IPRO 304:

Integration of Process Improvements

Fall 2010

Advisors: Professor W. Maurer and Professor S. Mostovoy

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 and a half 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, a data collection team and a data analysis team, with project management delegating and scheduling the tasks for the whole group. The first task was visiting the A. Finkl and Sons steel plant to collect data. The second part was analyzing the data.

The data collection team collected the data using the computer software program LabView and a single axis accelerometer. The resulting output was then saved and analyzed by the data analysis team using another computer program named diadem.

2. Purposes 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. MORE DETAIL

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 data collection group and the data analysis group. The teams decided which methods to research before we collected the materials to start testing. Single axis accelerometers and triple axis accelerometers were explored as possible methods of detection.

The IPRO needed to find the materials needed to perform the experiment at A. Finkl and Sons. The single axis accelerometer was acquired from the Illinois Institute of Technology.

A lecture by Chuck L from last semester was given to the class before testing on the computer program LabView, and how to collect the machine data using it.

4. Analysis

Currently there are two vibration analysis methods which have been explored and show promise. Both of these methods have a minimum requirement of only one uniaxial accelerometer with a sensitivity of around 500 mV/g.

Method 1 - Threshold Amplitude Triggering:

This first method is based on the concept of there being a threshold amplitude on the acceleration vs. time readings, or raw data, which normal readings would not cross. Data from previous semesters indicate that the breakage of a tooth is accompanied by a relatively large pulse. This pulse is characterized by its sudden start followed by a gradual damping (Figure 1). A trigger would be set to detect such pulses and, thus, breakages would be detected.

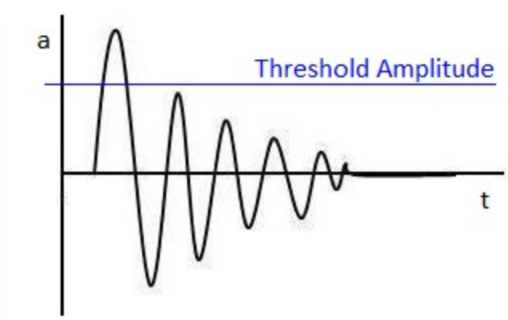

Figure 1 - Basic characteristics of the pulse created by a tooth breaking

The primary advantage of using this detection method is that it involves a minimal amount of calculation, meaning there would be little systematic lag. Also, it should be noted that data recorded during breakage events seem to indicate that there is quite a substantial difference between the initial amplitude of a breakage pulse and those of the readings before and after (Chart 1).

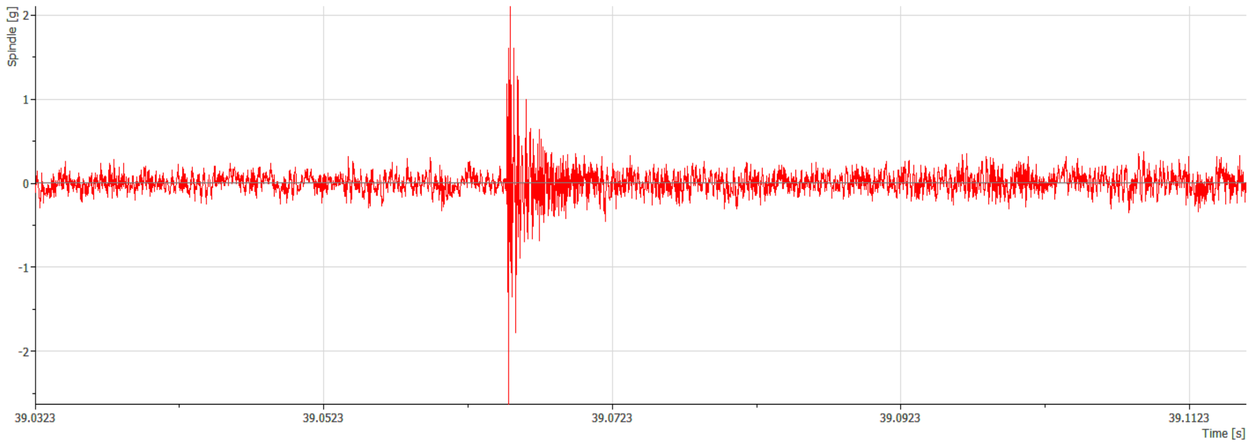

Chart 1 - Example of actual breakage pulse

On the downside, however, the threshold amplitude method can only detect a breakage during the actual event and may be subject to error due to certain background noises or changes in cutting parameters, among other things. Thus, by itself, this first method might not be sufficiently error proof, although, it could still be useful when combined with an actual breakage check, such as the one described by the next analysis method.

