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Review and Analysis of Mechanical Cutting Tools for Rubber Stamping

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***Abstract* – Rubber industry is one of the major industries in Malaysia. Rubber stamping machine is a machine that cuts rubber sheets into desired shapes and dimensions, facing challenges due to the elastic properties of rubber sheets. These challenges include long process time and non-identical dimension. This review paper focuses on the design of the rubber-stamping machine to address the challenges by reducing process time and producing identical dimensions products. The rubber-stamping machine was fabricated, and analysis was performed to verify its efficiency. The core of the designs is to ensure the user safety, friendliness, and increase productivity and product consistency. Based on the findings from existing studies, the review highlights significant improvements in machine design and operational efficiency. The paper also discusses the impact of these innovations on the competitiveness of rubber stamping operations and provides insights into future directions for research in mechanical design and automation systems. This review can be a crucial resource for developers and manufacturers looking to enhance the efficiency and product quality of rubber-stamping machines, contributing to the advancement of manufacturing practices in the rubber industry.**

Keywords— Rubber Stamping, Mechanical Cutting Tool, Rubber Industry, Process Efficiency.

I. INTRODUCTION

Rubber is still in high demand across a wide range of businesses, mainly due to the tyre industry [1] non-tyre industry such as glove manufacturing [2]. However, there are issues with the current rubber-stamping methods, including labour-intensive manual operations, limited productivity, and uneven product quality. The creation of a rubber-stamping device that attempts to overcome these issues is presented in this study. The machine's design prioritises safety and user-friendliness while also increasing productivity and product consistency. The project's goals, methods, and design process are described in the article, along with the materials chosen and the outcomes of experiment. Through a structured approach outlined in a Gantt chart, the paper demonstrates a systematic progression from initial research to final implementation, culminating in comprehensive conclusions and recommendations for future work.

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This research focuses on the design, development, and evaluation of an automated rubber-stamping machine intended to enhance productivity and consistency within the rubber product manufacturing process. The research explores the intricate design considerations involved in crafting a mechanical cutting tool tailored explicitly for rubber stamping, ensuring it aligns with industrial manufacturing standards. Emphasis is put on the integration of user-friendly features and safety mechanisms into the machine's design in order to streamline operations and mitigate potential hazards for operators.

Aside from design considerations, the paper also delves into the practical implementation of the rubber-stamping machine within real-world manufacturing environments. This includes a thorough examination of its integration into existing production processes under testing conditions. Through experimental evaluations, key performance metrics such as cutting speed and throughput are analyzed to provide insights into the efficiency of the automated system.

Furthermore, the precision and consistency of products' dimensions produced by rubber-stamping machine are evaluated. The importance of the embedded system in controlling optimal temperature of the machine's operation is also discussed as additional insights on what is needed to maintain the machine's reliability. By offering insights and recommendations derived from these findings, this paper aims to contribute to the advancement of knowledge in automated manufacturing systems for rubber products.

In the majority of the rubber product manufacturing industry, the first step taken by the manufacturer is to cut the rubber sheets into a smaller desired shape. The rubber sheet needs to be cut into smaller pieces to prepare for the coming process. The existing stamping process used to cut rubber sheets is too time-consuming, low productivity and the product produced is inconsistent. The existing stamping process is done manually. In this paper, development of rubber-stamping machine is conducted. A new design for the rubber-stamping machine has been developed to fully replace the existing product. The stamping machine will fully take over the human work to increase productivity and increase the consistency of the product made. Finally, the stamping machine uses the control system to improve the efficiency of the machine. With this improvement, it will increase the effectiveness and sustainability of the entire process.

