INDIAN INSTITUTE OF TECHNOLOGY
GANDHINAGAR

ME 206

STATICS & DYNAMICS

Professor: Jayaprakash K R

Experiment-5

Group Number: 3

Group Members:

NAME	ROLL NO.
ASHMIT CHHOKER	22110040
ASTITVA ARYAN	22110041
CHANDRA SHEKHAR	22110056
DEBOJIT DAS	22110067

Abstract:

This study presents a comprehensive analysis of the Center of Percussion (CoP) on an equilateral triangular plate subjected to oscillatory motion around a vertex, with forces applied perpendicular to the plate's surface. By meticulously measuring the plate's oscillatory responses, we identified the CoP—the point at which applied forces cause minimal rotational disturbance. Our empirical findings are then juxtaposed with theoretical predictions derived from fundamental mechanics principles. This synthesis of theoretical and experimental methodologies enhances our grasp of basic mechanical concepts. Our findings not only validate the precision of theoretical models in predicting dynamic system behaviors but also deepen the understanding of CoP phenomena in mechanical systems.

Objective:

1. Determination of the Center of Percussion (CoP): Our primary goal is to accurately identify the CoP of an equilateral triangular plate with uniform thickness. This involves conducting observations and analyses of the plate as it oscillates about one of its vertices, with particular attention to ensuring that the force applied during these oscillations is normal to the plate's surface.

2. Comparison with Theoretical Models: A crucial objective is to compare the experimentally determined CoP with the CoP predicted by theoretical calculations. This comparative analysis is vital for validating the experimental approach and methodologies we have employed.

Experimental Setup

Fig. 1: The experimental setup with the triangular plate (with marked locations of analysis) suspended from a rigid support.

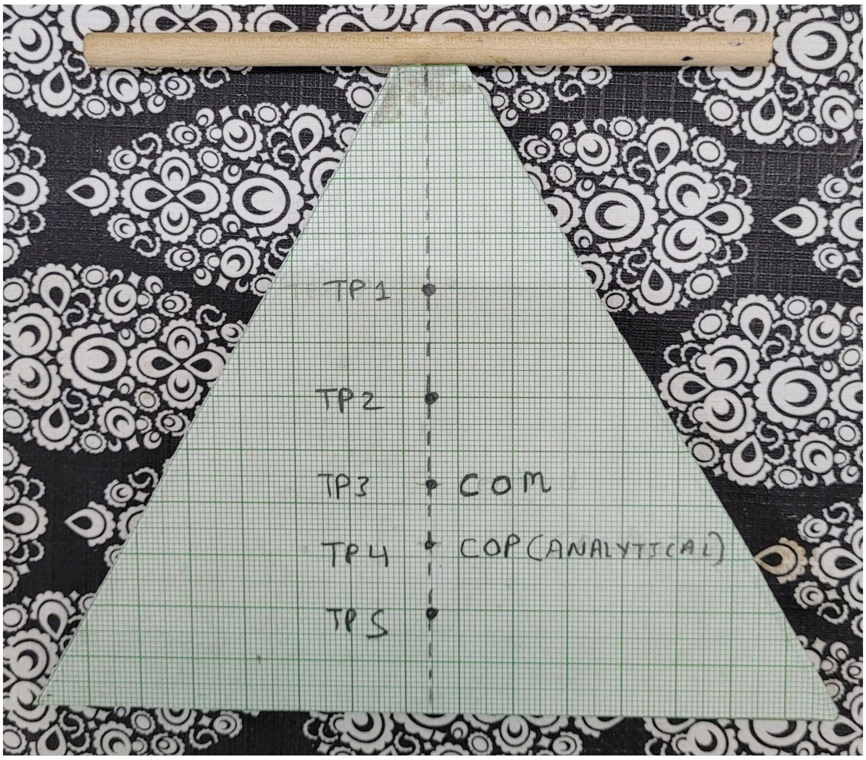

Fig. 2: The Triangular Plate with a graph sheet pasted on it and attached to a chopstick wood cylindrical rod. TP1, TP2, TP3 (COM), TP4 (CoP) and TP5 are the points where the triangular plate is hit