It should be made clear that detecting when the threshold amplitude is crossed is simply the fundamental aspect of this method and not its sole component. That is to say that, once a threshold trigger has been activated, the pulse or waveform responsible would be analyzed to determine whether or not it matches the distinct shape of a breakage pulse.

Method 2 - Power Spectral Density Comparison:

This tooth breakage detection method differs from the first primarily in that it involves an actual breakage check. In other words, it is not concerned with detecting the instantaneous breakage event. Instead, this method provides a means of determining whether or not a tooth has been broken after the breakage pulse has disappeared. Such a determination is made possible through observing any changes in the power spectral density (PSD) of the frequency range corresponding to the vibrations created by the interaction between the milling head teeth and the steel being cut.

As previously illustrated, any analysis based solely on the raw data would be quite limited, for it would have to be based primarily on fluctuations in the amplitude of the resultant wave. Since the resultant wave is, by definition, the wave created by the superposition of all of the vibrations detectable by the accelerometer, it is quite difficult to determine the source most changes that can be observed. The breakage pulse is one of the few exceptions since it is distinct in its shape and is very noticeable due to is very large amplitude, relative to that of the rest of the resultant wave. In order to single out and observe the vibrations having to do with the milling head teeth it is necessary to switch over from the time domain to the frequency domain.

Fourier analysis is based on the theorem that any wave or pulse, no matter the shape or complexity, can be created through a combination of harmonic functions that have different frequencies. Skipping over the mathematical details, this type of analysis enables one to separate a resultant wave into the various simple single frequency waves that it is comprised of. More specifically, Fourier transforms perform this operation. For the purpose of this project, fast Fourier transforms (FFT's) are used, which are simply Fourier transforms which are made a little easier for computers to calculate.

While Fourier transforms would work for the analysis of this project, clearer results can be seen through examining either the power spectrum or power spectral density (PSD) of the raw data. All three of these yield similar images, however, the image from the Fourier transform by itself contains many frequencies which are insignificant, given their small energy contributions to the accelerometer placed as close as possible to the vibrational source of interest. Squaring the Fourier transform yields the power spectrum and then dividing each amplitude by its corresponding frequency gives the PSD of the data. The following three charts illustrate the differences and similarities between these three representations of the resultant wave make-up. In this case, the wave being analyzed corresponds to a center cut (i.e. no overhang) performed at Finkl with no teeth missing or broken.

