THE EFFECT OF IMPACT LOCATION ON RESULTING SOFTBALL BAT STING

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ABSTRACT

After hitting a softball, there is occasionally a very painful stinging sensation in the hands of the batter. To find the location on softball bat that results in the least bat sting, an impact hammer was used hit a bat barrel at various locations and the resulting vibration was measured. This data was analyzed by creating Bode Plots and measuring the peaks of the transfer function. Impact locations farther from the "sweet spot" of the bat (around 0.1m to 0.2m from the tip of the bat) produced more intense acceleration responses and a higher gain at 160 Hz. Impact locations in the "sweet spot' range resulted in smaller acceleration responses as well as very small gains. This suggests a correlation between the impact location on the bat barrel and the resulting response by the bat as well as the resulting bat sting felt in the handle.

INTRODUCTION

Most people who have picked up a bat at some point in their life, whether professionally or for fun, know that hitting a ball wrong will lead to a painful stinging sensation in the hitter's hands. However, experienced hitters will recognize that bat sting, caused by vibrations in the handle of the bat, is directly connected with where a ball is hit along the barrel of the bat. Therefore, most experienced hitters aim to hit a ball at the "sweet spot" of a bat. This spot is located between about one-fourth and one-half the length of the bat barrel, and produces the fastest batted-ball speed with the least amount of bat sting [1]. Although there are many papers and experiments that study the mechanics of bats and the causes of bat sting, there is a lack of literature comparing the effect of various brands and materials of bats on bat sting and the physics is not fully understood

It is important for even the average player to understand the causes of bat swing so that they can adjust the mechanics of their swing to optimize batting performance while minimizing bat sting. Therefore, the vibrations from impacts at different locations on the bat barrel were measured for various bat brands to understand the mechanics and behavior of each bat. Bats made by three different companies (Demarini, Louisville Slugger, and Xeno) were tested.

Each bat was clamped down in a vice by the handle of the bat where a batter's hands would normally be. To simulate the bat-ball impact, an Impact Hammer PCB was used to hit the barrel of the bat at measured increments of 8 centimeters, which were marked on a piece of tape that was attached to the bat for guidance. To measure the movement at the tip of the bat and at the handle of the bat due to a hit by the impact hammer, a Vernier 3-axis accelerometer was taped to both locations. The vibrations measured were used to calculate the location on the bat with the least bat sting.

BACKGROUND

2.1 SOFTBALL BAT DESIGN

In recent years, there have been many new technologies implemented in softball bat design. Originally made in wood, softball bats first transitioned to aluminum, then almost completely to composite material. Although early composite bats made from graphite were unable to compete with the popular aluminum single-walled bats, newer iterations made from carbon fiber quickly dominated the market. In the early 2000s, composite material bats like the gray Velocit-E "Ultra" were almost banned from organizations such as the Amateur Softball Association because they were so high performing that it was dangerous for fielders [6]. Therefore, manufacturers began changing the design of bats, compromising performance in order to remain within legal limits, but adding features such as double-walls, composite shells over aluminum barrels, two-piece composite bats, internal dampers, and more. Because composite bats now dominate the market, a composite bat will be tested to find out how these design changes affect the bat sting felt.

2.2 SOFTBALL BAT VIBRATION MODES

A softball bat experiences numerous vibrational bending modes after a collision with a softball, and each vibrational mode has nodes where there is no displacement

[5]. The locations of the nodes and anti-nodes are important for the perception of bat sting felt (figure 1a). The batter's hands are located around the anti-nodes in the second and third mode of the bat. At these frequencies, more vibrations are felt in the hands, resulting in more bat sting felt in the hitter's hands. Upon impact, there is also internal hoop bending in the material of the bat barrel (figure 1b) and the bat barrel will compress and elongate periodically.

a. **b.**

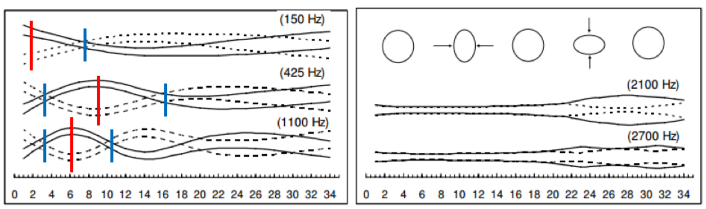


Figure 1: (a) Bat Bending Modes and (b) Hoop Bending Modes: When using vibrational analysis to analyze batted-ball performance of bats, Andrew Sutton and James Sherwood showed three modal shapes for a bat and the average frequency at which these oscillations occur [7]. The red lines in the left picture indicate anti-nodes while the blue lines indicate nodes. The right picture represents the internal flexing of the round cross-section of the bat barrel compressing and elongating when excited by an impact.

