Feel & Control in Tennis:

Improving Damping in Tennis Rackets

Design for Increased Dampening

Tennis • Feel • Dampening

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Ray Ewry Sports Engineering Center

TEAM

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Abstract

Improving control and feel in tennis rackets through vibration-dampening techniques is a commonly used practice among tennis players. Previous research efforts give documentation on damping characteristics of rackets as well as damping methods in other sports such as baseball, but there is a limited amount of current research on products and devices that succeed in decreasing the harsh vibrations transmitted from a tennis racket to a player's arm. This project explores the effects of a tennis racket's vibrational characteristics by adding a weighted, silicon dampener into the butt cap of a tennis racket through experimental modal analysis. A racket was tested with multiple dampers that included 3g and 14g of tungsten weight to understand its impact on relevant metrics such as the first bending frequency and damping ratio. These results were analyzed by measuring the force and acceleration in the racket. The input force and lingering acceleration can be used to calculate damping properties. Figure 1 plots the acceleration vs. time of the rackets with each of the dampeners against the racket with no damper. This graph specifically highlights the reduction in vibration resulting in a decrease in nervousness in the damped rackets.

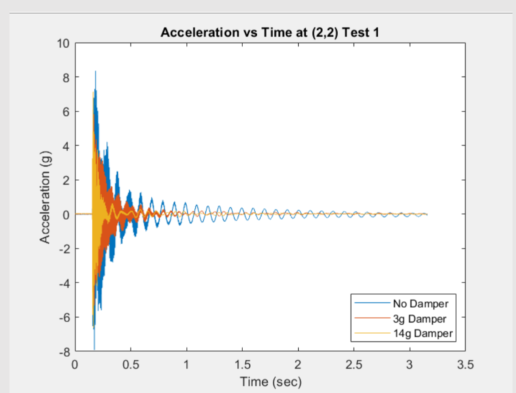

Figure 1: Acceleration vs Time at Edge of Racket

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Project Overview

Feel and control in tennis is something deeply desired amongst tennis players. Although there is some evidence regarding the dampening of tennis rackets, there hasn't been much regarding improving the feel players receive. Development of feel and control parameters based on a racket's acceleration signal were done prior in this project. The relevant parameters are the first bending frequency, damping ratio, shock ratio, and nervousness. The frequency of the first mode can be found in the frequency response function. The damping ratio is a measure of how fast the oscillations decay. Shock ratio is the ratio between the felt and applied force. Nervousness is the measurement of the lingering oscillations that remain.

It was previously determined that the natural first bending mode occurs at 142 Hz. Dampers were then designed to reduce the vibrations at 142 Hz. It was expected that the frequency of the first node would be maintained or slightly increase as the peaks would be "wider". Additionally, the damping ratio is expected to increase, and the nervousness decreases as the dampers are implemented. Finally, the shock ratio should remain the same as dampers do not have a significant effect on the peak initial force. Comparing the two dampers, the 14g damper should have a larger effect as the heavier mass increases its dampening abilities.

The target goal of this semester is to test these hypotheses to determine the overall vibration dampening impact of weighted dampeners in the butt cap of tennis rackets. An additional goal is to determine the impact dampeners have on the "feel" players receive from the racket.

Project Method and Results

The damper was designed with the internal dimensions of the handle of tennis racket of 23.5 x 10 x 15 mm. The materials used are dragon skin silicone 20 for the outer shell and tungsten metal for the weight. The final designs were created through iterating until the first bending mode frequency of 142 Hz was recorded using modal analysis. These can be visualized in Figure 2. The experimental testing apparatus consisted of a force transducer tipped hammer, accelerometer, and two rubber bands to suspend the racket in air. Testing consisted of hitting the racket with the damper at 23 separate locations across the string bed 3 times each using the hammer. The force and acceleration data from each recording were then exported as CSV files into MATLAB to be analyzed. Each locations data was run through a previously created MATLAB GUI that generates calculations for natural frequencies, damping ratio, shock ratio, and nervousness. Separate MATLAB code was written in order to see results.