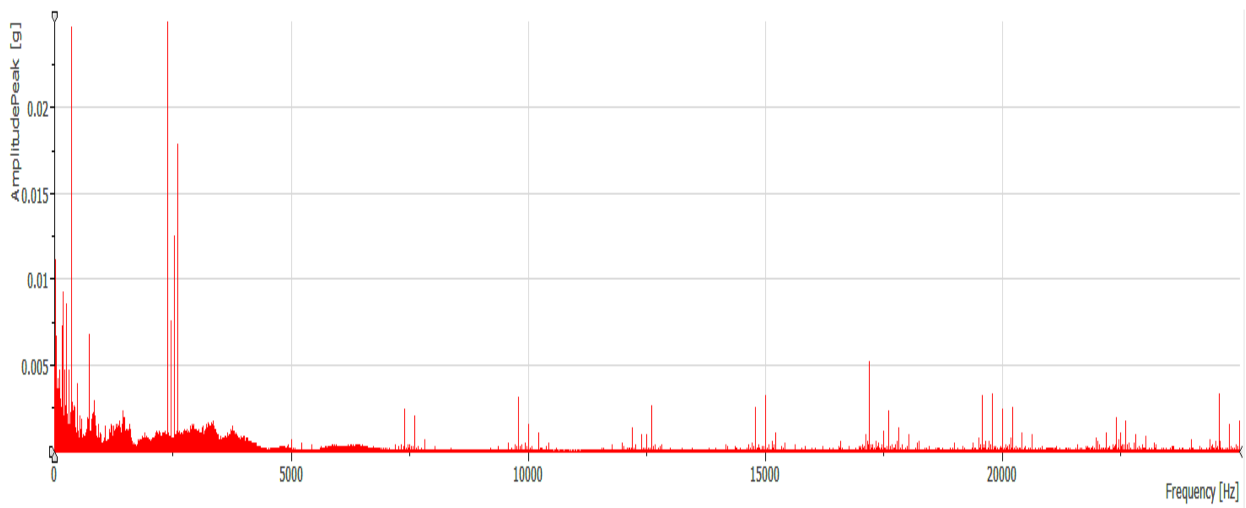

Chart 2 – FFT of no-scale example cut

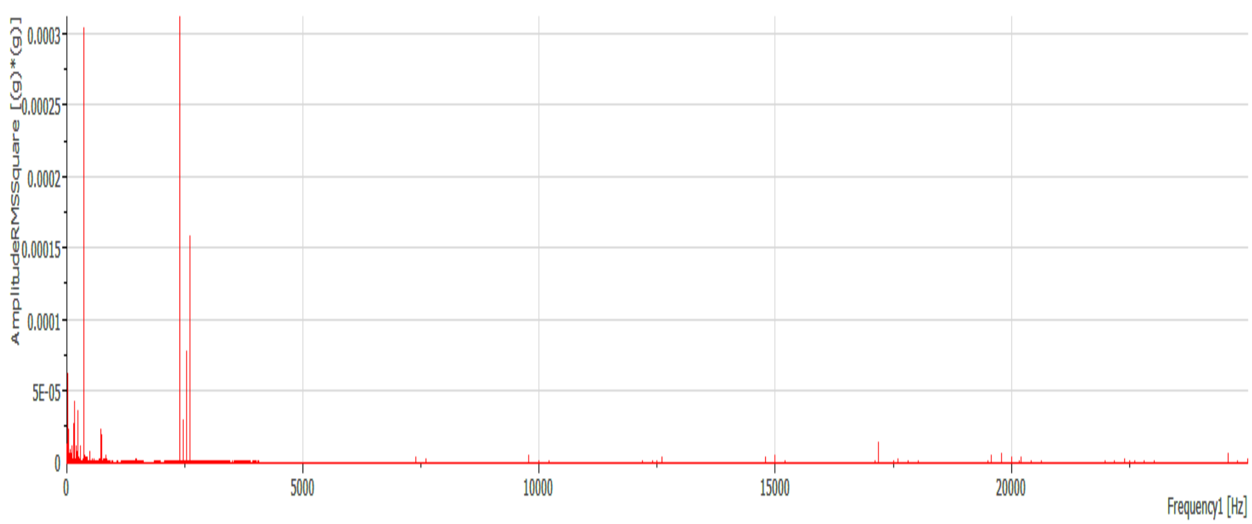

Chart 3 – Power spectrum of the same example cut

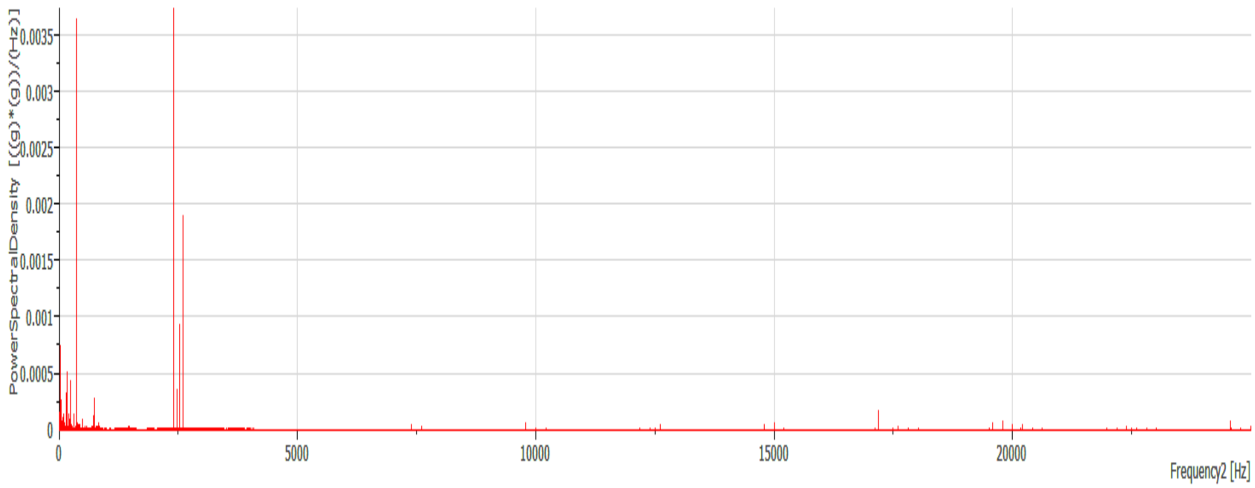

Chart 4 – PSD for the cut

As can be seen above, the power spectrum conversion makes a very noticeable difference in clearing out what professionals believe to be simply distractions. The PSD conversion, on the other hand, mainly affects the relative amplitudes of the various frequencies, although, the change is in not drastic.

To create a PSD in DIAdem simply proceed as if you were making an FFT by clicking on the appropriate button from the signal analysis list. Once the FFT creation window pops up, input the time and signal channels to be used and then, from the FFT tab, select "Power Density Spectrum" from the averaging dropdown list. Just to be clear, a PSD is not technically an FFT, however, it gives a similar distribution that is time averaged.

