Design and Construction of an Automated Adjustable-can foil Sealing Machine

Adizue U. L, Agbadah S. E, Ibeagha D. C, Falade Y. O

Abstract— **Finishing and Packaging has been a major activity for every production Industry in recent times, as proper finishing and packaging helps keep a business green. In Nigeria today, there has been an increasing demand for canned products such as engine oils, fruit juice, greases and oil treatments etc. which require foil seal before capping or without capping as the case maybe. In some of our small scale and growing industries, sealing of canned products is being carried out by the use of locally fabricated manual type sealing machines whose draw backs includes man labor intensive, machine multiplicity and bottlenecks. While the imported equipment worth millions of naira for small and medium scale industries to afford. This work centered on the design and construction of a portable automated adjustable-can foil sealing machine which is a final unit operation for finishing and packaging department of some can-product industries. The equipment works within temperature range of 0-200oC, it accommodate can weights of 3.3kg to 10kg, heights from 82mm – 314mm, lengths from 54mm – 233mm and widths from 43mm – 106mm and was found to have an efficiency of 78%, which compares favorably with 90% efficiency derivable from the imported type and at a more cheaper and affordable cost.**

Index Terms— **Adjustable-can, automated, bottlenecks, foil sealing, efficiency**

I. INTRODUCTION

Sealing is a process of closing securely, and hermetically, cans' or jars' content of the products. More so, the product could be cap or cap-less finish after sealing is done. Sealing machine is used in different manufacturing and processing applications such as food and beverages, bottled water and juices, dairy products, pharmaceuticals, chemical industry, edible oils, agricultural products, lubricating oils, oil treatments, herbicides / pesticides, cosmetics and personal care.

Induction cap sealing is a non-contact sealing process by which a foil disk or "seal" is bonded on a container. Developed more than thirty five (35) years ago, induction sealing was originally intended to prevent leakage of chemical from plastic bottle caps [1].

Today, this unique process can be used with almost any styled container and closure for sealing foods, drugs, beverages, solvents and chemicals.

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Finishing and packaging of products in the production industries has been a very crucial activity which cannot be over emphasized. The quality and marketability of a particular product to a large extent depends on the type of finishing and packaging it under went. One of the processes in which this could be achieved is through sealing. Thus the design of an automated adjustable can sealing machine will enhance such operation.

A. Literature Review

A great number of researchers have been made in the bid to provide proper finishing and packaging for products which requires foil seals. Applicable to plastic bottles and containers, foil sealing machinery is used in pharmaceutical, beverages, cosmetics, oils and chemical industries. This ensures reliable sealing, purity retention,

Hermetic sealing, secure packaging, Easy peel off and leak proofing [1].

In the early 90's, hand sealing was done with the use of gloves to press a heated foil on jars. This method was not reliable to a great extent and encounters a lot of difficulty in proper sealing. Then there was this local fabricated manual type which utilizes a foot pad to operate the sealing head which descends to seal the foil on the jar, (it incorporated a heating element at the sealing head). In the recent past, the emergence of production industries with the latest technology have led to the design and manufacture of equipment to give an improved and excellent finishing and packaging. Some of the leading firms that have ventured into such equipment are Pack leader machinery Inc. in Taiwan, Eltech groups United Kingdom and Crand all international. However, the series as produced by Eltech group includes; Semi-Automatic Induction Cap Sealer (Eltech S-500) which does a semi-automatic can foil sealing of 8 to 10bottle per minute for cap diameters between 20-120mm. It is suitable for batch production and ideal for laboratory use [2]. Also the automatic induction cap sealing machine (Eltech-1000); which is used for high speed-cap sealing applications. This consists of the high efficiency and microprocessor control panel, induction head unit and efficient water circulation system. This system requires water coiling and is available with or without conveyor. The automatic induction cap sealing machine (Eltech-2000) can seal containers having diameters from 10mm up to 63mm production speeds up to 120 bottles per minute and has similar features as the Eltech-1000.

According to research, the cost of these sealing machines ranges from 3046USD to 10,000USD [2],[3] and importation cost which is very expensive and cost of maintenance through the expatriate are on a very high side for the small scale industries to manage in Nigeria.

It is not in the author's knowledge or anywhere in literature where a similar design and fabrication has been made either semi-automated or automated can foil sealing machine in Nigeria.

