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Prototype of Eco-Pounding Machine with Snail-Disc Mechanism and Electric Motor Drive

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Abstrak.
Eko-pounder semakin umum digunakan dalam industri mode, terutama di kalangan Usaha Kecil Menengah (UKM). Namun, proses manufakturnya lambat, melelahkan, dan berisiko cedera. Makalah ini mengusulkan desain mesin eko-pounder menggunakan piringan siput dan mekanisme motor. Strukturnya dianalisis per komponen dalam hal analisis statis dan kelelahan. Dari analisis statis, kunci adalah komponen paling kritis dengan faktor keamanan statis sebesar 18.1. Sementara itu, dari analisis kelelahan, batang penghubung adalah komponen paling kritis dengan faktor keamanan kelelahan sebesar 13.7. Semua komponen memiliki umur tak terbatas.

Kata Kunci: *Eco-pounding machine*, *snail-disc*, analisa kekuatan struktur.

Abstract.
Eco-pounding is becoming more prevalent in the fashion industry, especially among Small Medium Enterprises. However, its manufacture process is slow, tiring, and injury prone. This paper proposes an eco-pounding machine design using a so-called snail-disc mechanism and electric motor drive. Its structural strength is analyzed per component in terms of static and fatigue analysis. From static analysis, the key is the most critical component with static safety factor of 18.1 Meanwhile, from fatigue analysis, the rod is the most critical component with fatigue safety factor of 13.7. All components have an infinite life.

Keywords: Eco-pounding machine, snail-disc, structural strength analysis.

INTRODUCTION

Eco-printing is essential in fabric printing for environmental sustainability [1]. Interior, merchandise, and textile design all have a place in the sphere of art and design's development of sustainability. Environmental issues, namely, how to make clothing that decomposes without harming the environment, are one of the topics that are currently emerging and in demand in the textiles industry this is known as eco fashion [2]. The plants used are plants which have a high sensitivity to heat, because it is a key factor in extracting color pigments [3]. It incorporates compressing plant materials onto a fabric and extracting pigments from leaves to create unique designs and patterns [4]. Since it uses natural materials, eco-printing is viewed as an environmentally friendly alternative to traditional cloth printing. Furthermore, according to a survey conducted in 2022, there is an increase of 20 percent of consumer's willingness to purchase sustainable products [5]. The rise of eco-printing has developed more sustainable and innovative methods in the fashion industry including circular fashion and eco-friendly fashion [6]. The global sustainable fashion market size is expected to reach $8.25 billion by 2023 and is rapidly expanding which further empathize opportunities for new enterprises to develop their businesses [7]. Since the demand for sustainable products is high, eco-printing has a promising potential for profitability in the market. This gives an immense potential for businesses, particularly Small Medium Enterprises (SME's), to manufacture profitable eco-printing products.

Within the eco-printing spectrum, there are various eco-printing procedures that provide varying levels of quality. One of the techniques is called eco pounding. Eco pounding allows leaves pigments to be transferred simply by the pounding motion [8] Also, eco pounding enables the user to print many designs on the fabric using the same leaves, unlike other techniques that require onetime use leaves. This process allows an aesthetic touch to the fabric cloth while also achieving the highest and longest-lasting pattern designs [8]. For these reasons, the eco-pounding technique is preferred.

The employees that perform the eco pounding technique must pound the fabric by hand for an extended period. Unfortunately, conducting such repetitive tasks pose a significant risk for both the physical and mental health of the workers. Physically, repeating the same movements for an extended period may result in conditions such as tendinitis, peritendinitis, and carpal tunnel syndrome [9]. The same repetitive action has a negative impact on employees' mental health, leading to extreme boredom and increased risk of depressive systems, which causes them to feel demoralized and have a fervent desire to quit their jobs [10]. Aside from potential danger to health, eco pounding technique yields a slow production rate, and at the same time, the demand for the products keeps skyrocketing. This is because of the pounding approach that still relies on human workforce. The manual workload is highly inefficient, and thus an automatic system is needed as requested by SME's.

As a response to the workers and SME's concern, this work proposes a design of automatic pounding machine that works more efficiently than human workload, while still preserving the workers' artistic value to the fabric.

METHODOLOGY

Design Process

For creating eco-pounding, this report follows Shigley's design process. To ensure that the product is satisfying, some phases must be iterated over until the desired requirements are achieved. To start off with the project, some information must be needed through research and literature review.