II. Literature Review

A. Overview

As of 2019, Malaysia holds the sixth position globally in both natural rubber production and exports, with a significant role in the rubber products industry. It is the world's largest consumer of natural rubber and the top producer of rubber gloves. In 2020, Malaysia achieved an annual export value of US$7.3 billion (RM29.8 billion) for rubber gloves, experiencing a 12%-year over-year growth due to increased demand amid the COVID-19 pandemic. However, an outbreak at top glove factories on November 25, 2020, adversely affected their trade. Malaysia contributes to 46 percent of the world's total rubber production, annually producing around 1- 5 million tons of rubber. Since the 1990s, rubber production has declined from 615,222 tons [3]. In August 2023, natural rubber (NR) exports totaled 57,488 tons, marking an 11.0% increase compared to July 2023 (51,784 tons). This growth is attributed to NR-based products such as gloves, tires, tubes, rubber threads, and condoms. Gloves, the primary export in rubber-based products, reached a value of RM1.0 billion in August 2023, reflecting a 9.4% increase from July's RM0.96 billion [4].

Stamping process which is also known as pressing process [5], is a procedure of product is produced by placing a flat and smooth sheet of material as input into the press and then large force was exerted to force and shapes the output products into desired shape. The emergences of metal stamping might just be found with the hammer 6 blows that blacksmiths used to shape or forge 15 metal for use as everyday objects. Although it seems very unlikely from shaping metal using a machine as we are doing today, the beginning of how a "ram", as the hammer was used to shape metal on an anvil which acting as the "bolster". Around roughly 2000 B.C., blacksmiths started to use stamping tools for metal forming and the civilizations began to produce their own coins using hand tool to "stamp" bronze, silver and gold that needed to relief of the coin etched in the die and punch. Rubber stamping is more favorable in mass production because a large quantity of products can be produced by using a single die.

This section gives a general introduction of the several metalworking techniques that are frequently used in the sector, with a focus on stamping press machines and their wide range of uses. Stamp press machines play a crucial role in the precise moulding of metal by die deformation, guaranteeing the production of 2D or 3D items with precise dimensions or shapes. Important procedures in metal working such as bending, embossing, drawing, punching, and cutting are covered in detail, along with their working mechanisms and applications. For example, embossing is used to create raised or recessed patterns on sheet metal, whereas bending is the process of forming shapes along a straight axis. Furthermore, cutting and punching procedures allow for the division of things and the formation of holes, respectively. Drawing uses tensile forces to stretch metal into desired shapes [6]. Figure illustrations accompanying each process provide visual clarity, enhancing understanding for readers.

The paper also discusses the difficulties and operational nuances that come with each metalworking process. For example, in bending processes, the material's natural tendency to return to its original shape because of residual stresses following deformation demands that bending angles and material properties is to be carefully considered [7]. Similarly, to prevent flaws like wrinkles or material breakage, drawing procedures need to carefully balance the stretch and flow of the material. The automation of metal forming procedures using CNC machines, which allows for exact control and customisation of produced shapes, is also covered in the debate [8]. Researchers and practitioners in the field of manufacturing and metalworking can gain useful insights from the practical examples and illustrations that further clarify the principles covered [9].

B. Stamping Machine

The stamping machine literature review covers a wide spectrum of studies and innovations targeted at improving many parts of the stamping operations [6]. Huang et al. [10] have developed a stamping monitoring system by capturing the signals in the stamping process and using one-dimensional convolutional neural network to classify the tool wear condition. Dzulfikri et al. [11] have integrated deep learning technique for fault diagnosis in stamping machines using a convolutional neural network (CNN) to analyze vibration and acoustic signals captured during the stamping process. These studies shed light on the complex procedures that go into creating press tools that are suited for tasks like piercing and blanking [12]. Furthermore, new developments in stamping technology are introduced by technologies such as pneumatic presses [13] and hot stamping press machines [14] . Each of these technologies focused on different priorities. For example, hot stamping press machines use many air cylinders to maximise pressure and efficiency, while pneumatic presses attempt to give maximum power with lowest space occupancy. Moreover, innovations such as burr-free shearing of thin metal sheets [15] and pneumatic shoe stamping machines offer creative ways to achieve burr-free shearing of thin metal sheets and stamping of trademarks on shoe heels, respectively.