B. Justification of this work

The essence of designing and production of the automated adjustable-can foil sealing machine are as follows;

- To eliminate the stress involved in the manually operated type.
- To eliminate multiplicity of machines for products of varying dimensions (cap diameters, width, height and length) by incorporation of an adjustable knob.
- To reduce human error and fatigue by incorporation of an automated system (control system)
- To produce a portable reliable and more efficient sealing for our packaging industries.
- To save cost as compared with the imported automated machine.

II. MATERIALS AND METHODS

2.1 Material selection

The entire materials used for this work were locally sourced for and can be categorized into two groups; mechanical and electrical .In the selection of the mechanical components of the materials {mild steel, angle bar, square pipe and sheet}, considerations were made in its mechanical and physical properties. Mild steel is an alloy of iron and carbon with its carbon content varying from about 0.1% up to 0.3%. A number of factors {whether the material can be manufactured or processed into the desired shape, could economical solution to the design problem be achieved?} were considered. More so, materials should be made to withstand vibrations and other environmental conditions.

The electrical panel or casing consist of the thermocouple, ammeter, voltmeter, relay/contactor, photocells, cartage heater, cables, temperature controlling unit, pressure switches, power input selector, electric motor, electric gear motor and on/off switches which were purchased in the market and assembled.

The external power supply of 220V is supplied into the system through the power input switch. This starts the electric motor which drives the compressor and simultaneously, the thermo-controller used in this equipment is a digital type, which measures temperature from 0°c to 500°C. It has an inbuilt relay, which maintains a pre-selected temperature. Also, the external relay {contactor} regulates the actual power of the cartridge heater**.** It also incorporates a voltmeter and ammeter for measuring the voltage and current to the cartridge heater respectively.

Thus applying the relation;

$$P = IV \quad (1)$$

Where P = power in watts

I = current in Amperes

V = voltage in Volts

The power input to the heater is then determined.

For the transformer unit,

$$E_s N_s = E_p N_p , \quad [12]$$

Therefore,

$$\frac{E_s}{E_p} = \frac{N_p}{N_s} \quad (2)$$

Where Es = voltage of secondary coil

Ns = number of turns of secondary coil

Ep = voltage of primary coil

Np = number of turns of primary coil.

2.2 Methods

2.2.1 Design calculation

Design is a major aspect of every manufacturing process. In designing, a lot of factors were taken into consideration in order to come up with the best design for the production of the component, equipment or machine.

In designing for the production of the automated adjustable-can foil sealing machine, the following factors were taken into consideration;

- Type of load and stresses caused by load
- Motion of parts
- Selection of materials
- Frictional resistance and lubrication
- Form and size of the parts
- Convenient and economical features
- Safety operations
- Workshop facilities available
- Cost of construction etc.

However, the best design of a machine is one which is more economical in the overall cost of production and operation.

2.2.2 Selection of motor for conveyor system

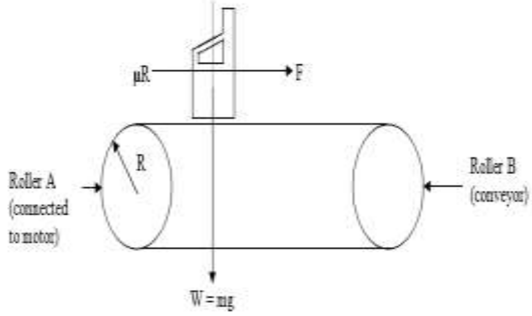

Fig 1: Conveyor system

Where; F = Force required to move conveyor (N), R = Normal reaction (N), M = Mass of Jar/can + content (Kg), g = acceleration due to gravity (g = 9.81N), a = acceleration of Jar on motion and μ = Friction coefficient of conveyor belt (fabrics)

Thus, force must overcome the resistance (μR) of the belt;

$$F = ma + \mu R \quad (3)$$

From Motion Law, $S = Ut + 1/2at^2$ (4)

Initial Velocity U = 0, then $a = 2S/t^2$ (5)

Substituting equation (5) in equation (1), we have the expression in equation (6)

$$F = m\,(2S/t^2) + \mu R \quad (6)$$

Where S = distance the Jar covers to sealing point and t = Time taken to sealing point.