In the process of identifying the problem definition, the eco pound techniques need to be done properly to maintain the look and the aesthetic of the product. Based on Sheyla 's research, the number of times a person could pound the hammer are determined by both quantitative and the skill of the person itself [8].

While making a lot of adjustments, the problem definition can be decided, and the design concepts are displayed. From this stage onwards, the selected design is chosen and analyzed under static and fatigue loading. Optimization is done if the design does not meet the criteria of safety, or it is too redundant. When this stage is done, the prototype is expected to be created and presented in front of the SME as a completion of the design process.

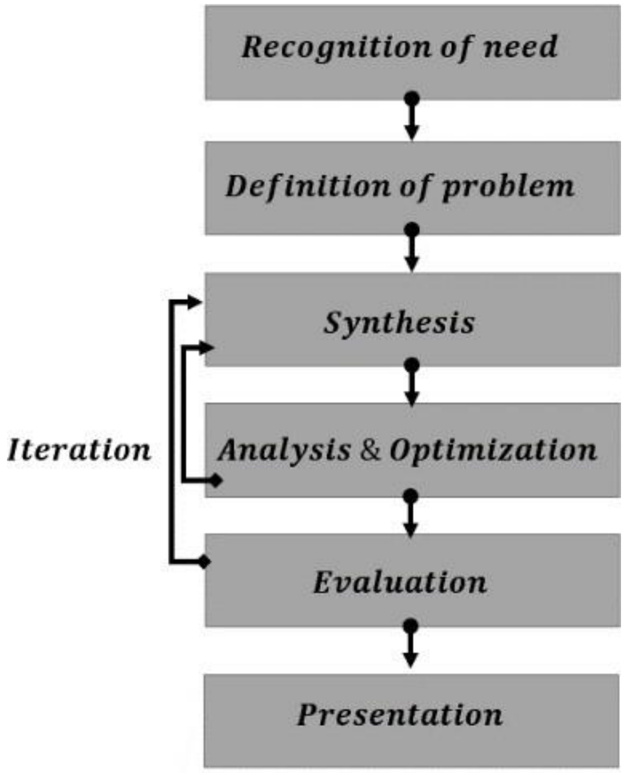


Figure 1. Phase of design process

Synthesis

Over the past month, our team has brainstormed about the suitable design for the Eco Pounding Machine that will be potentially used by SME for a more efficient pounding technique. A disc with a snail shape, so-called snail-disc mechanism is proposed as the final candidate for the design.

The shaft connected to the motor receives torque from the motor and rotates the disk, causing the small connecting rod above it to move the long vertical piston upward. This upward motion compresses a spring, which continues until the disk hits a slope, causing the vertical piston to slam down to the base. The disk then rotates again, moving the piston upward with the help of the spring, creating a pounding mechanism that repeats until the motor is turned off.

