Active Automobile Engine Vibration Analysis

Technical Report number 1

Submitted by:
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Abstract

As the world population and relative cost of fossil fuels increase, it is becoming necessary for drivers to be more cognizant of the operating condition of their vehicles. It is also clear that the international community is becoming more dependent on the use of commuter automobiles. As such, it is imperative that people take better care of their vehicles in order to reduce repair costs and atmospheric pollution and increase efficiency and longevity. The preliminary version of the Active Automobile Engine Vibration Analysis system provides adequate proof that a single accelerometer is sensitive enough to fulfill this task. Also, the beta version of this system informs the driver when their engine has deviated from its baseline performance and that catastrophic failure may occur without the proper maintenance.

The current basis for the analyses and graphical outputs of the system are centered on the Fast Fourier Transform. The subsequent frequency spectra provide valuable insight into the modes of vibration from the engine block to the chassis of the vehicle.

Table of Contents

Summary

This program is designed to provide diagnostic feedback about engine performance in a vehicle. The basic methodology revolves around the application and analysis of the Fast Fourier Transform. Through the synthesis of an engine frequency signature by means of manipulating the total frequency spectrum of accelerometer data in the X, Y and Z axes, it is possible to establish a baseline performance for future comparison. As it exists, the program compares the baseline frequency signature to subsequent spectra and informs the user of deviation from optimal engine performance. The proof of principle provided by this experiment is a necessary step in the overall development in this program as an active identifier of specific engine faults.

1.0 Introduction

With the rapid growth of urban regions throughout the world comes the necessity for reliable transportation. Contemporary automobile manufacturers, without a doubt, strive to produce dependable vehicles that consumers can operate for many years without the worry of constant repair. However, no vehicle is infallible. Thus, with the increase in vehicle sales and the natural imperfect nature of machinery comes the requisite for immediate automobile fault detection. Often, large machinery failures result from a lack of planned maintenance or the ignorance of much smaller defects. With the Active Automobile Engine Vibration Analysis System, drivers are informed of improper operation before it propagates into catastrophic failure, thus reducing potential repair and automobile rental costs. Despite the recent economic downturn, vehicle registration has increased in recent months. Consequently, the demand for proper automobile care will increase as well.

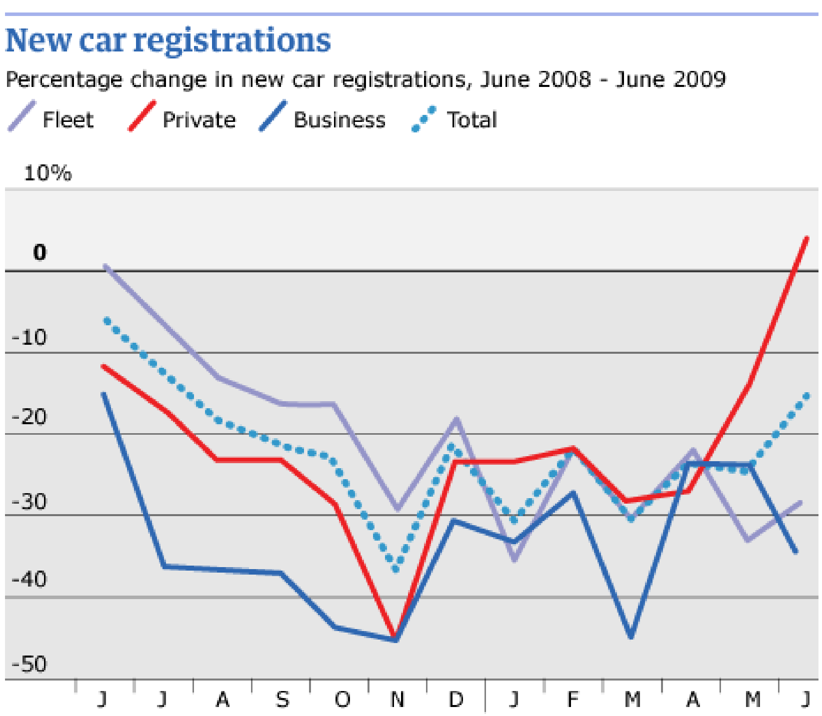


Figure 1: Source: Wearden, Graeme. "Slump in UK Vehicle Sales Eases Off, SMMT Says | Business | Guardian.co.uk." *Latest News, Comment and Reviews from the Guardian |* *Guardian.co.uk*. Guardian News and Media Limited 2010, 6 July 2009. Web. 12 May 2010. <http://www.guardian.co.uk/business/2009/jul/06/vehicle-scrappage-uk-sales-smmt>.

All rotating machinery, such as the internal combustion engine, generates specific vibration frequencies. These frequency signatures are unique to each engine and any fault that might develop from prolonged or improper use. Thus, an engine operating with a specific fault will demonstrate a frequency signature that is unique to that engine type and that exact fault. Therefore, with the active vibration analysis system, it is possible to detect that a fault or series of faults have occurred.

Since the invention of the accelerometer, many applications for the device have been developed. One example of this is the automobile airbag deployment system. As the vehicle immediately decelerates, the accelerometer detects this change in velocity and initiates airbag inflation. This very same device can be employed to monitor the vibrations of the automobile's engine. However, a much more sensitive device would need to be utilized for the purpose of fault detection.

2.0 Hardware Architecture

2.1 Accelerometer Location and Mounting

In order to detect vibrations in a solid object, the placement of the accelerometer is crucial. The engineer must be cognizant of the fact that it is possible for these vibrations to be dampened by any type of soft material. Therefore, for optimal performance, it is vital that all vibration detection sensors, such as the accelerometer used in this system, be hard mounted to a surface that is on the same side of the resilient supports as the rotating machinery. With this accomplished, the vibrations that occur due to the rotation of the equipment will be transmitted through the solid surfaces of the machine to the location of the accelerometers for detection. For the purposes of this experiment, the accelerometer was placed firmly on the center console of the vehicle. This choice will not affect the subsequent data because the accelerometers used are extremely sensitive and are able to detect vibrations transmitted through the rubber engine mounts. It is also important to note that the accelerometer and the plastic case were not modified in any way. Upon mass production, however, the accelerometer will be secured inside a protective case which will be mounted to any standardized horizontal or vertical surface of the engine block.

2.2 Orientation

While the exact orientation of the accelerometer is not important, the device should not be mounted on any oblique surface. Therefore, the axes of the accelerometer must be parallel to the axes of the vehicle. Furthermore, it is important to observe the orientation of the accelerometer in order to accurately analyze data obtained during data acquisition trials. For the analysis performed by this program, it is necessary for the relative Z axis of the vehicle and the accelerometer to be the same in order to eliminate artifact harmonics in the data spectra. The orientation of the accelerometer used for this experiment is illustrated on the following page in figures 2 and 3.

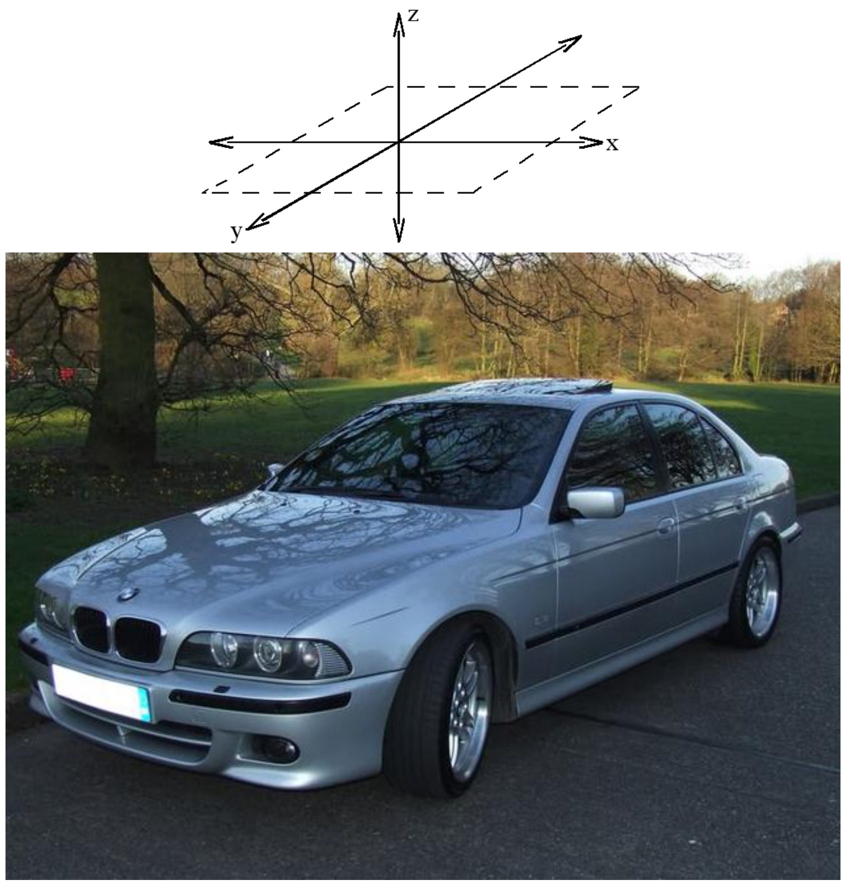


Figure 2: Orientation of the accelerometer with respect to the test vehicle

Figure 3: Position of the accelerometer within the vehicle cab

3.0 Software

3.1 Software Function

This program is comparative software meant to analyze the performance of a vehicle engine with respect to a baseline frequency signature acquired from an initial set of accelerometer readings immediately obtained after the vehicle is tuned. A subsequent Fourier analysis is performed while maintaining the engine at a specific RPM. For the purposes of this study, the engine was sustained at five thousand RPM, which corresponds to approximately 83.333 Hz. Upon calculating and storing the entire frequency content of the refurbished engine, an amplitude cutoff limit is set in order to retain the fundamental frequency corresponding to the prescribed number of revolutions per minute as well as its harmonics. This modified power spectrum density is what serves as the basis for the program's function. When the vehicle is restarted, the software is initialized and the operator then increases and maintains the engine to the same RPM used after the tune up. The frequency content is again stored, calculated, and modified with the same relative cutoff factor. This power spectrum density is then compared to the baseline spectrum with respect to the number of harmonics in the new frequency signature. After continued use of the vehicle, the number of harmonics in the successive spectra will increase compared to the number in the baseline frequency signature.

A second function of this software is that it outputs a surface plot of the Fast Fourier Transform over intervals of 0.2645 seconds. This serves as an active means of monitoring the stability of the vehicle as it is being driven and thus, can provide valuable insight should a driver be involved in an accident. The frequency content at the specific time of the accident can be re-obtained and analyzed.

