***Abstract* –** A. Finkl & Sons, Inc is looking for a way to detect a break in their milling machine so that it can be replaced quickly and efficiently.

Background

A.The problem that A. FInkl & Sons wants us to concentrate on is that of the detection of broken teeth on their milling machine. Milling machines are used to cut and finish metal. A rotating head on the milling machine has a number of inserts, also referred to as teeth, which cut the material as it rotates. The material moves under the rotating head so that the entire surface can be milled. The mills are used to remove material of large forged steel parts to properly fit the customer's specifications.

Currently, A. Finkl & Sons keeps an operator by the mill when it is running and that person is in charge of turning off the mill when a tooth breaks. The only form of detecting if a tooth has broken is to constantly check the solid piece of steel for any unusual marks. This form of checking is too long, because most mistakes will not be noticed until after a long while and then the operator has to check every single tooth on the rotating head. If the broken tooth is not fixed or noticed in time, it presents drastic problems. By having one tooth that breaks while milling, it causes strain on the milling machine and more weight on the other milling teeth, therefore causing more inserts or teeth to be susceptible to breaking as well. By finding a solution to better detect when an insert breaks, it will save A. Finkl & Sons much time and money, enabling them to manufacture more quantity of pieces and better quality.

Objectives

Continue off the research of the previous semester's research to find a solution to the given problem. Here is a brief description of the technology that will be employed.

we are focusing on is the accelerometer. There are two aspects to the accelerometer technology, wireless or wired.

There were a few companies that were investigated, for example, Honeywell and G-Link. However, Techkor is the better of the three because the G-Link is too slow for the required frequency. Honeywell has not answered our inquiries at the moment. We have a high frequency issue and Techkor is the only one that demonstrates the capacity that we need on measuring vibrations. We will be conducting our research solely based on the accelerometers.

Find an algorithm that will read accelerometer input and detect the tooth breaking on the milling machine. This algorithm will read the input data from the accelerometer software. It will signal to the machine to stop the manufacturing process so that the teeth may be rotated, or replaced.

Methodology

I. Verify Previous Work

Fall 2008 Ipro 304's members made a good decision for using accelerometer to measure the vibration level caused by broken inserts. They were able to show the difference between a run that had broken inserts with run that didn't have any by plotting the energy of acceleration. However, the method could not show the time series of all the acceleration data. In other words, that method would not be able to tell exactly when the inserts were broken.

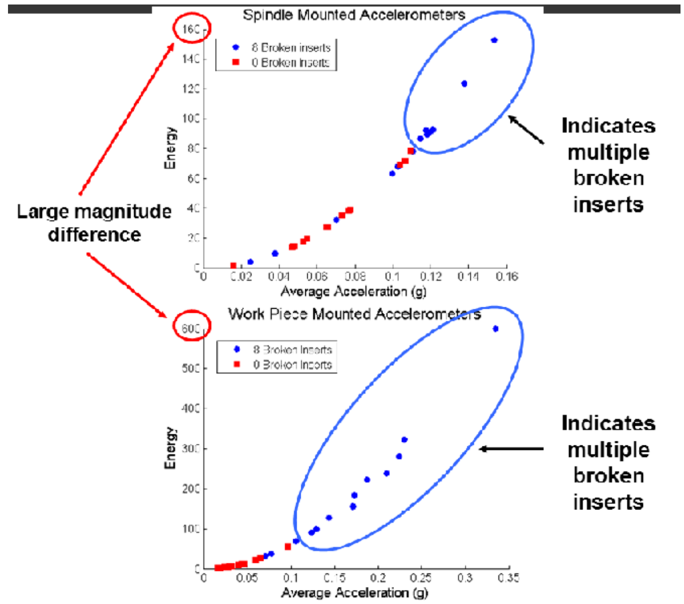

FIGURE 1

Fall 2008 Ipro 304's approach to detect broken inserts

II. Current Approaches

By using the same accelerometer approach, we came up with additional ideas for this semester project such as root mean square (RMS) and power spectrum density analysis (PSD).