2.3 TRANSFER FUNCTIONS

Transfer functions are extremely useful when using frequency domain analysis of the response of a system by relating the output of the system to the input or stimulus. For the same system, the output response will depend on the varying input to the system, but the transfer function should be the same regardless. The magnitude of a transfer function is defined as:

$$\boldsymbol{G(s) = abs\left(\frac{O(s)}{I(s)}\right)} \tag{1}$$

where the O(s) is the magnitude of the Fast Fourier Transform (FFT) of the output and I(s) is the FFT of the input.

EXPERIMENTAL DESIGN

To suspend the tested softball bat horizontally while supporting the large amount of moment, the Demarini softball bat was clamped at the handle in a V-block using a horseshoe clamp. This mechanism was then clamped inside a vice to restrict any unwanted movement.

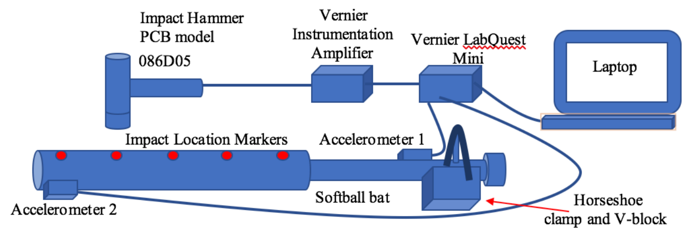


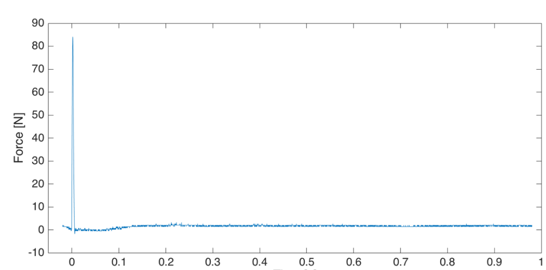
Figure 2: Experimental Setup. Two accelerometers were taped to the secured bat and attached to a Vernier LabQuest Mini for data collection. An impact hammer was connected to an instrumentation amplifier and the LabQuest Mini to amplify and collect the impulse data taken upon impact with the softball bat barrel. The bat was tested at marked locations that were incremented by 0.08m, starting at 0.015m from the end of the bat.

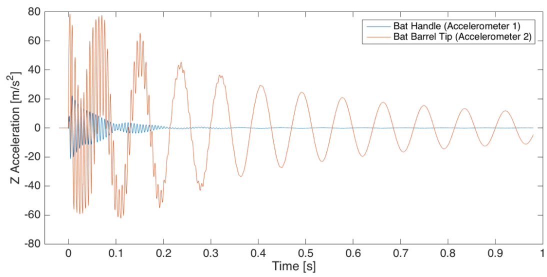
To measure acceleration (m/s^2), two 3-axis accelerometers measuring in the z-direction were zeroed and attached to the bat handle, where a batter's front hand would approximately be located, and the tip of the bat barrel. A 086D05 PCB Impact Hammer with a sensitivity of 0.23 mV/N measured impact force by recording potential (mV) as a function of time (s). All data was collected through a Vernier LabQuest Mini and saved on a Macbook Pro.

RESULTS AND DISCUSSION

Three trials of data were collected at each of the six locations incremented on the softball bat barrel. Figure 3a and 3b represent the raw data collected at the tip of the bat (about 0.015m from the end of the bat barrel), and figure 4a and 4b represent the raw data collected near the upper-middle of the bat barrel (about 0.175m from the end of the bat barrel.)

