IPRO 304:

Integration of Process Improvements

Fall 2009

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Sponsor: A. Finkl and Sons (Chicago, IL)

TABLE OF CONTENTS

1. Executive Summary

A. Finkl and Sons, a steel manufacturer in Chicago, IL, approached Illinois Institute of Technology two years ago to find possible solutions to a common problem in their manufacturing process. This project focuses on the detection of broken tungsten carbide inserts on a vertical milling machine. The carbide inserts are used to remove scale and square a work piece. The IPRO broke up into two main groups, an electrical design and machining group, with project management delegating and scheduling the tasks for the whole group. The first task was to create a test plan to use on the milling machines. This was updated several times before milling took place.

The electrical design group researched different methods to detect broken inserts. They decided to use accelerometers and microphones. After purchasing the correct materials, the electrical design group decided to use LabView to analyze their data. The electrical design group collected and analyzed the data from two accelerometers and a microphone.

The testing of our objective took place in Lab 012 and Lab 141 in the Engineering One building. The machining group worked on two different types of milling machines: a manual milling machine and a computer numerically controlled milling machine (CNC). With the assistance of experienced machinists, the analysis group detected broken carbide inserts on the milling machine.

IPRO 304 also visited A. Finkl and Sons to conduct the experiment on their machines to verify that the test plan detected broken inserts. The procedure proved correct and useable to obtain data when carbide inserts break. In order to more accurately measure when the carbide inserts break or chip, the team will develop a computer program to detect the broken or chipped inserts.

2. Purpose and Objectives

A. Finkl & Sons Co. was founded in 1879. Finkl is the world's leading supplier of forging die steels, plastic mold steels, die casting tool steels and custom open-die forgings, processing 100,000 tons of steel each year. Since the 1800s, Finkl has maintained a commitment to manufacture 100 percent of its products in Chicago. These products are distributed domestically and to more than 18 countries worldwide. They sell their products to other manufacturers, like plastic processors, die casting companies and closed-die forging plants. With more than 100 patents to its credit, Finkl's steel formulations and steelmaking technologies set worldwide standards. Finkl's facilities are on the leading edge of technology, using the most automated processes in the world. In recognition of Finkl's product quality, Finkl was the first integrated steel manufacturer in America to receive ISO 9000 certification.

Currently, A. Finkl & Sons is facing an issue with regards to the detection of broken cutting inserts in the milling machines used to machine and finish the metal product. A milling machine simply consists of a rotating face mill, which contains a given number of cutting inserts, which ultimately cut the material as the face mill rotates. The face mill remains stationary, while the workpiece is being moved under the rotating face mill so that the material can be appropriately milled. Milling machines are used for the purpose of removing material of large steel slabs to properly fit customer specifications as well as for aesthetics. At present, A. Finkl & Sons detects broken cutting inserts by means of having operators at each machine and checking the surface finish of the milled workpiece for unusual marks that illustrate the characteristics of a surface finish marred by a broken cutting insert. The operator, once marks have been detected by visual or audible inspection, will then replace the broken cutting inserts. If a cutting insert does in fact break during the milling process and is not observed, a larger load is being applied to the milling machine as well as the remaining cutting inserts on the face mill. This ultimately causes the other cutting inserts on the face mill to be more susceptible to breaking. By means of finding a solution to detect if a cutting insert has broken as well as automating the process such that one operator can operate multiple milling machines, A. Finkl

& Sons will save much time and money. Such a solution to the given problem will also enable a higher production rate of high quality steel products.

In order to determine a solution to the given problem, research for this semester has been centered on the use of accelerometers to detect broken cutting inserts. It is proposed that by means of placing accelerometers on the milling machine, one can detect a broken cutting insert by a differing accelerometer output signal. Using computer software, the acceleration and frequency at a given instant can be measured and recorded. The power spectrum density can then be derived from these signals. Each form of measurement can be compared to a baseline signal of the milling machine with no broken cutting inserts to that of a signal of a milling machine with broken cutting inserts. Distinct differences are hoped to be seen in the given measurements so that a broken cutting insert can be ultimately detected without the visual or audible inspection of a machine operator.

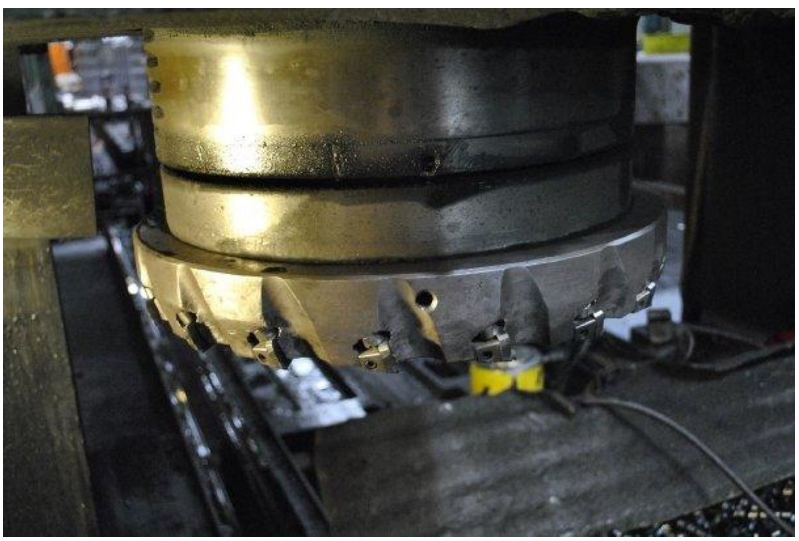

Figure 1 18” diameter milling cutter on A Finkl & Sons’ milling machine

3. Organization and Approach

The semester started off by creating the two main groups and the project plan for the duration of the project. The two main groups created were the machining group and the electrical design group. The teams decided which methods to research before we collected the materials to start testing. Accelerometers and microphones were explored as possible methods of detection.

The IPRO needed to find the materials needed to perform the experiment at Illinois Institute of Technology. With the milling machine provided by Armour College, the additional supplies needed were microphones, accelerometers, arbor, mill head and tungsten carbide inserts. After these materials were gathered, the IPRO created the test plan.

A safety lecture was provided by Russ and Professor Sheldon Mostovoy, before testing began. Testing ran for a month and a half and in that time, the team moved to a Haas CNC mill from the Bridgeport machine in Engineering One Building. The teams also tested the procedure at A. Finkl and Sons to see if the data could be replicated.

4. Analysis

Accelerometers

Variables

Our tests were conducted to isolate the variables one at a time. Because we were able to determine the parameters for testing, we set the depth of cut, rpm and number of broken inserts to the values we determined beforehand. Changing these variables one at a time and measuring the results have given us better insight to how the parameters interact with the accelerometer data.