From our analysis, m = 4.615 Kg, S = 467 mm = 0.467 m, t = 10s, μ = 0.28, R = mg

∴ F $\simeq$ 12.72 N

More so, Roller shaft is driven by a motor, but Torque on roller = Torque on Pulley (Law of transmissibility of forces)

Thus, F x R = f x r (7)

F = Force on Roller, f = Force on pulley, R = radius of roller, r = radius of pulley

∴ f ≃ 81.41 N

Thus to select a motor for the conveyor, then the torque generated by motor must be greater than torque on roller in order to drive it (Torque of roller < Torque from motor) [4], [8].

Therefore, from equation (7)

Torque of roller = F x R

= 12.72 X 0.08

= 1.02 Nm

Considering a motor of 1hp = 740w, 1440rpm.

$$T = \frac{60P}{2\pi N}$$

Where T = Torque of motor in N-m

P = Power of motor in Watts

N = Speed in rev/min, and π = 3.142

Therefore, T = 4.91 N-m

Since $T_{motor} > T_{conveyor}$ (4.91 > 1.02 N-m); then, a motor of 1hp rating is selected to drive the conveyor [4].

2.2.3 Selecting the belt length for the motor /compressor link and motor/conveyor link

- For V-Belt Drives (Open Belt Drive)s

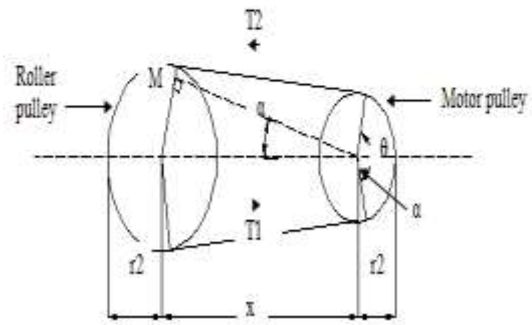

Fig 2: Belt drive system

The Angle of contact; θ

θ = (180 - 2α) (8)

Where, Sin α = $\frac{r_2 - r_1}{x}$, [4], [8] (9)

r_2 = radius of roller pulley, r_1 = radius of motor pulley, x = centre distance

Given that $r_2 = \frac{D_2}{2} = \frac{120mm}{2}$ = 60mm = 0.06m

D_2 = Roller pulley diameter, D_1 = Motor pulley diameter, x = 275mm = 0.275m

$r_1 = \frac{D_1}{2} = \frac{85mm}{2}$ = 42.5mm = 0.0425m

From equation (8) α = Sin^{-1} [($r_2 - r_1$)/x]

= Sin^{-1} ((0.06 – 0.0425)/0.275)

= Sin^{-1} 0.0636 = 3.65°

Angle of contact:

θ = (180 - 2 α) x $\frac{\pi}{180}$ in radian, [4] (10)

= 172.7 (π/180)

= 3.015 radians; θ ≃ 3 radians

Angle of groove 2β = 30, [4] (11)

∴ β = 15

Thus, tension on belt can be calculated by

2.3 log (T_1/T_2) = μ. θ Cosec β, [4] (12)

Where T_1 = Tension on tight side, T_2 = Tension on slack side, μ = Coefficient of friction on belt = 0.28

Substituting data into equation (12)

∴ $T_1 = 25.77\ T_2$ (13)

Also relationship between speed of motor and pulley diameter

$N_2/N_1 = d_1/d_2$ (14)

Given; N_1 = 195 rpm, d_1 = 85mm, d_2 = 120mm

∴ $N_2 = \frac{N_1 \times d_1}{d_2} = \frac{195 \times 85}{120} = N_2$ = 138.125 rpm

And N_1 = 138 rpm

Also, recall speed of motor in m/s

$$V = \frac{\pi d N}{60} \quad (15)$$

$$\therefore v = \frac{\pi d_1 N_1}{60} = \frac{\pi d_2 N_2}{60}$$

∴ V = 0.87 m/s

More so, Power transmitted by belt

P = ($T_1 - T_2$) V , [4] (16)

∴ P($T_1 - T_2$) V = 740

$T_1 - T_2 = \frac{740}{0.87}$ = 850.57 N

∴ $T_1 - T_2$ = 850.57 N (17)

Substituting equation (13) in equation (17)

25.77 $T_2 - T_2$ = 850.57 N

∴ $T_2 = \frac{850.57}{24.77}$ = T_2 = 34.34 N

From equation (13), $T_1 = 25.77\ T_2$ = 884.94 N

Thus, tensions on V-belt are; T_1 = 884.94 N and T_2 = 34.34 N

- Length of open belt drive is as expressed in equation (18), [4], [8]

$$L = \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(r_2 - r_1)^2}{x} \quad (18)$$

$$L = \frac{\pi}{2}(120 + 85) + 2(275) + \frac{(60 - 42.5)^2}{275}$$

L = 873.16 mm ≅ 873 mm

From the standard pitch length table of V-belts according to IS: 2493 – 1974, [4], [8]

We selected type-A belt of length 925 mm, since 873 mm is not in standard table.