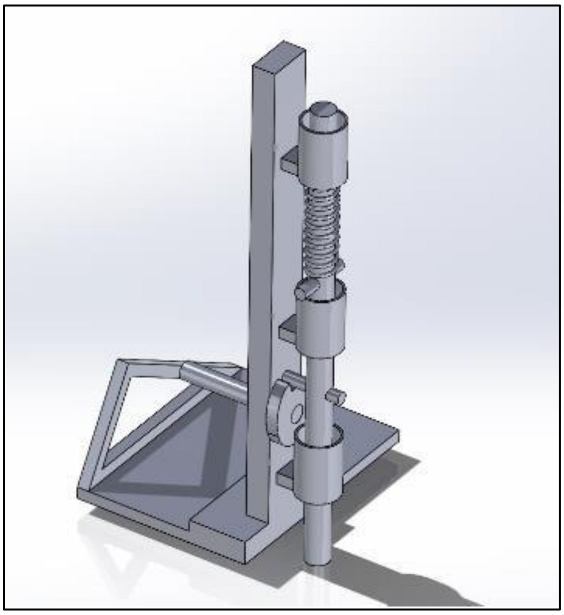


Figure 2. Snail disc mechanism and electric motor drive

Manufacture

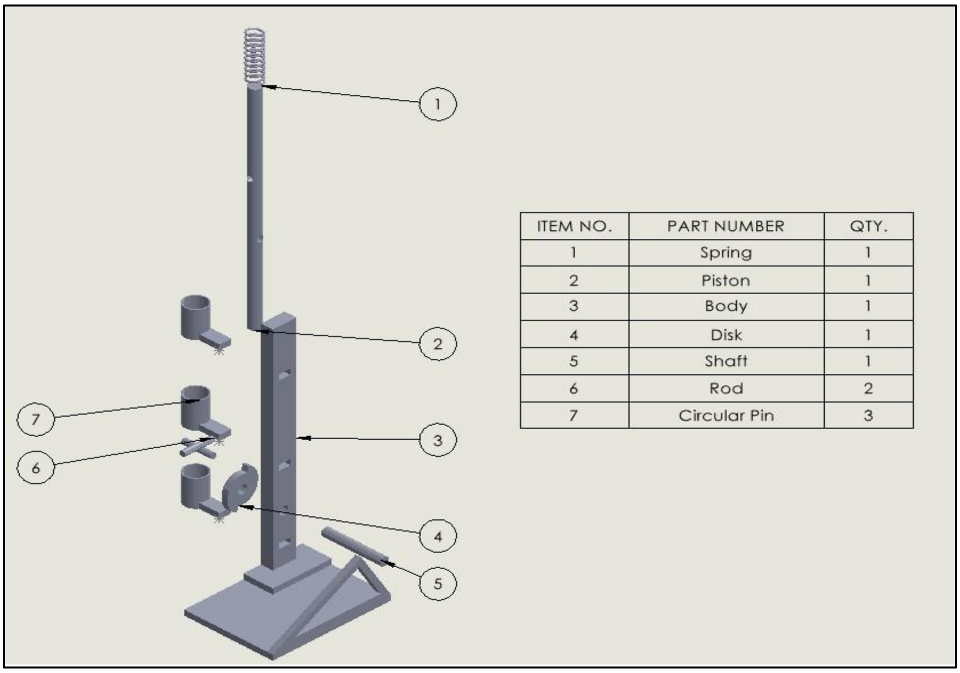
The standard manufacturing process of each part is listed in Table 1. Most of the materials are already commercialized and quite common in the market minor, and only minor machining is required to manufacture the parts. The only exception is the disk which required a specific die to be manufactured.

Table 1. Parts and manufacturing process.

No	Part	Material	Number of Item	Standard Manufacturing Process
1	Piston	S45C	1	Cold Roll
2	Rod 1 & 2	S45C	2	Cold Roll
3	Body AL2080	Aluminum	1	Extrusion
4	Bearing SK 12	Aluminum	1	Machining
5	Bearing SCS 12	Aluminum	2	Machining
6	Hammer Rubber	Rubber	1	Extrusion
7	Hammer Plastic	Plastic	1	Extrusion
8	Disk	S45C	1	Die Forging
9	Piston	S45C	1	Cold Roll
10	Body	Aluminum 2080	1	Extrusion
11	Base	Aluminum 2080	1	Extrusion
12	Spring	Aluminum	1	Cold Roll
13	Key	Steel 304	1	Cold Roll

Finalized Design Component

There are a lot of components that make up the machine. To understand each type of component, the exploded view of the design for eco pounding machine is displayed in Figure 3. Using smart dimension in SOLIDOWRKS, the dimension of each component is labelled on the table beside.



ITEM NO.	PART NUMBER	QTY.
1	Spring	1
2	Piston	1
3	Body	1
4	Disk	1
5	Shaft	1
6	Rod	2
7	Circular Pin	3

Figure 3. Exploded view of the design

Figure 4 shows the prototype after fabrication that will be used for demonstration. Some adjustment on the components shape were applied so that it can be assembled. The plastic components were made by 3D printing and some parts were made by metallic material such as steel and aluminum.

Figure 4. Machine prototype

Formula for Static and Fatigue Analysis

To conduct the analysis, firstly FBD analysis is performed, followed by static stress analysis, and then fatigue analysis. The equations to aid with the analysis are listed below [11].

Free Body Diagram Analysis

$$\sum F_x(\rightarrow +) = 0 \tag{1}$$

$$\sum F_y(\uparrow +) = 0 \tag{2}$$

$$\sum M(\circlearrowleft +) = 0 \tag{3}$$

Static Analysis

$$\sigma = \frac{32M_{Max}}{\pi d^3} \tag{4}$$

$$\tau = \frac{16T}{\pi d^3} \ or \ \frac{3V}{2A}\ (rectangular) \tag{5}$$

$$\sigma_{max,min} = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} \tag{6}$$

$$\tau_{maximum} = \sqrt{\left(\frac{\sigma_m}{2}\right)^2 + \tau_m^2} \tag{7}$$

$$\sigma'_{max} = \left[\left(\frac{32K_f M_a}{\pi d^3}\right)^2 + 3\left(\frac{16K_{fs}T_m}{\pi d^3}\right)^2\right]^{\frac{1}{2}} \tag{8}$$