The main variables we chose to isolate were RPM, Depth of Cut, Number of Starting Broken Inserts.

Location of Accelerometer Data Acquisition:

Data taken from the material was the cleanest and most reliable data. This is in turn because of the absence of noise from the mill and surrounding equipment. The material's dominant source of vibration is from the mill head itself, and the inserts that are cutting away at the material.

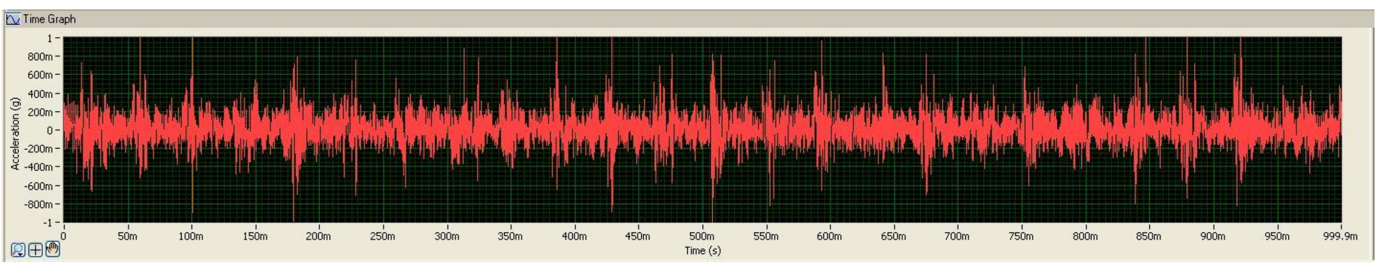

Figure 2 Accelerometer Placed on Material.

Data taken from the spindle housing directly above the mill heads contact point with the material was a reliable but noisy environment. The data reflected the same spikes and features as the data collected from the material but the dominant features were lower compared to the material data, and the low areas from the material data were higher in amplitude due to the noise from the machine.

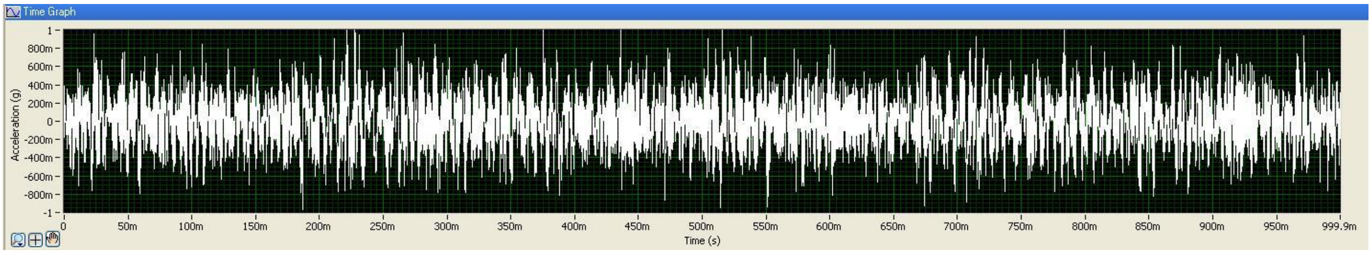

Figure 3 Accelerometer Placed on Spindle

Proximity of the accelerometer (on the material) and where the mill was cutting caused amplitudes to be larger when the mill was cutting closer to the accelerometer and amplitudes to be smaller when cutting farther away from the material.

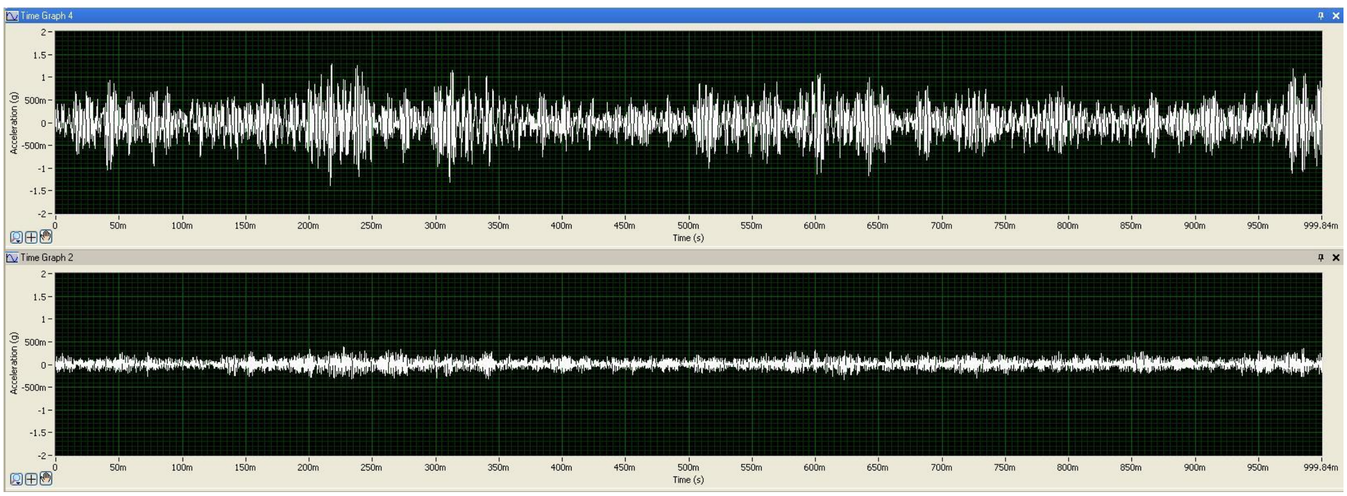

Figure 4 Proximity of Accelerometer to Cutting Location

Amplitude:

One large generalization we could produce from the results was that anything that required more load to be put on the spindle caused higher amplitudes in vibrations. This was expected and confirmed in the testing. We saw this both from the data recorded from the spindle/machine and from the accelerometer attached directly on the material.

These higher amplitudes were created in various ways. Depth of cut and feed rate caused the greatest change in amplitude, where RPM changes depended on the other two to give a valid cutting speed. This increase in amplitude causes more wear on the inserts and gives a greater chance for the insert to become chipped or even shatter.