3.2 Software Analysis

Data Retrieval and Storage

Before the ""dongle"" program is initialized, the user must ensure that the vehicle is operating at standard system temperatures. Also, there are three modes from which data is collected: mode one data is taken when the vehicle is idle, mode two data is taken while the vehicle engine is being maintained at a set RPM, and mode three data is acquired when the vehicle is being driven at a specified speed after the initial transient acceleration. For the data collected in this experiment, for mode one, the engine was maintained at 5,000 RPM and the mode-three velocity was ten miles per hour. All of the analysis was performed on 9.9874 seconds worth of accelerometer readings in the X, Y, and Z directions. This time interval will be the default setting for the program's analysis. After allowing the vehicle temperature to increase to the appropriate normal operating value, the "dongle" program is initialized to record eleven seconds worth of data and the accelerometer sensitivity is set to the default 1.5 g value. After the "dongle" program finishes running, the data from the trial is saved to a text file. The successive text files contain data for each measurement made by the "dongle" in columns under the name of the measurement. In order for the program to read the data properly, these headings must be deleted. The time, X axis, Y axis, and Z axis data are in the first, second, third, and fourth columns, respectively. After deleting the measurement headings, the text file is renamed to correspond to the mode in which the data was recorded.

Next, the program is initialized. The user is prompted for two pieces of data. The first is the number of revolutions per minute at which the engine is being maintained and the second is the acceptable number of harmonics beyond that of the baseline frequency signature.

The program then loads the appropriate columns of data into three vectors assigned to each of the three modes. A fourth vector is then initialized for the time readings. The time step is then calculated and used to set the number of data points to be extracted from each mode. The default time length used to determine this number is 9.9874 seconds. For this experiment, 9.9874 seconds corresponds to 12,160 points. The program then initializes three data vectors named after each axis and allocates the appropriate accelerometer measurements to these vectors.

Data Analysis

A significant part of the analysis performed by the program is based on the use of the Fast Fourier Transform. Three separate vectors are initialized to contain the Fast Fourier Transform of the three data modes for each axis. As with the raw data vectors, each one of these arrays is named after its respective axis. Next, the Fast Fourier Transform, or FFT, of data from each mode is taken and saved in the initialized vectors. Since the transform yields a complex spectrum, in the same loop, the magnitude is taken of the transform and allocated to another data vector that expands within the loop.

After qualitative analysis of the FFTs for each mode, it was determined that the Z-axis data acquired in the second mode at 5,000 RPM yielded the highest relative peaks and lowest relative noise floor in the FFT. In order to simplify the analysis performed by the program, the comparative parts of the program exclusively use the FFT from this mode as their basis.

Using the second mode Z-axis FFT, a frequency signature is formulated by imposing a cutoff factor in the frequency domain relative to the peak value of the entire FFT. This value is calculated by correlating the frequency of the maintained RPM to its index within the FFT vector. Due to the inexact nature of maintaining an engine at a specific RPM, the odometer reading is not completely reliable. The program attempts to mitigate this inaccuracy by looking for a relative peak within an interval centered at the index corresponding to the ideal RPM frequency. The program searches twenty previous and subsequent indices for this relative peak. To avoid indexing errors within Matlab, the program prompts the user to choose a specific RPM above 120 when it is first started. Using the peak amplitude within this interval, the program calculates the factor difference between the absolute and relative peak. Eliminating the frequencies that have amplitudes below the absolute peak divided by this cutoff factor generates a new frequency spectrum, which is the frequency signature of the engine. The program uses the FFT spectrum of the tuned engine to determine this cutoff factor and subsequent signature. The reason behind this is based on a qualitative observation about the spectra pertaining to a tuned and un-tuned engine. The relative noise floor, or the amplitudes of the frequencies that did not have visible harmonics in the FFT, was significantly higher in amplitude with respect to the absolute peak of the FFT in the data from the un-tuned engine. From this observation, it was determined that the simplest way to perform an engine diagnostic would be to compare the relative noise floors of a tuned vehicle engine to one that is in need of maintenance. Since the spectrum of a non-idling engine spreads across many frequencies, it is not prudent to rely simply on the total number of harmonics in the spectrum as a comparative basis. Thus, a relative cutoff factor was imposed to filter out the frequency corresponding to 5000 RPM and its harmonics. It was observed that the absolute peak of the FFT did not correspond to 83.333 Hz, leading one to believe that multiple fundamental frequencies exist in a vehicle, even when maintained at a specified RPM. To include these harmonics, the cutoff factor is multiplied by a constant that was deemed sufficient for a more complete frequency signature. As the software exists, the difference in the number of harmonics within both spectra is calculated and compared to a user-input limit. A subsequent output statement informs the user if the difference is less than, equal to, or greater than this limit.

As mentioned earlier, the program also outputs a graphical representation of the FFT over successive 0.2645 second intervals as the vehicle is being driven. For this graph, the mode three data pertaining to the Z-axis is split into two vectors containing intervals of 320 data points since the time step is approximately 82.133 milliseconds. The first vector is comprised of intervals from the original mode three Z-axis data vector in successive order. The second vector is filled in a similar manner except that the 320 data point sections are taken with an initial 160 data point delay. This semi-recursive data allocation scheme yields an FFT surface that better represents the propagation of harmonics in the vehicle as one drives. A third vector is then initialized and filled with the FFTs in an alternating order, starting with the non-delayed vector. Again, to avoid indexing errors, in the last interval of the delayed FFT vector, the program sets the second half of the vector equal to the first. Since this approximation has no valid basis, the surface plot of the evolving FFT does not include this interval.

Currently, the program outputs an FFT surface plot that spans over all 9.9874 seconds of the mode three trials. Initially, the program was written to output the successive FFT intervals individually, but this caused the program to freeze after only a few iterations. The reason behind this error is unknown. Also, the program outputs an FFT surface plot of the mode two data and the FFT graphs of all three modes for all three axes. For the consumer application, only graphs pertaining to mode two and three of the Z-axis would be displayed for the user to view.

The program is presently written to read data from two sets of files pertaining to the tuned and un-tuned vehicle “dongle” trials respectively. In actuality, the program would be run once following a tune up, and the baseline frequency signature would be saved to a text file. Then, for real-time use of this software after the tune-up, it will be necessary to integrate the program with the “dongle” program so that the input data from the accelerometer can be read and analyzed immediately. This is a more sophisticated undertaking which was not attempted. Instead, the main objective was to provide proof of principal that the accelerometer on the “dongle” is sensitive enough to provide useful diagnostic information about a vehicle’s engine performance.

4.0 Performance Measurements

4.1 Introduction

As previously stated, the primary purpose of the program is to calculate the difference in the number of harmonics between a baseline and subsequent frequency signatures. Although the diagnostic function of this software is tied most closely to this comparative process, the program saves the frequency spectra of all three data modes for all three axes and outputs them as well. Enabling the software to do this permits further frequency analysis development beyond the current scope. The initial vision of the program mandated that it would identify frequency signatures specific to certain engine faults. In order to fully carry out this endeavor, one would require an engine that could have faults inserted for the sake of analysis. After extensive searching, it became apparent that obtaining such an engine would not be possible since it would be damaged throughout the course of the experiment.

The three data modes in which the trials were carried out are not ideal. The idle mode referred to as mode one is contingent upon several external factors that could not be controlled. Although both sets of mode one data were acquired on the same street, the test vehicle was not at the same exact position on the street during both trials. Slight changes in the list of the vehicle, or relative direction of gravity, may affect the standing waves established by the engine in all three data collection modes. Consequently, the respective tuned and un-tuned engine spectra for these modes may not correlate as closely as previously assumed. Specifically, the additional harmonics in the un-tuned spectrum may result from this list difference rather than faulty engine performance. Also, the list may give rise to dampening of the fundamental frequencies and their respective harmonics, thus causing the noise floor to seem higher in level than it may have been if the vehicle were in the same exact position as the initial trial.

The mode two data, taken at 5,000 RPM in the trials also possess faults. In the FFT spectra, it was discovered that the fundamental frequency corresponding to presumed 5000 RPM was not exactly 83.333 Hz as calculated. In fact, both the tuned and un-tuned data in the z-axis had different fundamental frequencies that were offset from this value**.** The initial tuned engine spectrum had a fundamental frequency at 82.47 Hz while the corresponding frequency in the final un-tuned engine spectrum was at 83.3 Hz. This means that, although the odometer displayed that the engine was being maintained at 5,000 RPM, in actuality, the respective RPM were slightly different. The fact that the fundamental frequencies pertaining to the RPM were different in the respective spectra weakens the validity of the subsequent correlations and the resulting conclusions that were drawn. It is possible that different RPM can give rise to different modes of standing waves in the vehicle. Also, the engine was not maintained at constant RPM. In both trials, after holding the accelerator down for a brief period, the RPM would exceed 5,000 and the pedal would be slightly depressed. Depressing the pedal would then cause the RPM to fall below 5,000. Oscillations such as these detract from the relative accuracy of the program's calculations and frequency signature formation.

Mode three data, which was taken at ten miles per hour, is the most variable compared to the modes one and two. The trials were performed on 27th street since it is one of the least occupied roads in the vicinity of USC. However, when driving the vehicle, slight accelerations and decelerations were applied in an attempt to keep the speed at ten miles per hour. As with maintaining the engine at a constant RPM, this oscillation of the pedal distorted the fundamental frequency in the FFT spectra of the tuned and un-tuned engine. The influence of list on this mode of data collection creates effects that are more sophisticated. Though an attempt was made to drive along the same path and direction on 27th street for both data trials, it is unlikely that the test vehicle traversed the same exact path with the same exact pedal depression pattern during both trials. These variations yield different modes of standing waves that would be affected not only by the changing list along the different paths, but also by the changing velocity at different points in the respective paths.

4.2 Mode One Data

As previously stated, mode one refers to data acquired when the test vehicle is stationary and at idle. During idle, the frequency spectrum corresponds to the rate at which components in the engine and transmission are rotating or moving without depressing the accelerator. Some of these major constituents include the crank shaft, cam shafts, and alternator. There is a multitude of other pieces of engine equipment that can dampen and affect the propagation of standing waves throughout the chassis of the vehicle. Since all of the components could not be accounted for, the respective frequency response will not be analyzed. Figures 4 (a)-(c) show the FFT spectra of all three axes in this mode. The tuned engine spectra are titled as "Initial Data" and the un-tuned spectra are titled as "Final Data". Upon inspection, it can clearly be seen that the orders of magnitude of the initial and final data are the same across all three axes. Furthermore, the relative peaks in the respective spectra have similar distributions and therefore do not provide a good comparative basis between the tuned and un-tuned engine data. Therefore, in the program, the FFT spectra of the mode one data are recorded and displayed but not analyzed. It can be presumed that when the vehicle is at idle, the only dampening effects would result from the material characteristics of any components used in the fabrication of the automobile and the angle at which it sits with respect to gravity.

