Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 5	Month	: October
p-ISSN	: 1693-5462	Volume	: 22	Year	: 2024

Article Processing Dates: Received on 2024-04-17, Reviewed on 2024-05-17, Revised on 2024-10-01, Accepted on 2024-10-04 and Available online on 2024-10-30

Design and implementation of a microcontroller-based aluminum can pressing machine using a lead screw mechanism

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Abstract
The beverage industry is experiencing significant growth, yet the management of aluminum can waste continues to rely on manual methods, such as stepping on or striking cans to reduce their volume. Utilizing the Ulrich method, this development process involved identifying machine requirements, selecting design concepts, and embodying the design. Ultimately, the design concept 2 was chosen for its effectiveness. Subsequently, planning, calculations, and analyses were conducted to identify the core and supporting components necessary for constructing the machine. The next stage involved creating detailed drawings of the machine, followed by fabrication and testing. During testing, the can pressing machine demonstrated the ability to exert a maximum load of 20,110.5 N, with a torque of 220.990 Nm and a power output of 0.5 HP (356.95 watts). The PZEM-004T microcontroller was utilized to monitor the operational control of the electric motor. The machine successfully reduced the volume of cans by 56.5%, decreasing their initial height from 345 mm to 150 mm, and it is capable of processing 75 cans per minute. This design not only optimizes space but also enhances operational efficiency, providing a practical solution for can waste management in the beverage industry.

Keywords:
Aluminium cans, Ulrich method, presses, machine design, microcontroller, machine testing.

1 Introduction

In its development, aluminum cans have become a sought-after material for waste collectors, who sell them to scrap dealers for reprocessing in factories to create new materials. Recycling can be defined as the process of creating a new product from materials that have been used and discarded; for example, a used aluminum beverage can.

In the city of Surabaya, collectors of used beverage cans, including those in the North Medayu area of the Rungkut sub-district, still employ manual methods for processing can waste. This involves compacting cans by stepping on them or striking them with a hammer or other tools. Such practices pose risks, as the impact from stepping on or repeatedly hitting the cans can lead to injury. According to research studies, aluminum recycling can save approximately 60% of landfill space. If most aluminum used is recycled, it helps conserve natural resources. Additionally, the energy required to produce new aluminum is significantly reduced through the recycling process. The environmental benefits of aluminum recycling include a reduction in pollution levels [2].

Based on observations and literature studies, the concept of developing an aluminum can pressing tool powered by environmentally friendly electric motor technology has emerged. In addition to utilizing electric motor power, the design of this can pressing machine incorporates the compressive force of a threaded shaft or lead screw.

With this approach, the researcher aims to reduce accumulated can waste through the implementation of a modern can pressing machine, supplemented by a PZEM-004T sensor capable of measuring voltage, current, power, and energy from alternating current.

With the description, the researcher will reduce the accumulated can waste and alternative can waste, by using a more contemporary can pressing machine and accompanied by a PZEM-004T sensor which is a sensor that can measure voltage, current, power, and energy from alternating current.

2 Research Methods

2.1 Design Drawings

Fig. 1 is a design drawing of a can pressing machine utilizing a lead screw.