Figure 2. Final Damper Designs (3g left, 14g right)

Project Method and Results (cont.)

Analyzing the acceleration signals, the dampers had a significant impact on reducing the amplitude as time increased at certain locations of the racket. Since the sweet spot of the racket is naturally dampened, the dampers had limited effects at locations near the center, specifically at the 10th main and 10th cross, 6th main and 12th cross, and 14th main and 12th cross (Figure 3). However, at locations near the frame of the racket and away from the nodal lines, the dampers rapidly reduce the acceleration. These differences are highlighted with increased damping ratios and decreased nervousness for the dampers. The 14g damper consistently has a larger damping ratio while the 3g damper has an increased damping ratio for the most part and occasionally has a smaller damping ratio. The nervousness for the 3g and 14g damper decreases at all impact locations supporting the dampening in acceleration in the rackets.

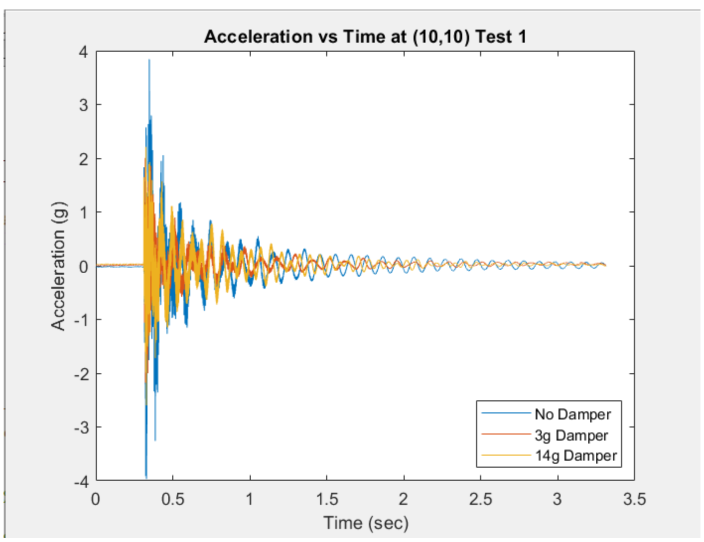


Figure 3. Acceleration vs Time at Sweet Spot

To determine the natural frequency of the first mode, the frequency response functions were analyzed between having no damper, the 3g damper, and the 14g damper. Comparing the two, it can be seen that the 14g damper has a significantly lower peak amplitude and a larger frequency throughout the various testing locations (Figure 4). The 3g damper is less consistent as it occasionally decreases the peak magnitude.

As expected, the shock ratio remained relatively constant regardless of the dampers. Dampers have a limited effect in reducing the initial acceleration felt by the handle. The average natural frequency is 144.70 ± 0.813 without a damper, 140.78 ± 1.07 with a 3g damper, and 155.33 ± 3.66 with a 14g damper.

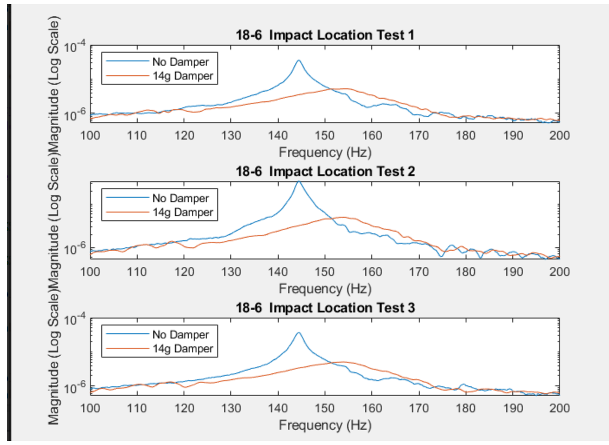


Figure 4. Frequency Response Analysis at 142 Hz for 14g Damper

The average damping ratio is 0.010326 ± 0.006668 without a damper, 0.019302 ± 0.011417 with a 3g damper, and 0.06475 ± 0.067926 with a 14g damper. The average nervousness is 1.984 ± 0.346 without a damper, 1.181 ± 0.419 with a 3g damper, and 1.113 ± 0.345 with a 14g damper.