$$n_y = \frac{S_y}{\sigma'_{max}}\ (Conservative) \tag{9}$$

Fatigue Analysis

$$S_e = k_a k_b k_c k_d k_e k_f\ S'_e \tag{10}$$

$$\frac{1}{n} = \frac{16}{\pi d^3}\left(\frac{1}{S_e}\sqrt{4\left(K_f M_a\right)^2 + 3\left(K_{fs}T_a\right)^2} + \frac{1}{S_y}\sqrt{4\left(K_f M_m\right)^2 + 3\left(K_{fs}T_m\right)^2}\right)\ (Soderberg) \tag{11}$$

RESULTS And DISCUSSION

Free – Body Diagram Analysis

Figures 5 to 9 display the engineering drawings of selected parts that are whose units are centimeters along with their respective free-body diagram (FBD).

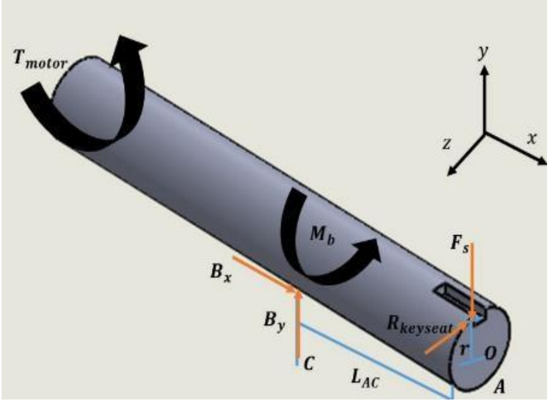


Figure 5. Shaft's free-body diagram.

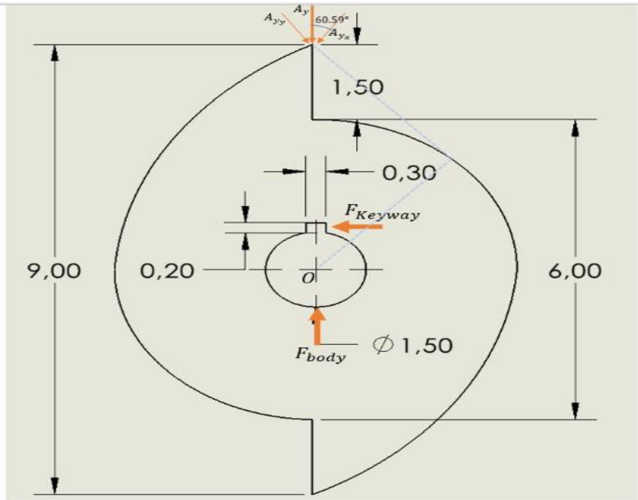


Figure 6. Disk's free – body diagram

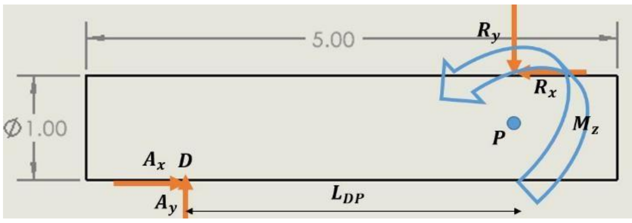


Figure 7. Rod's free – body diagram

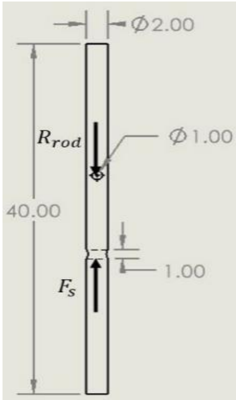


Figure 8. Piston's free – body diagram

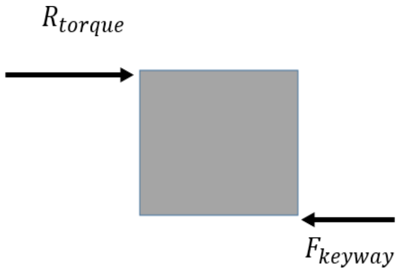


Figure 9. Key's free – body diagram

Before doing the analysis, some forces are predetermined. Spring force, F_s, is determined by subtracting the approximated pounding force with the weight of the piston. Meanwhile, based on the specification, the motor has a speed of 200 RPM and power of 12 W. This specification can be used to calculate for the motor's torque, T_{motor}. Table 2 shows the calculated value from FBD analysis.