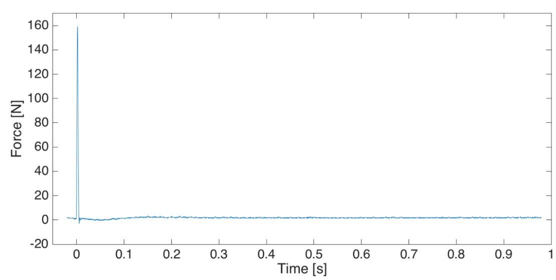
a.



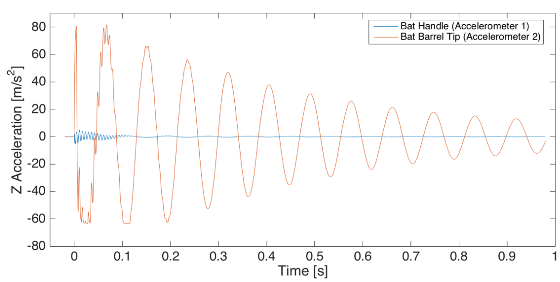


b.

Figure 3: Impulse Input Graph and Resulting Acceleration Graph at 0.015m. The Potential (mV) vs. Time graph was converted to Force (N) vs. Time to display a more meaningful variable. In the resulting acceleration graph, damping can be observed in both the accelerometers. Damping of the flexing of the bat material within the first 0.3 seconds can be observed in addition to the overall damping of the z-axis movement of the bat. Interestingly, there is an increase in response amplitude around 0.1s in both graphs despite a damping trend beforehand.



a.



b.

Figure 4: Impulse Input Graph and Resulting Acceleration Graph at 0.175m. The Potential (mV) vs. Time graph was again converted to Force (N) vs. Time to display a more meaningful variable. Closer to the “Sweet Spot” of the bat (between 0.1m and 0.2m from end of bat), this location of impact resulted in an overall lower amplitude of response in the bat handle, and a smaller amount of flexing in the material of the bat in the first 0.3 seconds compared to the previous results in figure 2.

The resulting graphs for Z acceleration at an impact location farthest from the end of the bat were similar to the graphs in figure 2. The response at 0.175m shown in figure 3, within the range of the “sweet spot” of the bat, was relatively different compared to the other responses in terms of amplitude of internal bat barrel flexing (160Hz response).

The data collected from LoggerPro was used to generate an FFT graph (figure 5) to display peak resonant frequencies. Further analysis will reveal that the 160 Hz peak frequency is the main cause of the bat sting felt in the hand. The data from each experiment was exported as a .csv file and imported to MATLAB for further analysis. After converting potential (mV) to force (N), force was set as the input of the system. The acceleration of the handle of the bat was set as the output of the system. Then, the FFT of both input and output were calculated and used to calculate the magnitude of the input and output as well as the transfer function. The transfer function gain graph was defined as the magnitude of the output divided by the magnitude of the input. Figure 6a represents the gain bode plot at 0.015m from the tip of the bat, and figure 6b represents the gain bode plot at 0.175 from the tip of the bat, near the upper-middle of the bat barrel.

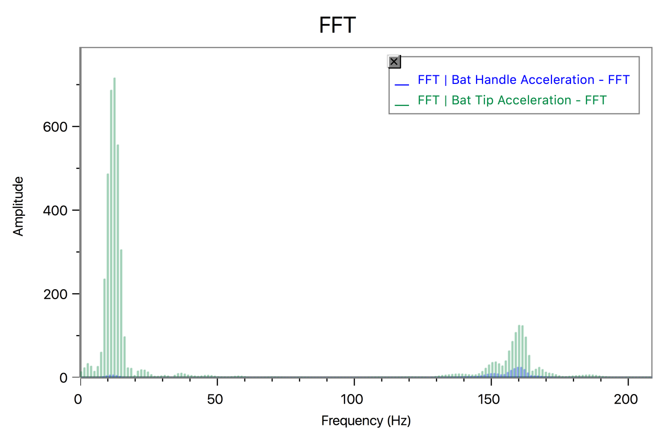


Figure 5: LoggerPro FFT Graph at 0.015m from tip. The FFT graph for the data in figure 2 shows two peaks for both sets of data collected. These peaks represent the resonant frequencies: one at 12 Hz and another at 160 Hz. These are important to note because the resulting peaks in the calculated transfer function are located at these frequencies.

