IPRO 304
Integration of Process Improvements

Spring 2010

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Executive Summary

The aim of IPRO 304, Integration of Process Improvements, was to determine an effective and reliable way to detect the failure of cutting inserts during milling operations. The inserts are used to remove scale and finish a piece of steel. When a cutting insert fails, it often fails catastrophically and places extra, potentially damaging, stress upon the remaining inserts. It is crucial to quickly detect these insert failures in order to prevent the cascading breakage of the remaining inserts and minimize any damage to the steel. In particular, the quick detection of these events would also save a significant amount of time and money for IPRO 304 sponsor, steel manufacturer A Finkl & Sons, Chicago, IL.

To tackle the problem, the group divided into two separate teams, the mechanical team and the analysis team. The teams then began developing a testing procedure to continue upon last semester's work with accelerometers. Using the laboratory CNC milling machine located at the Illinois Institute of Technology (IIT), the team began collecting milling data using a single-axis accelerometer, later expanding to a triaxial accelerometer in conjunction with a tachometer. Using professional analysis software (LabView and Diadem), the analysis team analyzed the collected data and discovered that by using Power Spectral Density (PSD) analysis, it was possible to detect the presence of broken inserts due to changes in the PSD. Once this proved a reliable method of detection for the CNC machine, the group then began to apply their findings at Finkl's production facilities. Initial testing was promising, and a preliminary system was designed to automatically detect the failure of cutting inserts. The IPRO concluded that it is possible to detect cutting insert failures at Finkl, but additional testing will be needed to determine the exact parameters and conditions that would signify the failure before an automated system can be put into production at Finkl.

Objectives and Purpose

The Interprofessional Projects (IPRO®) Program at Illinois Institute of Technology

An emphasis on multidisciplinary education and cross-functional teams has become pervasive in education and the workplace. IIT offers an innovative and comprehensive approach to providing students with a real-world project-based experience—the integration of interprofessional perspectives in a student team environment. Developed at IIT in 1995, the IPRO Program consists of student teams from the sophomore through graduate levels, representing the breadth of the university's disciplines and professional programs. Projects crystallize over a one- or multi-semester period through collaborations with sponsoring corporations, nonprofit groups, government agencies, and entrepreneurs. IPRO team projects reflect a panorama of workplace challenges, encompassing research, design and process improvement, service learning, the international realm, and entrepreneurship. (Refer to http://ipro.iit.edu for information.) The Integration of Process Improvements team project represents one of more than 40 IPRO team projects for the Spring 2010 semester.

Sponsor – A. Finkl & Sons

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.

Problem and Objectives

During the milling operations at an industrial steel producer like A. Finkl & Sons (Chicago,IL), a substantial amount of time and money is lost due to the fact that cutting inserts break catastrophically and without warning. The goal of this project is to devise an effective means by which a cutting insert breakage event can be quickly and reliably detected, thereby minimizing damage to the steel and other cutting inserts, and also freeing technicians to attend multiple machines at a time. This increases the productivity of their operations, and it has the potential to save A. Finkl & Sons substantial costs per year in time lost in rework and prematurely broken cutting inserts.

The core objective is to automate the process by which cutting insert breaks are detected. To accomplish this, the team will collect acceleration data using accelerometers from the laboratory at IIT. The team will then indentify breakage conditions and create a methodology derived from those conditions that can automatically detect breakage events. Testing will then be transferred to Finkl to verify findings, making alterations to the method as necessary. Finally, these findings will then be presented to Finkl staff.

Organization and Approach

To better approach the problem, the IPRO split into two separate teams, the mechanical testing team and the analysis team. The mechanical testing team was responsible for operating the milling machinery and collecting data from the accelerometers. The analysis team was responsible for analyzing the collected data and altering test plans accordingly. This organizational breakup worked for the team initially, but as the semester progressed, the distinction between the two teams began to disappear, with many members performing duties from both groups. As the teams dissolved, the IPRO advisors took on an active role in the IPRO, providing technical advice for the group and the motivation to get all the team members to work together.

After dividing into teams, the IPRO began formulating test plans to build off of previous work with accelerometers. Alternative methods of insert failure detection were explored, such as monitoring for temperature changes, but the accelerometers were the most promising and feasible option, leading the teams to focus on them. Using LabView and two single-axis accelerometers, the team began collecting data under the supervision of Craig Johnson, the machine shop supervisor for IIT. Later, upon acquisition of a triaxial accelerometer and a tachometer, data collection was expanded to include those devices, and data analysis began in earnest. The purpose of the accelerometers was to capture a change in amplitude of certain frequencies as a function of time. These changes in amplitude formed some of the basis for analysis.