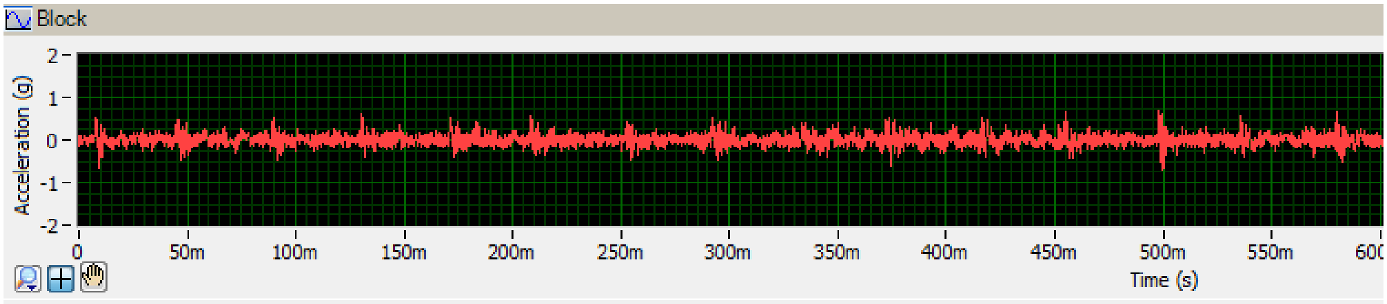

Figure 5 125 RPM Test

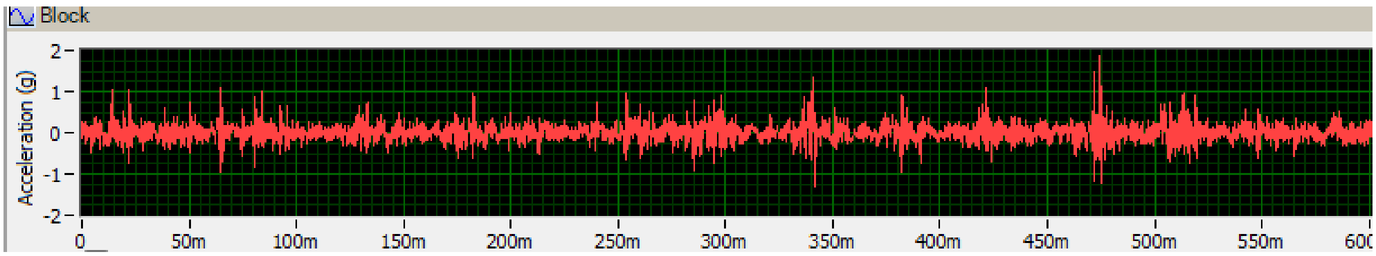

Figure 6 150 RPM Test

This relationship is especially informative because most of the cuts on the material at Finkl are made on the scale portion of the material. That is, taking away material from the top of the piece that fluctuates on the x, y, and z axis relationally to the spindle head. This will cause an amplitude change even within a single rotation due to the material. Thus, finishing cuts are the only

Individual Inserts:

It was noticed that we can see inserts making contact with the material. Through the accelerometer readings, we can see spikes at precisely the same interval as the time between one insert making contact with the material and the next insert making contact. If all the inserts were uniformly worn, it became difficult to determine where a insert contact was made. However if a insert was not uniformly worn like the rest of the inserts it would cause an increase in amplitude for the insert that is next to make contact. This is due to the broken insert making less contact with the material, and the insert following it to pick up the job of cutting the extra material.

It is very helpful to be able to see individual inserts and their impact results with the material. The accelerometers take the data in real time and are able to analyze and record each insert and its history. It is important to note we were able to view inserts hitting from the material and

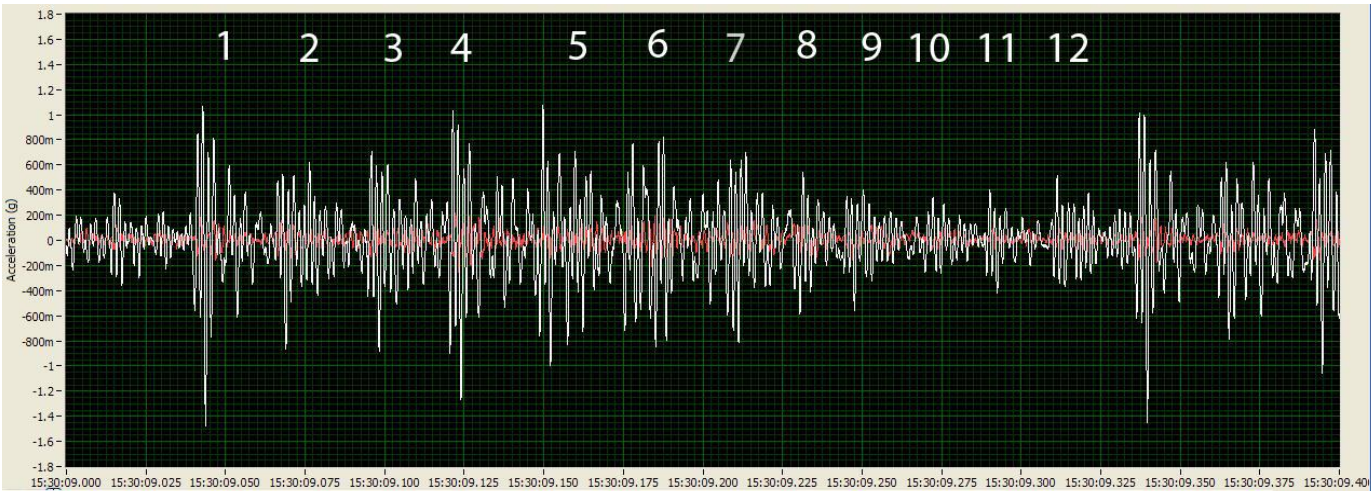

Figure 7 Individual Inserts Shown during 1 Revolution

Dominant Frequency

It has been noticed that there is no dominant frequency or attribute that is created or noticeable when there are broken inserts compared versus no broken inserts. The data supports that using the Power Spectrum to isolate the frequencies for the overall frequencies being transmitted to the accelerometers there is nothing dominant between the runs. Frequencies change drastically between machines and even between some variables being changed.

See the Appendix E for the Frequency Figures.

Problems with Testing

There were a variety of factors that made analysis of the Bridgeport significantly more difficult than on the CNC machine. The first is defects within the machine itself. The machine is almost seventy years old and the table our block rests on has become bowed. This significantly affected our results because we were unable to produce a consistent depth of cut. To reduce this effect, we've done all cuts of the far side of the table where it is the least bowed. Further, we came across several issues with the auto feed, where the table would stop moving forward altering our feed rate. This has forced us to spend precious time waiting for the machine to be repaired and to retest flawed trials. Variables like feed rate had to be removed because the machine was unable to cope with the additional stresses required to test the stimuli. These issues forced us to make several changes to our experiment to minimize error and to stay on schedule.