At this point, the data still needs to be narrowed down to the frequencies that correspond with the vibrations of interest. This whole method is based on the idea that a broken tooth will cause a noticeable change in the frequency spectrum associated with the insert-steel interaction. To begin identifying these frequencies, it is helpful to be aware of if any other vibrations, which would probably be associated with the rest of the running machine, are dominant in the area of the accelerometer. In other words, it's important to find out if any of the frequencies with large spikes on the PSD are being created by other sources which aren't of interest. If there are none for which this is the case, then, due to the intentional positioning of the accelerometer, it seems safe to assume that the dominant frequencies are of primary interest. The following chart shows the PSD of the machine running in midair, or while not cutting (Chart 5).

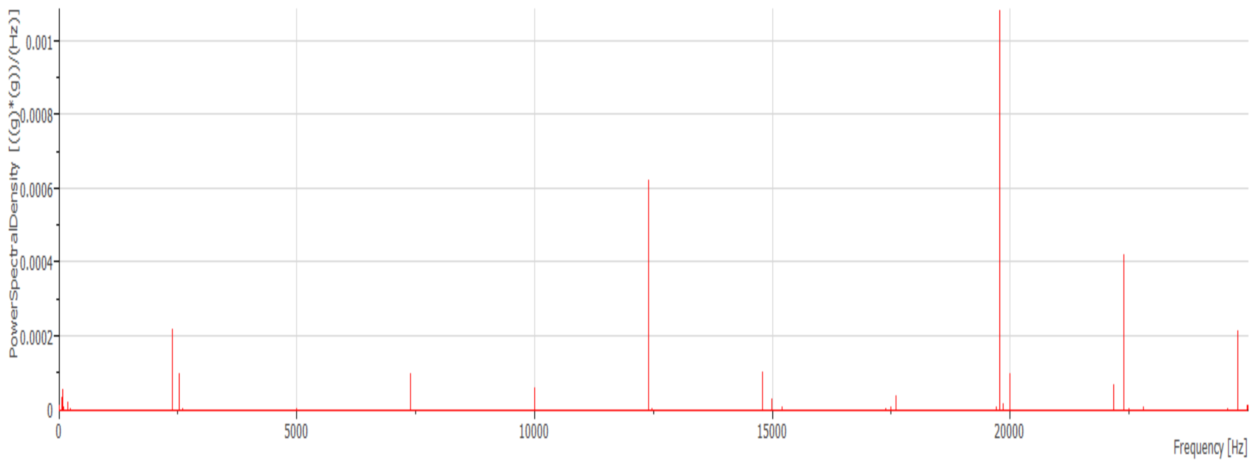

Chart 5 – Baseline PSD created from data recorded while machine was running, but not making contact with the steel

The following chart (Chart 6) is from the PSD of the example cut and is zoomed in to the range in which the dominant frequencies are located.