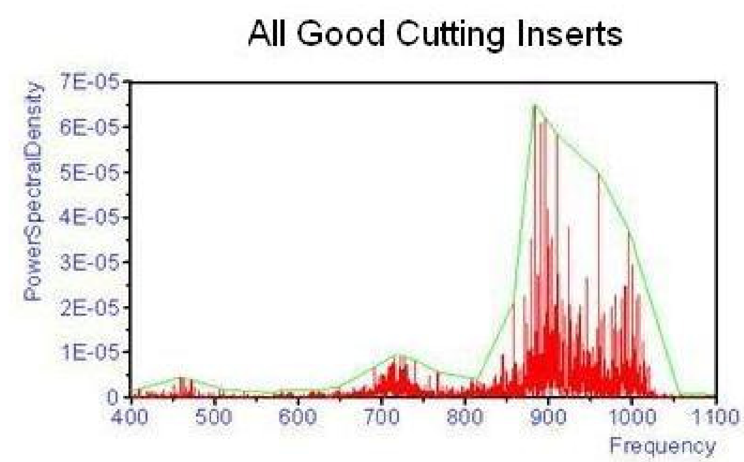
After extensive testing in the IIT labs, the group then began preparations to apply the failure detection methods discovered at IIT to Finkl's production facilities. Contact with Finkl's liaison for IIT was initiated, and a plan was put into action. Using the accelerometers and the same data acquisition and analysis software from IIT, data was collected from production milling machines at Finkl.

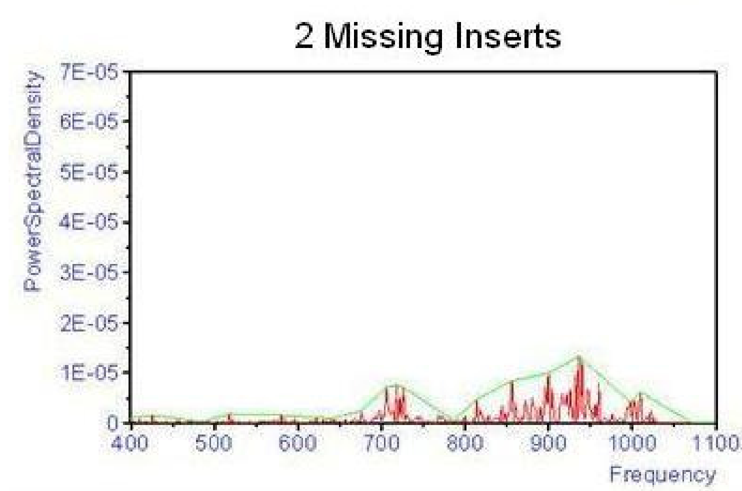
Unfortunately, testing encountered some difficulty at Finkl since IPRO members had to work with milling operators to collect the data. It was nearly impossible to recreate the controlled environments of the lab in a production facility, which lead to further issues in collecting enough data to verify that the detection methods from IIT could indeed by applied to Finkl. However, the IPRO did manage to get enough testing done to form some preliminary conclusions which were subsequently presented to Finkl management.