However, even with the issues that plague the Bridgeport, certain patterns can be seen consistently on the mill, and even more clearly on the CNC machine. Individual insert impacts can be seen on many of the mill runs. Additionally, an overall waveform that we believe to be related to rotation of the mill head can be seen on our measured data. We believe that with additional testing, we may be able to observe these same results on A. Finkl & Sons larger milling machines.

Microphones

Objective

The objective of using microphone for our testing is to monitor the difference of sound pressures produced by the milling machine, from which we collect useful information to identify the broken inserts.

Theoretical Background

To measure the pressure components in a sound wave a condenser microphone was selected. Its output is proportional to the alterations of the sound pressure in the time domain and its directivity characteristic is non-directional, which means that the efficiency of pickup is the same in all directions.

Noise is a consequence of each cutting process and depends on the vibration of the surroundings. Some noise sources are vibration of machine, vibration of the floor and even human voice. These noise sources will affect the measurement result more or less. In order to record the sound pressure under similar conditions as much as possible, the microphone is placed in the same position during each run.

In addition, due to the many single parts which compose the machine tool, the frequency response of the machine tool is non-linear, in general. Thus, most probably the cutting process will not contribute to the frequency spectrum of the recorded noise equally for different sets of cutting parameters (cutting speed, feed rate).

Experiment Data

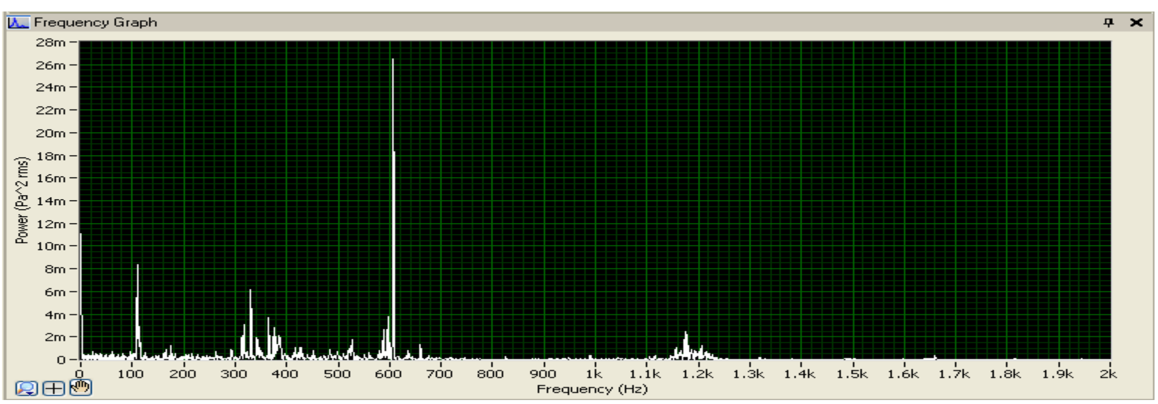

Figure 8 Microphone Frequency of 0 broken inserts (RPM 125)

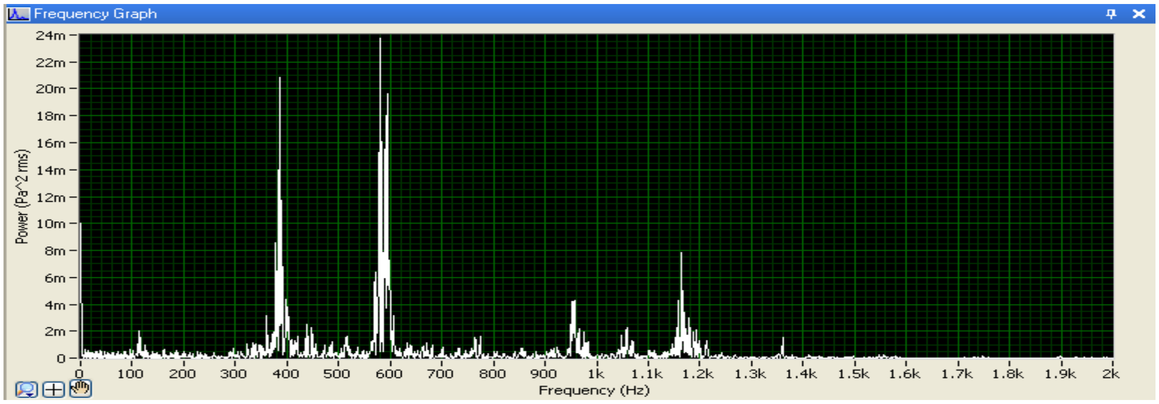

Figure 9 Microphone Frequency of 3 broken inserts (RPM 150)

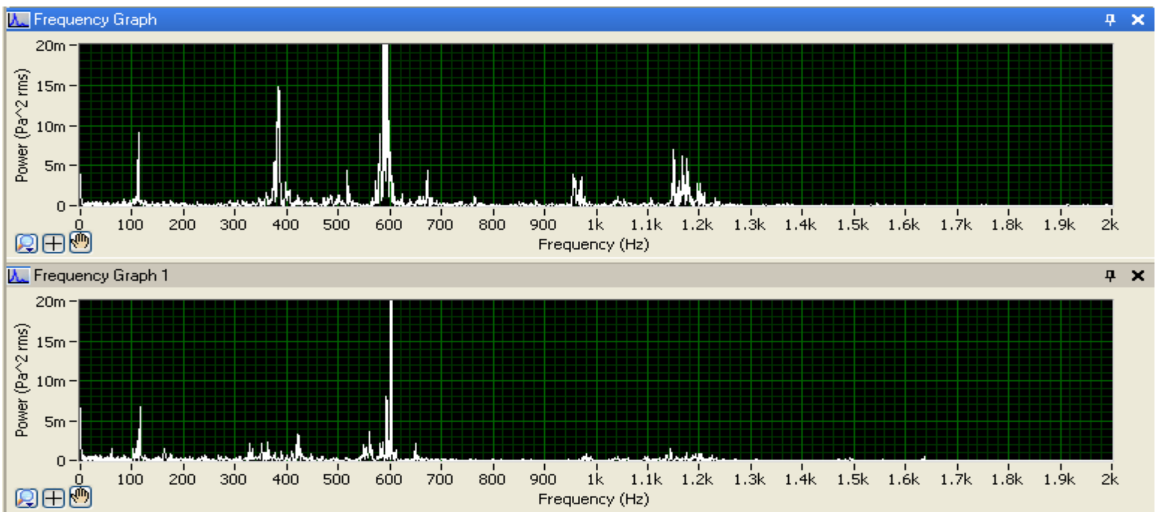

Figure 10 Microphone Frequency of 3 broken inserts and 0 broken inserts (125RPM)