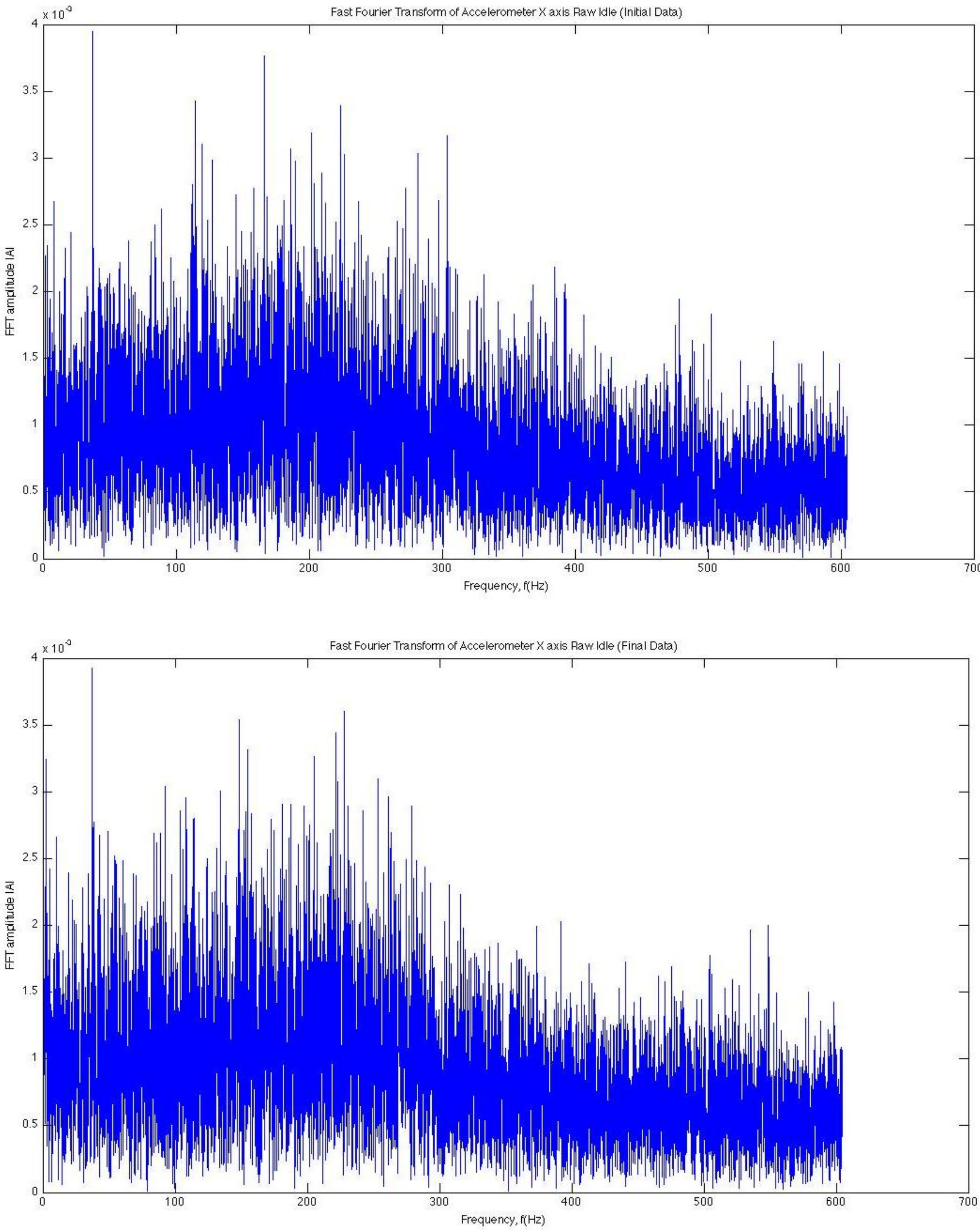

Fast Fourier Transform of Accelerometer X axis Raw Idle (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
Fast Fourier Transform of Accelerometer X axis Raw Idle (Final Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)

Figure 4(a):

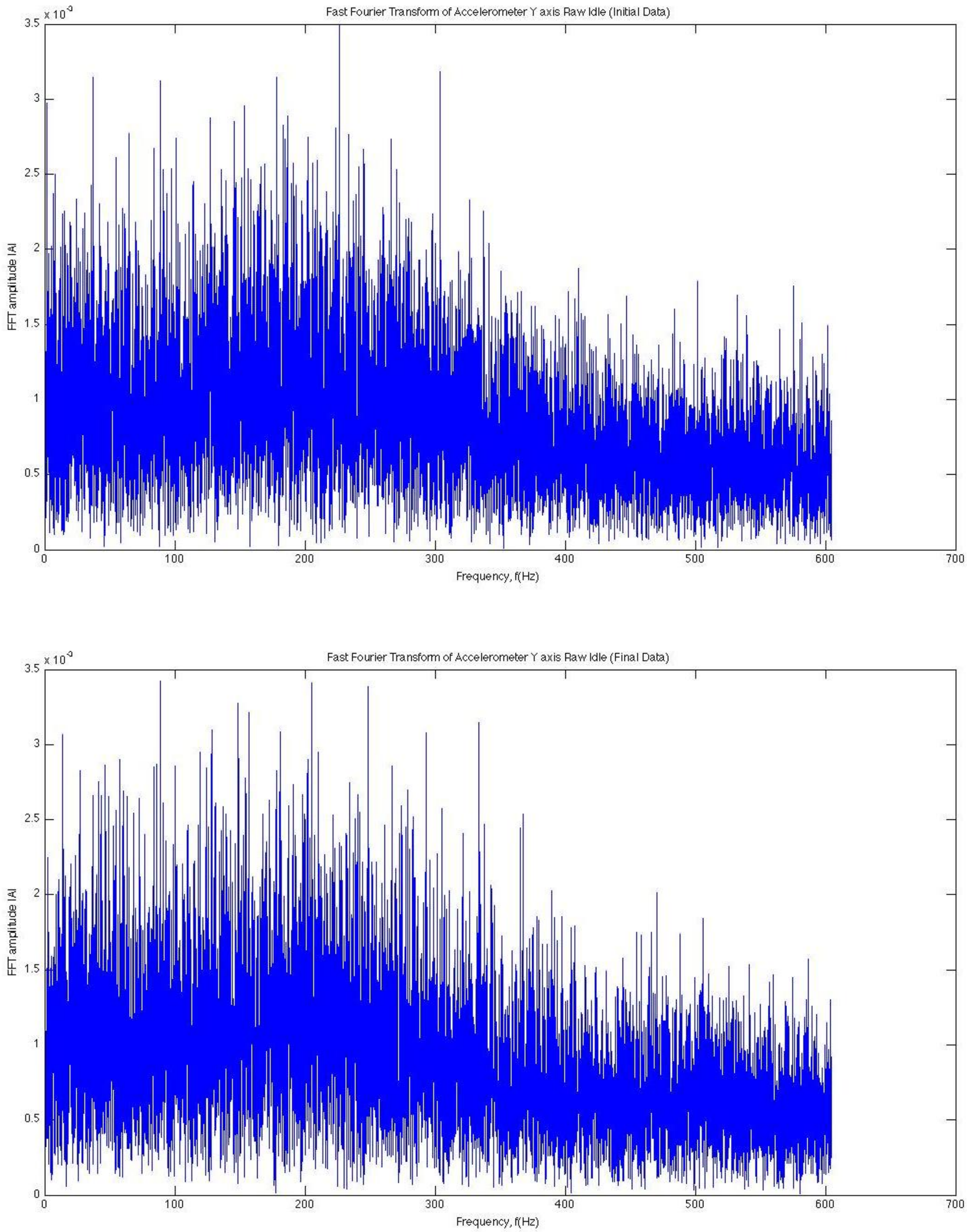
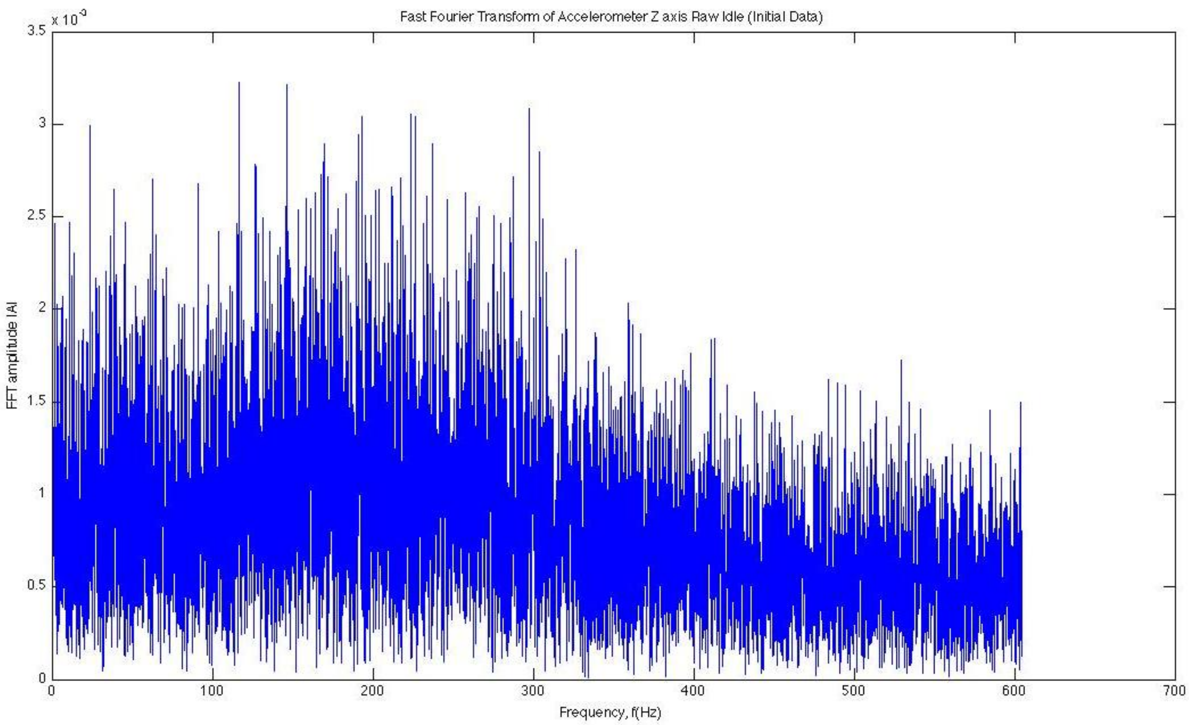

Fast Fourier Transform of Accelerometer Y axis Raw Idle (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
Fast Fourier Transform of Accelerometer Y axis Raw Idle (Final Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)

Figure 4(b)


Fast Fourier Transform of Accelerometer Z axis Raw Idle (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
0
0.5
1
1.5
2
2.5
3
3.5
100
200
300
400
500
600
700