Thus the design and selection is safe.

2.2.4 Design for the roller

From figure 3, Where; W_H = Weight of Hollow shaft, W_1 = Weight of Solid shaft 1, W_2 = Weight of Solid shaft 2

W_3 = Weight of Roller = $W_H + W_1 + W_2$ (19)

Mass density of steel, P_S = 7850 Kg/m^3

V_1 = Volume of Shaft 1 = $\pi r^2 l_1$ (20)

$V_1 = \pi$ X $(0.0125)^2 \times 0.145 = 7.12$ X 10^{-5} m^3

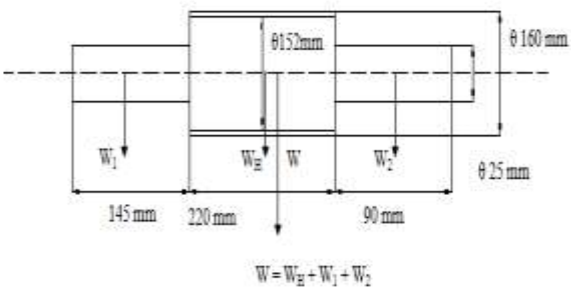

Fig 3: Schematic diagram for roller A

Mass of solid shaft 1 = density × Volume (21)

$M_1 = PV_1$

∴ $M_1 = 7850 \times 7.12 \times 10^{-5}$ = 0.56 Kg

$W_1 = 0.56 \times 9.81 = 5.49$ N
V_2 = Volume of shaft 2 = $\pi r^2 l_2$ (22)
$V_2 = \pi \times (0.0125)^2 \times 0.09$
$= 4.42 \text{ X } 10^{-5} \text{ m}^3$
$\therefore M_2 = PV_2$
$M_2 = 7850 \times 4.42 \times 10^{-5} = 0.35$ Kg
$\therefore W_2 = 0.35 \times 9.81 = 3.43$ N
V = Volume of Hollow shaft = $\pi (R^2 - r^2)$ l (23)
Where R = radius of external diameter, r = radius of internal diameter
$\therefore V = \pi (0.082 – 0.0762) \text{ X } 0.220 = 4.31 \text{ X } 10^{-4} \text{ m}^3$
$\therefore M_H = PV$
$M_H = 7850 \text{ X } 4.31 \text{ X } 10^{-4} = 3.38$ Kg
$\therefore W_H = 3.38 \text{ X } 9.81 = 33.16$ N
Thus weight of Roller $W = W_H + W_1 + W_2$
W = 33.16 + 5.49 + 3.43 = 42.08 N