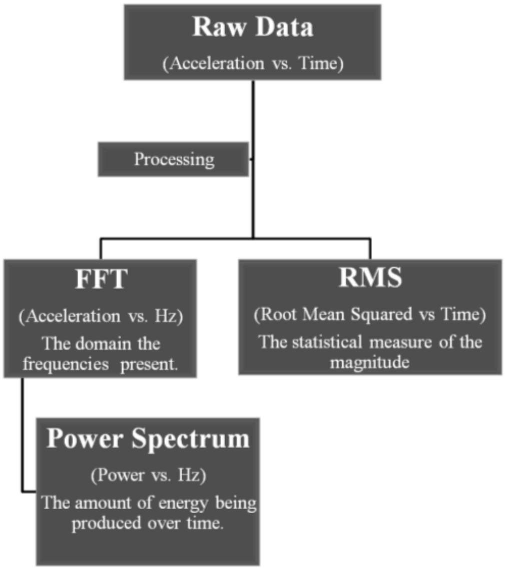

FIGURE 2
APPROACHES FOR THIS SEMESTER

RMS approach has several advantages. First it shows time dependence of acceleration energy of several continuous runs. Analyzing the RMS also shows a quick view of what was happening during all the runs. In addition, RMS can also show the dependence of acceleration on cutting materials, depth of cut, speed of cut, and others.

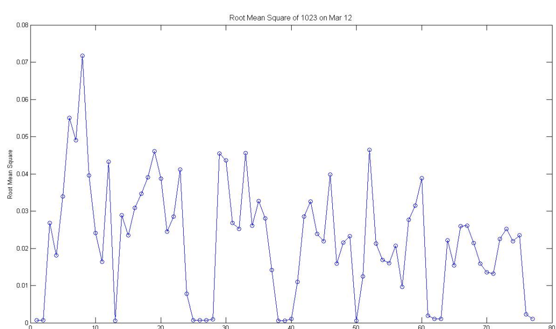

FIGURE 3
RMS PLOT OF A SINGLE ACCELEROMETER DURING SIX RUNS

On the other hand, the PSD method gives a more in depth look of a single run. Figure 4 is one typical PSD plot of a two minute-window of one run without any broken insert (usually 8 windows in one run). The acceleration signal has most frequencies focus in a narrow range.

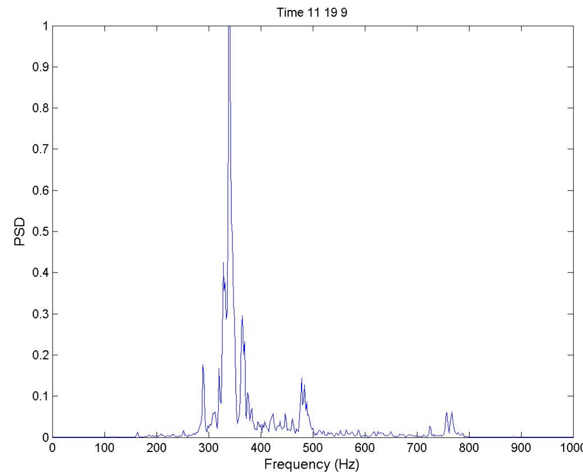

FIGURE 4
POWER SPECTRUM WITHOUT BROKEN INSERT

However, as soon as an insert breaks, the PSD plot will suddenly change and look like figure 5. As one, two, or even more inserts break, there are additional vibration elements that will affect the frequency spectrum. Therefore, the frequency range in figure 5 is very wide.

