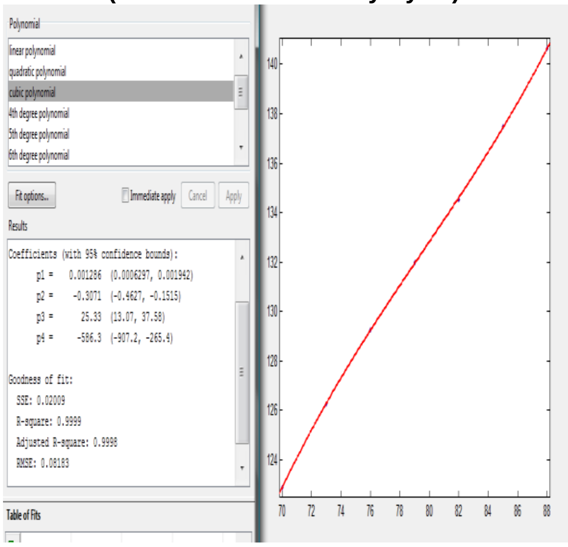


The response is quadratic and equation for measuring speed with respect to PWM is

$$f(x) = -0.006964x^2 + 2.022x + 15.46$$
$$R\text{-square} = 0.9987$$

For PWM duty cycle ranging in between 70% to 90%, the steady state speed vs. PWM is plotted in Fig. 8.

Fig. 8: Speed vs. PWM
(From 70% To 90% Duty Cycle)



The response is cubic and equation for measuring speed with respect to PWM is

f(x)=0.001286x^3 -0.3071 x^2+ 25.33x – 586.3

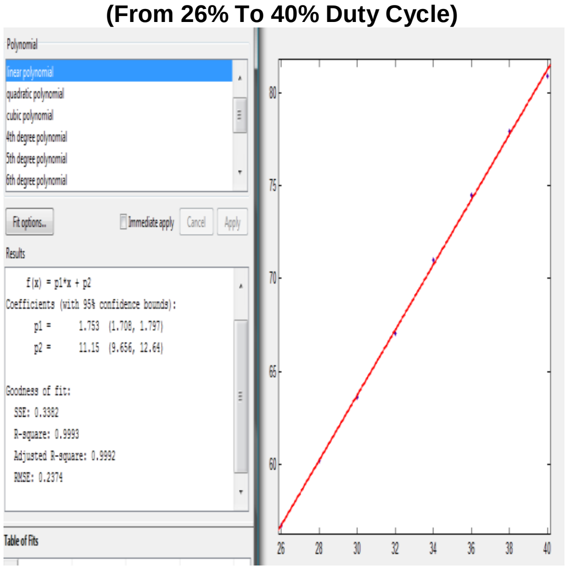
R-square= 0.9999

FFT vs. PWM

By using table 1, the mathematical equations for DC motor frequency components with respect to PWM duty cycle are determined in MATLAB by using Curve Fitting Tool.

For PWM duty cycle ranging in between 26% to 40%, the F_{max} vs. PWM is plotted in Fig. 9.

Fig. 9: F_{max} vs. PWM
(From 26% To 40% Duty Cycle)



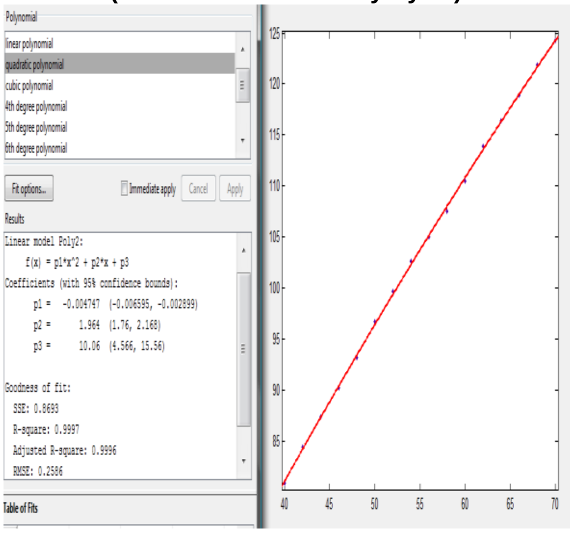
The response is linear and equation for measuring F_{max} with respect to PWM is

f(x) =1.753x+11.15

R-square= 0.9993

For PWM duty cycle ranging in between 40% to 70%, the F_{max} vs. PWM is plotted in Fig. 10.