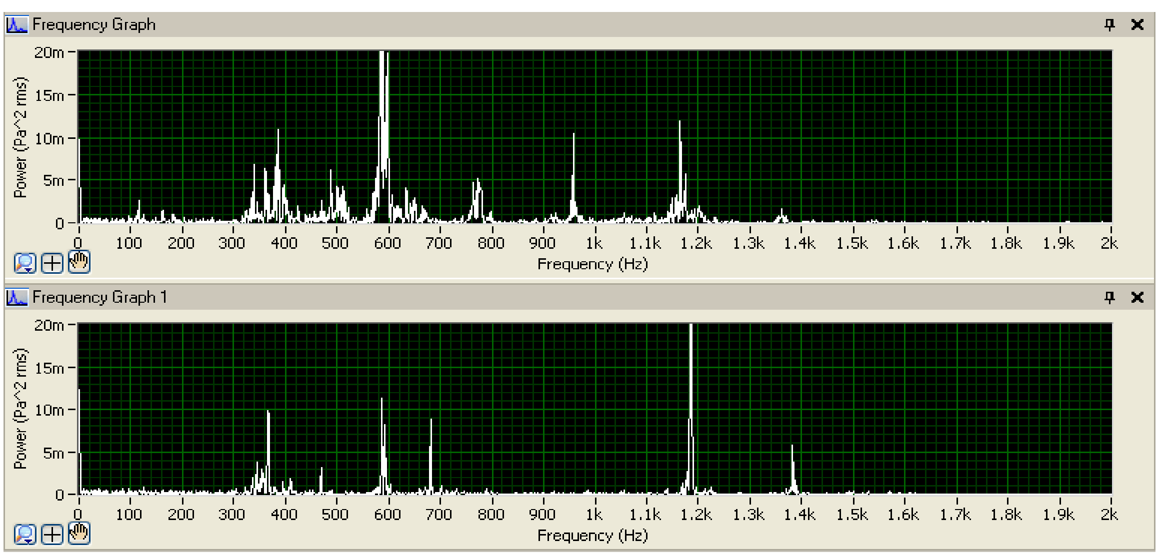

Figure 11 Microphone Frequency of 3 broken inserts and 0 broken inserts (150RPM)

From the graphs show above, there are some frequency components exist in every run. They spread from about 300 Hz to 700 Hz, with a peak at 600 Hz or sometimes at 300 Hz. These frequency components are from the sound created by the machine, not from the cutting. They are so powerful that they have might actually hide some information from the cutting process in this frequency range.

Despite of the confusion from the machine sound, by comparing the signal of a 3 broken inserts run and a 0 broken inserts run, there is still some useful information can be found. They are show in the table below.

Table 1 Frequency Relation to Broken Inserts

Test	Broken Inserts	RPM	Freq. ~1k	Freq. 1.1k-1.2k
0	0	125	No	No
3	0	150	No	Narrow and High
5	3	150	yes	Wide and low

Unfortunately, we cannot draw any concrete conclusion from these differences because they are not strong enough to indicate the detection of broken inserts. More work needs to be done to separate the sound created by the cutting from the noise sources, like vibration sound from the machine, human voice and ambient noise.

From the data collected with the accelerometers though, there is doubtfully a large dominant frequency being created when an insert is broken. Microphone data is just too broad to isolate specific areas of the milling process.

Analysis and Conclusion

From the graphs show above, there are some frequency components that exist in every run. They spread from about 300 Hz to 700 Hz, with a peak at 600 Hz or sometimes at 300 Hz. These frequency components are from the sound created by the machine, not from the cutting. They are so powerful that they have might actually hide some information from the cutting process in this frequency range.

Despite of the confusion from the machine sound, by comparing the signal of a 3 broken inserts run and a 0 broken inserts run, there is still some useful information can be found. They are show in the table below.

Table 2 Frequency Relation to Broken Inserts

Test	Broken Inserts	RPM	Freq. ~1k	Freq. 1.1k-1.2k
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3	0	150	No	Narrow and High
5	3	150	yes	Wide and low

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From the data collected with the accelerometers though, there is doubtfully a large dominant frequency being created when an insert is broken. Microphone data is just too broad to isolate specific areas of the milling process.

Future work

As we mentioned above, the vibration sound of machine has created severe interference to the measurement. One important thing to do is to separate the signal desired from the interference. Using microphone array instead of one microphone can help us to achieve this goal.

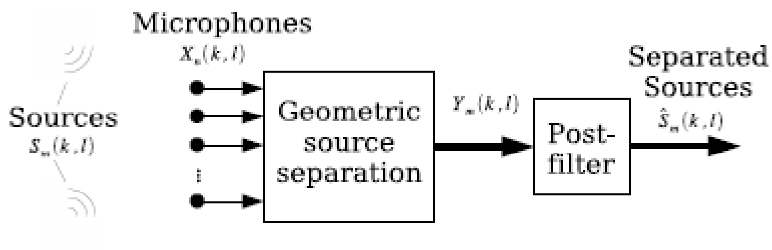


Figure 12 Diagram of Microphone Setup

The figure shown above is composed of three parts: 1) A microphone array; 2) A linear source separation algorithm implemented as a variant of the Geometric Source Separation algorithm; 3) A multi-channel post-filter.

The microphone array is composed of a number of omni-directional elements mounted on the robot. The microphone signals are combined linearly in a first-pass separation algorithm. The output of this initial separation is then enhanced by a (non-linear) post-filter designed to optimally attenuate the remaining noise and interference from other sources.

With the help of microphone array, we will be able to filter out the interferences and focus on the sound from the cutting only.

5. Conclusion

Over the course of this semester's work, the team arrived at X important conclusions. These conclusions were arrived at after rigorous testing on both a Bridgeport mill as well as a CNC Mill; the testing procedure and results have been provided prior to this section. The conclusions are as follows:

1) There is a regular, observable interval where each insert makes contact with the metal. This contact time is seen as a spike in the time domain readings of the accelerometer
2) The amplitude of these spikes apparently depends on feed rate, rpm, and the depth of the cut.
3) Upon adding broken inserts, it is possible to observe two things. First, there is a clear difference in the PSD of the accelerometer readings when inserts are broken. Second, the amplitude of the spikes caused by the broken inserts in the time domain is noticeably different from that of the frequency domain. This, therefore, allows us to note when cutting inserts fail.