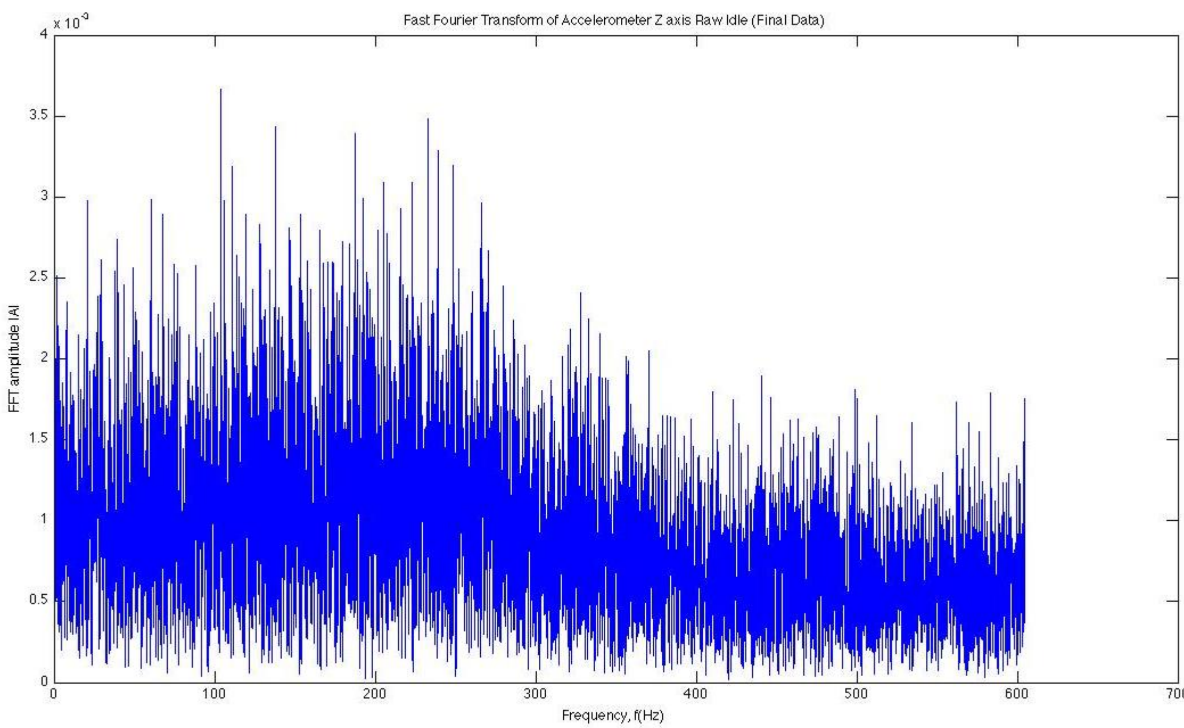

Fast Fourier Transform of Accelerometer Z axis Raw Idle (Final Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
0
0.5
1
1.5
2
2.5
3
3.5
4
100
200
300
400
500
600
700

Figure 4(c)

4.3 Mode Two Data

X-Axis:

While the fundamental frequency corresponding to 5000 RPM or approximately 83.333 Hertz is evident in the un-tuned engine data, it cannot be resolved in the tuned data as seen in figure 5(a). Furthermore, the first, second, third and fourth harmonics correspond to relative peaks in the tuned engine spectrum. In the un-tuned engine spectrum, however, only the first, second and third harmonics are distinguishable. In both spectra there exist relative peaks at approximately 124 Hz. While the origin of this peak is unknown, it can be identified by a direct proportionality using the circumferences of the pulleys for the various belt-driven engine components. As may be expected, the un-tuned engine spectrum has more relative peaks than that of the tuned engine. It is also worth noting that the peak value in the un-tuned engine spectrum is less than half than that of the tuned engine spectrum. Since the fundamental frequency cannot be clearly identified in the tuned engine data, this axis was not selected to serve as a basis for the diagnostic purposes of this program.

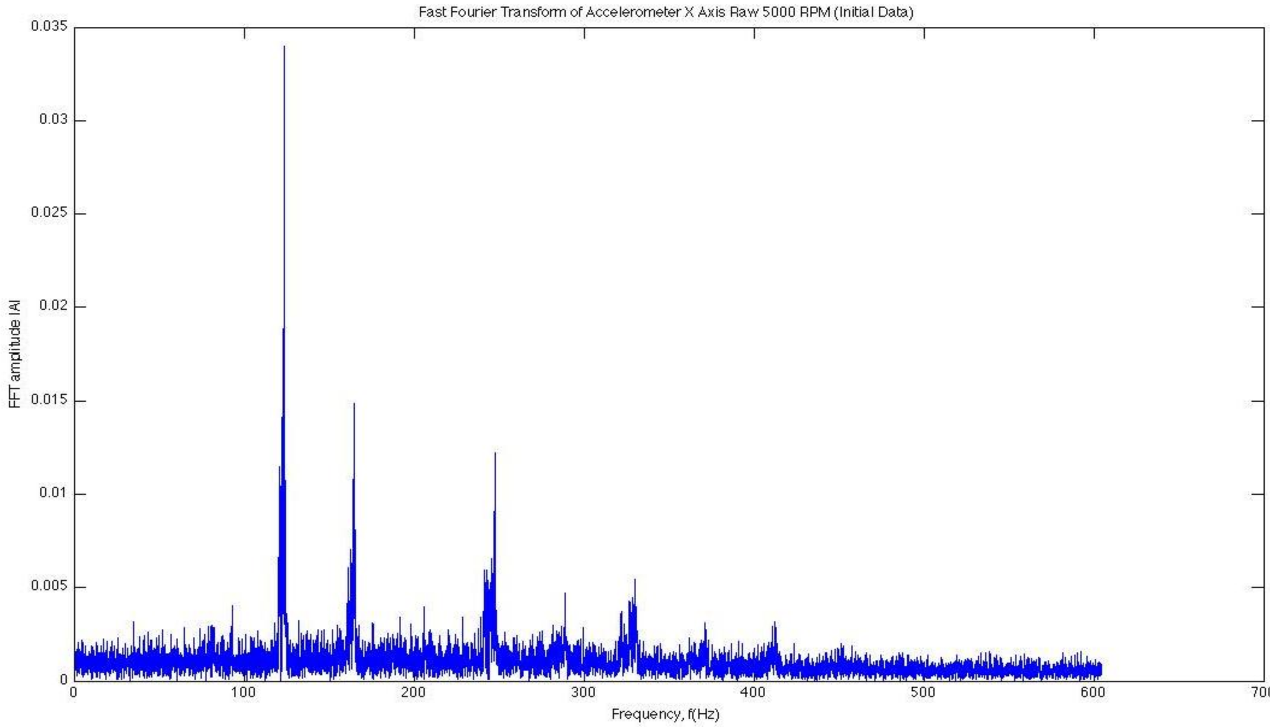
Y-Axis:

Again, the revving frequency is not distinguishable in the tuned spectrum, however, unlike the x-axis, it is not distinguishable in the un-tuned engine data either. Also, the first five harmonics are clearly visible with the exception of the second harmonic. Without further experimentation, it cannot be determined why the second harmonic is not evident. While the unknown 124 Hz relative peak does not appear in either of the sets of data, its first harmonic is at the absolute peak of the un-tuned engine spectrum. It is interesting to note that this is also approximately the second harmonic of the revving frequency. This phenomenon may also be explained by a direct proportionality of the various pulley circumferences. Figure 5(b) demonstrates that the order of magnitude for the tuned and un-tuned spectra is identical. Also, their relative peaks correspond to the same approximate frequencies. Due to these similarities, the y-axis data was also not chosen for the purposes of fault analysis.

Z –Axis:

The spectra of the tuned and un-tuned engine for the Z-axis both have relative peaks at the frequency corresponding to 5000 RPM. Also, the 124 Hz relative peak is clearly visible in both FFT graphs. As with the X and Y-axes, multiple harmonics of the frequency corresponding to 5000 RPM are at relative peaks in the tuned and un-tuned engine data. For the tuned spectrum, the first through the fourth harmonics are distinguishable. As discussed earlier, the second harmonic of the 5000 RPM frequency is also the first harmonic of the 124 Hz frequency. In the un-tuned FFT spectrum, the first through the fifth harmonics are identifiable as relative peaks except for the fourth harmonic. The order of magnitude varies by a factor of three between the un-tuned and tuned engine data. Unlike the X and Y-axes, though the relative peaks in both spectra occur at similar frequencies, their amplitude is considerably higher than adjacent frequencies. This can be clearly seen in figure 5(c). Thus, it is easier to establish a relative noise floor for these spectra. The apparent difference in magnitude between the peaks and the relative noise floor makes these spectra ideal for the diagnostic processes of the program.

Upon choosing the mode two Z-axis data as the foundation for the diagnostic analyses in the program, a mathematical scheme was designed to create a frequency signature for a tuned and un-tuned engine. More specifically, a relative cutoff factor was calculated by taking the quotient of the magnitude of the absolute peak in the tuned engine FFT spectrum and the amplitude of the frequency corresponding to 5000 RPM. Initially, the cutoff factor was not weighted. However, after qualitatively observing that this factor caused entire sets of harmonics to be attenuated, it was decided that increasing the factor would help preserve these frequency bands. By lowering the relative threshold amplitude, fewer frequencies were filtered out, and thus, the signature was more robust.


Fast Fourier Transform of Accelerometer X Axis Raw 5000 RPM (Initial Data)
FFT amplitude |A|
Frequency, f(Hz)
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0.03
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0.02
0.015
0.01
0.005
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0
100
200
300
400
500
600
700