Fig. 10: F_{max} vs. PWM
(From 40% To 70% Duty Cycle)



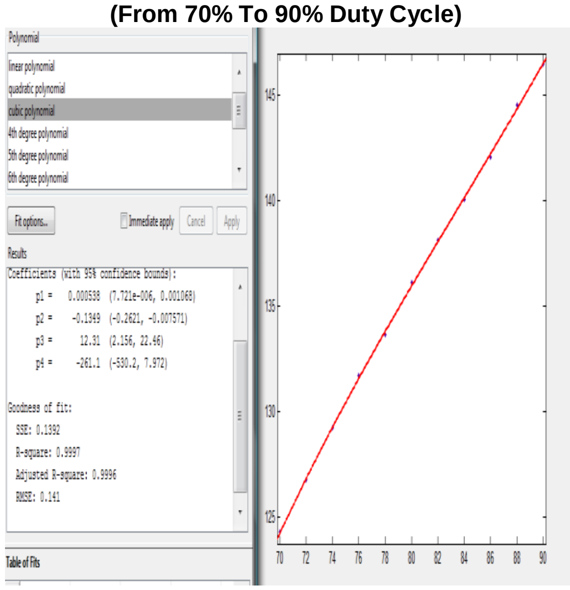
The response is quadratic and equation for measuring F_{max} with respect to PWM is

f(x) = -0.004747x^2 + 1.964x + 10.06

R-square= 0.9997

For PWM duty cycle ranging in between 70% to 90%, the F_{max} vs. PWM is plotted in Fig. 11.

Fig. 11: F_{max} vs. PWM
(From 70% To 90% Duty Cycle)



The response is cubic and equation for measuring F_{max} with respect to PWM is

f(x)=0.000538x^3 -0.1349 x^2+ 12.31x – 261.1

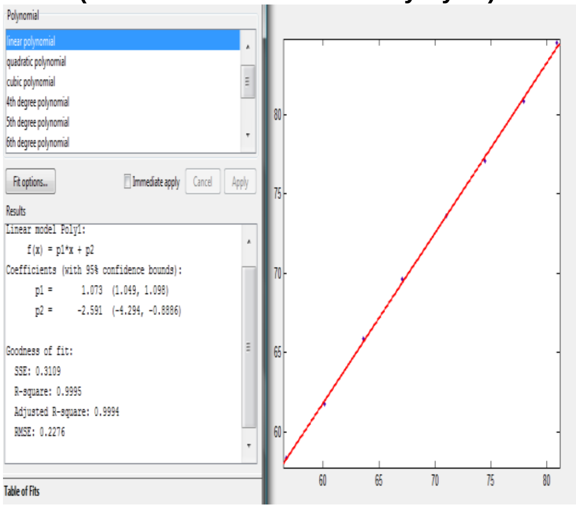
R-square= 0.9997

Speed vs. FFT

By using table 1, the mathematical equations for DC motor speed with respect to frequency components are determined in MATLAB by using Curve Fitting Tool.

For PWM duty cycle ranging in between 26% to 40%, the speed vs. F_{max} plotted in Fig. 12.

Fig. 12: Speed vs. F_{max}
(From 26% To 40% PWM Duty Cycle)



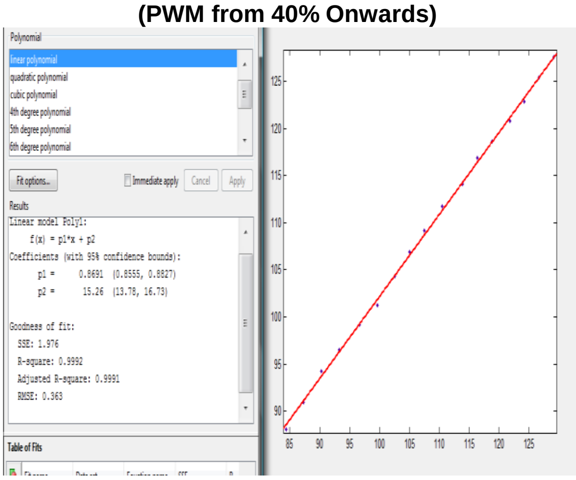
The response is linear and equation for measuring speed with respect to F_{max} is

$$f(x) = 1.073x - 2.591$$

R-square= 0.9995

For PWM duty cycle ranging from 40% onwards, the speed vs. F_{max} is plotted in Fig. 13.

Fig. 13. Speed vs. F_{max}
(PWM from 40% Onwards)



The response is linear and equation for measuring speed with respect to F_{max} is

$$f(x) = 0.8691x + 15.26$$

R-square= 0.9992

The software program and developed hardware for real-time signal processing has been verified by comparing its results on MATLAB. For verification, let us take any time-domain signal Y=1.5 sin (2π50t) and FFT gives frequency domain representation of time-domain signal. The frequency response on LCD and its verification through MATLAB for signal Y are shown in Fig. 14 and Fig. 15.

The signal for Y may be a combination of various sinusoidal signals having different frequencies and amplitudes. For example, Y1=0.5 sin (2π50t) +sin (2π100t) +1.5 sin (2π200t) the frequency response on LCD and its verification through MATLAB for signal Y1 are shown in Fig. 16 and Fig. 17.