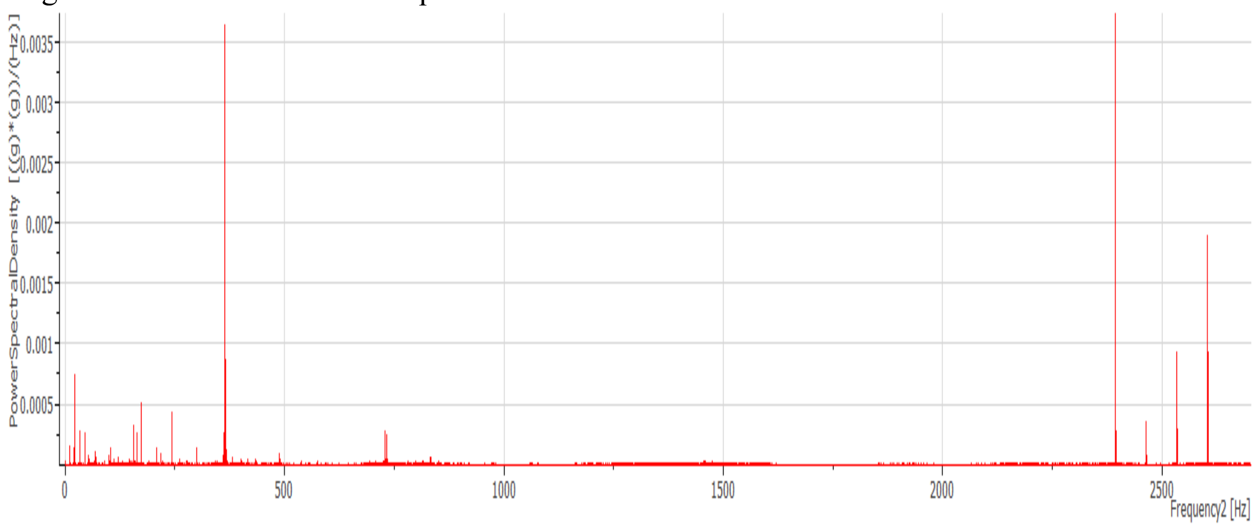

Chart 6 - PSD of example cut zoomed in to range where dominant frequencies are located

Chart 6 can then be compared to Chart 7, below, which is the baseline PSD zoomed into the same region.

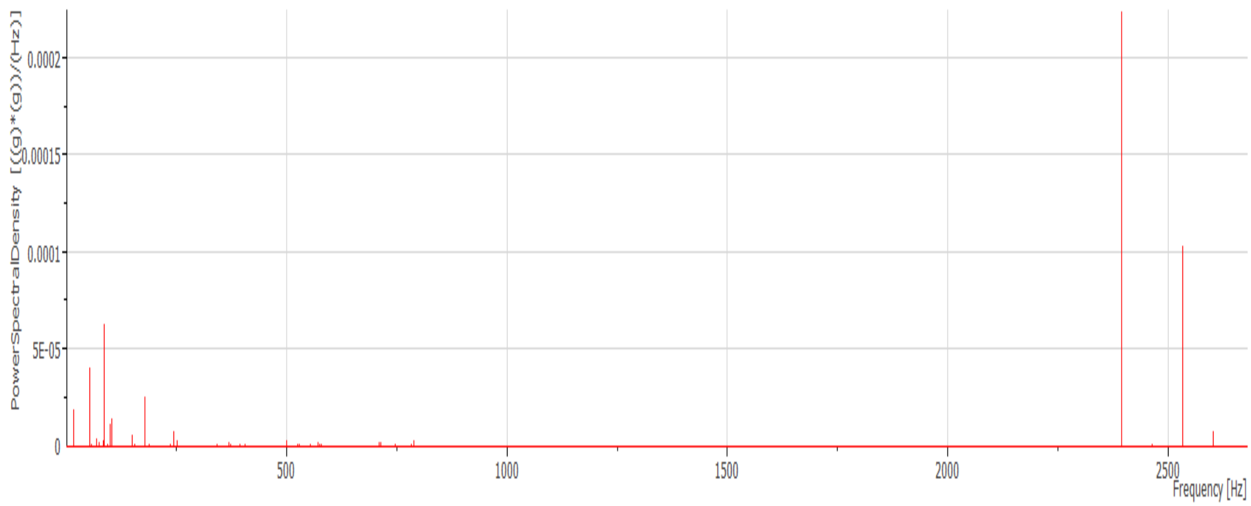

Chart 7 - Baseline PSD zoomed for comparison with PSD of example cut

Comparing the above pair of charts, it can be seen that the dominant frequencies in the 2500 Hz region can be accounted for by the machine running, or potentially some other background noise. Thus, they should not be studied, despite the fact that there is some variation in this region between the two PSD's. Instead, it is clear that the frequency at around 365 Hz should be focused on since it is very much a dominant frequency, in terms of amplitude, and arises only after cutting begins. Using this method, a computer could easily be programmed to determine the frequency ranges on which it should focus during the cutting process.