Results

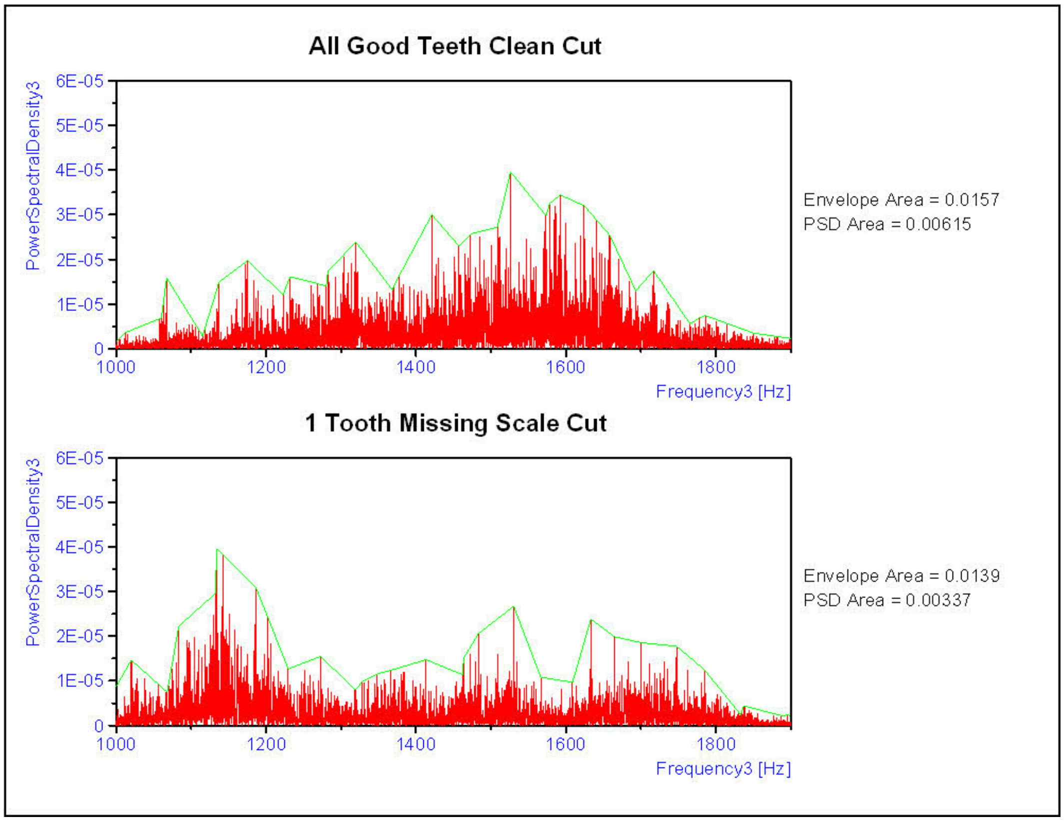
Short blocks of acceleration versus time data were gathered from individual test trials, and the data was subjected to Fast Fourier Transform (FFT) analysis to convert this to an acceleration versus frequency spectrum. In this spectrum, the frequencies present during milling could be analyzed, an important consideration since the cutting action of the inserts likely possesses its own unique frequencies (as opposed to frequencies related to machine noise, cutting chatter, and any other factor not related to the cutting action). Then, the acceleration-vs-frequency spectrum was subjected to Power Spectral Density (PSD) analysis, using LabView Virtual tools, to extract the power carried in the cutting frequencies.

With the PSD extracted mathematically from the original acceleration profiles, it was noted that when one or more of the cutting inserts were removed, the PSD would undergo certain distinguishable changes; an effect needed to produce a breakage detection condition. In some cases, it was noted that the magnitude of the PSD curve would drop significantly when inserts were removed from the milling head, as seen here:





In other cases, it was noticed that the frequencies would shift positions and/or certain frequencies would drop out entirely leading to a thinning of the PSD, as seen here:

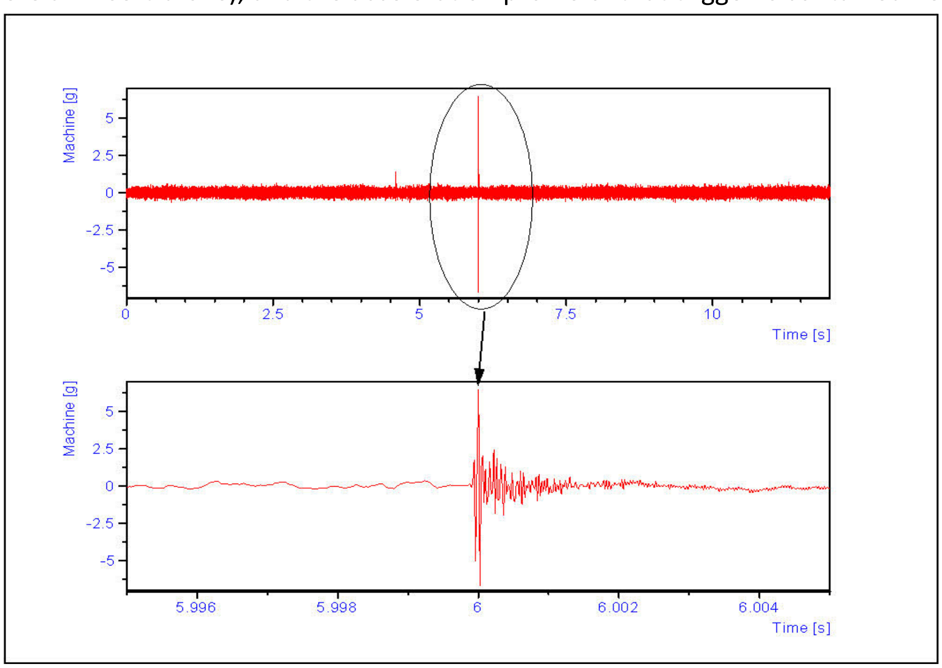


In the first case (of a drop in PSD with missing inserts), breakage detection can simply be accomplished by integrating the area under the PSD curve (whether by enveloping the peaks and integrating the envelope or directly integrating the PSD) and looking for a drop in PSD area above a certain threshold. In the third case (of a thinning of the PSD frequency spectrum), a direct integration of the PSD curve (not of an envelope) along the frequency domain will yield a comparison point for breakage detection, because even though the magnitudes of the PSD do not drop the curve thins out and yields a drop in the area under the curve. For the second case (of a frequency shift), integration yields no breakage condition, so some other method would need to be established to identify the proper shifts related to a breakage. To determine which PSD change predominates, controlled testing will need to be completed onsite at the Finkl production mills. This onsite testing will allow this IPRO to identify which condition(s) usually occur at Finkl, and exactly what threshold changes occur when an insert breaks. The work of this semester proved the usefulness of PSD analysis in detecting these breakages on a laboratory CNC milling machine, and showed that the first condition (of a drop in PSD) predominates on the CNC machine.

To monitor for a change in PSD such as seen in the above figures, acceleration data from the milling process is collected for a finite period of time (say one half a seconds) and logged. Then, a following block of time for the same finite period is also collected. It's PSD is then compared to the PSD from the first block of time. If there is no change in the PSD curve greater than the established threshold identified to be a broken insert, the first block of data is dumped and a new one collected for additional comparisons. This yields continuous, real-time monitoring for the presence of a broken insert.

Building on the previous semester's concept of isolating individual milling variables and changing them one at a time, our laboratory testing also yielded an understanding of the effect of certain variables on the PSD of the acceleration profile. It was noticed that increasing the depth of cut and feed rate would generally increase the power present in cutting. Despite this, as long as variables were reasonably constant between one pass with all good inserts and another with broken or missing ones, the PSD still yielded a distinguishable change. While this consistency cannot be guaranteed at a production facility like A Finkl & Sons, it can be made a reasonable assumption by narrowing the PSD sampling time block to a point where only moderate changes in these variables are present in the data. It is assumed at this point that the changes due to a breakage event would be much larger than the changes due to alterations to any of these variables over the same timeframe, given that the sampling time used for comparison is short.

The above discussion of results details the group's findings while using Power Spectral Density analysis of measured acceleration data. Another concurrent study was conducted into using the accelerations resulting from the actual breakage event as a breakage detection method. To accomplish this, an acceleration level was set as a trigger point, with any accelerations above this trigger level implying a breakage has occurred. Breakage events could not be artificially produced in the lab due to built in safety features in the CNC machine that disallowed high enough loadings, so this method was explored onsite with a Finkl machine. Inadequate time only allowed for a few trial attempts, and the trigger level was set too low (at only 1 g), so numerous triggers were detected. Nevertheless, one trigger appeared to coincide with a possible breakage event (since it was the only one collected during a pass where an insert broke), and the acceleration profile of that trigger is contained here:



This trigger was unique because the acceleration increases rapidly ahead of it (so there was no "ring in" as would be seen if this were the result of machine noise), and it has a steady "ring down" (ring-down being the manner in which the accelerations return to normal after the trigger). The team theorized that the way to identify a trigger as a breakage event is 1) by a unique amplitude (not too high and not too low), and 2) by a unique ring-down profile. Different events (such as a hammer hitting the work piece or a heavy object that was dropped nearby) could potentially cause an acceleration of similar amplitude, but all these events (including an insert breaking) would likely have their own unique ring-down profile. This method is promising and appears to be an effective way of breakage detection, but more onsite testing is needed to build a database of breakage event profiles.

Conclusions and Recommendations

Over the course of this semester, the team has come to several important conclusions. These conclusions are based upon extensive laboratory testing using the HAAS machine at IIT, and initial testing at the A. Finkl and Sons facility. The following is a list of the conclusions reached by the IPRO 304 team this semester:

- Time domain analysis conducted last semester is a great visual aid. However, augmenting it with PSD analysis makes it easier to automate a failure detection system.
- There are changes in the PSD when inserts are missing or broken inserts are present on the HAAS machine.
- The PSD analysis works for various cutting conditions on the HAAS machine.
- PSD analysis can successfully detect insert failure on HAAS machine at IIT.
- PSD analysis from initial testing at Finkl produced promising results. A difference is present, but the PSD behaves much differently than on the HAAS machine.
- Additional testing needs to be done at Finkl in order to adapt the PSD algorithm used on the HAAS machine to the much larger Finkl machines.