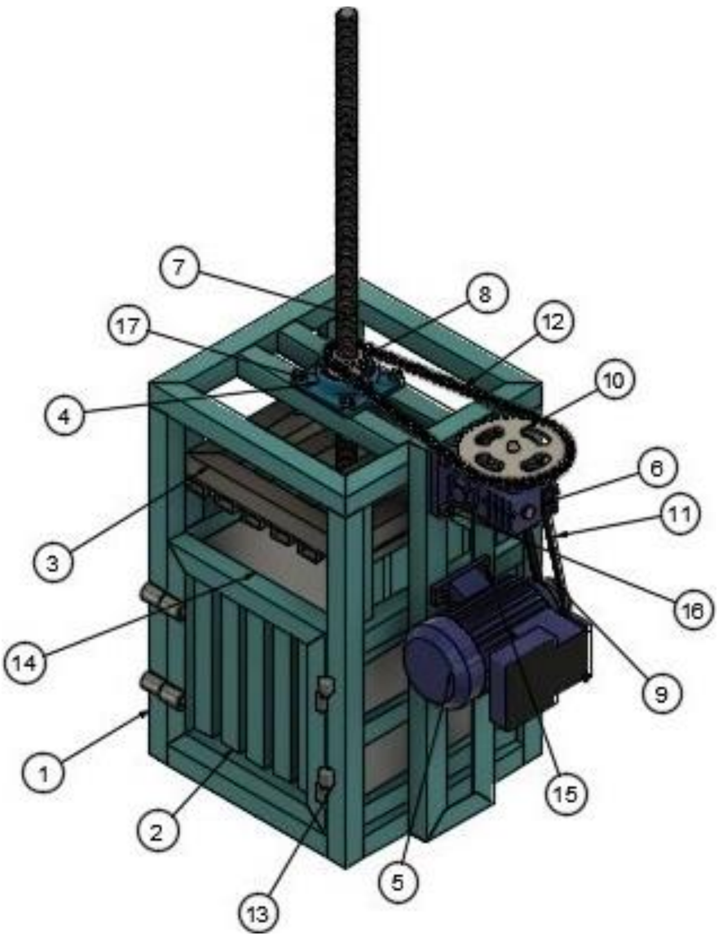

Fig. 1. Design sketch of a tin can pressing machine utilizing a lead screw.

Description:

1. Frame	10. Sprocket gear 43T
2. Bottom plate	11. Vbelt
3. Pressing plate	12. Chain
4. Pillow block	13. Door hinges
5. Electric motor	14. Door
6. Gearbox	15. Bolts & nuts M10 motor
7. Lead screw	16. Bolts & nuts M14 gearbox
8. Sprocket gear 15T	17. Bolts & nuts M14 pillow block
9. Pulley	

2.2 Tool Working Principle

The pressing room has a capacity of 355 mm × 355 mm × 367 mm. It can accommodate approximately 75 incoming cans per press cycle. This machine is designed with an electric motor drive that employs a pulley and sprocket gear for power transmission, along with a gearbox to reduce the motor's high rotational speed. In operation, the cans are compressed by a pressing plate connected to a screw mechanism, resulting in a gradual reduction in their volume. The process continues until the volume of the cans aligns with the predetermined calculations.

2.3 Tools and Materials

The tools and materials that will be used in the manufacture of can pressing machines by utilizing lead screw as shown in Table 1.

Table 1. Tools and materials

Tools	Materials
Welding machine	Hollow profile 35×35×1.2 mm
Grinding machine	Elbow profile 35×35×2.5 mm
Drilling machine	Iron plate
Elbow	Iron shaft
Lathe machine	Pulley
	Vbelt
	Sprocket gear
	Chain
	Reducer
	Electric motor
	Bolts and nuts

2.4 Manufacturing Process

In making the can pressing machine by utilizing lead screw, the materials used are hollow profile, angle iron, and plate iron. The tools used are welding, grinding, gurdi, and lathe machines. The steps are:

1. Prepare tools and materials
2. Look at the work drawings
3. Make a frame using hollow profiles and elbows
4. Making the main components
5. Installation of electric motor
6. Installation of reducer
7. Pulley and vbelt installation
8. Installation of lead screw
9. Installation of sprocket gear and chain

3 Results and Discussion

3.1 Discussion

The list of requirements used as a reference to the design concept of a can pressing machine using a lead screw, which is shown in Table 2.

3.2 Selection of Design Concepts

In this final project design, the selected method is concept selection utilizing a decision matrix model with concept assessment stages. Filtering is unnecessary due to the presence of only three alternative design concepts. The selection criteria are established based on the specifications outlined in the previously described list of requirements, which includes operations, dimensions, tool weight, manufacturing, and cost. Table 3 provides an explanation of the concept assessment.