As mentioned earlier, once a tooth breaks it is expected that the frequencies being monitored should change. The most dominant of those frequencies should be reduced somewhat, due to its losing one of its sources while others in the same region, which were either non-existent or small in amplitude before, should increase. The rise of a new frequency or increase in another could possibly be explained by changed interaction of the tooth following the broken tooth with the steel. The following Charts illustrate this change (Charts 8 and 9).

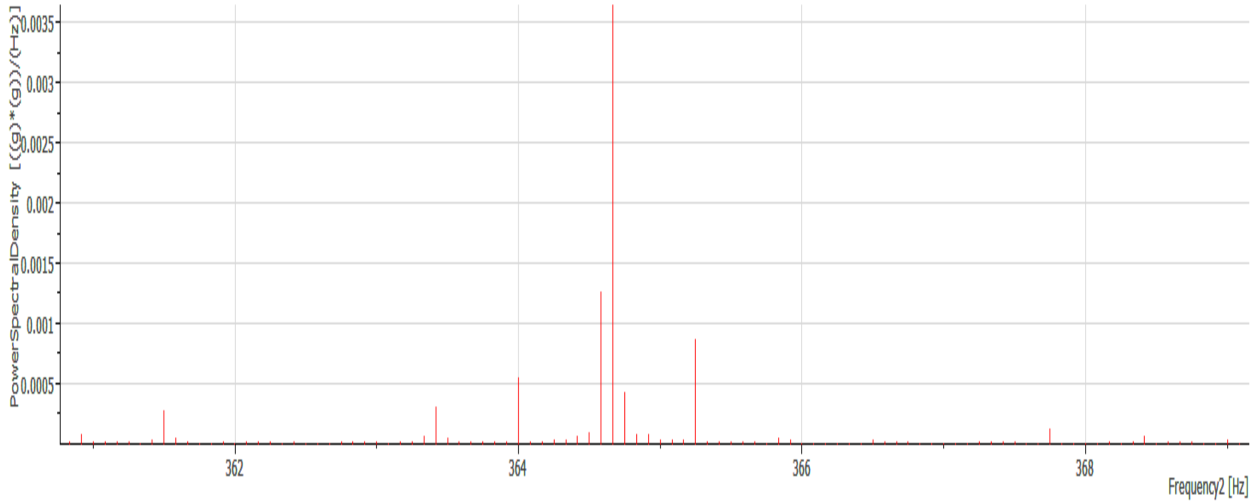

Chart 8 – PSD of example cut used earlier, zoomed into specific region of interest