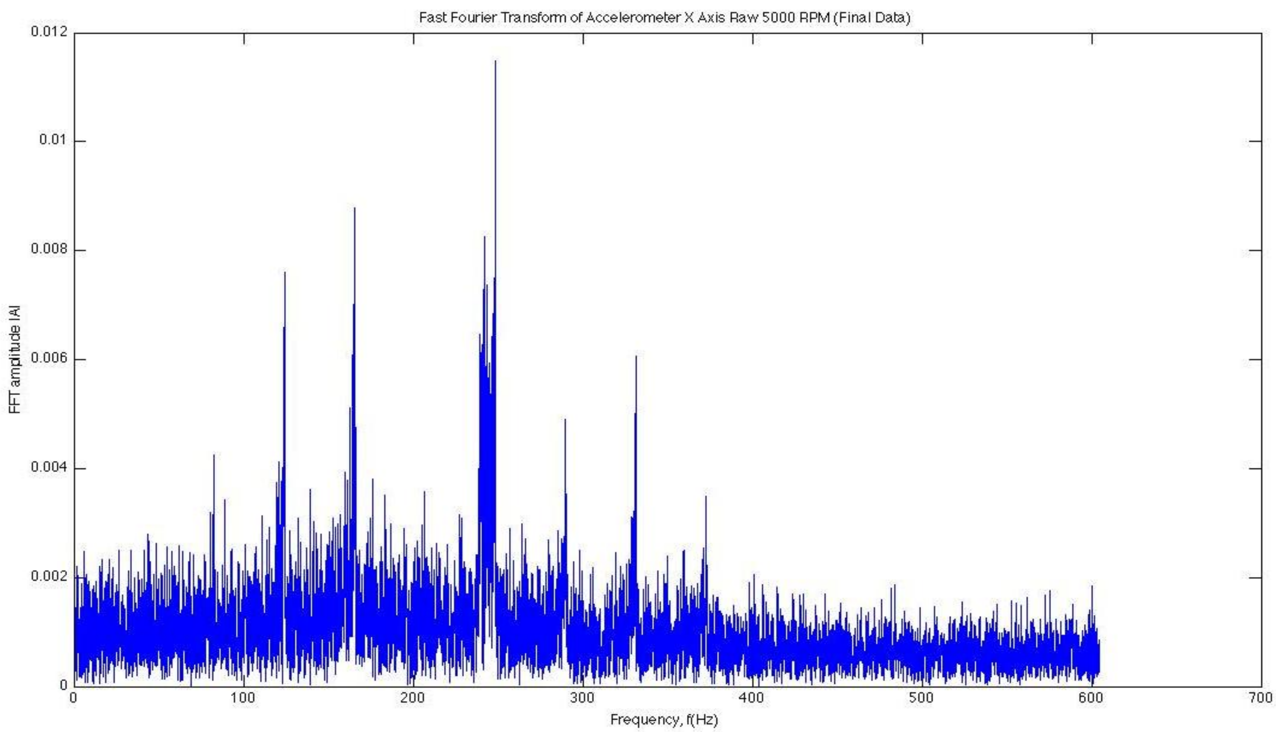
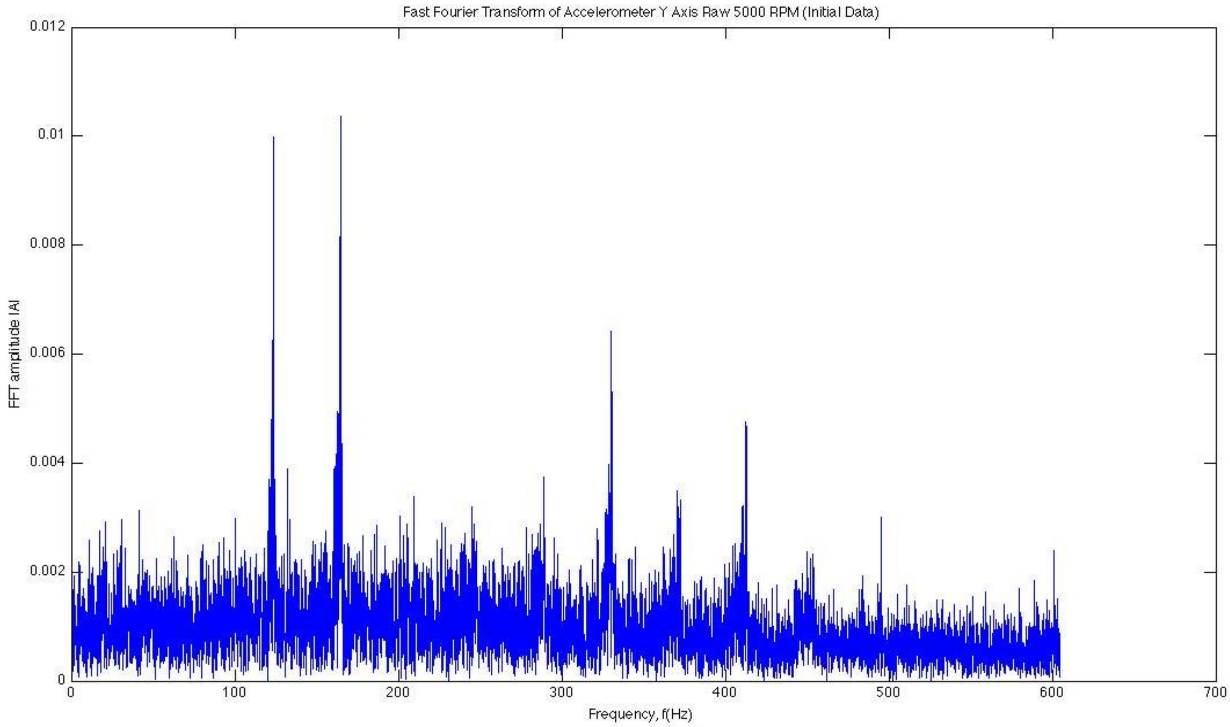

Fast Fourier Transform of Accelerometer X Axis Raw 5000 RPM (Final Data)
FFT amplitude |A|
Frequency, f(Hz)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
100
200
300
400
500
600
700

Figure 5(a)


Fast Fourier Transform of Accelerometer Y Axis Raw 5000 RPM (Initial Data)
FFT amplitude |A|
Frequency, f(Hz)
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0.01
0.008
0.006
0.004
0.002
0
0
100
200
300
400
500
600
700

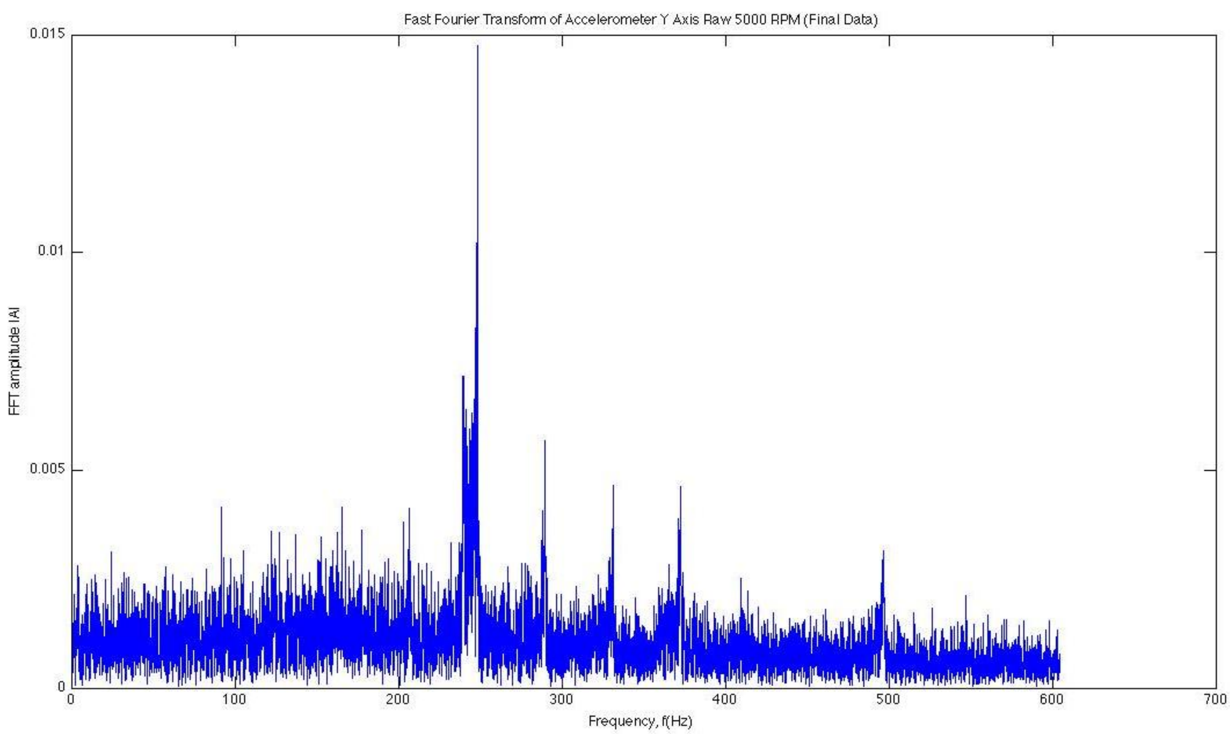
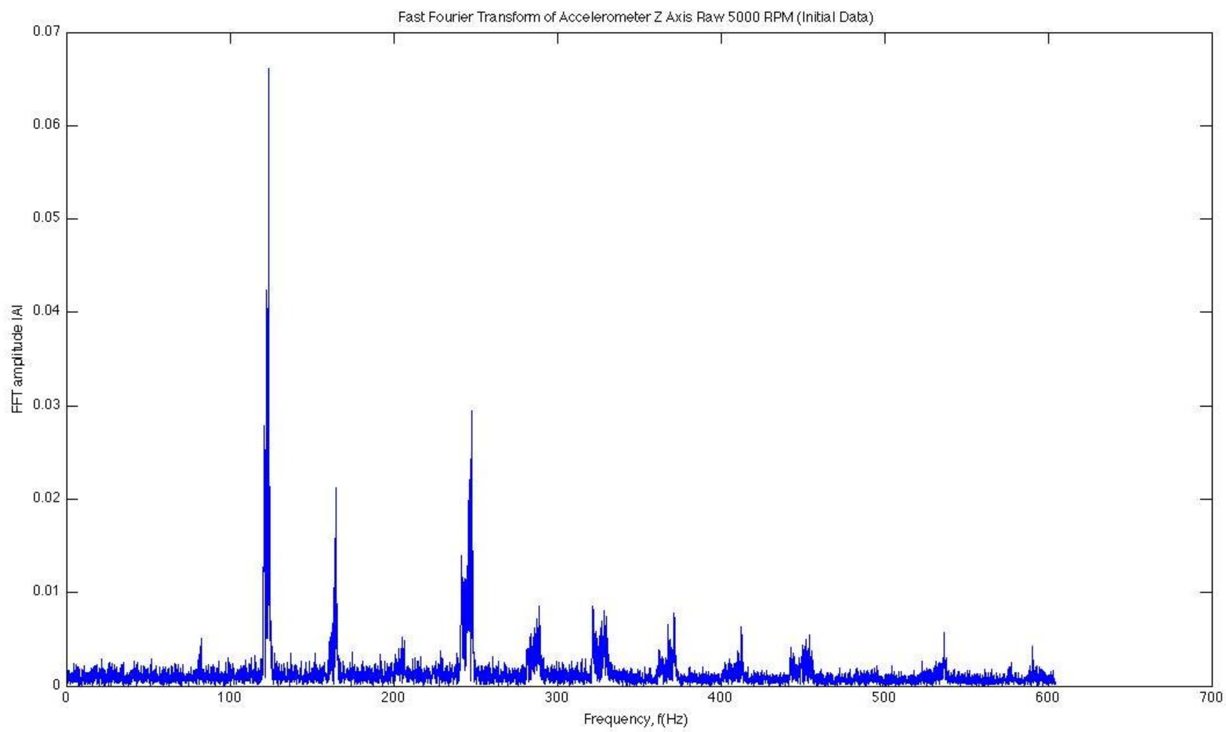

Fast Fourier Transform of Accelerometer Y Axis Raw 5000 RPM (Final Data)
FFT amplitude |A|
Frequency, f(Hz)
0.015
0.01
0.005
0
0
100
200
300
400
500
600
700

Figure 5(b)


