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Design and Fabrication of Smart Tap for Finger Protection During Hammering

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Abstract

This study presents the design and fabrication of an innovative Smart Tap tool aimed at improving efficiency and precision in construction and woodworking activities. Although various market-ready nail holders are available, many lack ergonomic integration with the user's grip and provide limited control to prevent nail or screw buckling during installation. The Smart Tap addresses these limitations through a user-friendly, ergonomically designed nail holder created in SolidWorks, which conforms naturally to the hand for improved ease of use and accurate placement. An impact test was conducted to evaluate the durability and performance of the holder under dynamic forces. Among three tested thicknesses, the 6 mm variant demonstrated the highest energy absorption and was selected as the optimal design. The tool was fabricated using advanced three-dimensional (3D) printing techniques, ensuring high dimensional accuracy and efficient translation from digital design to a functional product. The results confirm the Smart Tap's effectiveness in minimizing nail buckling and enhancing operational precision, offering clear ergonomic and functional advantages over existing designs and demonstrating strong potential for broader application in hammering-related tasks.

1. Introduction

Hammers are commonly used in various household tasks, like housekeeping, woodworking, and electrical work, but they often result in minor injuries, which can lead to more severe consequences. Hammer users often experience small injuries, such as finger or hand knocks. While nail holders are available to prevent finger knocking, they are often too large and cumbersome, making them challenging to store and carry everywhere. Although various market-ready nail holders are available, many lack ergonomic integration with the user's grip and provide limited control to prevent nail or screw buckling during installation. To address this, there is a need for more convenient and user-friendly products with ergonomic design and smaller sizes to enhance user experience.

Smart Tap is a tool designed for safer and more convenient nail hammering. It features magnets that securely hold the nail, eliminating the need to grip it manually. The product has a strong grip and a magnetic head, ensuring the nail stays firmly in place during hammering. This saves time and reduces the risk of accidentally hitting fingers with the hammer. The key benefit of Smart Tap is its ability to provide stability and control, preventing the nail from slipping or shifting and allowing for more precise and efficient nail placement. It is also designed to hold and organize different nail sizes and prevent the buckling of nails or screws while hammering or drilling. The tool is valuable for various tasks such as household work, woodworking, electrical wiring, and other do-it-yourself (DIY) projects. It enhances usability, accuracy, and efficiency in nail-hammering, making it a valuable addition to any toolbox.

This tool is a beneficial addition to any toolbox as it enhances usability, improves accuracy, and streamlines the hammering process. This study is significant due to an incident reported by the Occupational Safety and Health Administration (OSHA), highlighting the real and severe consequences of inadequate safety measures during construction work [1]. This study has three main objectives. The first objective is to design a tool to protect fingers when hammering nails. The second objective is to assess the durability of the Smart Tap tool through the impact test. The final objective is to fabricate Smart Tap using advanced technology, specifically the 3D printer. Each objective enhances usability and efficiency in nail-related tasks, showcasing a comprehensive approach from design to fabrication.

1.1 Design Development

Design development is a crucial step in the design process, where the initial concept is refined into a more detailed and comprehensive solution [2]. This involves shaping the basic idea into a tangible form, considering factors like utility, aesthetics, ergonomics, manufacturability, and user experience. Product design and development are a never-ending loop of iterative feedback and recurring inputs from development team members, executives, sales and marketing departments, and production teams. Shorter innovation processes, developing customer involvement in product development, and increasing degrees of interdisciplinary in the design of new goods are recent trends in product design and development [3].

In the design process, a basic design is initially created and continuously refined as new information emerges. The systematic process guides designers from the initial concept to the final implementation [4]. As illustrated in Fig. 1, the problem definition stage is crucial as it helps designers clearly understand the issue they are addressing and set specific goals [5]. Research provides valuable insights, aiding decision-making. Brainstorming generates numerous ideas without judgment, fostering a diverse range of concepts. Prototypes are early versions that allow designers to test solutions with real users and gather rapid feedback. The "select and finalize" step involves refining design concepts and considering functionality, user experience, aesthetics, and technology. Product analysis evaluates strengths, weaknesses, and overall performance for inspiration. The redesign aims to enhance the user experience based on customer input, prototype testing, competitive analysis, and market sales [6].