2.2.5 Shear force and bending moment analysis

- Considering roller A, assuming the combined weight W = 42.08N acting downward

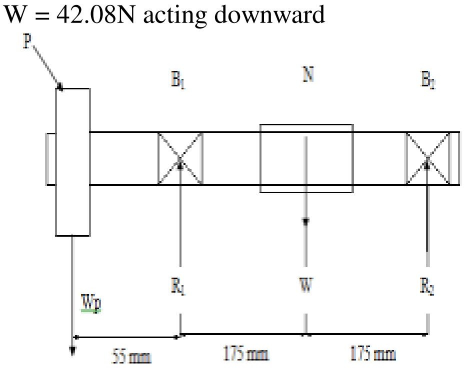

Fig 4: schematic representation of forces on roller

Where P = Pulley, Wp = weight of pulley = 0.86 N, W = weight of shaft = 42.08 N, B_1 = Bearing 1, B_2 = Bearing 2, R_1 = Reaction at bearing 1 and R_2 = Reaction at bearing 2
At equilibrium,
$Wp + W = R_1 + R_2$ (24)
$0.86 + 42.08 = R_1 + R_2$
$\therefore R_1 + R_2 = 42.94$ N (25)
Taking moment about B_1
$0.86 \times 55 + R_2 \times 350 = 42.08 \times 175$ (clockwise moment = anticlockwise moment i.e (**CM = MƆ**)
$\therefore R_2 = 20.90$ N
Taking moment about B_2
$350 \times R_1 = 42.08 \times 175 + 0.86 \times 405$
$\therefore R_1 = 22.04$ N
Thus, $R_1 + R_2 = 22.04 + 20.90 = 42.94$ N
From equations (24) and (25); $Wp + W = R_1 + R_2 = 42.94$ N
Hence the expected Reactions at bearing 1 and 2 are 22.04 N and 20.94 N respectively
Hence the design is safe

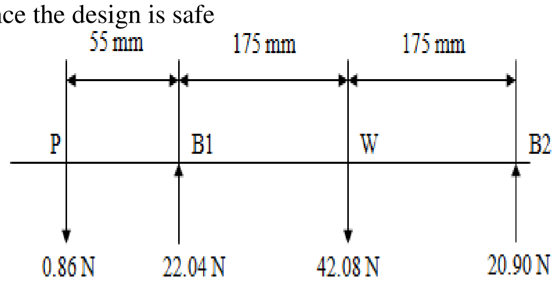

Fig 5: Free force actions

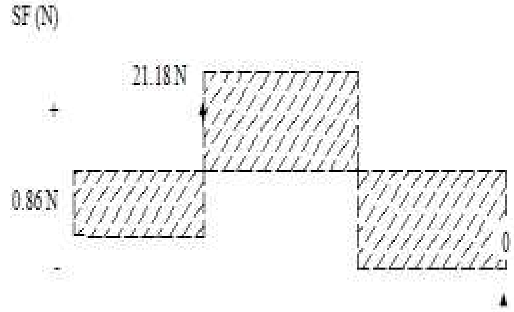

Fig 6: Shear force diagram on roller

- Bending moment analysis, BM (N-mm)

For points between $PB_1 = - 0.86x$ (26)
points between PW = - 0.86x +22.04(x – 55) (27)
For points between PB_2 = - 0.86x + 22.04(x – 55) – 42.08(x - 175) (28)
From eqn (26) @ x =55, PB_1 = - 47.3 N - mm
From eqn (27) @ x = 175, PW = 2494.30 N - mm
From eqn (28) @ x = 405, PB2 = - 2312.7 N- mm

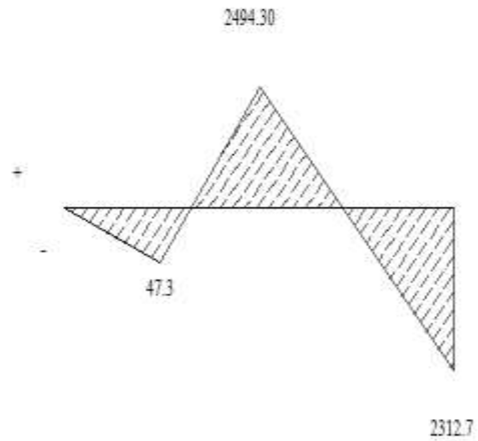

Fig 7: Bending moment diagram

Thus, Maximum moment is at the point of greatest weight i.e. weight of Roller = 42.08. Therefore, the design is safe.

- Considering roller B

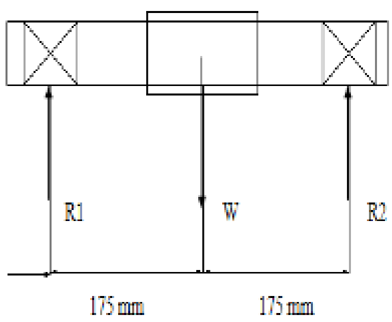

Fig 8: schematic diagram of roller B

At equilibrium,
Total upward force = Total downward force, [5]
:. $R_1 + R_2 = W$
$R_1 + R_2 = 42.08$ N (29)
Taking moment about B_1
Clockwise moment = Anti-clockwise moment
$W \times 175 = R_2 \times 350$