C. Hydraulic Stamping Machine

Hydraulic stamping machine is one of the popular variants of stamping machine. In this class of stamping machine, hydraulic fluid is used as the working medium in hydraulic stamping machines with controllable valves to control the fluid. Based on Pascal's Principle, hydraulic systems ensure the transmission of force through confined spaces, enabling smooth movement of loads during lifting operations [16]. Beside control valves, the working principle of a hydraulic system involves pressure regulators, hydraulic cylinders, and an electrical motor that drives the hydraulic pump. These parts work together to control the flow and pressure of the hydraulic fluid to ensure machine's maneuverability, controllability, and accuracy[17]. Jancarczyk et al. [18] have proposed a vibration analysis in hydraulic presses using a three-axis accelerometer, data acquisition unit, and dedicated measurement software.

D. Mechanical Cutter

In the manufacturing sector, mechanical cutting techniques are essential because they allow for the accurate shape and manufacture of a wide range of materials. Drilling, milling, and turning are a few examples of the efficient and adaptable mechanical cutting techniques. Lathes are used in turning to remove extra material and shape materials into the required shape. Cutting fluid is frequently used to lubricate and regulate the temperature of the lathe's components. By regulating the movement of the table around a rotating blade, milling machines—whether CNC or NC—offer the capacity to produce complex and symmetrical designs. These mechanical cutting techniques such as sawing and turning are essential for creating a large variety of parts and goods that are utilised in many different industries [19].

The efficiency and adaptability of production processes are constantly being improved by advancements in mechanical cutting technology. Similarly, by allowing automatic tool changes during machining operations, The mechanical cutting technology has advanced significantly with these inventions, improving manufacturing processes' productivity, accuracy, and efficiency [20].

Nevertheless, there is still room for improvement in mechanical cutting instruments despite these developments. Even while they work, the current designs have drawbacks like a limited lifespan and the requirement for manual hammer action. Further developments in design and technology may result in the creation of cutting tools with increased robustness, effectiveness, and user-friendliness, expanding the potential of mechanical cutting in the manufacturing sector.

III. RESEARCH METHODOLOGY

Rubber testing is the process in which several variants of rubber are investigated to determine their mechanical and physical characteristics to help in designing a cutting tool for rubber stamping application. This evaluation is essential to figure out which rubber variety is most suited for stamping. The considerations include attributes like flexibility, abrasion resistance, hardness, thickness, and tensile strength. The gathered information is used to optimise the cutting tool's design and guarantee stamping efficiency. Performance analysis directs design changes towards flexibility and durability evaluations offer information about how well-suited the materials are for extended usage. Evaluations of chemical resistance and processability maintain quality assurance standards by ensuring rubber qualities that are consistent for efficient stamping applications. Through the methodical execution of these tests, the objectives are to choose appropriate rubber materials, improve the cutting tool's design, and guarantee its reliable operation in rubber stamping, thereby raising productivity, accuracy, and durability. Figure 1 shows the flowchart of the rubber testing.

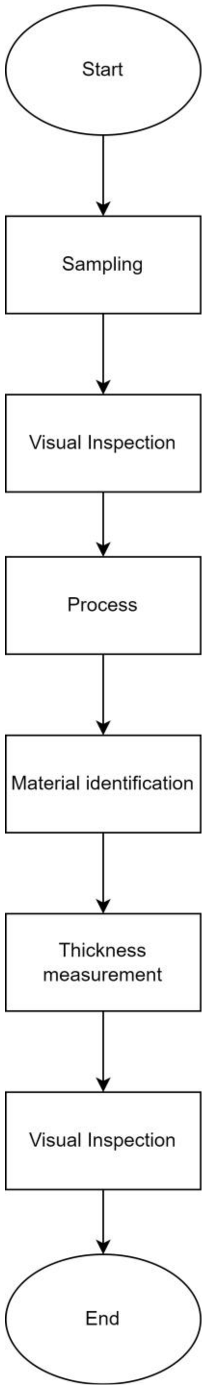

FIGURE 1. The flowchart of the process of rubber testing.