Based on the Table 3, the conclusion obtained is that the selected concept is design concept 2 which has a relative value for the rate of 28% and for the weight score of 31%. The weight score is obtained from a review of the selection criteria with a portion of the order of priority or innovation compared to existing products.

3.3 Result

The results of making a can pressing machine by utilizing a lead screw as shown in Fig. 2.

Table 2. List of requirements

Requirement list		
S/H	Aspect	Responsible person
	Operational	Design team
S	A model that is not too complicated and easy to operate	
H	The model can press more in one operation of 50 cans per press 3.	
	Dimensions	Design team
S	Has compact dimensions (435 mm × 435 mm × 750 mm)	
	Tool weight	Design team manufacturing team
S	Cans be moved/pushed by at least 2 people	
H	Weight not more than 50 kg	
	Manufacturing	Design team manufacturing team
S	Can be manufactured easily	
H	Components and materials are readily available	
H	The workmanship is in accordance with detail drawing	
	Cost	Design team manufacturing team
S	Production costs within reasonable limits	
H	Selling price is affordable to the general public	

Description:
S = Condition
H = Expectation

Table 3. Concept assessment matrix

Selection criteria	Weight	Concept assessment matrix							
		Concept 1		Concept 2		Concept 3		Existing	
		Rate	Score	Rate	Score	Rate	Score	Rate	Score
Operational	20%	3	0.6	3	0.6	3	0.6	1	0.2
Dimension	10%	3	0.3	2	0.2	1	0.1	4	0.4
Tool weight	10%	3	0.3	2	0.2	1	0.1	4	0.4
Manufacture	30%	3	0.9	4	1.2	2	0.6	1	0.3
Cost	30%	2	0.6	3	0.9	1	0.3	4	1.2
Absolute value		14	2.7	14	3.1	8	1.7	14	2.5
Relative value (%)		28	27	28	31	16	17	28	25
Score		3		1		4		2	

Fig. 2. Can pressing machine by utilizing lead screw and a microcontroller-based monitoring system.

3.4 Discussion

The discussion that will be discussed is the process of making and the results of the can pressing machine by utilizing the lead screw, the process is:

3.4.1 Material Used

The material that will be pressed on the used beverage can pressing machine is an Aluminum can with a length of 115 mm and a diameter of 70 mm as shown in Fig. 3.

Fig. 3. 330 ml Aluminum can.

3.5 Tool Specifications

The specifications of the used beverage can pressing machine using a lead screw mechanism can provide useful information as a consideration for reference by users. The dimensions used are millimeters as show in Table 4.

Table 4. Machine specifications

Spesifications	Dimension
Frame height	710 mm
Frame width	435 mm
Frame length	435 mm
Lead screw length	800 mm
Lead screw diameter	22 mm
Support height	750 mm
Support length	150 mm
Support width	35 mm
Pulley diameter	50.8 mm
Sprocket gear ratio	43T : 15T
Electric motor	0.5 HP, 1400 rpm
Gearbox	WPA 1:50

3.6 Calculation of Press Force

From the experiment, it can be seen that the force required to press the can is 41 kgf. Then the amount of force applied to the can can be calculated.

$$F = m \times g$$
$$F = 41\ kgf \times 9.81\ \mathrm{m/s^2}$$
$$F = 02.21\ \mathrm{N}$$

Since one press requires 50 cans, the pressing force is multiplied by the number of cans to be pressed.

$$F = 402.21\ N \times 50\ \text{Cans}$$
$$F = 20110.5\ \mathrm{N}$$

3.7 Screw Calculation

Screw data:
Major diameter (do) = 22 mm
Minor diameter (dc) = 16.5 mm
Pitch diameter (d) = 19.5 mm
Pitch (p) = 5 mm
Range = single
Thread thickness (t) = 2 mm
Nut height (h) = 20 mm
Active thread (n) = 4
Trapezium thread coefficient ($\mu 1$) = 0.12
Trapezium thread angle = 30º