$R_2 = \frac{42.08 \times 175}{350}$

$R_2 = 21.04$ N

Taking moment about B_2

$R_1 \times 350 = 42.08 \times 175$

$R_1 = \frac{42.08 \times 175}{350}$

$\therefore R_1 = 21.04$ N

$\therefore R_1 + R_2 = 21.04 + 21.04 = 42.08$ N, thus, the design is safe

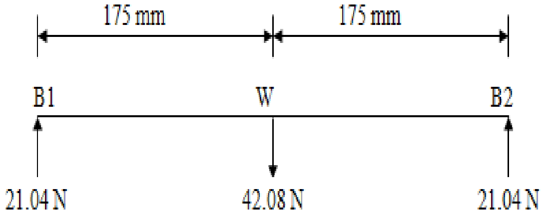

Fig 9: free force diagram

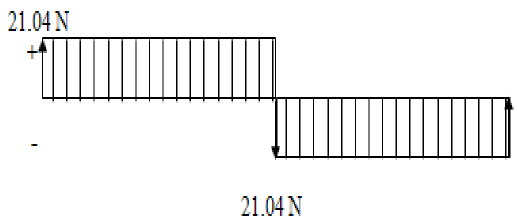

Fig 10: Shear force diagram

- Bending moment analysis BM (N-mm)

For points between B1W = 21.04x (30)

For points between B1B2 = 21.04 x – 42.08(x-175) (31)

From eqn (30), @ x = 0, B1W = 0

From eqn (30), @ x = 175, B1W = 3682 N - mm

From eqn (31), @ x = 350, B1W = 0

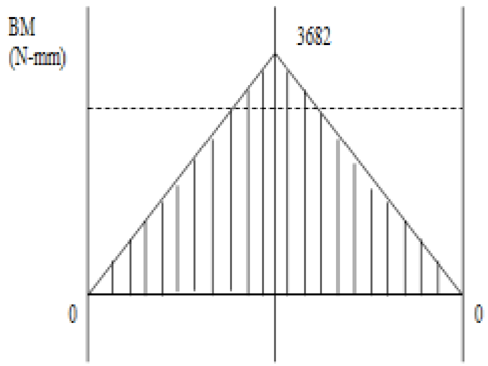

Fig 11: Bending moment diagram

2.2.6 Design for shear stress

For the shaft design, consideration is given mostly to the region of likely failure. This region is at the fillet point. (Stepped region)

3.2.1 Shear stress due to torsion

$\tau = \frac{Tr}{I_0}$ [4], (32)

Where τ = Shear stress (N/m^2), T = Torque (N-m), r = radius of stepped portion (m), Io = Polar moment of Area (m^4)

$Io = \frac{\pi d^4}{32}$ [4], (33)

Thus, Given Torque on shaft (roller); T = 1.02 Nm, from equation (6)

$r = \frac{d}{2} = \frac{0.025}{2}$, and d = 0.025m

Therefore Average shear force τ_{aver}

$\tau_{aver} = 1.02 \times \frac{0.025}{2} \times \frac{32}{\pi(0.025)^4}$

$\tau_{aver} = 332.425$ KN/m^2

Maximum shear stress τ_{max}

$\tau_{max} = K_t \times \tau_{aver}$ [4], (34)

Where K_t = Stress concentration factor

$\therefore$ Ratio of maximum diameter to minimum diameter (D/d) (35)

$\frac{D}{d} = \frac{160}{25} = 6.4$

$\therefore$ Ratio of radius of fillet to minimum diameter (r/d) (36)

$\frac{r}{d} = \frac{1}{25} = 0.04$

Therefore, theoretical stress concentration factor (Kt) for stepped shaft with radius (r) i.e. shoulder fillet is given in Engineering Design text books [4],[8].

For $\frac{D}{d} = 6.4$, $\frac{r}{d} = 0.04$;

From Table value for $K_t = 1.96$ [4]

$\therefore \tau_{max} = 1.96$ X 332.425 KN/m^2

From equation (34)

$\tau_{max} = 651.55$ KN/ m^2 = 651.55 KPa

Shear modulus of rigidity for mild steel G;

G = 79.3 GPa [4]

Since $\tau_{max} < G$ i.e. 651.55 KPa < 79.3 GPa

The design for the shaft is safe [4], [8].