Autodesk inventor is a Computer Aided Design (CAD) software application which is commonly used to design a 3D mechanical structure. It can also be used for simulation of product and development of various tools. In this project, Autodesk Inventor is chosen as a drawing tool as it is easy to use and ease of learning. Autodesk Inventor is used to draw and assemble components of the stamping machine virtually before being produced for real.

The first thing to determine in designing the stamping machine is the jack system. For this, there are two options available; hydraulic and electrical jacks. Between these two, electrical vehicle jacks are deemed to be better suited to be integrated into the stamping machine. After a thorough examination of features including size, complexity, control, dependability, cost, efficiency, maintenance, and control, the electronic vehicle jack was determined to be the best option. Its highly accurate control location and small size fit in perfectly with the project's goals, ensuring the rubber-stamping system's best performance and optimal use of available space.

The structural stability and integrity of the machine frame for the rubber-stamping system are carefully considered in this research. To support machine’s whole body and stabilise the whole structure while in use, the choice of machine frame is essential. The material from which the frames are made needs to be strong enough to support both the jack's force and the weight of the machine's parts. To do this, the frame is made of hollow square metal bars that minimise weight while still being able to provide proper strength and longevity. A strong wooden board serves as a protective barrier between the frame and the rubber sheet, shielding the cutter from harm. The frame’s dimension is also designed to be able to firmly hold the car jack.

The cutter is undeniably an essential part in the rubber-stamping machine, similar to a die in a blanking machine. Thus, careful consideration is necessary in deciding what kind of material should be used as cutter head. The sharpness of the cutter head, which should be designed to cut through rubber sheets quickly and efficiently, determines how well the rubber-cutting process works. Heating rods, which are incorporated into the cutter head to improve cutting performance, are made possible by holes that are placed strategically to ensure uniform heating. The cutter head is assembled by fastening it to a circular plate with bolts and nuts. A compression spring guarantees that the cutter head will return to its initial position after use. Notably, mild steel is used for the cutter head because of its remarkable toughness and high impact resistance, which are necessary to withstand the compressive pressures that are present during machine operation. The strong characteristics of mild steel—such as its high melting point, yield strength, and ultimate tensile strength—guarantee the cutter head's durability and dependability, keeping it in shape and functioning for a longer period.

The cutter head is tightened on to the round plate by bolt and nuts. The round plate is then fixed to the hydraulic jack by welding. This round plate will link the cutter head with the electrical car jack for the machine operations. The alignment of the cutting head, round plate and the car jack is the most essential process of the fabrication. The round plate is fabricated with mild steel and has an extruded feature to fix the position of the spring. Figure 2 shows the mechanical cutter head.

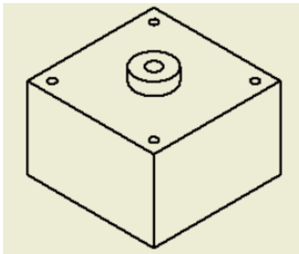

FIGURE 2. Mechanical cutter head.

Compression springs are staples in the field of mechanical engineering. They are made of an open-coil helical structure that is intended to withstand axially applied compressive stresses. Compression springs are versatile and can be configured to meet a wide range of mechanical needs. Some of the shapes that they can be available in are constant diameter cylinders, conical, concave, or convex patterns. These springs, which are usually fastened to a rod or inserted into a hole, compress, and shorten when pressure is applied. This stores potential energy, enabling the springs to return to their initial state when the force is released. Compression springs are essential to the rubber-stamping machine project because they allow the cutter head to return to its original position following each operation. This ensures the efficient and precise functioning of the machine, contributing to its overall reliability and performance [21]

It can be seen from a comparative study of mechanical properties that mild steel has a higher ultimate tensile strength and yield strength than aluminium 6061. These characteristics are crucial in figuring out a material's resistance to stress and deformation, which helps to maintain the structural integrity of parts like machine frames. Table 1 shows the comparison between the three most crucial properties between mild steel and aluminium 6061. Table 1 shows the comparison between the three most crucial properties between mild steel and aluminum 6061.

