Designing for Feel and Control in Tennis

Equipment Design for Athlete "Feel and Control"

• Feel •Control •Damping

Fall 2023

PURDUE UNIVERSITY

Ray Ewry Sports Engineering Center

TEAM

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Abstract

The feel and control a tennis racket provides is of major importance to tennis players, with the racket acting as an extension of their bodies. While feel and control are highly subjective performance metrics, there are certain aspects of tennis racket design that can improve feel for an athlete. Two of the main parameters for feel in tennis rackets are shock and nervousness. Shock is defined as the maximum impulse force felt at the hand when impact is first made, and nervousness quantifies the lingering vibrations post-impact. Prior research has suggested that the first and second bending modes of oscillation in a tennis racket are the most impactful on the feel for an athlete [1]. Therefore, the goal of this semester was to create a racket handle design to dampen frequency responses at the first and second bending modes to decrease shock and nervousness in a tennis racket. This was done through the design of multiple harmonic dampers tuned to these critical frequencies based on modal analysis simulations and physical testing. This design is still in progress, yet the results of the team's testing are promising and lay out a clear blueprint for upcoming work.

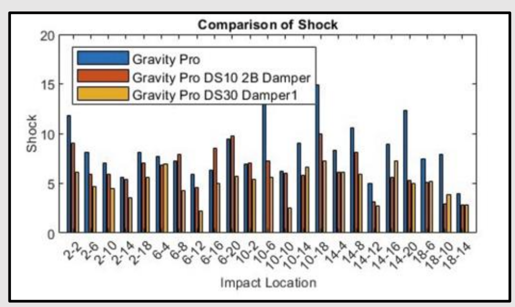

Figure 1: Shock comparison between rackets with and without dampers.

Designing for Feel and Control in Tennis

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Project Overview

The objective of this project is to build on the research done in the Fall 2022 and Spring 2023 semesters. These past semesters culminated in a literature review paper which identifies parameters and methods to optimize feel and control for the athlete. This paper highlights that a racket's physical properties (stiffness, weight distribution, and damping) each play an important role for feel in a tennis racket. The measurable parameters that can be altered with the manipulation of these physical properties are shock, nervousness, plow-through, and soundwave properties. For this semester's project, the team decided to create a harmonic damper to decrease shock and nervousness, which describe the initial peak vibration and lingering vibrational signal, respectively. The damper was designed to mute the frequency responses at the first and second bending modes of oscillation. Initial testing of the dampers yielded unsuccessful results, however there is a clear method of design and testing that has been identified to promote successful results in the future. Moving forward, the team will design without constraints on modal analysis software, as this provides a more accurate description of bending mode frequencies in laboratory testing. This method has proven to decrease shock (as shown in Figure 1), and by adding mass and refining the design experimental trends suggest that shock will further decrease along with nervousness.

Project Method and Results

The team began the testing process by creating multiple designs of a harmonic damper to fit in the end of a tennis racket (see Figure 2) in Inventor and SolidWorks. Following the creation of an initial design, iterations of modal analysis using the respective software were conducted, with tweaks to each design carried out after each iteration to oscillate at the first and second bending modes. For the racket used in our testing, the first bending mode is 142Hz, and the second bending mode is 411Hz. Once the desired frequencies were achieved on the virtual testing, the designs were printed using the ELEGOO MARS resin-based 3D printer. These prints were used to create the negative mold out of Dragon Skin Mold Star, which is a silicone rubber material. To finish the creation of the prototypes, the negative mold was used to cast a final part out of Dragon Skin 10, 20, and 30. A completed damper design is shown below in Figure 2.