1.2 Fabrication

Machining is a subtractive manufacturing process that precisely removes material to create the needed part. In this method, the workpiece starts larger than the final part. Machining offers higher precision than alternative methods, such as additive manufacturing [6]. Conventional machining is the traditional method of manufacturing, shaping and resizing a workpiece by removing material. Unlike advanced techniques like additive manufacturing, it relies on subtractive methods such as cutting and grinding. Different machines, like lathes, are used for specific tasks. The versatility of conventional machining allows the creation of diverse parts in aerospace, automotive, and general manufacturing industries. Despite newer technologies, the efficiency, accuracy, and cost-effectiveness of conventional machining make it a preferred choice. Skilled machinists are essential for ensuring the quality and precision of the final products. Conventional machining is classified into numerous categories. To begin with, milling is removing material from a workpiece by running it through a revolving multi-tooth cutter. The milling cutter's teeth have a cutting action that enables rapid machining [8]. Following that, turning is a machining technique used to form cylindrical components by removing material from a revolving workpiece [9]. Furthermore, the shaping process in machining comprises the removal of material from a workpiece using a shaping machine to create flat surfaces or complicated curves [10].

J. of Advanced Mechanical Engineering Applications Vol. 6 No. 2 (2025) p. 32-41

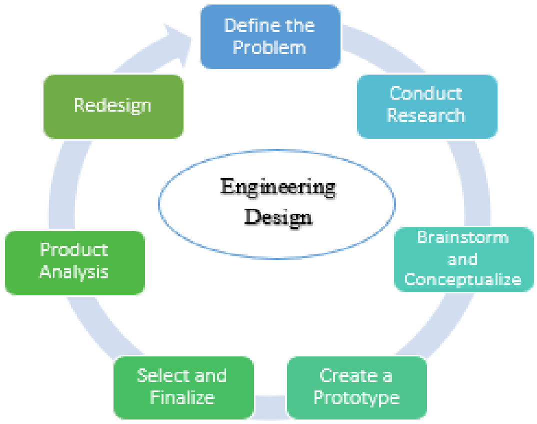


Fig. 1 *Engineering design process [4]*

Modern machining refers to the latest processes and technology for precisely shaping and fabricating components. It includes sophisticated procedures driven by computerization, automation, and cutting equipment that are cutting edge [11]. Contemporary machining processes rely on computerized numerical control (CNC) machines, enabling automatic control and precise programming. Examples include CNC milling and turning machines, which use rotating cutting tools, along with advanced methods like electrical discharge machining (EDM) and waterjet cutting. Additive manufacturing, including 3D printing, is significant for constructing complex parts layer by layer. Modern machining excels in achieving high accuracy, efficiency, and versatility, catering to diverse sectors such as aerospace, automotive, healthcare, and electronics. Modern machining is classified into numerous categories. First and foremost, EDM is an unconventional machining method that uses controlled electrical discharges to remove material from a workpiece selectively. This machining procedure removes material from a workpiece using electrical discharges or sparks [12]. Then, there is 3D printing. The method of building a 3D object layer by layer using a computer-generated design is known as additive manufacturing [13]. 3D printing, or additive manufacturing, is the technique of layering together a 3D item using a computer-generated design. 3D printing has improved considerably and can now play vital roles in a wide range of industries, including manufacturing, medical, architecture, customized art, and design, and can range from totally functional to mere aesthetic. 3D printing methods have reached their full potential and are now widely used in manufacturing, medicine, and various sociocultural sectors. In the past decade, there has been significant excitement about the potential of 3D printing as a primary production method, offering cost and time advantages over traditional procedures.