1. The torque that occurs, using the equation formula:

$$T = P_t \times l$$
$$= 41.01 \times 117$$
$$= 4798.17\ \mathrm{kg.mm}$$

To find out the force used to press, use the equation:

$$T = P_t \times l$$
$$4798.17 = P \times 19.5/2$$
$$4798.17 = P \times 9.7$$
$$P = 4798.17/9.75$$
$$P = 492.12\ \mathrm{kg}$$

2. Shear stress due to punter or torsion force, using the equation:

$$r = \frac{16T}{\pi (dc)^3}$$
$$r = \frac{16 \times 4798.17}{3.14(16.5)^3}$$
$$r = \frac{76770.72}{14105.27}$$
$$r = 5.44\ \mathrm{kg/mm^2}$$

The specifications of the used beverage can pressing machine using a lead screw mechanism can provide useful information as a consideration for reference by users. The dimensions used are millimeters as shown in Table 4.

3. Compressive stress due to axial force, using the equation:

$$\sigma c = \left(\frac{W}{Ac}\right)$$
$$Ac = \left(\frac{\pi}{4}\right)(dc)^2$$
$$= \left(\frac{3.14}{4}\right)(16.5)^2$$
$$= 213.72\ \mathrm{mm^2}$$
$$\sigma c = \frac{2412.35}{213.72}$$
$$\sigma c = 11.28\ \mathrm{kg/mm^2}$$

4. Maximum shear stress, using the equation:

$$r(\max) = \frac{1}{2}\sqrt{(\sigma c)^2 + 4r^2}$$
$$= \frac{1}{2}\sqrt{(11.28)^2 + 4(5.44)^2}$$
$$= 7.835\ \mathrm{kg/mm^2}$$

To make the machine safe to use, r (max) × sf = 7.835 × 2 = 15.67 $\mathrm{kg/mm^2}$. Recommended is carbon steel with a shear stress equal to or higher than the calculation results, JIS G 4102-SNC2 type can be used which has a higher or equal shear stress than the calculation results.

3.8 Motor Power Calculation

1. To calculate the torque use the equation:

$$T = F \times r_{screw}$$
$$= 20110.5\ \mathrm{N} \times 11\ \mathrm{mm}$$
$$= 221215.5\ \mathrm{Nmm}$$
$$= 221.2155\ \mathrm{Nm}$$

2. To calculate the power use the equation:

$$P = \frac{T \times 2 \times \pi \times n}{60}$$
$$P = \frac{221.22 \times 2 \times 3.14 \times 10}{60}$$
$P = 231.53$ watt

3. Motor power planning and correction factor using the equation:

Pd = Fc × P
= 1.5 × 231.53
= 347.295 watt ≈ 0.347295 kW
= 0.465 HP ≈ 0.5 HP

3.9 Pulley and Vbelt Calculation

1. The pulley data from the can pressing machine:
   Electric motor pulley diameter (D1) = 71 mm
   Gearbox input pulley diameter (D2) = 71 mm
   Electric motor rotation (n1) = 1400 rpm
   n$reducer$ = 28 rpm
2. Calculate the pulley ratio on the electric motor, using the equation:

Desired rotation (n2) = 28 rpm

Ratio gearbox = $\frac{nreducer}{n1}$

$$\frac{28}{1400} = 1:5$$
$$\frac{n2}{n1} = \frac{D1}{D2}$$
$$\frac{n2}{1400} = \frac{71}{71}$$
$$n2 = \frac{1400 \times 71}{71}$$
$$n2 = 1400$$

This means that the rotation of the electric motor remains at 1400 rpm. It can be concluded that the pulley ratio is 1:1.