Fig. 3: Front view of the setup

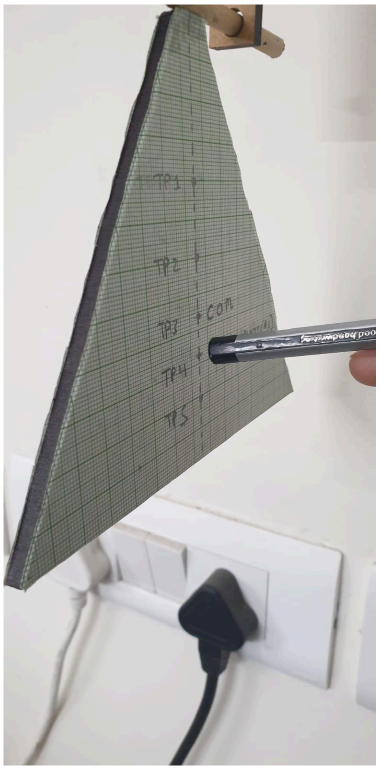

Fig. 4: Act of hitting the triangular plate at the analysis points

Scan this QR Code to view the experiment.

Educational Alignment and Practical Engagement:

1. Alignment with Learning Objectives:

Objective Correlation: This experiment specifically targets the dynamics of mechanical systems, with a focus on the practical application of these principles. By examining the Center of Percussion (CoP) on an equilateral triangular plate, we gained hands-on experience with concepts like oscillatory motion and force distribution, key elements in understanding kinematic motion.

Skills Development: Students enhance their skills in precise measurement, critical analysis, and application of theoretical mechanics to tangible experiments. This process not only reinforces their understanding of mechanical principles such as leverage and efficiency but also nurtures essential analytical skills vital for a career in mechanical engineering.

2. Bridging Theoretical and Practical Knowledge:

Theoretical Foundations: The experiment is rooted in fundamental theories of mechanics, particularly those relating to oscillatory motion and rotational dynamics. Students engage with these concepts theoretically, understanding the mathematical and physical principles governing mechanical systems.

Practical Implementation: The hands-on aspect involves applying these theoretical principles to determine the CoP of the plate experimentally. This real-world application demonstrates how abstract concepts translate into physical phenomena, providing a comprehensive understanding of theory and practice.

3. Preparation for Complexities-

Anticipating Real-World Challenges: The experimental setup mimics challenges faced in practical engineering scenarios, such as dealing with material imperfections and mechanical constraints. This prepares students to understand and manage real-world variables and uncertainties in engineering projects.

Adaptability and Problem-Solving: The experiment enhances adaptability, encouraging students to apply theoretical knowledge to practical, often unpredictable, situations. This fosters robust problem-solving skills as students learn to navigate and resolve real-time challenges, a crucial ability for successful engineering practice.

Application of Fundamental Principles:

The concept of the Center of Percussion (CoP) is not just a theoretical aspect of physics; it has significant applications in various real-life scenarios. Understanding the CoP helps optimize performance, enhance safety, and improve the design of various objects and systems. Here are three pertinent examples:

1. **Sports Equipment Design:**

   In sports like cricket, baseball, and tennis, the CoP plays a crucial role in the design of bats and rackets. The CoP is the point where the ball's impact causes the least shock and vibration to the player's hands. By designing equipment where the CoP aligns with the preferred hitting zone, manufacturers can enhance performance and comfort. For instance, in cricket and baseball bats, positioning the CoP optimally allows for more robust and controlled shots with minimal jarring of the hands and wrists, improving both the player's comfort and performance.