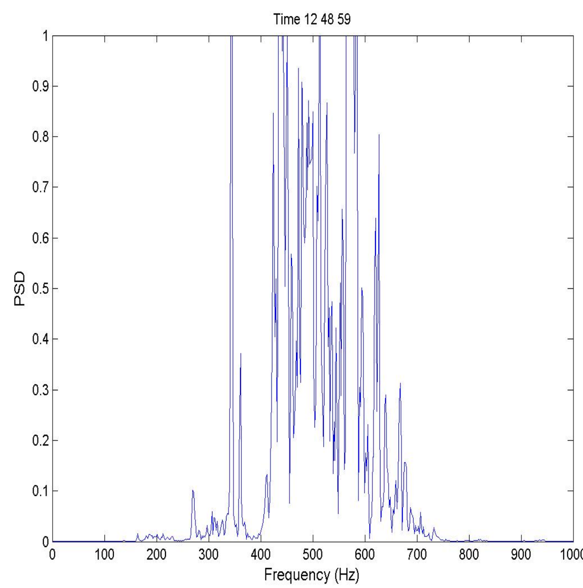

FIGURE 5
POWER SPECTRUM WITH BROKEN INSERT

As a result, we’ve come up with one method to detect broken inserts by scanning the PSD plots automatically. Set a normalized PSD of 0.6 as a standard. There are one to two peaks above the 0.6 value when there is no broken insert. Whenever one, two, or more inserts break, there will be more than 10 (at least) peaks raise above the 0.6 value, and that can be used to trigger the alarm to notify the operator or shut down the milling machine.

Beside the use of wireless accelerometer, we also used a wired accelerometer to compare with the wireless accelerometer's result since it has the advantages of constant data feed, robust, and its signal can be viewed using Labview.

Team Structure

The team structure of IPRO 304 conforms to the research oriented and results driven nature of the work conducted by the team members. Flexibility and initiative was required from all team members in order to adapt and maintain progress in pursuing the dynamic research of the milling insert failure, and the development of software and testing methods to facilitate data analysis.

Team roles were assumed by team members or assigned to them on as need basis in an efficient manner in order to ensure progress toward the long term goal of an early warning insert failure detection system. Three main subgroups formed within the team in order to focus on specific areas of the project: Information Technology (consisting of Anandha Abhay, Anthony Bergeron, and Jay Taggart), Data Processing (consisting of Vishal Patel and Vien Quach), and Data Analysis (consisting of Christopher Catalina, Jason Entler, Maxmillian Estrada, Alexander Kolbasov, and Sunghwan Yeo).

The Information Technology team focused on developing the software to interact with the data collection hardware in order to acquire the data in a useful format.

The Data Processing team focused on the use of MatLab code to process the data obtained from the Information Technology team and output the processed data, mainly with Fast Fourier Transforms, in a format useful for analysis.

The Data Analysis team focused on determining the underlying physical nature of insert breakage, and ascertaining the manifestation of a broken insert in the data provided by Data Processing.

Individual positions were also assigned throughout the semester as the need arose for team members to occupy the positions in order to ensure the progress of IPRO 304: Christopher Catalina was appointed as the liaison with A. Finkl & Sons (IPRO 304's sponsor), while Anandha Abhay, Jason Entler, and Jay Taggart were each assigned to coordinate and deliver various IPRO Nuggets throughout the course of the semester.

All of the team members participated in site visits to A. Finkl & Sons, and each team member took part in the data collection process in order to acquire and analyze as much data as possible.

Budget

IPRO 304 was fortunate this semester because there was very little money that was spent towards achieving our goals as an IPRO. There was some small capital expenditures and they are listed below.

1 Foldable tray table $26.00

2 Padded Folding Chairs $32.00

All of those items were purchased so we could collect data efficiently and effectively. These items were purchased at the beginning of the semester and where used throughout the whole semester for data collection purposes.

Code of Ethics

IPRO 304 believes that a code of ethics is fundamental to maintaining an honorable and respectable presence inside and outside of the classroom. Members of IPRO 304 shall conduct themselves in accordance with the ethics standards stated below.

- Conduct research and classroom discussion in a manner that is consistent with accepted honor and decency.
- We will strive to maintain the highest standards of honesty and integrity in all endeavors associated with the IPRO.
- Be civil and respectful in professional and academic interactions, avoiding discrimination, based on race, religion, or age.
- Act for the school as faithful agents
- Treat other students, professors and host fairly.
- Be constructive without malice in evaluating the work of students.
- Encourage the free and open exchange of ideas and information without fear of retaliation.