3. The data to calculate the pulley:
   Diameter of the electric motor pulley (D1) = 71 mm
   Diameter of the input gearbox pulley (D2) = 71 mm
   Distance between pulleys (C') = 200 rpm
   Pulley reducer rotation (n2) = 1400 rpm

Calculating the length of the vbelt plan used, using the equation:

$$L = 2 \times C + 1.57\,(D2 + D1) + \frac{(D2 - D1)^2}{4C}$$
$$L = 2 \times 200 + 1.57\,(71 + 71) + \frac{(71 - 71)^2}{4 \times 200}$$
L = 622.94 mm

Then the actual vbelt length is L = 630 mm, then the actual shaft axis distance can be calculated with the equation:

$$C = C' - \frac{L1 - L}{2}$$
$$C = 240 - \frac{622.94 - 630}{2}$$
$$C = 243.53 \text{ mm}$$

3.10 Calculation of Sprocket Gear and Chain

The sprocket data from the can pressing machine:
Diameter of speed reducer sprocket (P1) = 70 mm
Diameter of screw sprocket (P2) = 180 mm
Electric motor rotation (n1) = 1400 rpm
nreducer = 28 rpm

1. Sprocket gear planning
   It is known that the teeth (Z2) on the sprocket amount to 43 teeth, on the sprocket is known to be 10 rpm, and at the gearbox output of 28 rpm. Then it can be calculated the number of teeth required by the sprocket gear with the equation:

$$V.R. = \frac{n1}{n2} = \frac{Z1}{Z2}$$
$$\frac{28 \text{ rpm}}{10 \text{ rpm}} = \frac{43}{Z1}$$
Z1= 15

2. Calculating the number of links can be calculated using the equation:

$$K = \frac{z1 + z2}{2} + \frac{2x}{p} + \left(\frac{z2 - z1}{2\pi}\right)^2 \times \frac{p}{x}$$
$$K = \frac{15 + 43}{2} + \frac{2(165)}{15.875} + \left(\frac{4 - 15}{2(3.14)}\right)^2 \times \frac{15.875}{165}$$
= 15

Since the links used must be an even number, it is rounded up to as many as 52 links.

3. Chain length
   Can be calculated with the equation:

L = K × p
= 52 × 15.875
= 825.5 mm

3.11 Shaft Calculation

1. Calculating the plan moment, with equation:

$$T = 9.74 \times 10^5 \times \frac{Pd}{n}$$
$$T = 9.74 \times 10^5 \times \frac{0.52}{10}$$
$$T = 6460.2 \text{ kg.mm}$$

2. Calculating shaft shear stress (τa)
   The tensile strength of the material (σB) of carbon steel is 85 kg/mm^2. The safety factor that depending on the type of material (sf1) is 5.6. The safety factor depending on shaft shape (sf2) is 1.3. Correction factor for moments with loads subject to shock or large impact (Kt) is 3. While the factor bending (Cb) is 1. Then it is known:
   σB = 85 kg/mm^2
   Sf1 = 5.6
   Sf2 = 1.3
   Kt = 3 (load subjected to shock or large impact)
   Km = 1.5 (fixed bending moment loading)
   Mmax = 571.65 kg.mm
   Cb = 1
   With the equation:

$$\tau a = \frac{85}{sf1 \times sf\,2}$$
$$= \frac{85}{5.6 \times 1.3}$$
$$= 11.67 \text{ kg/mm}^2$$

3. Then the shaft diameter can be calculated with equation:

$$ds = \left(\frac{5.1}{\tau a}\sqrt{(Km \times M)^2 + (Kt \times T)^2}\right)^{\frac{1}{3}}$$
$$ds = \left(\frac{5.1}{11.67}\sqrt{(1.5 \times 571.65)^2 + (3 \times 6460.2)^2}\right)^{\frac{1}{3}}$$
= 20.39 mm

Based on the calculations obtained the minimum diameter of the shaft press is 20.39 mm, then this machine is designed using a shaft with diameter of 22 mm, this size is safe because the shaft diameter already meets the size of the minimum shaft diameter.