2. **Automotive Safety:**

   In vehicle design, particularly in crash dynamics, understanding the CoP can improve safety features. The CoP is a factor in how a car reacts during a collision. Knowing the CoP helps engineers design crumple zones and other safety features that can better manage the forces during an accident, thereby reducing the risk of injury to passengers. It's also crucial in the design of racing cars, where the CoP impacts the vehicle's stability and handling at high speeds.

3. **Architectural and Structural Engineering:**

   In architectural design and structural engineering, the CoP is integral in ensuring the stability of structures like bridges and skyscrapers, especially in earthquake-prone areas. By understanding the CoP, engineers can design structures that can withstand seismic forces more effectively. This involves strategically placing dampers and counterweights in buildings and bridges to absorb and redistribute seismic energy, thereby reducing oscillations and preventing structural damage during earthquakes.

4. **Musical Instruments Design:**

   The concept of the Center of Percussion is also significantly relevant in the design and playability of percussion instruments, such as drums and xylophones. In these instruments, the CoP relates to the point where striking produces the most effective sound. For instance, in a drum, striking at the CoP results in a sound with optimal resonance and minimal unwanted vibrations or overtones. Understanding and utilizing the CoP allows musicians to achieve the desired tone and quality of sound. Additionally, for instruments like marimbas or xylophones, the placement of the mallet strike in relation to the CoP affects the purity and volume of the note produced. This knowledge is crucial for both instrument makers and musicians, as it impacts the instrument's design, playing technique, and overall sound quality.

Each of these examples demonstrates the practical importance of understanding the Center of Percussion. This knowledge not only enhances performance and comfort in sports equipment but also plays a critical role in safety and stability in automotive design and architectural engineering. The principles learned from studying the CoP in an equilateral triangular plate thus find diverse and impactful applications in the real world.

Fabrication Details:

Our experiment employed a straightforward yet precise fabrication approach:

1. **Materials Used:** We used a Medium-Density Fibreboard (MDF) for its uniformity and stability.

2. **Integration of Technologies:** A laser cutting machine was utilized to accurately fabricate the MDF components, ensuring precision and uniformity essential for the experiment's success.

What is a Center of Percussion?

The **Center of Percussion (CoP)** is a concept in physics that finds practical applications in areas such as sports equipment design and usage. The CoP is often referred to as the **'sweet spot'** in contexts like baseball bats or tennis rackets. It is the point on an object where an impulsive force applied causes the object to rotate about an axis with minimal sudden motion or jerk at the handle, especially when this axis passes through the hand.

In a physical sense, when an extended object like a baseball bat is subjected to an impulsive force near one end, it rotates about an axis towards the other end. The impact point is where the force is applied, and the rotation axis forms a conjugate pair. **The CoP is essentially the impact point with respect to the rotation axis**. As the impact point moves closer to the object's center of mass, the rotation axis shifts accordingly. If the impact point is at the center of mass, the object translates without rotation, and the rotation axis is infinitely distant.

However, the concept of CoP becomes more complex when considering hand-held implements like bats and rackets. The hands holding the implement extend over a finite length of the handle, exerting a reaction force and changing the total mass and moment of inertia of the system. This modifies the axis of rotation and, potentially the location of the CoP. In fact, in hand-held implements, the ideal impact point or 'sweet spot' is often aligned with the node of the fundamental vibration mode rather than the theoretical CoP.

Mathematically, the CoP can be determined by considering the forces and torques acting on a freely rotating object, like a beam. An impulsive force applied at a distance from the center of mass causes both translational and rotational movements. The point on the beam where the velocity is zero during rotation aligns with the CoP. This is calculated based on the object's mass, the applied force, and its moment of inertia.

Understanding the CoP is crucial in optimizing the design and use of various objects where impulsive forces and rotational dynamics are involved.

Where can we find the Centre of Percussion Example?