TABLE 1. Comparison between the three most crucial properties between mild steel and aluminum 6061.

Materials properties	Density (g/cm3)	Yield Strength (MPa)	Ultimate Tensile Strength
Mild steel	7.85	215-250	410-500
Aluminium 6061	2.70	55	124

A sturdy machine design is highly dependent on the choice of the materials of the frame. Under extreme stress, materials can deform or crack. Therefore, it is important to choose material with high yield and optimal tensile strength. This is the consideration that leads to the use of mild steel material over aluminium 6061 since even though the latter has low density, it has lower strength and durability compared to mild steel. By prioritizing strength and durability, the selection of mild steel guarantees the frame's capability to support the machine's weight and endure the forces encountered during operation.

To optimize the cutting process and reduce tool wear, the temperature of the cutter head is carefully regulated. An Arduino microcontroller is integrated into the machine to facilitate precise temperature control. The Arduino uses sensors to monitor the cutter head temperature in real-time and adjusts the heating elements to maintain optimal levels. This automated system ensures consistent cutting performance, minimizes the risk of overheating, and allows for seamless integration with other machine components, thereby enhancing overall efficiency and precision in the cutting process. Figure 3 shows the flowchart of the temperature control system.

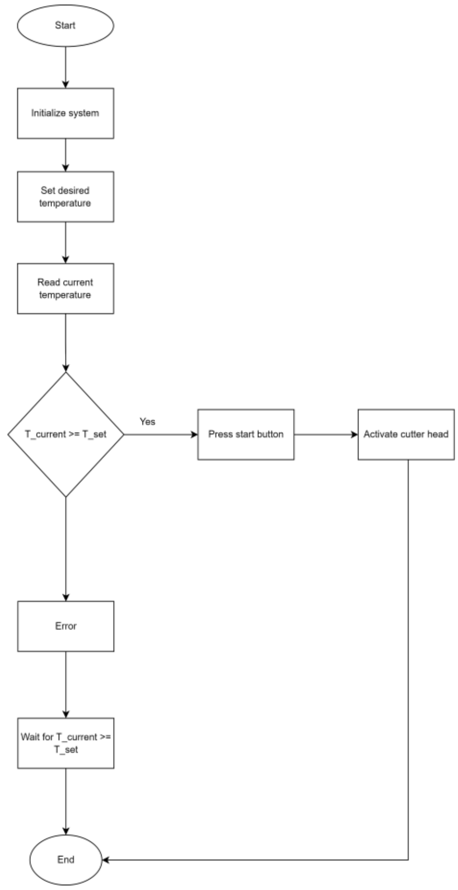

FIGURE 3. Flowchart of temperature control system.

The rubber-stamping machine's temperature management system comprises several crucial elements that collaborate to precisely control the cutter head's temperature. An Arduino board is the brain of the system here. This choice is due to how this board and its variants have been proven to be adequate for computational and control purposes such as the ones in [31] and [32]. As mentioned earlier, we will use a thermistor to read the temperature. This reading becomes the input for Arduino which controls the on/off of the heater operation. The Arduino's output side is connected to the relay modules, which are used as controlled switch to initiate and terminate the heat generation. In addition, a 12V AC to DC power supply powers the Arduino board, the heater, and the electronic car jack by converting AC current to DC. The system's flawless integration of these parts guarantees accurate temperature regulation of the cutter head, improving the efficacy and efficiency of the rubber cutting procedure.