3.12 Bearing Calculation

1. Calculate the bearing equivalent load using the equation:

$$W = Ks(X.V.WR + Y.WA)$$

V = Rotation factor
= 1; for all bearing types if the inside rotates
= 1; for self-aligning types if the inner part inside is fixed
= 1.2; for all types of bearings except self-aligning, if the inner part is fixed

W = 2 (0.56 × 1 × 15082.86 + 1 × 10158.25)
= 19009.3 N

2. Finding the life of the bearings used can using the equation:

$$L = \left(\frac{C}{W}\right)^3 \times \frac{10^6}{60n}$$

$$L = \left(\frac{25500}{19009.3}\right)^3 \times \frac{10^6}{60 \times 10}$$

$$= 4023.19 \text{ ours}$$

If in 1 day the machine is used for 8 hours, the bearing life is obtained is:

H = 4023.19 ours/ 8 hours
= 502.8 days
= 16.76 months ≈ 17 months

3.13 Testing Results

1. Pressing test
This test uses used cans that are already unused. Based on initial measurements on cans that are in the pressing room.
In the can pressing experiment obtained a reduction in the dimensions of the can in the range of 56.5%. In the pressing test shows that in one pressing experiment takes a variety of time various (Table 5).

Table 5. Pressing testing data

Initial dimension	Can experiment to-	Final dimension	Time
 ±230 mm	±60 cans (standing position and consists of 2 piles)	 ±100 mm	The time obtained during the pressing process until the can is pressed is 45 seconds.
 ±345 mm	Irregular position	 ±150 mm	The time obtained during the pressing process until the can is pressed is 51 seconds.

2. PZEM-004T sensor module testing This PZEM-004T sensor module test aims to find out how accurate this sensor works. This test is carried out by comparing the data results from PZEM-004T with a digital multimeter with a Digital Multimeter. Comparing the results of data from the two tools (Table 6).

Table 6. PZEM-004T sensor testing data with multimeter

Testing to-	Thickness of the can	Average PZEM- 004T Acurrent	Average Multimeter current	Error (%)	Load (n cans)
1	2 stacks cans (230mm)	1.63	1.61	1%	50 cans or 0.5 kg
2	Irregular position (460 mm)	1.87	1.84	1.5%	100 cans or 1 kg
		Average error (%)		1.25%	
Testing to-	Thickness of the can	Average PZEM- 004T Voltage	Average Multimeter Voltage	Error (%)	Load (n cans)
1	2 stacks cans (230 mm)	221	217.40	1.62%	50 cans or 0.5 kg
2	Irregular position (460 mm)	219	217.44	0.71%	100 cans or 1 kg
		Average error (%)		1.16%	

Based on the test results, the capacity of the can pressing machine can be calculated by the formula:

$$Q = w/t$$
$$= 0.75/0.8$$
$$= 0.93 \text{ kg/minute}$$

$$Q = 0.93 \times 60$$
$$= 55.8 \text{ kg/ours}$$

Based on the test results that have been done, the results obtained, that the machine can press machine by utilizing lead screw and equipped with a microcontroller-based monitoring system microcontroller-based monitoring system can press as many as 55.8 kg in 1 hour.

4 Conclusion

The conclusion of this study presents a design concept for a can pressing machine utilizing a lead screw system, developed using Autodesk Fusion 360 software. The methodology employed is based on the Ulrich method, which involved the creation of three distinct design concepts, each evaluated according to specified criteria.

1. Design concept 2 was selected as the optimal choice, with a microcontroller-based monitoring system demonstrating the capability to press up to 55.8 kg per hour. The overall dimensions of the lead screw-based can pressing machine are: a length of 694 mm, a width of 438 mm, and a height of 796 mm. The estimated weight of the machine is 53.4 kg.
2. Regarding the manufacturing components, the machine frame consists of 24 hollow sections connected by 40 joints, while the front and back doors comprise 18 hollow sections and 28 joints. The motor and gearbox assembly includes 4 elbow profiles and 4 connections.

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