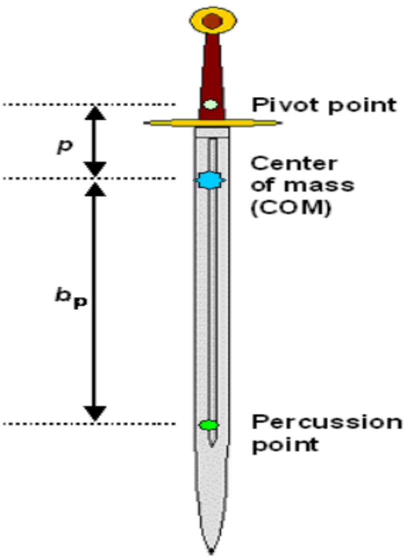

Fig. 5: Sword [1]

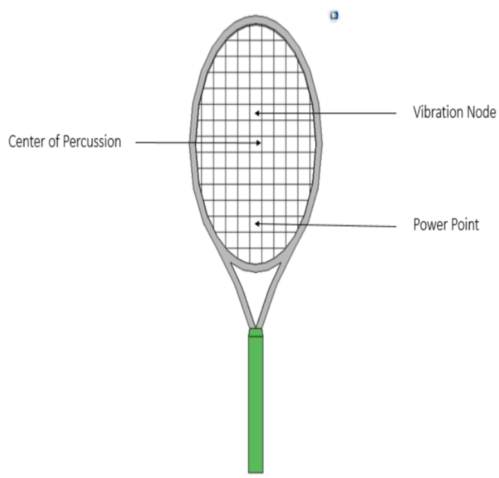

Fig. 6: Badminton Racket [2]

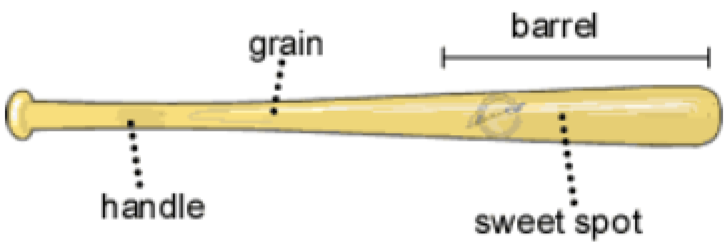

Fig. 7: Baseball Bat [3]

In the image of the sword, the CoP is indicated along the blade, distanced from the pivot point where the hand grips the handle and the center of mass (COM). The placement of the CoP is crucial for a sword, as it determines the point at which a strike would yield the most effective transfer of force without causing undue vibration back to the hand at the pivot point, ensuring a stable and controlled swing.

For the badminton racket, the CoP is shown towards the head of the racket, aligning with what is also known as the ‘sweet spot’. This is the ideal location to hit the shuttlecock for maximal energy transfer without causing excessive vibration through the racket, which could lead to a loss of control and power. The image also indicates the vibration node, which is a point of minimal vibration, and the power point, where players aim to strike for optimal play.

The baseball bat diagram identifies the CoP as the 'sweet spot' located on the bat's barrel. This is the point where hitting the ball would cause the least amount of sting or vibration to the hands on the handle and is believed to allow for the most powerful hit. The 'sweet spot' is essential for players to hit the ball efficiently and with maximum force, contributing to the distance the ball can travel when struck.

Each of these examples demonstrates the practical application of the CoP concept, emphasizing its importance in the design and utilization of sports equipment to maximize performance and comfort.

Procedure:

1. Assembling the setup

a) **The Triangular Plate:** An equilateral triangular plate (Length = 15cm) made out of MDF material was cut out using a laser cutter. One of its vertices was truncated and firmly fixated to a cylindrical cut piece (further referred to as “rod of triangular plate”) of chopstick wood of appropriate size. The triangular plate is intended to rotate about this rod. A cutout of a graph sheet of size equal to the surface area of the triangular plate was pasted to obtain reliable measurements and minimize errors while analyzing the experiment. (Refer to figures in the Experimental Setup section)

b) **The Suspending Structure:** Two MDF material-based vertical rods with holes at their ends were parallelly fixated to a rigid support with a short distance between them. The rod of the triangular plate was passed through the two holes at the end of the vertical rods, thus, creating a revolute joint. (Refer to figures in the Experimental Setup section)