Fast Fourier Transform of Accelerometer Z Axis Raw 5000 RPM (Initial Data)
FFT amplitude |A|
Frequency, f(Hz)
0
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0.02
0.03
0.04
0.05
0.06
0.07
100
200
300
400
500
600
700

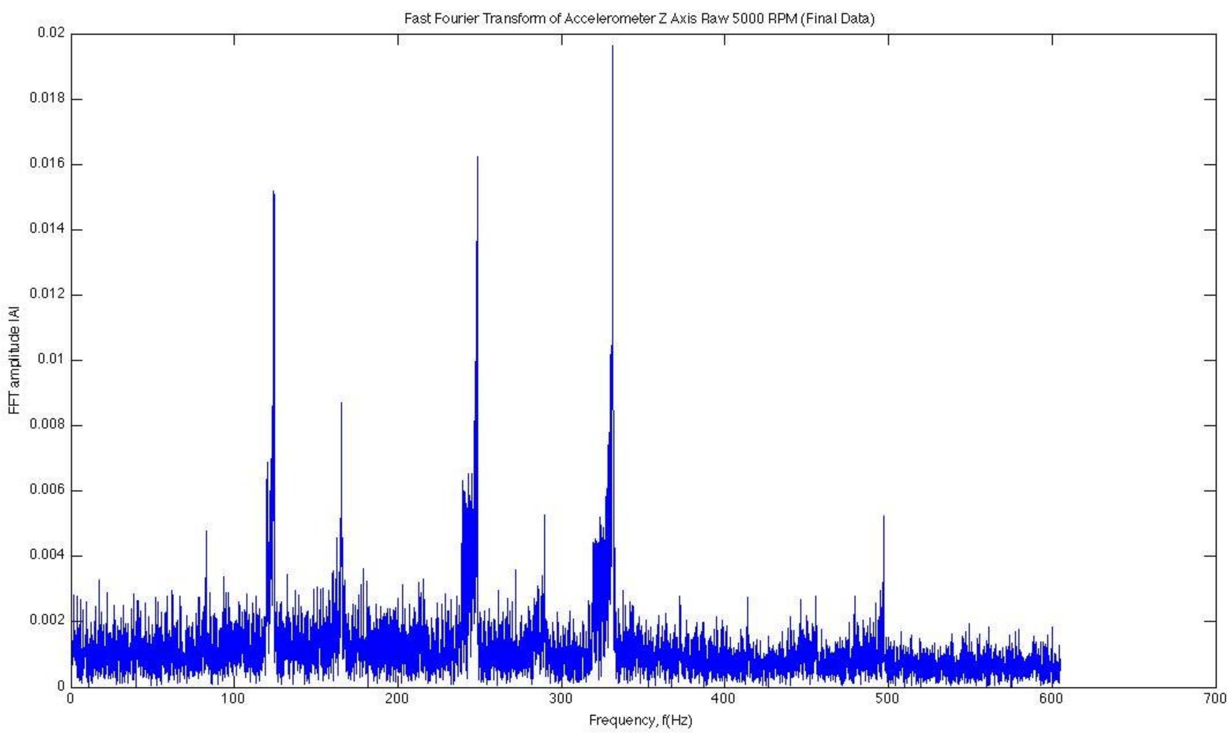

Fast Fourier Transform of Accelerometer Z Axis Raw 5000 RPM (Final Data)
FFT amplitude |A|
Frequency, f(Hz)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
100
200
300
400
500
600
700

Figure 5(c)

4.4 Mode Three Data

The data in this mode was taken while the test vehicle was being driven at 10 MPH eastbound on 27th Street near the University of Southern California. Figures 6(a)-(c) are extremely similar in spread to figures 4(a)-(c). Since there were no distinct peaks in the respective spectra, this mode of data was also eliminated as a potential basis for the diagnostic procedures of the program. Several factors that could have played roles in causing the data to yield noisy FFT spectra have already been discussed in the introduction of the Performance Measurements section.

Figures 7(a) and 7(b) represent the semi-recursive FFT spectra detailed in the software section. It is clear that the FFT spectrum changes with respect to time and the relative peaks change throughout the succession of the intervals. The un-tuned engine surface plot in 7(b) aptly shows that the test vehicle took longer to transmit the frequencies to the accelerometer since the amplitudes of the frequencies remain equal and constant for over fifteen intervals. This delay corresponds to a time delay of approximately 1.98 seconds.

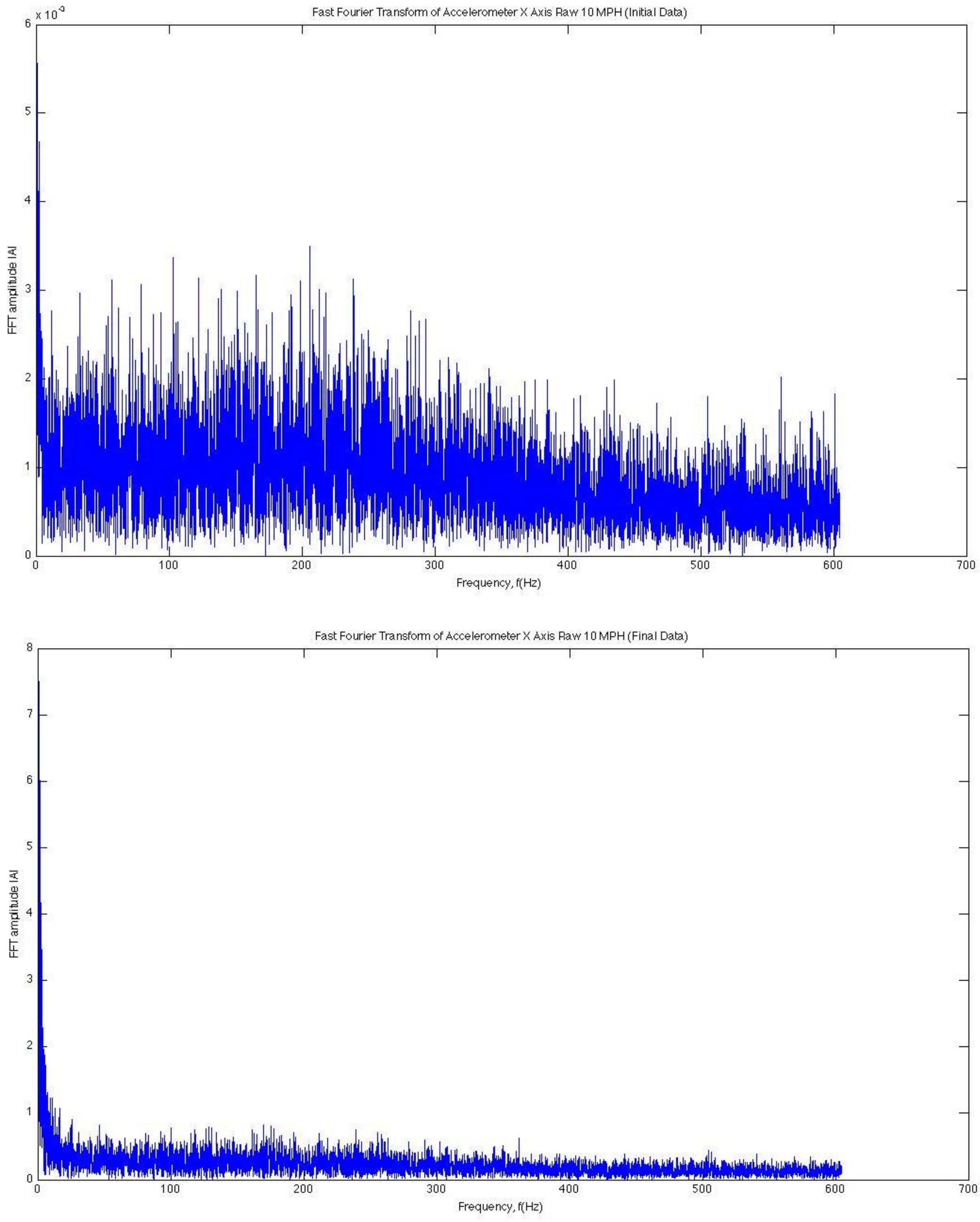
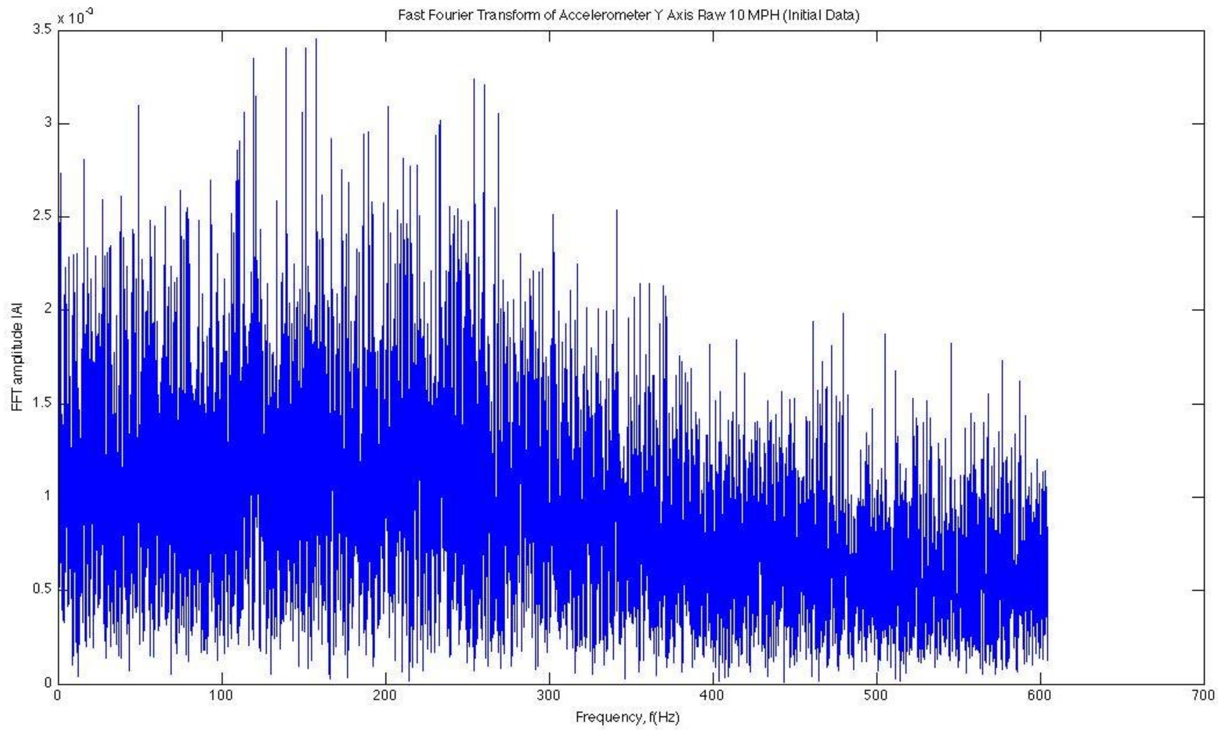