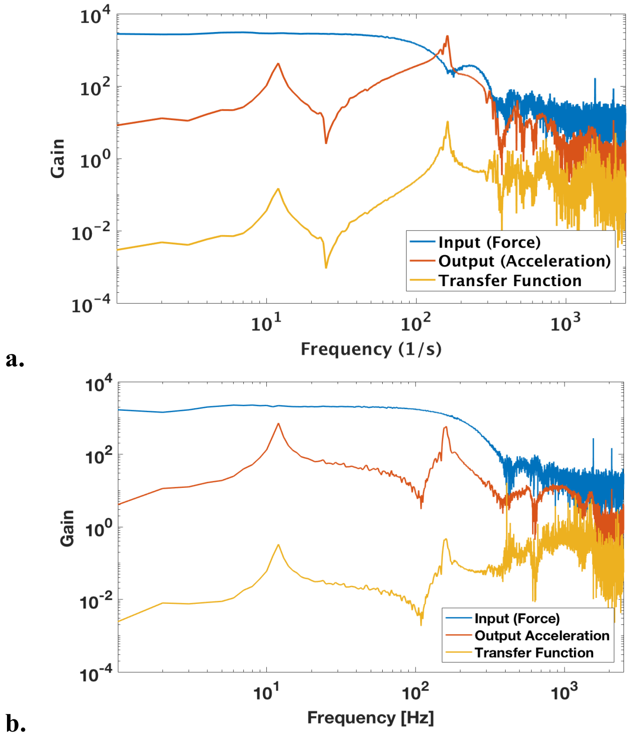


Figure 6: Gain Bode Plots at (a) 0.015m Impact Location and (b) 0.175m Impact Location The most important note for the resulting Bode Plots is the two peaks of the calculated transfer function. In every trial, both peaks were located at about 12 Hz and 160 Hz, but varied in magnitude depending on the location of impact. The lowest Gain for 160 Hz occurred at the 0.175m location, suggesting a proximity to the sweet spot of this bat. The data past 200 Hz is noise and can be ignored.

From the gain graph for every trial, the magnitude at each of the peak frequencies was recorded. These values were averaged and the uncertainty was found for each location and plotted as vertical error bars. Hitting a marked location on the barrel of a softball bat with an impact hammer is not extremely accurate, so an estimated standard deviation of about 1.25cm was used to find the uncertainty to plot the horizontal error bars. A linear best fit was used to model the average magnitude of gain for the 12 Hz frequency in figure 7a, and a second-degree parabolic fit was used to model the average magnitude gain for the 160 Hz frequency in figure 7b.