- Initial testing/data analysis supports original hypothesis
- Strong correlation between increased mass and damper effectiveness
- 14g damper has a higher first bending frequency, larger damping ratio, and reduced nervousness
- The 3g damper generally reduces vibrations
- Unknown what mass is required to consistently dampen the vibrations.
- Further research done on dampers with weights heavier than 3g and different damper designs
- Future testing on various racket frames

Ray Ewry Sports Engineering Center

About RESEC

The Ray Ewry Sports Engineering Center (RESEC) is named in honor of a record-setting Olympian and College of Engineering graduate, Ray Ewry. As a joint effort between Purdue College of Engineering and Intercollegiate Athletics, the center reflects Ewry's passion for both sports and engineering and creates research and learning opportunities to athletes and students alike.

What is Sports Engineering?

Sports Engineering is a multidisciplinary field that uses engineering principles to create solutions to the greatest challenges and opportunities facing sports today. The field utilizes scientific theory, practical application, and technical knowledge to address sports-related challenges through data-driven insights and a results-oriented approach. To contribute to this field RESEC aligns it's investigations with the following priorities

EXCITEMENT

Smart Performance & Fan Experience

How can we use the latest sensors, signal processing, and analytics to improve athlete performance and improve engagement with fans?

INTEGRITY

Fairness, Accessibility & Social Integration

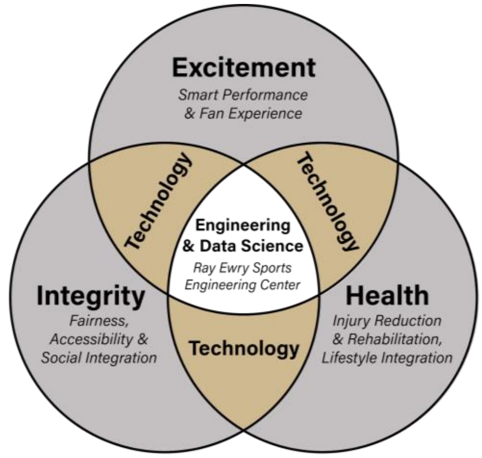
As technology in sports grows, what are the limits of human judgement, and how do we develop technology to ensure a level playing field?

HEALTH

Injury Reduction & Rehab, Lifestyle Integration

What aspects of advanced healthcare and science can be engineered into solutions for sports rehabilitation and performance?

Every sport must balance these priorities to create the best experience for all. RESEC searches for the technology to fill the gaps between each priority and facilitates collaborative research across Purdue through the application of engineering and data science



Research Technology Platforms

RESEC categorizes industry partners and academic affiliates into the following technology platforms for scaling and implementation to streamline collaboration.

- Smart Materials for Performance and Safety
- Accessible Technology for Societal Integration
- Equipment Design for Athlete Feel and Control
- Intelligent Prototyping for Rapid Development
- Digitalization of Sports Ecosystems
- Spectator Experience and Fan Engagement

When ideas arise from industrial partners or internal faculty affiliates, RESEC facilitates the operations necessary turn opportunities into action.

Education Offerings

Purdue's academic prowess offers a unique opportunity to engage talented students, staff and faculty members with sports engineering. In addition to research opportunities for undergraduate and graduate students, RESEC is proud to offer the first comprehensive Professional Masters Concentration in Sports Engineering in the United States. With these capabilities, we are equipping the next generation of sports engineers to redefine what's possible.