IPRO 304:

Integration of Process Improvements

Fall 2009

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 about 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. IPRO 304 chose an accelerometer as a force detection device when these carbide inserts have broken. The IPRO broke up into two main groups, an analysis and machining group, with two people delegating and scheduling the tasks for the whole group.

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 Bridgeport 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.

The IPRO decided to visit A. Finkl and Sons to conduct the experiment on their machines to verify that the procedure used detects broken inserts.

2. Purpose and Objectives

2.1 Information about Sponsor

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 a substantial issue with regards to the detection of cutting inserts in the milling machines used to machine and finish a 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 inspection, will then replace the broken cutting inserts. If a cutting insert does in fact break during the milling process and is not observed, more stress 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. Currently, A. Finkl & Sons spends over $400,000 a year replacing teeth. By means of finding a solution to detect when a cutting insert breaks and being able to automate the process such that one operator can operate multiple milling machines, A. Finkl & Sons will save much time and money and enable the manufacture of high quality machined steel slabs at a greater rate.

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 and 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 visual inspection of a machine operator.

#

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 data analysis group. The team decided which methods to be researched 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 teeth. 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 CNC mill from the Bridgeport machine in Engineering One Building.

#

4. Analysis

4.1 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 feed rate, depth of cut, rpm and number of broken teeth 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, Feed Rate, Depth of Cut, # of Starting Broken Teeth.

Location of Accelerometer Data Acquisition:

<u>Data taken from the material</u> 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 teeth that are cutting away at the material.

<u>Data taken from the spindle housing</u> 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 a higher amplitude due to the noise from the machine.

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.

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 teeth and gives a greater chance for the insert to become chipped or even shatter.

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.

Individual Teeth:

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

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

Dominant Frequency

It has been noticed that there is no dominant frequency or attribute that is created or noticeable when there are broken teeth compared vs none broken teeth. 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.

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.

4.2 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 teeth.

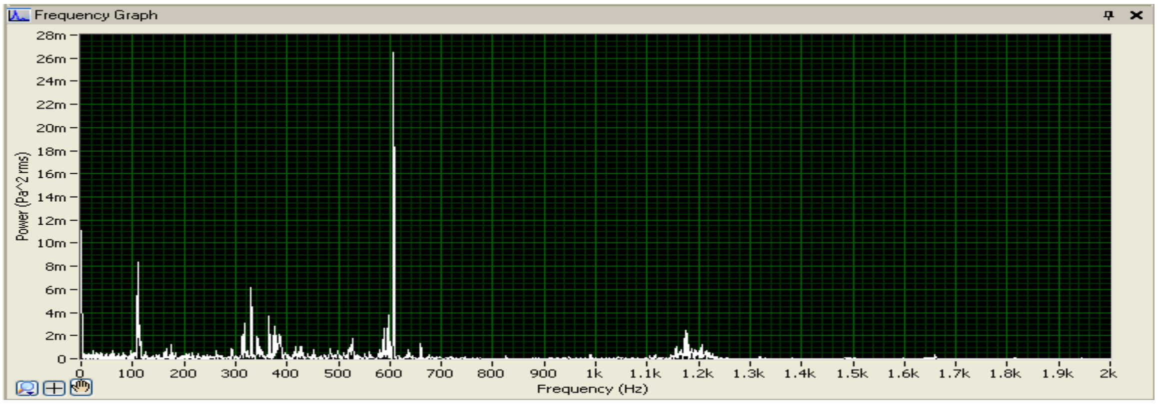
Theoretical Background

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.

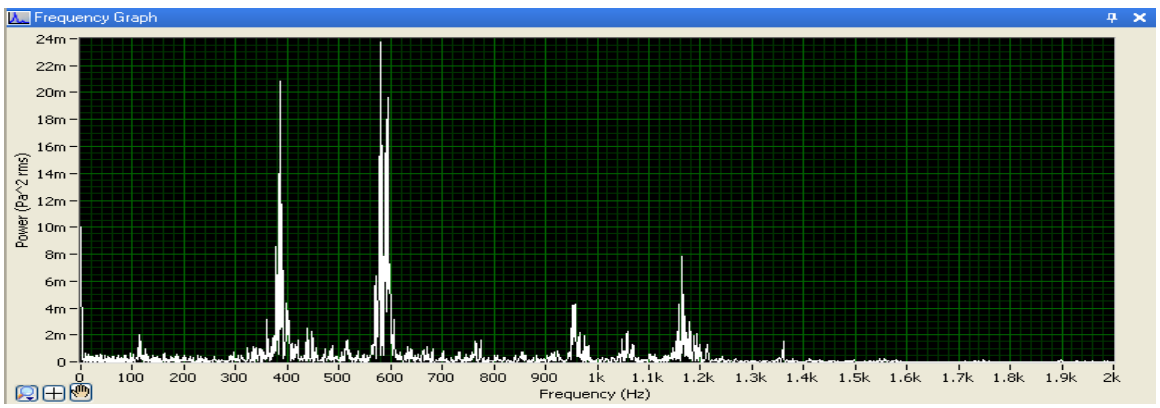
Noise is a consequence of each cutting process and depends on the vibration of the surroundings. Some noise sources are vibration of machine, vibration of the floor and even human voice. These noise sources will affect the measurement result more or less. In order to record the sound pressure under similar 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).