Table 2. Results of FBD Analysis.

No	Force/Moment/Torque	Value
1	F_s	5.76 N
2	B_y	
3	R_{rod}	
4	T_{motor}	1.0028 Nm
5	M_z	-1.59 Nm
6	A_y	-106.1 N
7	F_{body}	

8	R_y	
9	F_{keyway}	133.7 N
10	$R_{keyseat}$	
11	R_x	-133.7 N
12	A_x	
13	B_x	0 N
14	M_b	0.1152 Nm

Shear Force Diagram (SFD) and Bending Moment Diagram (BMD) of Critical Parts

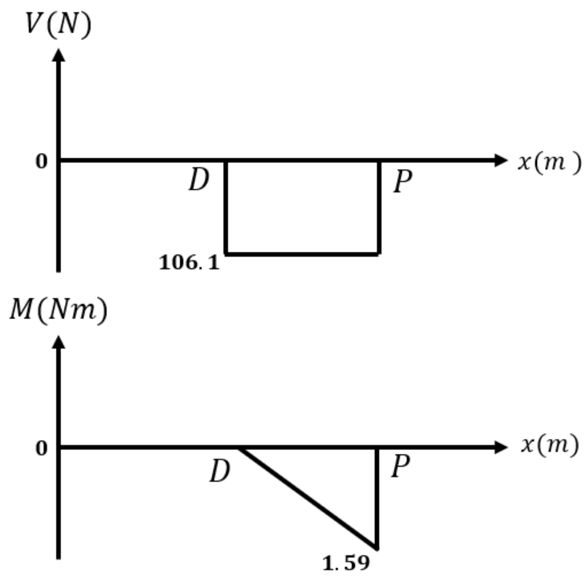


Figure 10. SFD (top) and BMD (bottom) of rod.

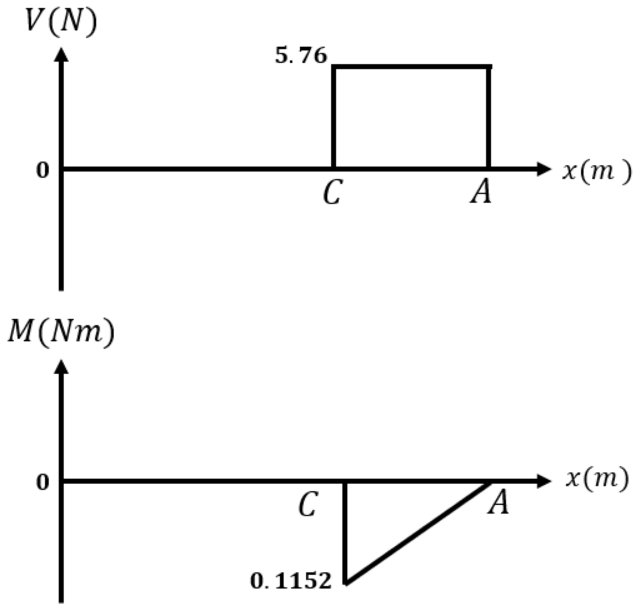


Figure 11. SFD (top) and BMD (bottom) of shaft in x-y axis.

Stress Analysis

After the FBD analysis, the stress components for each part can be obtained by considering the stress concentration factor and applying equations (4) to (8). Tables 3 and 4 display the stress concentration factors and the principal stresses of each part. Since the rod has no discontinuity, the stress concentration factors k_t and k_{ts} are set to be unity.

Table 3. Stress concentration factors of selected parts.

Part	k_t	k_{ts}	k_f	k_{fs}
Rod	1	1	1	1
Shaft	2.14	3	1.66	2.2

Table 4. Mid-range and alternating stress of components.

Part	Principal Stress (MPa)		
	σ_m	σ_a	τ_m
Rod	8.11	8.11	0
Shaft	0.58	5.77	0
Key	0	0	11.1

Static Analysis

Using equation (9), the safety factor of each component under static loading is listed here in Table 5. Static safety factor of critical components.

Table 5. Static safety factor of parts.

Component	Safety Factor
Rod	21.2
Shaft	54.1
Key	18.1

For the components, the typical factor of safety ranges is 3-5 for rods, 10-12 for shafts, and 1.5-2 for keys [12], [13]. By comparing these ranges with Table 3, the calculated safety factors for these components are all within the recommended ranges, indicating they meet the required safety standards. Therefore, all parts are considered safe under static loading conditions.