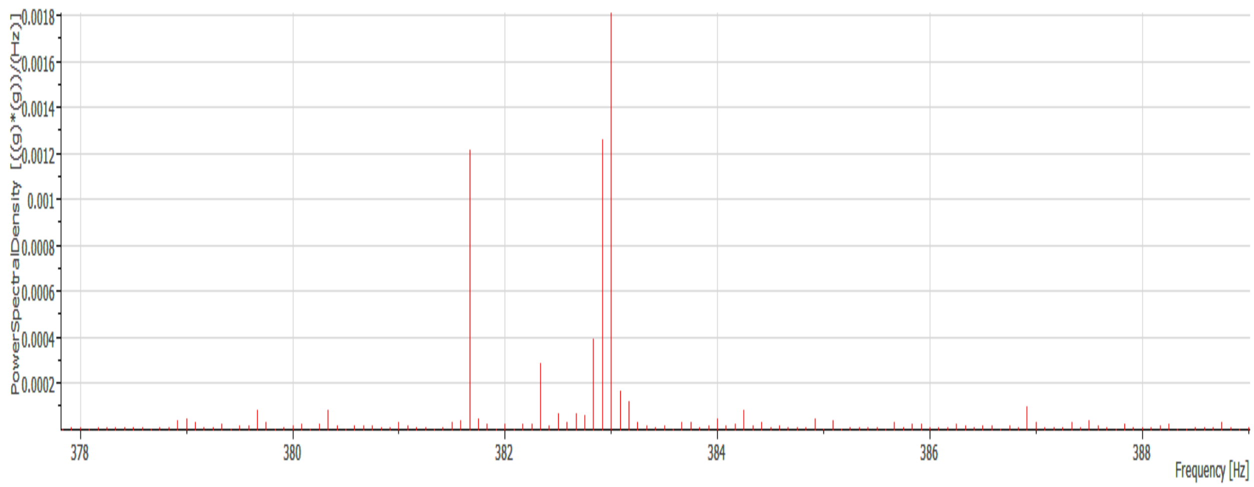

Chart 9 – PSD of cut with broken tooth, zoomed into same specific region of interest

It should be noted that the offset in the frequencies on Chart 9 is potentially due to the fact that the cut was being made into scale, not a smooth surface. Based on the study of other PSD's associated with scale cuts, it seems valid to say that the substantially reduced dominant frequency amplitude is due to the missing tooth. Also, it is likely that the rise of some of the other frequencies is due to the change in the cutting situation as well. Note that more compiled data in a later document can be used to verify this conclusion.

As far as automating the detection of such a difference is concerned, there are a couple methods which would be appropriate. The first would involve taking the area of the space occupied by the frequency spikes being monitored. A break could then be detected by monitoring any change in this area.

The second would involve either a convolution or cross-correlation of the monitored frequency ranges in order to determine whether or not they are the exact same shape. This process will be explained in greater detail once the specific methods being considered have been confirmed as being valid.

- How to compare before and after

For this method the time domain data is first taken over into the frequency domain via fast Fourier transforms (FFT). The resulting data indicate the various frequencies detected at a given moment along with the amplitude of the waves corresponding to each frequency. The power spectral density of a given frequency range is then found by

The use of Fourier Analysis was key to the progress that was made.

Through the comparison of unaltered PSD’s it was possible to clearly see when a tooth had been broken, in many cases. In these cases it was also possible to quantify the change through various methods having to do with amplitude and bandwidth and bandwidth comparison. Percent differences of up to 99% were seen.

Some groups of data were much harder to analyze than others and made the methods used seem ineffective. It seems that this added difficulty corresponded to slightly different data acquisition setups.

If this analysis were to be used permanently, such changes in data would not occur, for the accelerometers would be permanently fixed, along with the rest of the setup.

It is believed that, once the effect of accelerometer placement, has been studied further, it will be easier to improve the analysis methods tested this semester.

5. Conclusion

Future Work

The next step is to have an accelerometer permanently affixed to the spindle, either being bolted or soldered to the machine. The transducer would also have to be placed in a fixed position, and the cables connecting the accelerometer and transducer would need to be placed permanently with very little slack.

Having the accelerometer permanently affixed to the machine has to be part of the overall detection system for one major reason. It eliminates a variable in our analysis by making the placement and orientation of the accelerometer constant. We have found that the difficulty in analyzing the data from each collection session is not having the accelerometer in a constant position. Each time we collected data, the accelerometer had to be repositioned, but could never be in the same exact spot twice. When the program for detection is implemented, having the accelerometer in a fixed position is crucial for the program.

The position of the accelerometer needs to be close to the rotating head of the mill. Once soldered or bolted on, data samples would need to be collected and analyzed for “calibration”. With these results, the program for detection can be implemented.

6. Appendix

A. Budget

We used previous semesters materials all was available

B. Team Members

Name	Year	Major	Position
Jon Perry	4th	Mechanical Engineering	Data Analysis
Kyle Gillmeister	4th	Architecture	Data Collection
Mike Sullins	4th	Psychology	Data Analysis
Amar Rana	3rd	ECE	Data Analysis
Robert Hill	5th	Computer Science	Data Collection
Alexander Derdelakos	4th	Architecture	Project Manager
Francis Gotanko	4th	Material Science and Engineering	Data Collection

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 5th 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.

Liz Bilitz

Chuck Loeppert

Ray DeBooth

Jennifer Keplinger

Dave Snyder

Keith Crawford

Craig and Russ from IIT Machine Shop

D. Visual References