1.3 Hammering

Many designed tools can be created in the manufacturing industry for household, woodworking, electric wiring/wireman, and domestic work. Based on previous studies, numerous types of equipment are created to protect the fingers from hitting while hammering. There are various examples of existing products. Among them is the Magnetic Nail Holder, as displayed in Fig. 2. This product describes how it is very easy to hit fingers instead of nails when using a hammer, leaving bruises and scrabbling on the floor for dropped nails. However, this Magnetic Nail Holder, a tempered steel holder, retains the nail and even prevents it from buckling while hammering it in place for nails and screws. The diameter of this product is 0.6-6.35 mm, with 9 cm in length and 0.6 cm in width [14]. Furthermore, another existing product is the Universal Nail Holder, as shown in Fig. 3. The features of this product eliminate the possibility of finger injuries when hammering nails or tightening screws. It fits all standard nail and screw sizes. This product has an innovative design and is flexible. It is made in the United Kingdom. The subsequent product is the Hanwoit Finger Safe Nailer for Hammering-Nail Holder with Magnetic Suction (work on steel or iron nails that fit into the groove), as illustrated in Fig. 4. This product is a manual safety nailer, with a magnetic mouth and groove design to prevent them from falling. Hammer safely without the risk of finger injury. The safety nailer excels in heavy-duty tasks, even in tight spaces. A reliable companion for every household, especially for hanging paintings, photo frames, home decorations, and yard maintenance. Its easy, portable, compact, and agile features greatly enhance work efficiency with its practical and robust functionality. Although various market-ready nail holders are available, many lack ergonomic integration with the user's grip and provide limited control to prevent nail or screw buckling during installation. Thus, the Smart Tap proposed in this study addresses these limitations through a user-friendly, ergonomically designed nail holder.

Fig. 2 *Magnetic nail holder [14]*

Fig. 3 *Universal nail holder*

Fig. 4 *Hanwoit finger safe*

2. Methodology

The methodology used in this study encompasses four processes. A basic prototype is presented through verbal or written descriptions of the proposed product's functionality. Its suitability is discussed with the user or checked based on specific criteria. This is the starting point for introducing product design.

2.1 Design Development using Solidwork Software

SolidWorks software was used to design the Smart Tap before 3D printing. The dimensions of the Smart Tap were 60 mm in length, 80 mm in width, and 35 mm in height. In SolidWorks, the initial step began with 3D sketch on the front plane. The units are in millimeters, using the American National Standards Institute (ANSI) dimensioning standard. A new file was created and named, and each part was extruded and saved in the file. A new document was created for assembly, and individual part files were imported using "Insert Components" or dragging them in. SolidWorks tools help position and align parts using constraints and mates. The assembly document was saved and managed, handling file references, configurations, and versions as needed.

2.2 Fabrication

In this study, a tangible model was fabricated using 3D printing. The purpose was to assess the design and functionality of the product before mass production. It allows designers to evaluate the product's shape, fit, and function, making necessary adjustments. The prototype was tested to demonstrate its ability to protect fingers when hammering nails.

2.3 Impact Test

Time-taken testing involves measuring how long it takes for a prototype to perform a specific task, which is crucial for time-sensitive products. The process began with setting up the prototype in a controlled environment and measuring the time it took to complete a task. The testing equipment was designed for low-speed impact tests, with speeds below 15 m/s. It allows variable kinetic energy at different collision speeds and can conduct impact tests on specimens with diverse cross-sectional shapes. The maximum outer geometry was 60 mm, and the maximum height was 170 mm. Safety and affordability are critical considerations in the design [15].

The impact test assesses the energy a material absorbs during fracture, indicating its toughness and analyzing its brittle-ductile transition. The goal is to determine if the material is brittle or ductile, and three samples were tested to collect data. Only the absorbed energy or the amount of breaking after a hit was evaluated in the impact testing. The fracture toughness test is more detailed and aims to determine characteristics like plane strain fracture toughness, energy release rate, crack opening displacement, crack-tip opening displacement, and the Joule integral.

The instrument impact test is widely used in industry because it is simple to perform and produces data quickly and cheaply. On the other hand, impact energy only provides a pretty qualitative definition of brittleness. Using a local approach to measure fractures may impart a thorough material examination.