It must be noted, however, that the best results were obtained while performing tests on the CNC mill. This is because the CNC mill creates the least amount of extraneous vibration, which in turn registers as massive noise in the accelerometer readings. Moreover, further noise is added to the signal if 'scale' exists on the block being milled.

6. Appendix

A. Budget

Part	MSRP [$]	Discounted Price [$]	Money Saved [$]
Milling Cutter	840.00	567.00	273.00
R8 Arbor	99.61	44.82	54.79
Inserts	1233.00	715.80	517.20
CNC Arbor	169.52	132.23	37.29
	2342.13	1459.85	882.28

Part	Price [$]
Accelerometers	370.00
Cables	120.00
Microphone	40.00
Tow Straps and Eye Bolts	19.21
	549.21

Total [$]	2009.06

B. Team Members

Name	Year	Major	Position
Jessie Bauer	4th	Electrical and Computer Engineering	Electrical Design Team Leader
Tony Bergeron	4th	Computer Science	Electrical Design
Matt Campen	4th	Computer Engineering	Electrical Design
Erik Gruchalski	3rd	Mechanical Engineering	Machining Team Leader
Tae Ki Choi	5th	Architecture	Machining
Ryan Marx	4th	Computer Science and Computer Engineering	Electrical Design
Chaitanya Murti	4th	Electrical Engineering	Electrical Design
Brian Robbins	4th	Mechanical Engineering	Machining
Atinder Pal Sohal	4th	Electrical Engineering	Electrical Design
Amanda Stenson	4th	Mechanical Engineering	Project Manager
Alejandro Taboada	4th	Aerospace Engineering	Machining
Bingjian Zhang	4th	Electrical Engineering	Electrical Design

C. Acknowledgements

We would like to thank the following parties for helping us with any of our questions and giving us advice on how to approach this problem. Since this is our 4th semester, this list continues to grow, so in addition to the following people, we would like to extend our thanks to anyone who has helped us and is not listed below.

A. Finkl & Sons

Guy Brada – Chief Metallurgist

Liz Bilitz– Liaison to IIT students

PCB Piezotronics

Keith Crawford – Field Application Engineer

University of Texas

Illinois Institute of Technology

Dr. Ray DeBoth – Professor Emeritus

Professor Thomas Wong – ECE Department

Craig Johnson – Machine Shop Supervisor

Russ Janota – Director of Operations Mechanical Behavior

National Instruments

Bill Ornt – Software Engineer

D. Visual References

Figure 13 Broken Carbide Insert

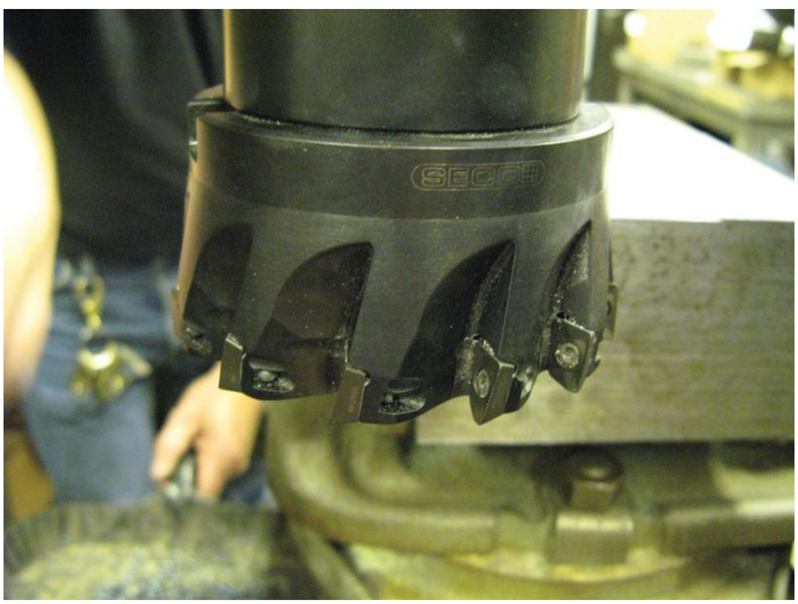


Figure 14 6” diameter milling cutter on IIT’s manual milling machine

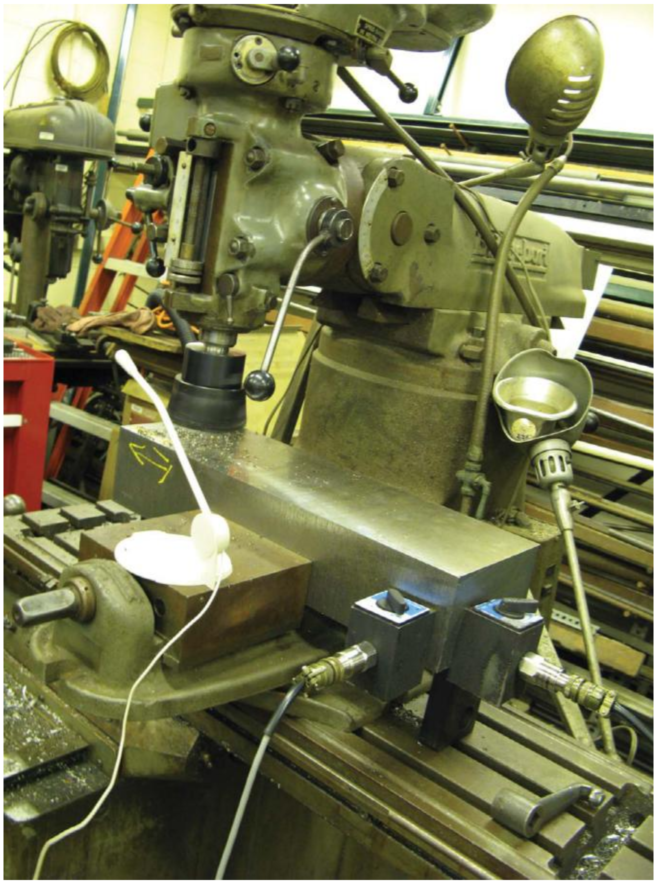


Figure 15 Bridgeport Manual Milling Machine

Figure 16 Haas CNC Milling Machine

Figure 17 A Finkl & Sons' Vertical Spindle Milling Machine

Figure 18 Custom made mounting for accelerometer on A Finkl & Sons' milling machine