IV. RISK ASSESSMENT

In order to run proper experiments, a series of safety precautions are implemented to avoid accidents related to electricity, heating element, and moving elements on the operator. Dangers due to electrical failure is prevented by using protection devices, properly grounding and insulating components such as Arduino board and power supply. The operator is also trained through proper standard operating procedure to safely work with the machine, including but not limited to the moving parts, how to handle the heating element of the machine, and the protocols for emergency response.

V. EXPERIMENT PLAN

Three different rubber materials; A, B,C and D with thickness of 3 mm, 5 mm,10 mm, and 20mm respectively, are assessed as part of the experiment. In order to determine if a rubble sample is suitable for the rubber-stamping application, each one goes through several phases of test. First, each rubber category is identified by through visual inspection. Next, important physical parameters like hardness, tensile strength, elongation at break, and compression set are measured. Then, abrasion resistance testing is performed to asses rubber samples' durability under stamping operation. Chemical resistance test is also performed to evaluate their resilience to compounds involved in stamping process.

To ascertain the materials' performance over time, climatic and thermal studies will replicate long-term use scenarios. Through an examination of the rubbers' viscoelastic characteristics, Dynamic Mechanical Analysis (DMA) will shed light on how the materials behave under various stress and temperature scenarios. The goal of methodically carrying out these tests is to determine the ideal rubber composition and thickness for rubber stamping applications, guaranteeing the best possible performance, robustness, and efficiency during the stamping process.

VI. CONCLUSION

A. Assembled Rubber Stamping Machine

After careful considerations especially with the choice of materials, the rubber-stamping machine is constructed with the help of Autodesk Inventor. The machine consists of several parts including but not limited to the round plate, compression spring, and mechanical cutter head. The round plate facilitates accurate cutting operations by acting as a vital contact between the mechanical cutter head and the rest of the machine. The use of a compression spring ensures the smoothness and prevision of the cutter head. Mild steel is used as the material for the frames to support the whole machine firmly.

B. Results of Rubber Stamping

A few experiments were conducted to test the practicability of the machine. For the stamping machine to become practicable, the stamping machine must have to cut the rubber sheet successfully. The experiments are conducted under several conditions so that the optimum working parameters of the machine can be determined. There will be higher probability that the final product can be consistent if the machine work in its optimum working parameters. Table 2 shows the result of the rubber material after undergoing the cutting process, which was executed at the appropriate temperature for varying thicknesses of rubber. The 3 mm and 5 mm thickness of rubber has 100% success rate at 50 ˚C and 60 ˚C. All the thickness rubber has less than 100% success rate when the cutter head temperature is 40 ˚C. For the 10 mm and 20 mm thickness rubber with 60 ˚C of cutter head has more than 50% success rate to cut through the rubber. The cutting process was carefully adjusted to ensure optimal outcomes for each rubber thickness, yielding precise and clean cuts. This highlights the machine's capability to handle different material dimensions effectively, resulting in a consistently high-quality final product. The adjustments made to account for different rubber thicknesses ensured that each piece was cut accurately, reflecting the machine's versatility and efficiency. Figure 4 shows the result of the rubber material after undergoing the cutting process.

TABLE 2. Type of Different Working Conditions for the Stamping Machine.

Thickness of rubber	Temperature of cutter head (˚C)	Number of successes within 10 tries
3mm	40	8
	50	10
	60	10
5mm	40	5
	50	10
	60	10
10mm	40	2
	50	2
	60	7
20mm	40	0
	50	0
	60	7

FIGURE 4. Result of the rubber material after undergoing the cutting process in required temperature.

The time taken for the temperature of the cutter head to reach the desired temperature is record over ten trials. This is to observe the heating times were representative. Table 3 shows the average time for the cutter head to reach the desired temperature. The results show a consistency in the time required for the cutter head to reach the desired temperature across the ten trials. The cutter head required 55 seconds to hit 35 °C required 345 seconds to hit 80 °C. The temperate at 25 °C required 0 seconds to hit because the room temperature is more than 25 °C. Figure 5 shows the graph of time to heat the cutter head against the temperature.