Fig 14. Frequency Response on LCD for Y=1.5 sin (2π50t)

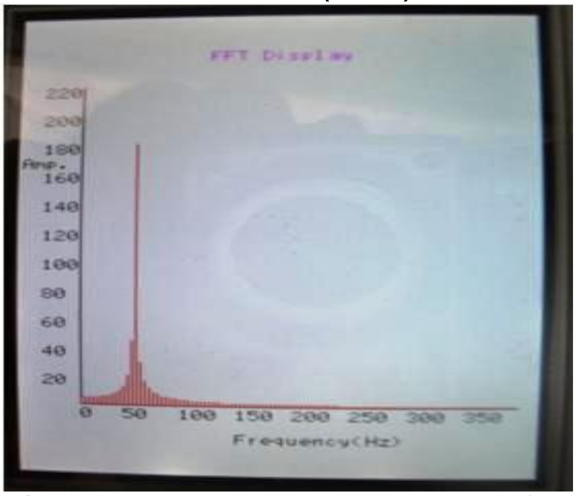


Fig 15. Frequency response on MATLAB for Y=1.5 sin (2π50t)

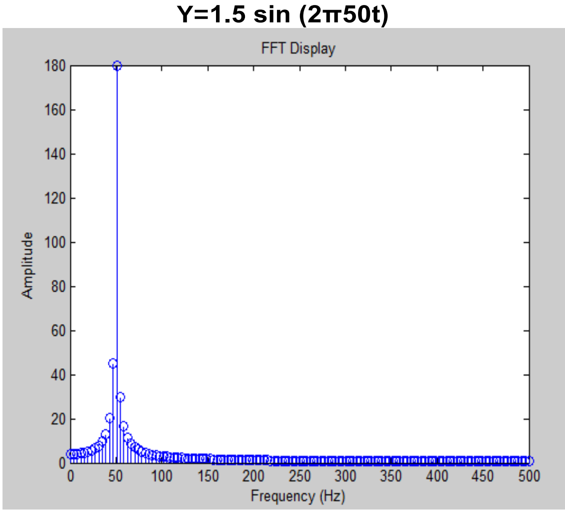


Fig 16. Frequency response on LCD for Y1=0.5 sin (2π50t) +sin (2π100t) +1.5 sin (2π200t)

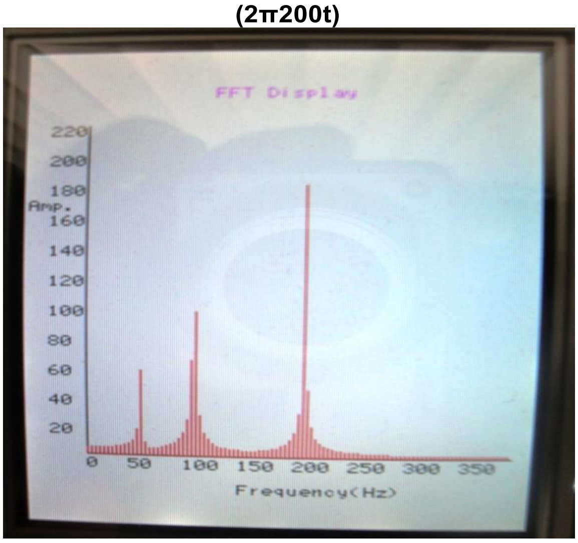
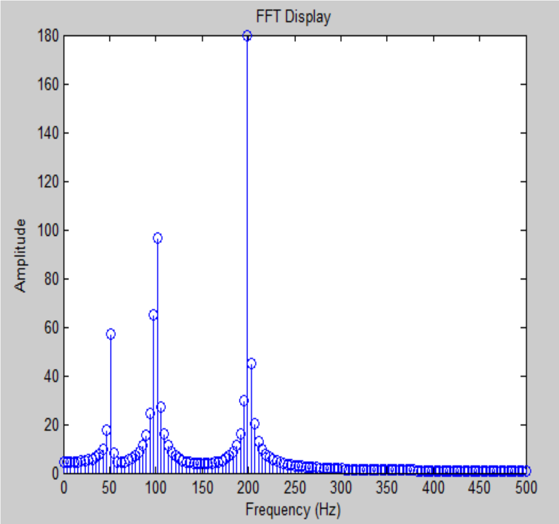


Fig 17. Frequency Response on MATLAB for Y1=0.5 sin (2π50t) +sin (2π100t) +1.5 sin (2π200t)



Conclusion

A real-time embedded system for measurement and estimation of DC motor speed characteristic has been developed on ARM microcontroller using Fast Fourier Transform and it has been concluded that the equation of measuring F_{max} with respect to PWM is linear for low value of PWM duty cycle and it changes to quadratic and cubic for higher value of PWM duty cycle. This is because all vibratory systems tend to behave nonlinearly with increasing amplitude of oscillations. Also, observations for F_{max} are taken with respect to PWM duty cycle beyond 25%, this is because at low values of PWM duty cycle the vibrations are not much powerful so as to capture by the external accelerometer. Finally, relations in between speed and F_{max}have been drawn so by calculating the F_{max}, one can calculate the speed of DC motor which leads to a vibration based speed characterization system.

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