E. Accelerometer Screenshots

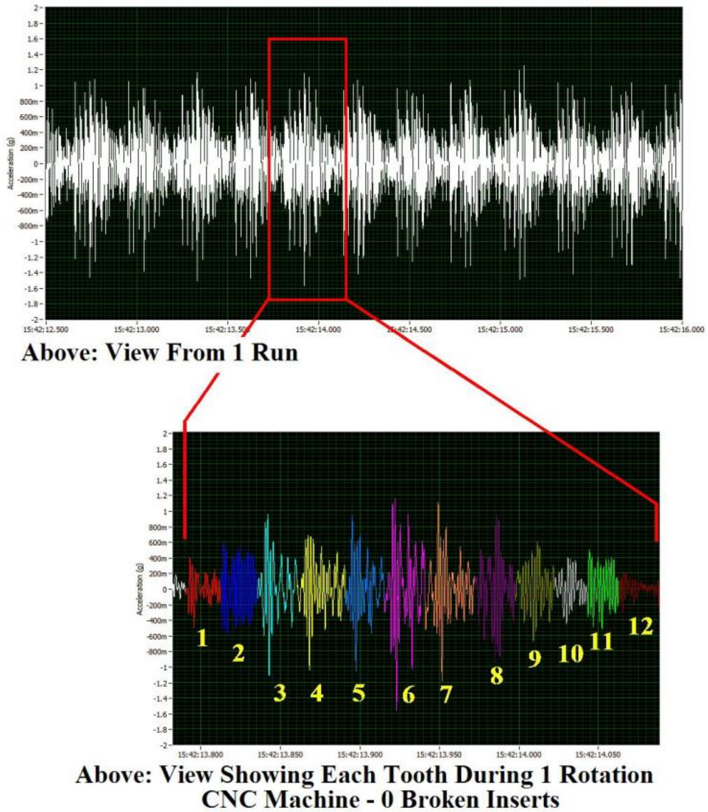


Figure 19

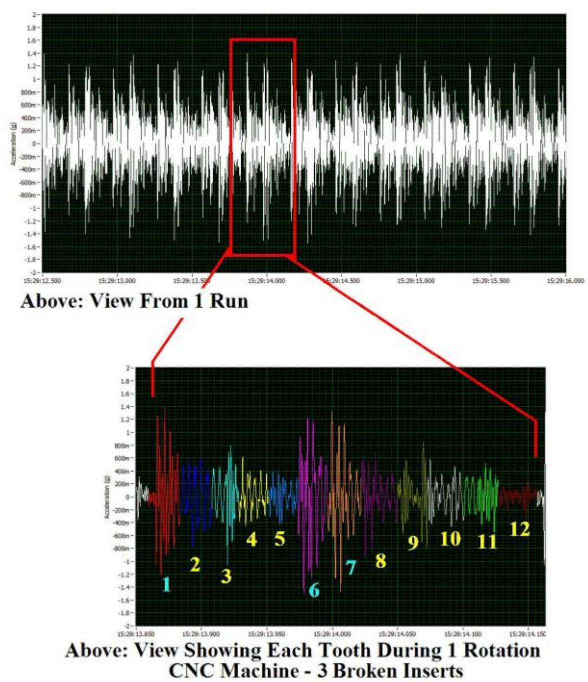
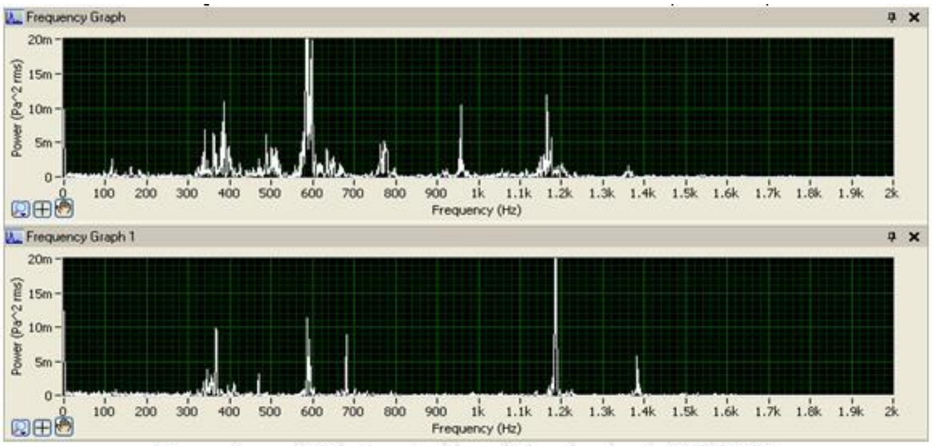
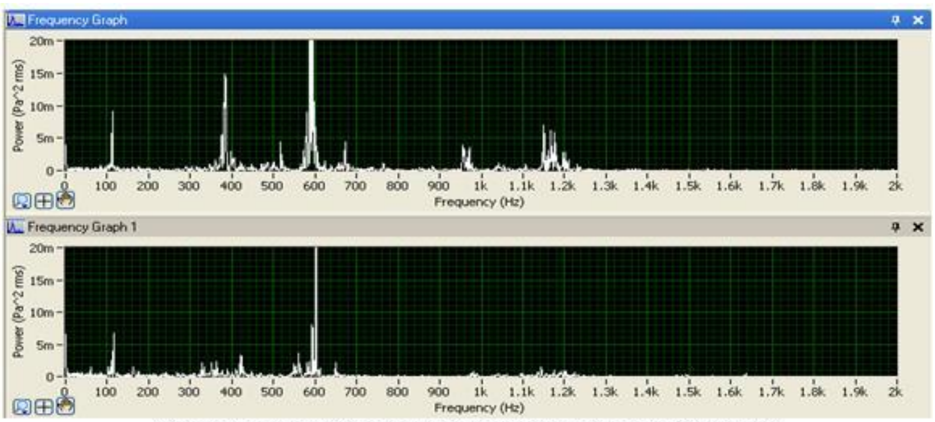


Figure 20



Comparison of 3 broken teeth and 0 broken teeth (150RPM)

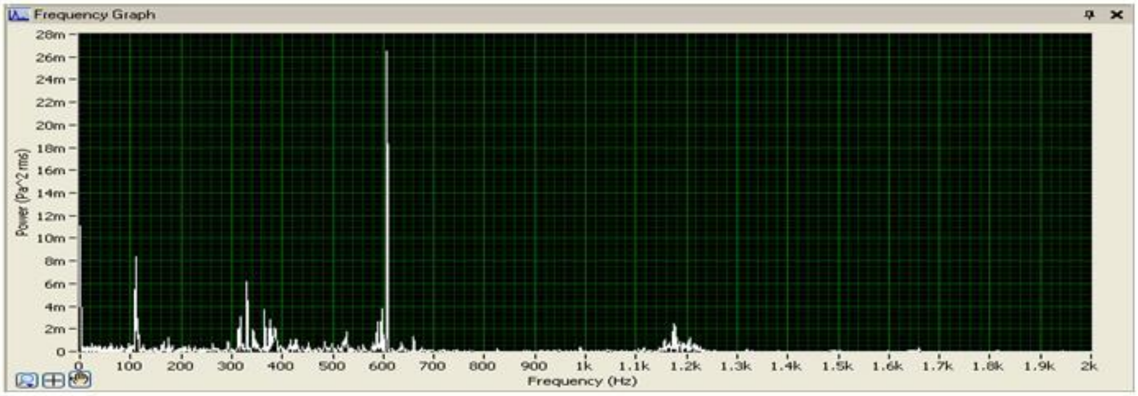
Figure 21



Comparison of 3 broken teeth and 0 broken teeth (125RPM)