Based upon the promising results from this semester, it is recommended that the project continue for another semester. The PSD analysis is able detect whether broken inserts are present on the cutting head in the HAAS machine. The laboratory testing at IIT produced the most complete data set, but initial testing at Finkl did prove promising. Finkl, being a production facility, made it difficult for the team to control essential cutting parameters. This increases the time necessary to gather sufficient data to develop an algorithm which can confidently detect insert failures. It is recommended that next semester's group conduct most of their testing at the A. Finkl and Sons facility, only using the HAAS machine to learn about the milling process, associated cutting parameters, and data collection procedures. The team should work closely with their Finkl liaison to try and control the machining parameters as much as possible. The success of this project is related to the amount and quality of data obtained from the Finkl machines. With a well designed experiment, the group will be able to minimize interference with production and still obtain valuable data that may finally solve the problem Finkl is facing.

Appendices

A. Team Roster

Name	Year	Major	Team
Emmanuel Flores	4th year	Materials Science & Engineering	Mechanical Testing
Corey Hawker	4th year	Computer Science & Engineering	Mechanical Testing
Charles Loeppert	4th year	Mechanical Engineering	Analysis
Ryan Marx	4th year	Computer Science & Engineering	Analysis
Ricardo Rodriguez	4th year	Chemical Engineering / Chemistry	Mechanical Testing & Analysis
David Snyder	4th year	Materials Science & Engineering	Analysis
Stefan Stevanovic	4th year	Mechanical Engineering	Analysis
Joshua Willett	4th year	Aerospace Engineering	Mechanical Testing & Analysis

B. Acknowledgements

The members of IPRO 304 would like to thank the following people for helping making this project possible.

A. Finkl & Sons

Guy Brada – Chief Metallurgist
Liz Bilitz – Liaison to IIT students

PCB Piezotronics

Keith Crawford – Field Application Engineer

Illinois Institute of Technology

Craig Johnson – Machine Shop Supervisor
Russ Janota – Director of Operations Mechanical Behavior

C. Visual References

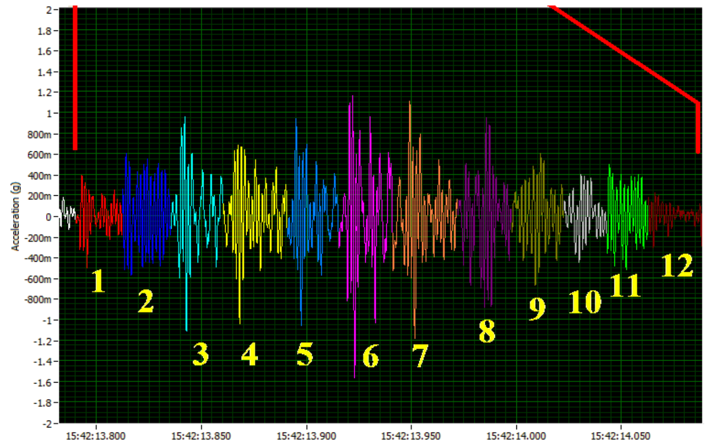
Figure 1. Broken Cutting Insert

Figure 2. A milling head from the HAAS CNC machine at IIT.