3. Results and Discussion

The designed and fabricated Smart Tap for finger protection during hammering successfully demonstrated its efficacy in preventing accidental injuries, marking a significant advancement in occupational safety. Integrating intelligent sensors and protective materials provides a reliable barrier against hammer-related accidents. It showcases a user-friendly and practical solution for enhanced workplace safety. This discussion underscores the importance of this innovation in reducing the incidence of finger injuries in construction and related industries, paving the way for the potential adoption of such smart technologies as standard safety measures. Continuous refinement and user feedback will contribute to the ongoing improvement of the design, ensuring its optimal performance and broader applicability in various work settings.

3.1 Design using Solidwork

SolidWorks software was used to design the Smart Tap, as shown in Fig. 5. It was then printed in a 3D shape. The tool started with five components: the right plate, left plate, holder stopper, magnet stopper, and hinge. The length of the Smart Tap was 60 mm, the width was 80 mm, and the height was 35 mm.

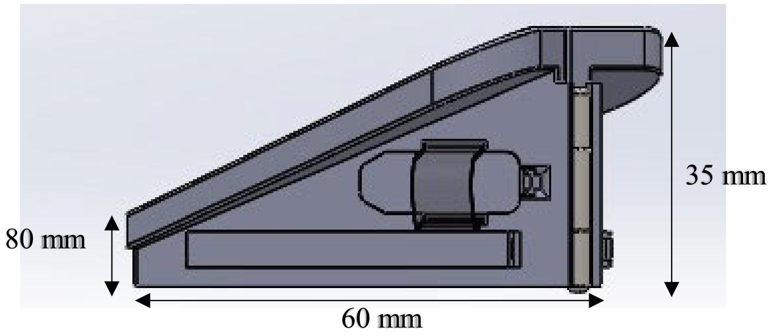
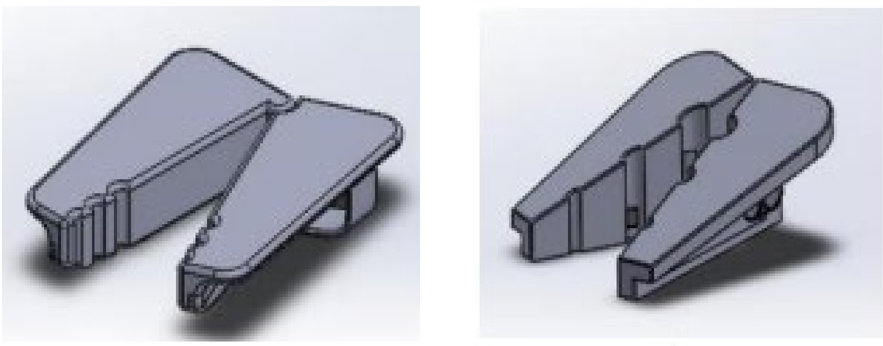


Fig. 5 *Dimension of smart tap*

3.1.1 Element Features (Improved Design)

Two types of sketches, Design A and Design B, were generated using Solidworks Software, from the study's concept design as illustrated in Fig. 6. Upon reviewing, Design A has several drawbacks such as the location of the nail hole at the front makes holding the nail difficult since it needs a lot of force to apply. Additionally, the overall length of Design A is short, thus making it harder for hammering. So, Design B was chosen to proceed with the next stage of study.



(a) **(b)**

Fig. 6 *Selection of designs: (a) Design A; (b) Design B*

3.1.2 Selection of Design (Design B)

Design B was selected for several reasons. Firstly, it offers a more efficient and user-friendly method for attaching nails, eliminating the need for maximal effort. Secondly, design B provides increased stability proportional to the nail length, allowing versatility with different nail sizes. Lastly, the flexibility of design B enhances usability and handling, providing a comfortable grip during operation. In summary, design B effectively addresses issues related to force application, stability, and user ease, making it a superior choice for holding and handling nails.