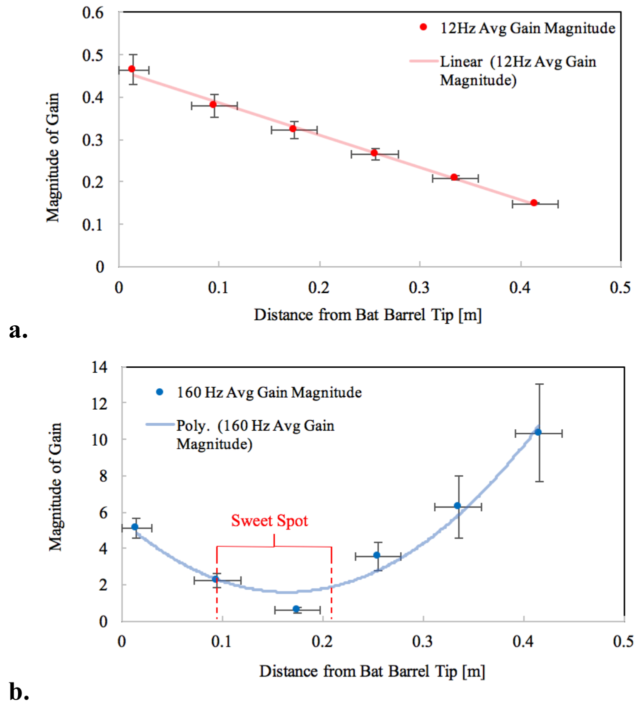


Figure 7: Plot comparing (a) Average TF Peak Magnitude at 12 Hz and Impact Location (b) Average TF Peak Magnitude at 160 Hz and Impact Location The average transfer function magnitude of the 160 Hz peak increases as the distance from the "sweet spot" (between 0.1m and 0.2m from end of bat) increases. Realistically, this makes sense because bat-ball contact further away from the "sweet spot" results in an increase in the stinging sensation felt in the hand. There is also very little variance in the average transfer function magnitude for the 12Hz peak, as shown by the scale of the gain magnitude, suggesting that bat sting felt may relate only on the magnitude of the 160 Hz peak.

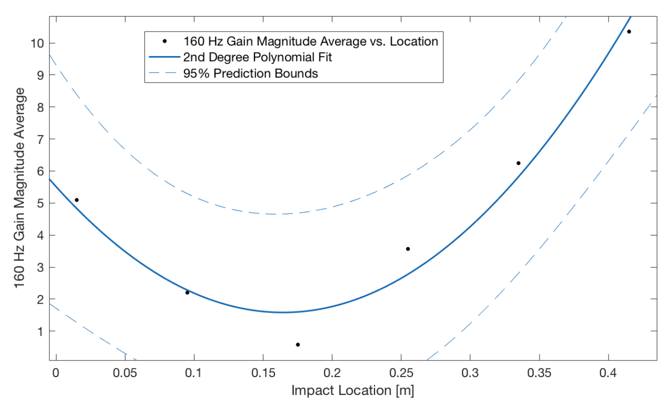


Figure 8: Uncertainty of Second Degree Polynomial Fit for 160 Hz Average Gain Magnitude vs Impact Location A second degree polynomial fit with the equation $f(x) = (145.6 \pm 67.4)\, x^2 + (-47.85 \pm 30.04)\, x + (5.514 \pm 2.734)$ was found for the 160 Hz

gain peak averages plot. The best fit curve was plotted with 95% confidence prediction bounds.

The location of sweet spot of the Demarini softball bat can be found by calculating the minimum of the parabolic fit and the corresponding uncertainty. In this case, the calculated sweet spot is located $0.164 \pm .12136$ meters from the tip of the bat. The bat is 0.8382 meters long with a 0.425 length barrel, and the location agrees with previous research stated a sweet spot should be between a quarter and a half the length of a barrel from the tip of the bat. Although there is a very large uncertainty, it is still realistic and does not extend beyond the tip of the bat or the end of the bat barrel near the handle.

There are a few limitations with this experimental approach. For example, it is very difficult to produce exactly the same response after an impact due to the variability in clamping force on the bat handle. This can be addressed by measuring the force in which the bat is clamped in order to reproduce the same results with multiple iterations of the experiment. Another example is the extremely large uncertainty for the location of the sweet spot on the bat. To decrease the uncertainty, more data points should be collected at each impact location if this experiment is repeated.

CONCLUSION

Based on the raw data and corresponding Bode Plots, there is definitely a correlation between the impact location on the barrel of the bat and the resulting response and transfer function. The "sweet spot" of this particular bat was determined to be located at 0.164 meters from the tip of the bat. Even though there is a large uncertainty with this location, it is still reasonable considering the length of the bat. Moving the point of impact further from the sweet spot of the bat resulted in an increase in the transfer function magnitude of only the 160 Hz peak, which corresponds to an increase in output (acceleration) at those points. This suggests that only the 160 Hz frequency affects the bat sting felt with bat-ball contact at locations farther away from the sweet spot!

In the future, if the clamping force on the handle is measured and kept constant, bats of different lengths and brands can be tested in order to compare the responses. This could result in more insight to the physics of softball bats and how different companies designed bats. This research is useful for those who do not understand the mechanics behind a softball bat and for those who want to minimize any painful stinging when they are hitting. This research could also be used by bat manufacturing companies to create internal or external sting dampeners to increase customer satisfaction.

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