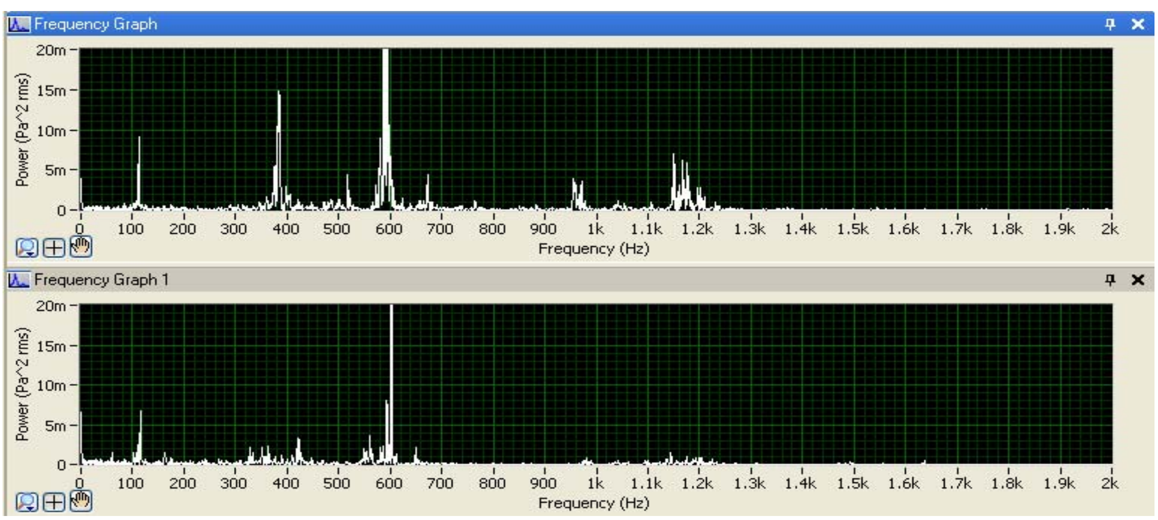
Experiment Data



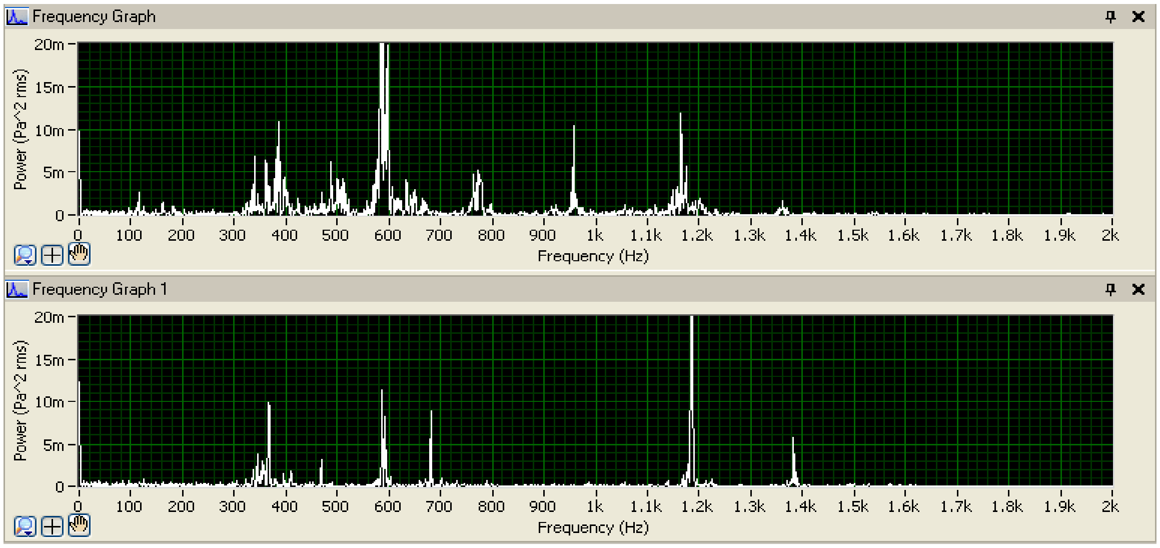
0 broken teeth (RPM 125)



3 broken teeth (RPM 150)



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



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

Analysis and Conclusion

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 teeth run and a 0 broken teeth run, there is still some useful information can be found. They are show in the table below.

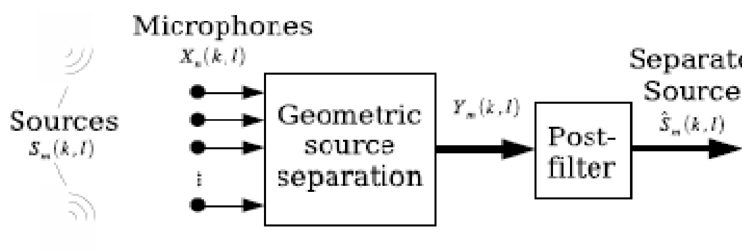
Test	**Broken Teeth**	**RPM**	**Freq. ~1k**	**Freq. 1.1k-1.2k**
0	0	125	No	No
3	0	150	No	Narrow and High
5	3	150	yes	Wide and low

Unfortunately, we cannot draw any concrete conclusion from these differences because they are not strong enough to indicate the detection of broken teeth. 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 to 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.



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 tooth 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 teeth, it is possible to observe two things. First, there is a clear difference in the PSD of the accelerometer readings when teeth are broken. Second, the amplitude of the spikes caused by the broken teeth 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

#

Appendix

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
	530.00

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