3.1.3 Selection of Material

Using polylactic acid (PLA) for the Smart Tap offers several benefits that are aligned with the study's requirements. PLA's stainless nature ensures corrosion resistance, protecting nails from rust. Its toughness and durability enable extended usage without frequent replacements [16]. The tool's lightweight construction enhances portability and usability in various scenarios. Lastly, PLA's cost-effectiveness allows for the creation of a functional and dependable tool at a low production cost, ensuring accessibility without compromising quality or performance. In summary, PLA's stainless characteristics, durability, lightweight, and cost-effectiveness make it an excellent material choice for the Smart Tap.

3.1.4 Different Hole Sizes

Incorporating holes of different sizes, specifically 1 inch, 3 inches, and 5 inches, as shown in Fig.7, in the Smart Tap design was intended to provide a strategic and multipurpose function. These holes act as precision guides, facilitating the secure insertion of nails of different lengths during hammering or drilling. The 1-inch hole accommodates smaller nails, ensuring a secure fit and precise alignment and preventing undesired movement. The 3-inch hole allows easy handling of medium-sized nails, enhancing the holder's usability for a broader range of applications. The largest hole, 5 inches, accommodates longer nails or screws, providing the versatility needed for various construction or woodworking activities.

The presence of holes of various sizes can enhance the nail holder's performance, facilitate the nail inserting process and accommodate various nail lengths accurately and conveniently. Whether undertaking complex construction or basic home repairs, the size of holes contributes to the holder's versatility, making it a helpful tool for experts and DIY enthusiasts.

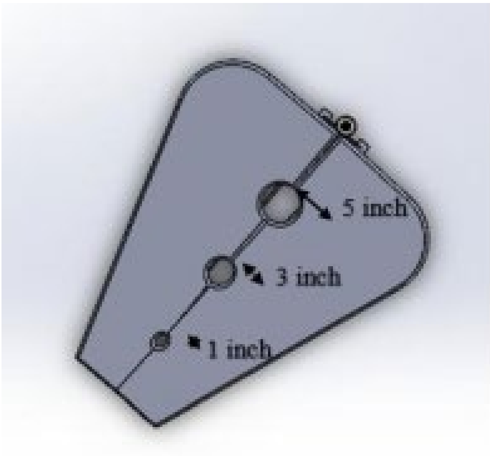


Fig. 7 *Hole sizes*

3.2 Sample Testing and Result

Before using the impact testing machine for three samples of different sizes (2 mm, 4 mm, and 6 mm), as shown in Fig. 8, a systematic procedure is essential. The material of the specimens was selected based on specific properties. Three samples were fabricated for each size with precise dimensions and defect-free composition, labeling each for identification. Temperature conditioning was also necessary.

Calibration of the impact testing machine is crucial to comply with safety measures and manufacturer guidelines. It was precisely aligned with precision during specimen setup for accurate impact force application. By following strict safety precautions, tests were conducted in sequence from smallest to largest size, and comprehensive data were recorded, ensuring reliability and consistency for subsequent analysis.

(a) (b) (c)

Fig. 8 *Impact testing process on samples. (a) The impact testing machine used. Initial setting and calibration; (b) The specimen being clamped and ready for testing; (c) 3 specimens from different sizes (thickness) of 2mm, 4mm, and 6mm after testing*

The concept of absolute energy and energy density substantiated the selection of 6-mm thick products over 2-mm and 4-mm counterparts. The greater size of the 6-mm product directly correlated with higher absolute energy values, primarily due to its greater volume and mass. The absolute energy of a material or product is directly related to its mass. In this case, a 6-mm thick product inherently possessed more mass compared to the 2-mm and 4-mm thick products. Increased mass translates to higher absolute energy, offering potentially greater capability or performance in certain applications.

Table 1 shows the data obtained from the impact test. Choosing the 6-mm thick product resulted in higher absolute energy and energy density due to its greater mass and volume. This choice is preferred in situations where greater energy storage or provision within a specific space or mass limit is crucial, providing enhanced efficiency or performance compared to thinner products.