Results

Our team has confirmed that an accelerometer could be used to detect broken inserts in a spindle. We have found that broken inserts effect the power spectrum relieved form the accelerometer in two ways. The first one is that the frequencies present prior to insert failure significantly grow in magnitude. The second one is the widening of the frequency spectrum.

The results we achieved during this semester are best represented by the two images below. The top one shows a typical power spectrum with no teeth broken and the bottom one two or three teeth broken. However, it is important to note that the peaks are not constant. They constantly rise and fall and a continuous data stream is required to see the changes in the behavior of the graph.

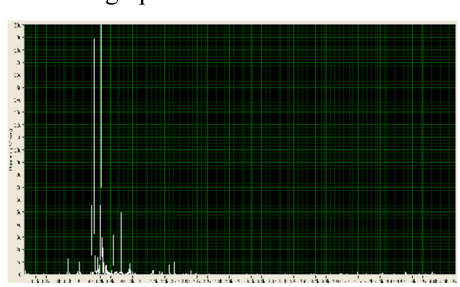

FIGURE 6

Normal Power Spectrum

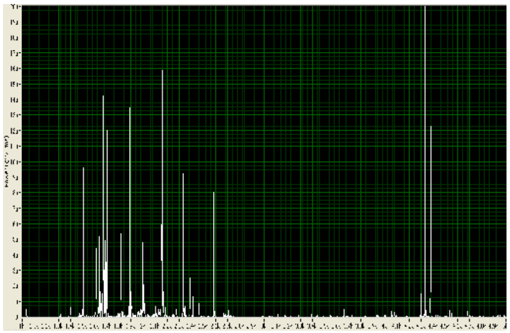

FIGURE 7
POWER SPECTRUM WITH BROKEN TEETH

OBSTACLES

We have faced many obstacles this semester that have been difficult hurdles for us to overcome.

- Last Semester's Work Invalid
  - Last semesters work was what showed that accelerometers could show that a broken tooth could be perceived by an accelerometer. However, their logic was faulty and the data they gave us was not valid so we had to start fresh with our own interpretations of the accelerometer data.
- Poor Documentation By Last Semester
  - Last semesters work didn't have a lot of backing behind it. Supposedly they spent about 2 weeks on the data collection and the results they came up with. There wasn't much knowledge or time spent on making the data given to us easy to digest and were on our own with interpretations until we got a hold of a few other people from last semester to help explain things.
- The Operator
  - Trust
    - The operator knows we are there cause we work right next to the workpiece. We try our best to stay out of his way but the long term effect of our work would be to make the operators job different and possibly harder. There was always the possibility through the sample collecting that the operator was giving us faulty data or intentionally trying to make the sampling hard for us to acquire.
  - Work Skill
    - The work skill of the operator has lead to some issues as well with collecting data. A few times the operator ran the piece too slow or too fast causing fluctuations with the data collection in comparison to older runs. Also at one point an operator error caused for the workpiece to be locked up for an hour and a half losing us precious time.
- Hardware Failure
  - Broken Accelerometer
    - One of the wireless accelerometers was broken since the beginning of the semester and thus causes us to be unable to take data with 4 accelerometers.
  - Battery Dead
    - One of the accelerometers battery died near the end of the semester and ascertaining one would prove to be a lengthy endeavor that would not get us the battery in time for presentational stuff as as well the main presentation for our sponsor.
- Software Failure
  - MatLab
    - We had to create our programs with MatLab in order to use the wireless data. This proved be be harder than we originally thought and there were many problems with creating and running the various programs we made throughout the semester.
  - Watchdog
    - The analysis software included with Watchdog was insufficient for the needs of the project
- Sponsor
  - Uncontrolled test environment
    - We were observers to take data while at Finkl. This meant that our tests were not controlled as they should have been in order to get reliable data under our terms. This is a large problem and has made it very difficult for us to be certain of any of the observations we have made.
- Class Mates
  - A certain classmate did not participate at all and was dropped from the class due to this. This was one less person to help gather data and analyze it.
- Wireless Accelerometers
  - We used wireless accelerometers primarily the whole semester and they gave us inaccurate snapshots of the accelerometer data. We eventually moved to wired accelerometers to give us a drastically larger picture of what was going on. The wireless accelerometers were choosen due to last semester.
- Hardware Limitation
  - Wireless accelerometers would only take snapshots and not lengthy data runs for us to use in determining broken teeth.
- Work Pieces Given To Us
  - Bowed pieces/inconsistent pieces were prevalent throughout the collection process and caused for much of the data taken to be useless.