Fast Fourier Transform of Accelerometer X Axis Raw 10 MPH (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
Fast Fourier Transform of Accelerometer X Axis Raw 10 MPH (Final Data)
FFT amplitude |A|
Frequency, f(Hz)

Figure 6(a)


Fast Fourier Transform of Accelerometer Y Axis Raw 10 MPH (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
0
0.5
1
1.5
2
2.5
3
3.5
100
200
300
400
500
600
700

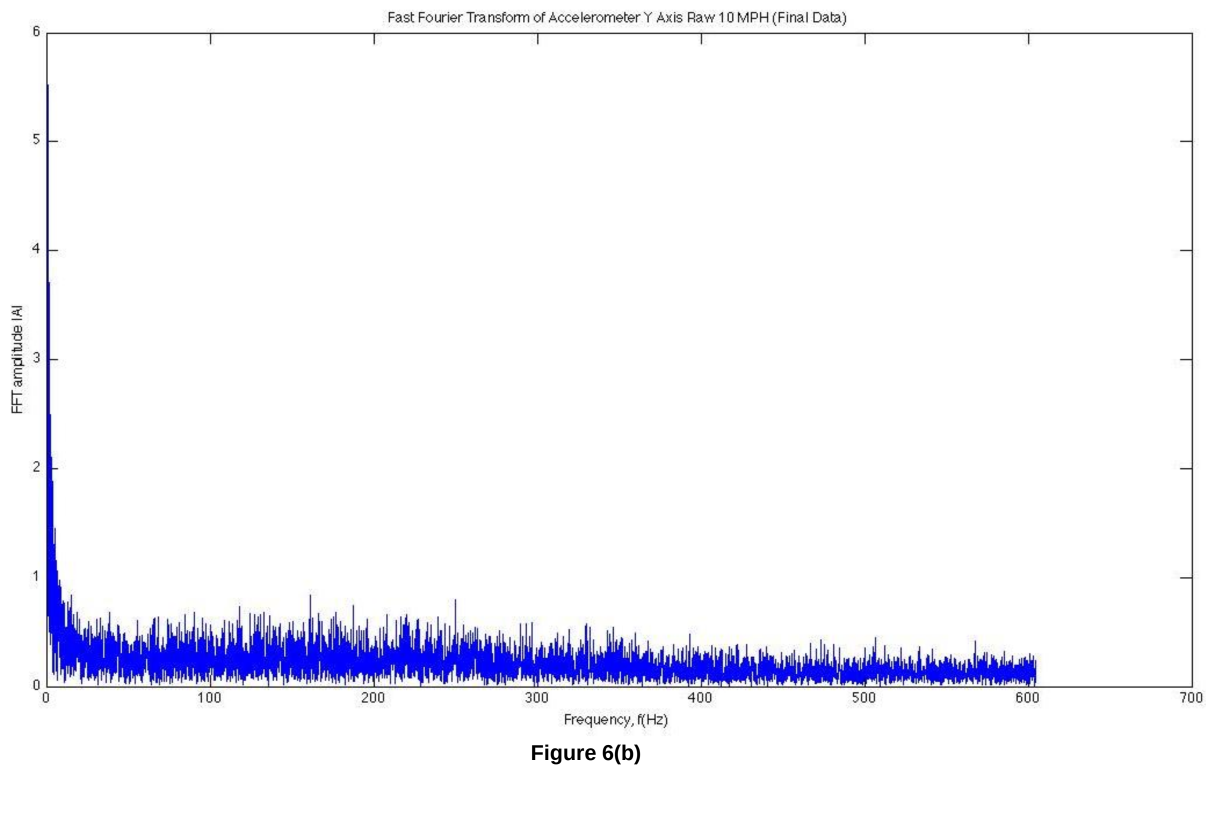

Fast Fourier Transform of Accelerometer Y Axis Raw 10 MPH (Final Data)
FFT amplitude |A|
Frequency, f(Hz)
0
1
2
3
4
5
6
100
200
300
400
500
600
700

Figure 6(b)

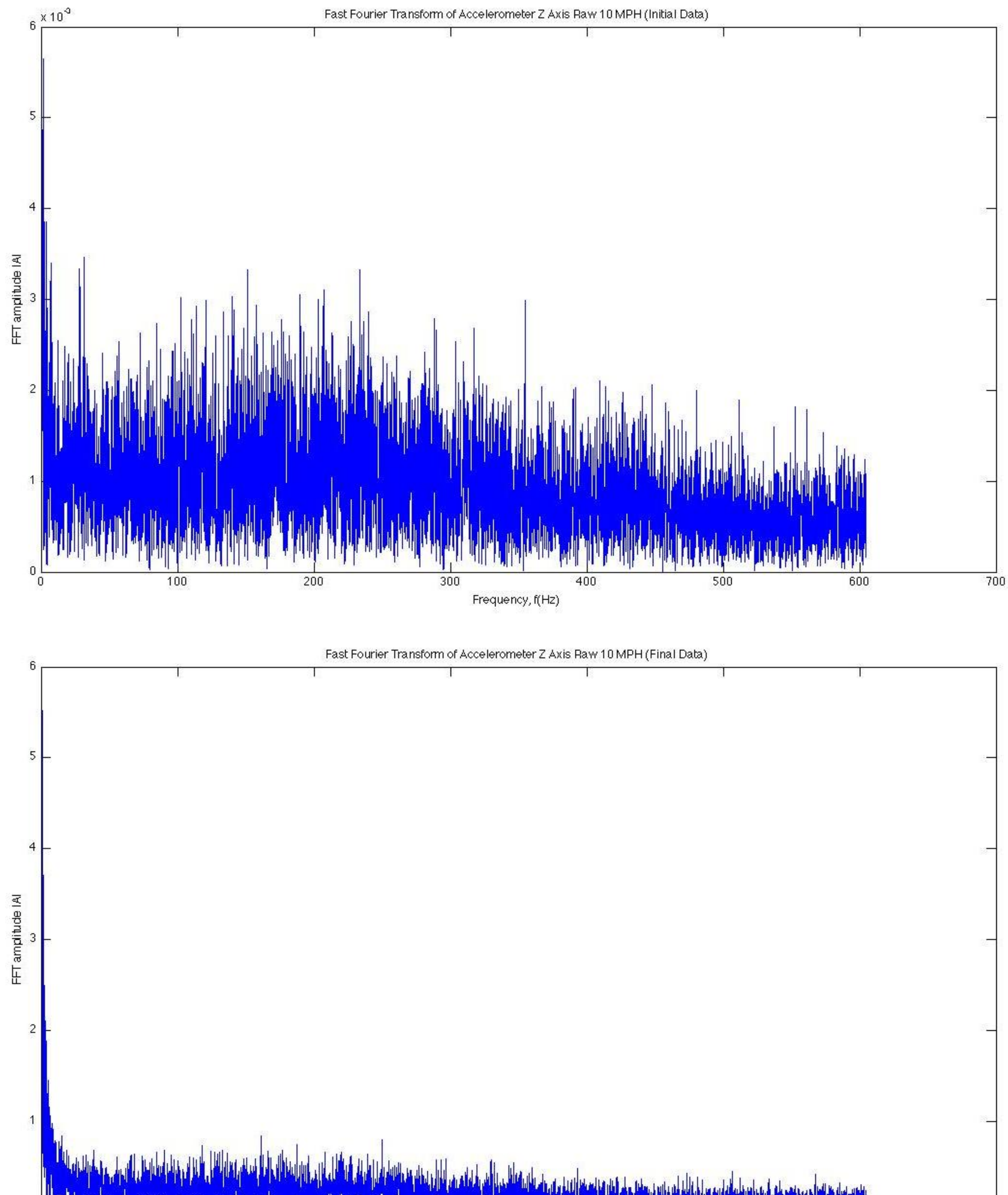
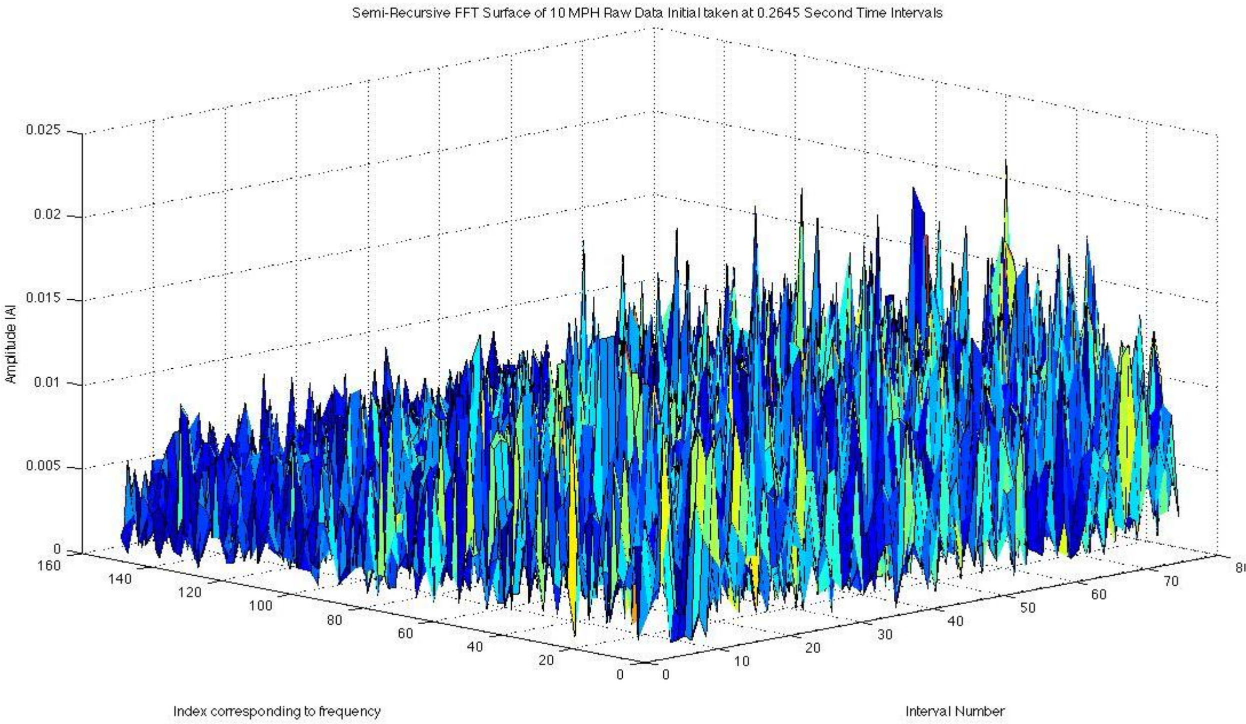

Fast Fourier Transform of Accelerometer Z Axis Raw 10 MPH (Initial Data)
x 10^-3
FFT amplitude |A|
Frequency, f(Hz)
Fast Fourier Transform of Accelerometer Z Axis Raw 10 MPH (Final Data)
FFT amplitude |A|
Frequency, f(Hz)