Fatigue Analysis

By applying equations (10) and (11), the endurance limit and fatigue safety factor using Soderberg failure criterion is calculated in Table 6 and 7.

Table 6. Ideal endurance limit of parts.

Critical Part	Ideal Endurance Limit (MPa)	k_a	k_b	k_c	Endurance Limit (MPa)
Rod	284.5	0.8396	0.969	1	231.5
Shaft	284.5	0.8396	0.928	1	221.7

Table 7. Fatigue safety factor of parts.

Part	Safety factor	Life prediction
Rod	13.7	Infinite life
Shaft	51.8	Infinite life

As the fatigue safety factor for both components are very much higher than one, the components are expected to have infinite life. Despite that, optimizations must be conducted to reduce redundancy or overly expensive materials since the safety factor is too high.

Budgeting

Using the dimensions mentioned in the design, the cost of the machine can be calculated. Based on Table 8, the total material cost is Rp 419.500. This amount is important for ensuring the project stays within budget and does not cost more than planned.

Table 8. Part's dimensions and material cost.

No	Part	Dimension	Price (Rp)
1	Crank Shaft	D: 15 mm L: 500 mm	45.000
2	Rod 1	D: 10 mm L: 40 mm	12.000
3	Rod 2	D: 10 mm L: 40 mm	12.000
4	Disk	D: 90 mm T: 10 mm	30.000
5	Piston	D: 20 mm L: 400 mm	90.000
6	Body	V slot 2080 L: 400 mm	80.000
7	Base	V slot 2080 L: 150 mm	10.000
8	Key	L: 3.5 mm H: 4 mm	500
9	Spring	ID: 12 mm T: 1 mm L: 100 mm	20.000
10	Motor	L: 77 mm H: 25 mm D: 6 mm	120.000

Optimization

Based on the analysis above several improvements can be optimized for the design. Many aspects have been thoroughly considered in designing the machine from the primary and secondary specifications. Minor improvement and external features can also be applied to the needs and conditions.

The first improvement that can be applied is its compactness. From the design shown in Figure 3, the mechanism is mostly located in a single body while the rest is attached to the base including the handle. For the base itself, a foldable construction can be considered since the functionality of the base is only used as a holding structure which can be interchangeable in accordance with the needs and conditions.

The handle itself is also customizable which can be made in along with the preference and necessity. The handle could be made using the 3D printing technique, the best way to minimize cost while also providing a suited match with conventional 3D print is using the prototype of 3D Printing H – Bot [14]. However, it came with another issue such as the lack rigidity due to the axis brackets and heavily dependent on arrangement [14].

Next is the mechanism itself which is a disk, piston, and rod. In this analysis the friction is assumed to be negligible. The friction could be reduced by using coating material. The material will be based on the reference, the material name is poly(N-isopropylacrylamide) pNIPAM-based cationic microgels, this coating will work as macromolecular lubrication this will promote the use of the frictionless area [15].

The addition of bearing to the contacted rod can also be considered [16]. However, the mechanism must be adjusted since adding bearing might prevent movement in the mechanism.

The material of the mechanism can also be changed to reduce cost or decrease the machining time of the mechanism. The materials for the mechanism are used is the AISI 1020 – Cold Drawn, this is a low carbon steel that is mostly used by industrial driver [17], which is the motor, can also be improved using a more powerful motor with higher torque to optimize the speed of the pound.

Since the static and fatigue factor is too high, there will be adjustments by changing the material with lower yield or ultimate strength or changing dimensions to increase the maximum stress experienced by the component.

Conclusion

In this work, a prototype of eco-pounding machine with snail-disc mechanism and electric motor drive has been successfully developed and manufactured. The design process started as the fixed position and later changed into a more flexible kind of approach. It could be moved around the edge of the cloth with ease based on the design. The component of the prototype will be manufactured and bought from the commercial store. Based on static analysis, the most critical part is the key, with a static safety factor of 18.1. Meanwhile, from fatigue analysis, the rod is the most critical part with a fatigue safety factor of 13.7. All the components are expected to have an infinite life. In the future, this prototype can be optimized by performing several modifications.

The design compactness can be enhanced by using foldable mechanism for the base. The handle can be customized by utilizing H – bot 3D print. To reduce friction, the components (disk, piston, and rod) can be coated using pNIPAM – based cationic microgel. The piston's mobility can be enhanced by adding bearing. To save cost and manufacturing time, the material of the prototype can be changed with AISI 1020- Cold Drawn. Lastly, a motor drive with higher torque could optimize the pounding speed.

Acknowledgement

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