Recommendations

Any future work should begin with understanding the Lab View program and how to use it effectively. For instance the signal that is analyzed using the default settings is in one second intervals. However, one revelation on the milling head at 36 rpm is approximately 1.6 seconds. Since the one second interval does not contain the complete signal from an entire revolution of the milling head this may be causing more fluctuation in the power spectrum. By getting lab view to analyze the signal of a complete revolution the power spectrum might have less fluctuations and the progression of how the signal changes due to a broken tooth may be easier to spot.

Expertise in signal processing should also be immediately sought. At this stage evidence of a broken tooth is expected to cause a change in the signal being acquired. There may be other types of methods to analyze, compare or filter a signal to detect a change that were not known to this group. Ultimately, the signal being acquired needs to be quantified in some way that that allows a program to give a warning that a change has occurred. Lab View does have built in alarms that might be useful for this task.

Use of wired accelerometers needs to be expanded. Wired accelerometers were used only at the end of the semester after wireless accelerometers proved inadequate. Only one accelerometer was used. Using multiple accelerometers at the same location as well as multiple locations on the work piece is strongly suggested. It is not clear how consistent the signal seen by two accelerometers is. Also, it is known that the signal does vary with proximity to the milling head, but the significance of the variation is not fully understood at this point.

Currently it is not known if all the vibration frequencies are attenuated the same within the material. Use of multiple accelerometers in multiple locations might help to see if any frequencies are attenuated more than others. An experiment could be done with an ultrasound device and a finished work piece to help better understand this effect.

Once the team gains a full understanding of the problem and challenges a well designed experiment should be presented to Finkl. During this semester a lot of time was wasted taking data on runs that were not useful or just waiting for a run that had the right conditions to be useful. A well designed experiment could accomplish more in hours than what days of observation could. This might be difficult however because it will interrupt Finkl's productivity but it is absolutely necessary in order to better understand the problem.

The final product Finkl desires is wireless. While the wired accelerometers are being used to help develop a process to detect broken teeth that process needs to be evaluated for wireless use. If there are not any wireless accelerometers available on the market that have the specifications to meet the process, some sort of hybrid wired/wireless system should be investigated.

Acknowledgements

IPRO 304 appreciates the help of everyone who made this semester successful. We would especially like to thank Gary Gregga for providing all the necessary information including material properties of the carbide inserts used for the milling process. We would like to thank Guy Breda who is the chief Material Engineer at A. Finkl and Sons for being patient with our observations and conclusions. We would also like to thank everyone at A. Finkl and Sons for allowing us to observe and record data on site and the operators who described their jobs fully and gave IPRO 304 their own input to the problem. Everyone at A. Finkl and Sons was very polite and created a very calm environment to conduct our study and so we are very grateful for that. We would like to thank Liz Bilitz, a former student at IIT who is currently an employee at A. Finkl and Sons, for being our liaison. Miss Bilitz did everything in her power to make it possible for us to conduct our study and was available every time IPRO 304 visited A Finkl and Sons. We would like to thank Paritosh Mokhasi and Vladmir Frankfurt of IIT who provided their excellent opinions whenever IPRO 304 was unable to proceed. They provided different methods and ways of analysis that helped to narrow the parameters. Finally, we would like to thank professors William Maurer and Sheldon Mostovoy for their excellent guidance.