Figure 6(c)



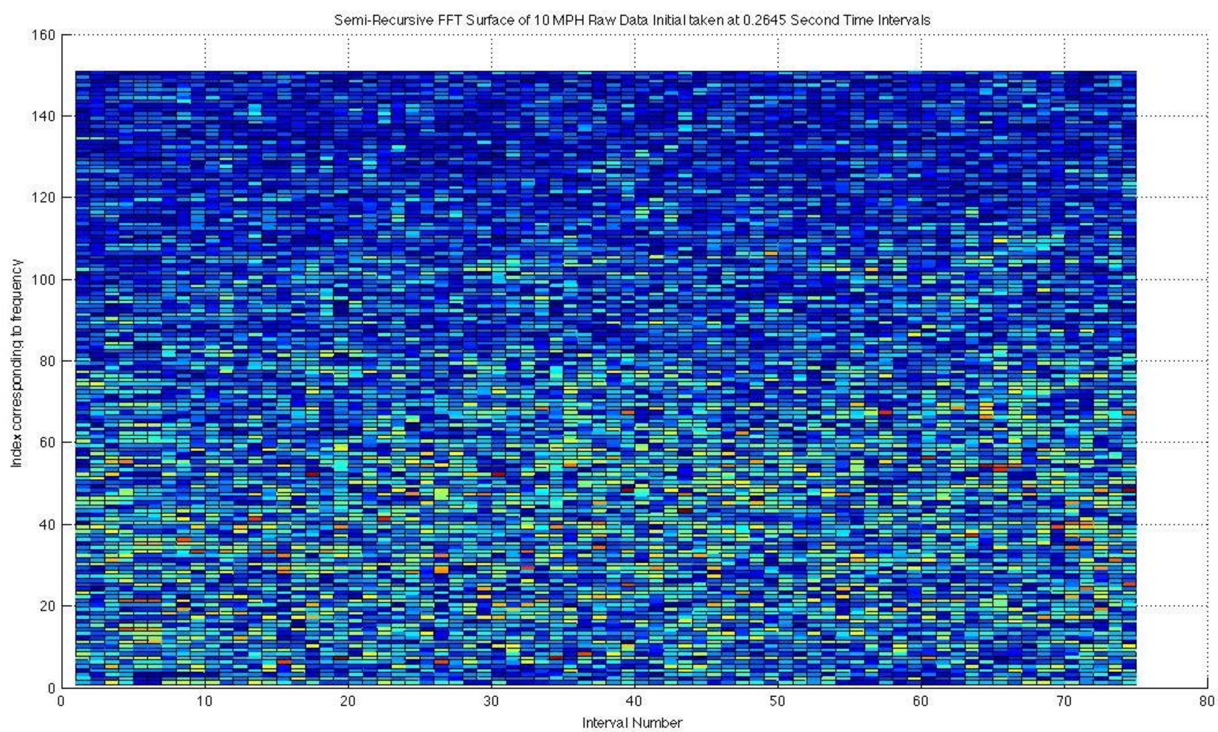
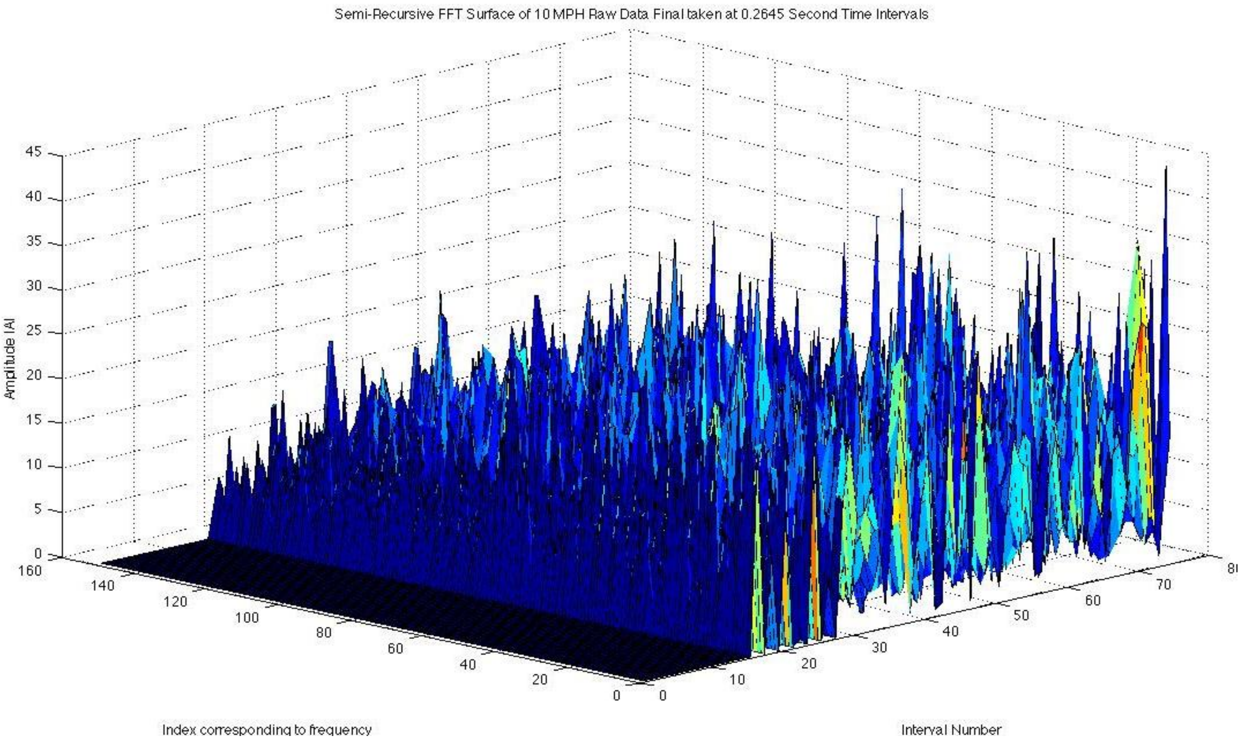


Figure 7(a): This figure shows the surface plot of the mode three tuned Z-axis FFT surface plot from a side and top view. Each interval is 0.2645 seconds length and is linearly interpolated with the adjacent interval. As well, the indices on the left of both plots correspond to increasing frequency. Index number 151 refers to a frequency of 608 Hz.



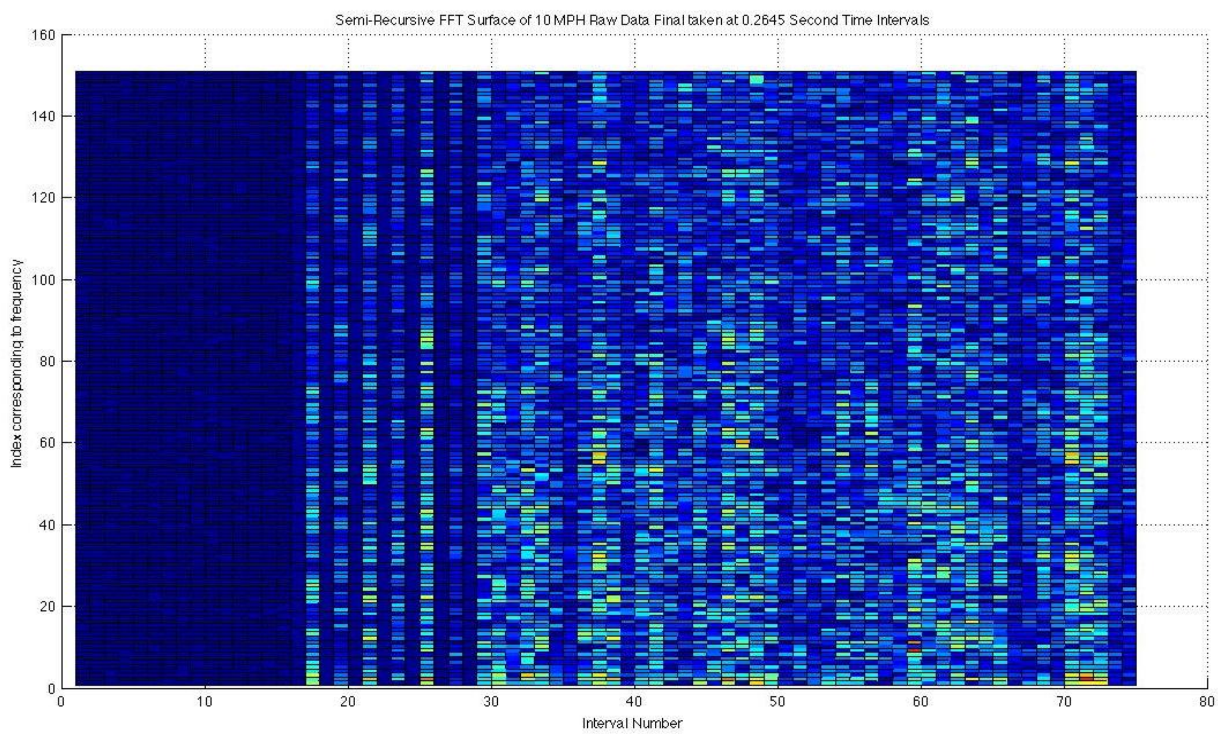


Figure 7(b): This figure shows the surface plot of the mode three un- tuned Z-axis FFT surface plot from a side and top view. Each interval is 0.2645 seconds length and is linearly interpolated with the adjacent interval. As well, the indices on the left of both plots correspond to increasing frequency. Index number 151 refers to a frequency of 608 Hz.

5.0 Conclusions

Proof of operation was adequately demonstrated in this experiment. The accelerometer on the "dongle" was proven to be capable of detecting the vibration frequencies and modes of the test engine. A preliminary method for fault detection was developed to inform the user when the test vehicle deviated from the baseline frequency signature. Further development of this system will focus on identifying the frequency characteristics of individual faults in specific engines. Due to the fact that this will require extensive experimentation and analysis, this was not pursued. However, the proof of operation established by this experiment validates further investigation and development of this subsequent procedure.

Due to the complexity of operation, this version of the program is not yet suitable for commercial use. It requires further refinement and smooth integration with the issued "dongle" program in order to provide truly active analysis of engine performance. Furthermore, a target market niche must be determined for which the program will be specifically designed. Currently, performance engine enthusiasts are a viable target customer group since they can provide initial market entry and extensive exposure. With this exposure, the general consumer can eventually be targeted.

Implementation will be achieved through integration of this program with existing aftermarket navigation equipment. As the installation of this system can be difficult due to necessary penetration of the vehicle firewall, professional assistance must be sought by the end user. This might lessen the appeal of the system, however, after further market analysis, it may be determined that interest in this system will prevail. This notion is strengthened by the fact that the accelerometer in this system can replace and outperform the various sensors located throughout commuter vehicles.

6.0 Distribution List

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