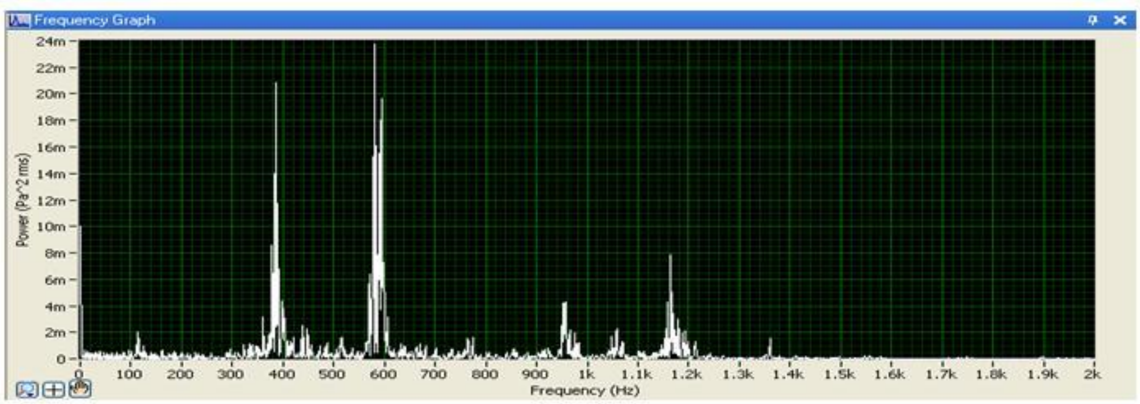
Figure 22

F. Microphone Screenshots



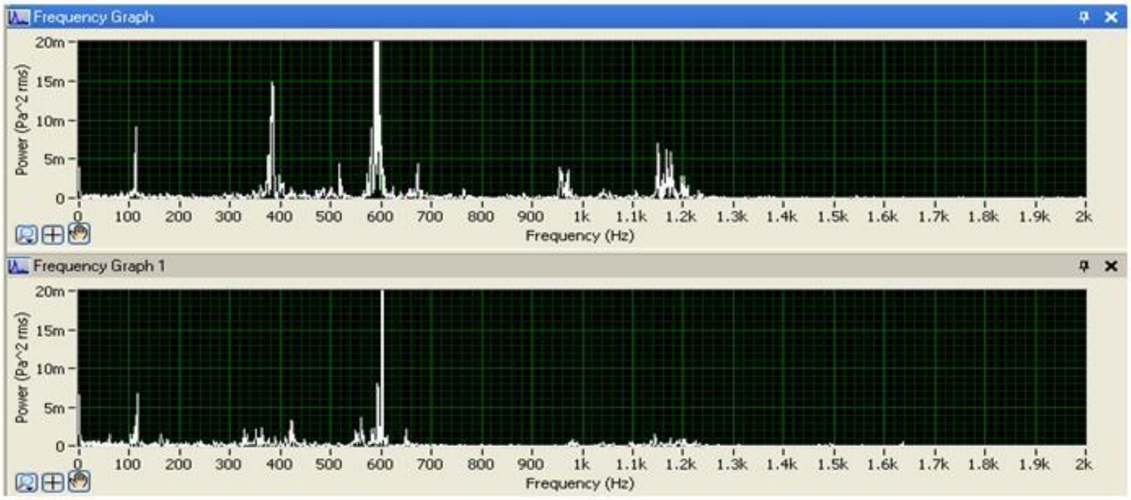
Microphone Frequency of 0 broken teeth (RPM 125)

Figure 23



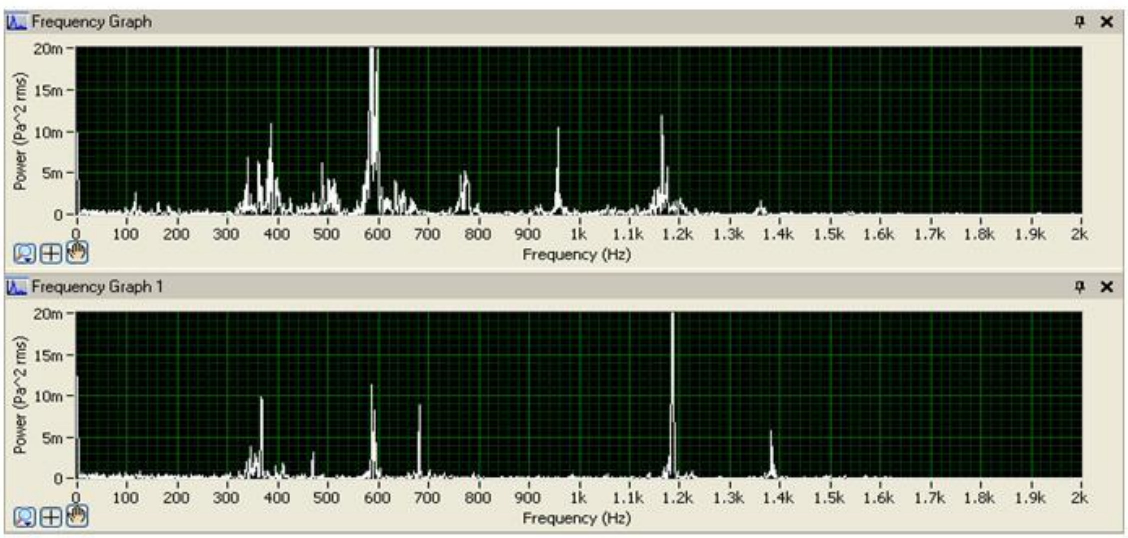
Microphone Frequency of 3 broken teeth (RPM 150)

Figure 24



Microphone Frequency of 3 broken teeth and 0 broken teeth (125RPM)

Figure 25



Microphone Frequency of 3 broken teeth and 0 broken teeth (150RPM)

Figure 26