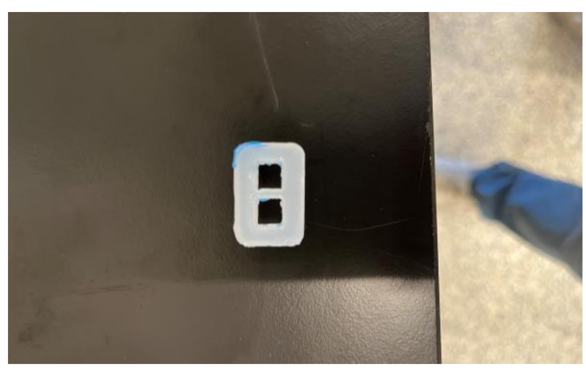


Figure 2: Fully fabricated damper

Project Method and Results (cont.)

Following fabrication, each damper was inserted into the handle end of the tennis racket and tested. The testing setup was an accelerometer attached to the handle to measure shock and nervousness after the racket strings were struck with a force inducer. For more information on the testing setup for this project, please refer to the experimental testing group's work. The results of these tests yielded initially unsuccessful results, as the dampers muted frequencies outside of the first and second bending modes. However, after further investigation of these results, this error was traced back to the virtual modal analysis setup. The team had initially tested the dampers with the edges constrained, however this did not reflect how the dampers would behave in practice. When a damper was tested without constrained edges, it performed as intended. As shown in Figure 1 as the "Gravity Pro DS30 Damper1", this design without constrained edges reduced shock. Therefore, moving forward, the team can further reduce shock, damping ratio, and likely nervousness by creating many designs without constrained edges and increasing mass of the damper by adding a brass or tungsten mass.

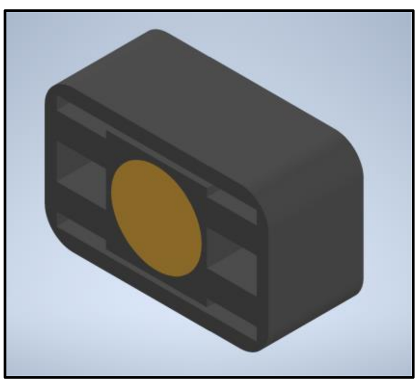


Figure 3: Prototype to test in Spring 2024.

Shown above in Figure 3 is a potential design to test moving forward. This design is tailored to the first bending mode with unconstrained edges and a brass insert to increase mass.

This design can be modified to meet the needs of the second bending mode of oscillation. After creating these designs for the first and second bending modes, the next step of this project will be to gather data to determine which bending mode has the largest impact on shock and nervousness. This will allow the team to optimize feel and control according to the research done in previous semesters.

Conclusions and Future Work

- The addition of a harmonic vibration damper can alter a racket's response to stimuli without altering a racket's swing weight and stiffness.
- Decreasing shock and nervousness is desirable for optimizing feel and control.
- Moving forward, dampers will be designed with unconstrained edges to properly match the virtual modal analysis with experimental results.
- Team will continue testing damper designs to further decrease shock and nervousness.
- In the future, test the dampers with actual tennis athletes to determine if the feel and control of a tennis racket with the addition of a damper is desirable.

References

[1] "Acoustics and Vibration Animations," Vibrational Modes of a Tennis Racket (2014), https://www.acs.psu.edu/drussell/demos/tennis/tennis-1.html (accessed Jan. 6, 2024).

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

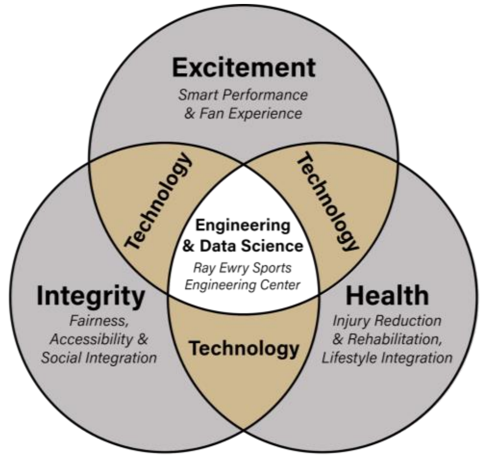
As technology in sports grows, what are the limits of human judgement, and how do we develop technology to ensure a level playing field?

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.