Table 1 *Data obtained from impact test*

Sample/ Thickness	Absolute Energy [%]	Re [Kj/m2]
	1.51	13.79
2 mm	1.59	13.70
	1.53	13.80
	1.84	17.06
4 mm	1.82	17.25
	1.80	17.77
	2.20	19.68
6 mm	2.23	18.70
	2.21	19.65

3.3 Fabrication Using 3D printing

Ultimaker 3D printer is excellent for creating concept models, working prototypes, and short runs due to its speed and precision. Although Cura was used in this study to fabricate high-quality 3D models, the user is responsible for ensuring the printed object is suitable for its intended use. Matching material properties with machine settings is crucial. Ultimaker is an open filament platform, and using Ultimaker-certified filament yields the best results. The process parameters significantly impact the accuracy, efficiency, and characteristics of the created additive. Several parameters were involved in this process, namely noise, filament size, melting temperature, printing speed, layer thickness, and infill density, as summarized in Table 2.

Table 2 *Printing parameters*

Nozzle size	2.85	mm
Filament size	2.85	mm
Melting Temperature	200	°C
Printing Speed	180	mm/s
Fan Speed ON	100	%
Layer Thickness	8	mm
Infill Density	1.24	g/cm3

3D printing technology offers high precision, customization, and faster production for Smart Tap fabrication compared to traditional methods. As shown in Fig. 9, the Ultimaker 2+ 3D printer using fused deposition modeling (FDM) was employed in this study. The digital model created in SolidWorks was exported in STL format and processed in Ultimaker Cura to define printing parameters such as layer height, infill density, and print speed. The filament spool was oriented counterclockwise, straightened for smooth feeding, and loaded into the feeder once the print head reached the set temperature (190–220°C for PLA). The printer automatically fed the filament through the Bowden tube until extrusion began from the nozzle. Printing then proceeded layer by layer according to the predefined toolpath until the complete geometry was formed. After cooling, the part was removed from the build plate and cleaned to achieve a smooth finish. This process enabled accurate and efficient conversion of the digital design into a functional prototype. Fig. 10 shows the final printed product, named Smart Tap, while Fig. 11 illustrates its application during hammering. The tool demonstrates its practicality in securely holding nails and maintaining alignment throughout impact, reflecting the effectiveness of the design and fabrication process.

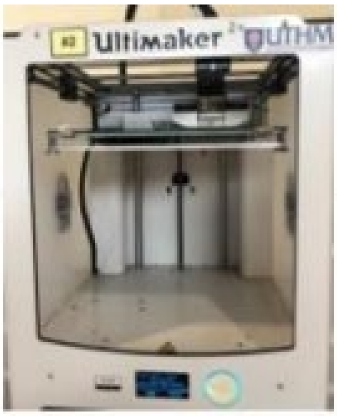


Fig. 9 *The Ultimaker 2+ 3D printer*

Fig. 10 *Final product*

Fig. 11 *Smart Tap usage while hammering*

4. Conclusion

In conclusion, a comprehensive approach involving the design of a functional nail-holding tool, impact testing for durability, and fabrication using 3D printing yielded promising results. The innovative Smart Tap design effectively addresses common issues during hammering, particularly nail buckling and placement accuracy.

Rigorous durability testing confirmed its reliability under dynamic conditions. The use of 3D printing demonstrated the efficiency of modern manufacturing in producing complex, precise components with ease. Overall, this work highlights the potential of integrating advanced design and fabrication techniques to develop tools that combine enhanced functionality with efficient production.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception:*** *Nur Liyana Nabihah Rosman, Tengku Nur Azila Raja Mamat;* ***data collection:*** *Nur Liyana Nabihah Rosman;* ***analysis and interpretation of results:*** *Nur Liyana Nabihah Rosman, Helmy Mustafa El Bakri, Nurrul Hafeezah Sahak;* ***draft manuscript preparation:*** *Nur Liyana Nabihah Rosman, Tengku Nur Azila Raja Mamat, Fadhilah Abdul Razak. All authors reviewed the results and approved the final version of the manuscript.*

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