2. Performing the experiment

a) **Marking the hitting points:** Five analysis points were marked on the graph sheet of the triangular plate along the median. The Centre of Percussion (CoP) and Centre of Mass (COM) of the triangular plate were analytically computed. The analysis points have been named ***TP1, TP2, TP3 (Centre of Mass), TP4 (Centre of Percussion) and TP5***. (Refer to figures in the Experimental Setup section)

b) Hits were made in the order TP1, TP2, TP3, TP4, TP5, and on the triangular plate normal to the surface with the same impulse each time. The plate was made still before every hit, and the magnitude of vibrations in the vertical parallel rods were observed just as the impulse was applied.

Observations and Results:

The Center of Percussion (CoP) was analytically obtained at (from the axis of rotation):

$$\frac{3\sqrt{3}}{8}l = \frac{3\sqrt{3}}{8} \times 15 \text{ cm} \ \approx 9.743 \text{ cm}$$

From the base of the triangular plate, CoP comes out to be at **3.25cm** along the median.

The vibrations decreased as we went closer to the analytically derived location of the C.O.P, becoming invisible to the naked eye at that location, and increased as we got far away. This tells us that the analytically derived C.O.P is also experimentally showing the defining property of C.O.P.

The experimental analysis can be viewed by scanning this QR Code.

Conclusion & Discussion:

The primary aim of our experiment was to locate the Center of Percussion (CoP) of an equilateral triangular plate. **The analytical calculations positioned the CoP 3.25cm from the base along the median.** During the physical trials, a notable decrement in vibrations was observed as impacts approached this analytically determined CoP. At the predicted CoP, vibrations were minimal and nearly imperceptible to the naked eye. Conversely, as impacts were made further from this point, vibrations visibly increased.

These observations strongly support the analytical predictions, suggesting that the experimentally determined CoP coincides with the theoretical CoP. The decrease in observable vibrations at the CoP confirms its defining property — a point where the impact results in a minimal reactionary force on the pivot point. This experiment thereby validates the concept of the CoP and its practical determination in a mechanical system.

Learnings:

Theoretical vs. Practical Knowledge: The experiment reinforced the importance of bridging the gap between theoretical knowledge and practical application. Understanding the nuances of real-world conditions is crucial for effective mechanical design.

Precision in Construction: The necessity for precise manufacturing and alignment in mechanical systems was evident. Even minor deviations can significantly impact the system's performance.

What could have been done better?

Improved Experimental Setup: Redesigning the experiment to minimize friction and wear by using higher-quality materials could yield results more consistent with theoretical predictions. Using sensors (like piezoelectric vibration sensors) could have enabled us to get a quantitative measure of the vibration. Being able to produce a constant impulse with which the sheet is hit normal to the surface of the sheet at all times would have given every test case a fair standing without any conscious or unconscious biases for any of the test points and, thus, would have provided much more accurate results.

Iterative Testing and Analysis: Conducting multiple iterations of the experiment with adjustments based on initial findings could help identify and minimize sources of error.

References:

[1] *Batnode The Node of Vibration*. Available at: http://www.exo.net/~pauld/activities/baseball/batnode.htm (Accessed: 28 November 2023).

[2] H. Föll *Precussion Point*. Available at: https://www.tf.uni-kiel.de/matwis/amat/iss/kap_c/backbone/rc_3_7.html (Accessed: 28 November 2023).

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[4] *Today we take a look at the center of percussion.* Available at: https://youtube.com/shorts/Hjgkxd7OG-k?si=2hQw_cEy25alG3yL (Accessed: 28 November 2023).

[5] Rod Cross; *Center of percussion of hand-held implements*. Am. J. Phys https://pubs.aip.org/aapt/ajp/article-abstract/72/5/622/1038992 (Accessed: 28 November 2023).

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