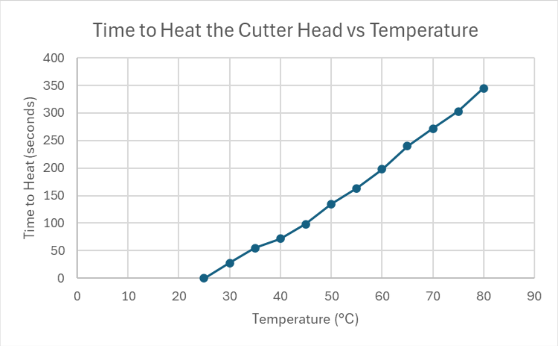

FIGURE 5. Time to heat the cutter head against temperature.

C. Discussion

A comprehensive approach to the development and design of a rubber-stamping machine is presented by the thorough examination of the hydraulic stamping machine, mechanical cutter, fuzzy logic application, car jack selection, machine frame design, cutter head fabrication, compression spring integration, material selection, temperature control system, and stress analysis. Every part and procedure that is covered has a distinct contribution to the machine's dependability, effectiveness, and functioning.

TABLE 3. The average time for the cutter head to reach the temperature.

Temperature (°C)	Average Time to Heat (seconds)
25	0
30	28
35	55
40	72
45	98
50	135
55	163
60	198
65	240
70	272
75	303
80	345

The core of the stamping machine is the hydraulic system, which is powered by Pascal's Principle and provides exact control over the stamping operation. Its combination with a controllable valve guarantees top performance in a range of scenarios. The mild steel mechanical cutter is made to be strong and resilient, which is necessary to bear the pressures during stamping operations. A compression spring is used to guarantee steady machine operation. The choice of material, especially mild steel as opposed to aluminium, is to further ensure the structural robustness and stability of the machine, especially in handling the stamping forces. Temperature monitoring and control system is integrated to the cutter head's heating components. Monitoring is achieved through thermistor, while Fuzzy Logic Control (FLC) is implemented in Arduino. The output of FLC is executed with the help of relay module. This whole system ensures the cutter head to always be in the optimal temperature during the machine operation.

VII. Conclusion

This paper presents a new development in the field of rubber-stamping gear. By means of an all-encompassing methodology that includes hardware design through Autodesk Inventor, material selection, and rigorous analysis, a sturdy and easily manipulable machine has been created. The machine comprises of a sturdy mild steel-based frame, and temperature-controlled cutter head to ensure reliability of the machine. A Fuzzy Logic Control is implemented in Arduino board with thermistor at the input side to monitor cutter head's temperature, and a relay on the output side to turn on and off the heating process of the cutter head. This way, optimal temperature is always ensured to achieve optimal rubber-stamping products.

All things considered; the project's results show how well theoretical ideas may be translated into practical solutions. For enterprises dependent on these kinds of operations, the rubber-stamping machine is a useful tool since it can precisely cut rubber sheets into the desired forms. The knowledge gained from this project will be applied going forward to additional improvements in machinery design, with an ongoing emphasis on raising user satisfaction, productivity, and efficiency.

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Author Contributions

Maanoj Nair: Writing – Original Draft Preparation;

Kai Jie Low: Writing – Review & Editing;

Kai Liang Lew: Writing – Review & Editing;

Iksan Bukhori: Writing – Review & Editing;

Suleiman Aliyu Babale: Writing – Review & Editing;

Chia Shhyan Lee: Writing – Review & Editing;

Conflict of Interests

No conflict of interests were disclosed.

Ethics Statements

Our publication ethics follow The Committee of Publication Ethics (COPE) guideline. https://publicationethics.org/

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