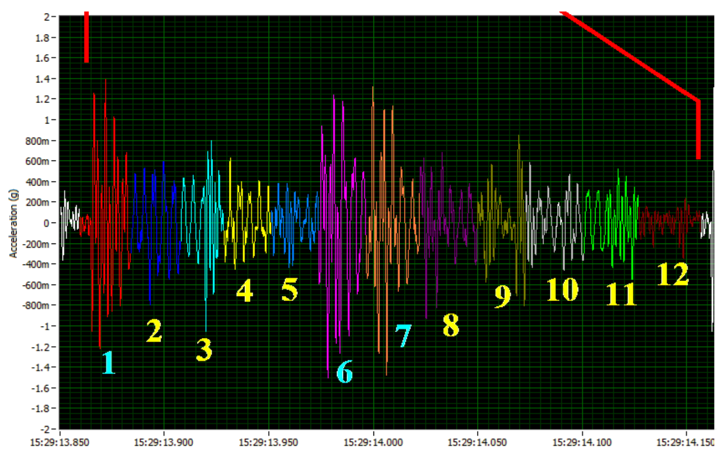
Figure 3. HAAS CNC machine

Figure 4. Finkl milling machine

D. Accelormeter Data



Above: View Showing Each Tooth During 1 Rotation
CNC Machine - 0 Broken Inserts



Above: View Showing Each Tooth During 1 Rotation
CNC Machine - 3 Broken Inserts

Figure 5

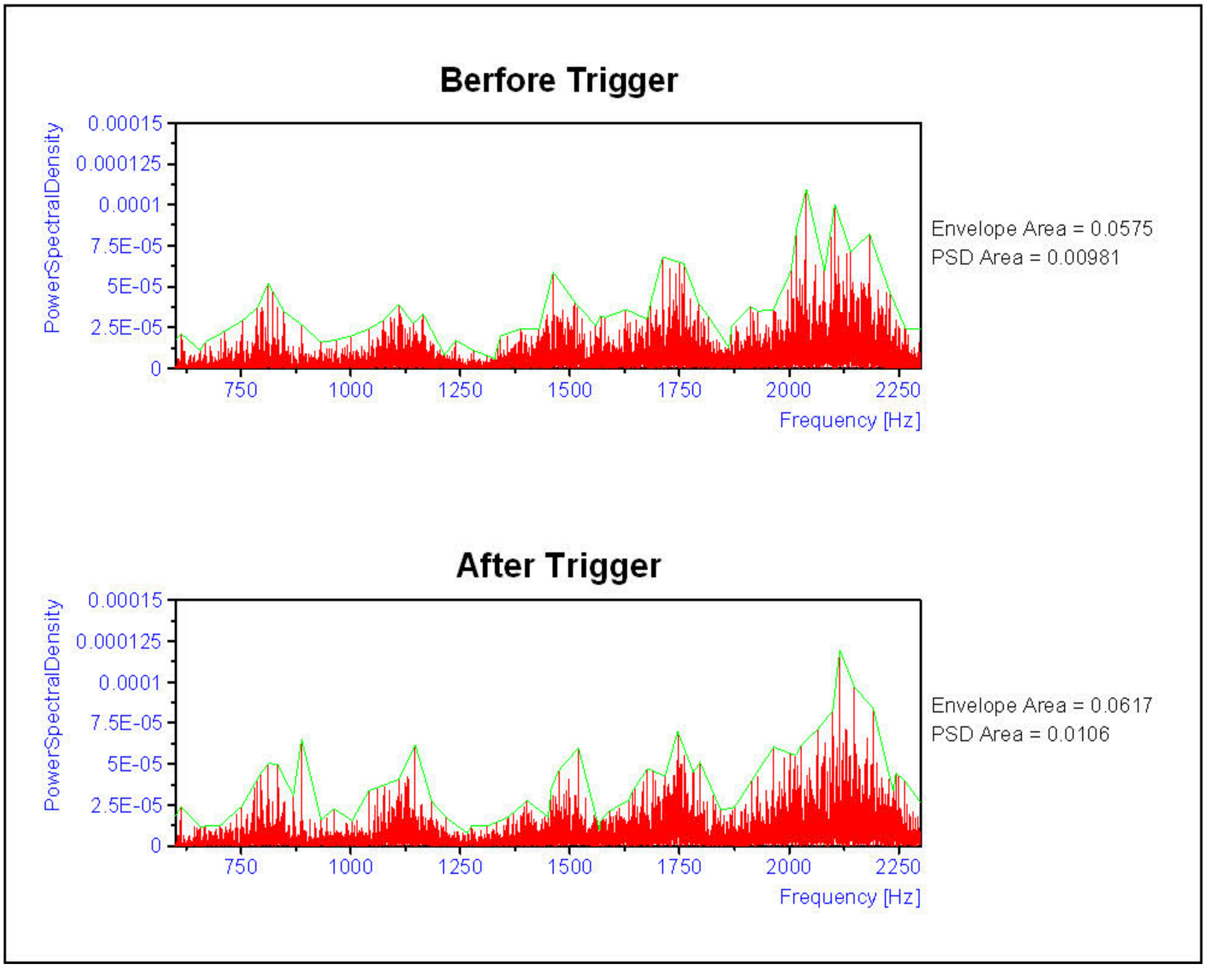


Figure 6. Shows the difference in received accelerometer data before and after a trigger is captured.