2.2.7 Shear stress due to bending

$\therefore \tau = \frac{T}{Z}$ (37)

$\therefore Z = \frac{\pi d^3}{32}$ (38)

Where τ = Shear Stress (N/m^2), T = Torque, (Nm), Z = Area due to Bending moment (m^3)

Therefore, $\tau_{aver} = T \times \frac{32}{\pi d^3}$ (39)

$\therefore \tau_{aver} = 1.02 \times \frac{32}{\pi (0.025)^3}$

$\tau_{aver} = 664.85$ KN/m^2

Maximum shear stress τ_{max}

$\tau_{max} = K_b \times \tau_{aver}$ (40)

From Engineering design tables, for K_b; stress concentration factor due to bending at

$\frac{D}{d} = \frac{160}{25} = 6.4$, $\frac{r}{d} = \frac{1}{25} = 0.04$ is given as $K_b = 2.75$

$\therefore \tau_{max} = 2.75$ X 664.85 KN/m^2 from equation (40)

$\therefore \tau_{max} = 1828.34$ KN/m^2 = 1828.34 KPa

Since shear modulus of rigidity for mild steel G = 79.3 GPa [4],[8]

$\tau_{max} < G$ (1828.34 KPa < 79.3 GPa), The design for shaft is safe.

2.2.8 Selection of pneumatic cylinder

A pneumatic cylinder simply converts air pressure into linear motion. When selecting the pneumatic cylinder, we paid attention to:

- How far the piston extends when activated, known as "stroke" or "length of travel", thus; Based on the height of sample Jar/can we selected a pneumatic cylinder with "stroke" = 80 mm
- Surface area of the piston face, known as "bore size", thus; Based on the lid diameter of the sample Jar (with diameter = 400 mm)

- we designed the sealing head to have an Area of r = 200 mm = 0.2 m.
- Action type of pneumatic cylinder. Based on our design we selected a reciprocating action type for effective "stroke"
- Pressure rating; Based on our design we require at least a pressure of 2450 N/m^2 (2.5 Kg/cm^2) for sealing with the kind of sample Jar. Thus, we selected a pneumatic cylinder that can exert up to 3 bar (3 X 10^5 N/m^2). Fig 12 and 13 show the pictures of the Pneumatic cylinder and Solenoid valve respectively.

Note: The minimum pressing force required in sealing the aluminium foil lid coated with polypropylene film is 2450 N/m^2.

Fig 12: Pneumatic cylinder

Fig 13: Solenoid valve

2.2.9 Selection of a compressor

Based on the force or pressure expected to be exerted by the pneumatic cylinder, choice of which compressor to be used can be made easily. Thus we selected a compressor that can generate up to 4 bar (4 X 10^5 N/m^2)

A compressor works with compressible fluids and the specific work for an isentropic compressor process can be expressed with the following.

$P_1V_1^k = P_2V_2^k$, [6],[7] (41)

Where V = volume (m^3)

$K = \frac{C_p}{C_v}$ = ratio of specific heats (42)

Specific work done by compressor is given by

$W = \frac{k}{(K-1)} RT [(p_2/p_1)^{(K-1/K)} - 1]$ [6].[11] (43)

Given K_{air} = 1.4J/Kgk and R_{air}= 286.9 J/Kg.K

For compressor work at 20°C, compressing the air from 1 bar to 3 bars (desired to exert sealing force).

Then, from equation (43)

$W = \frac{1.4}{(1.4-1)} \times 286.9 \times (273 + 20) [((3 X 10^5)/ (1 X 10^5))^{(1.4-1)/1.4} - 1]$

$W = 3.5 X 286.9 X 293 [(3)^{0.2857} - 1]$

$= 294215.95 (0.3687)$

$W \approx 114,000$ Nm/Kg

Dividing by acceleration of gravity the head can be calculated

$h_{air} = \frac{114000 \ Nm/Kg}{9.81 \ Kg/s^2}$

$h_{air} \approx 11620$ in air column

2.2.10 Selecting a temperature

More so, the melting point of this kind of plastic is 130°C so the sealing machine temperature should be 50°C higher than this. Thus, the sealing machine should therefore create up to 200°C temperature.

To achieve this, we incorporated a cartridge heater and a temperature controlling unit to regulate the temperature in order to bridge overheating.

Thus the thermal conductivity of the aluminium foil lid can be calculated with the Fourier's equation of heat conduction, which is given as

$Q = - KA\frac{dT}{dx}$ [6], [7] (44)

Where K = Thermal conductivity of the specimen (Aluminium Foil) [W/mK], A = Uniform area perpendicular to the direction of heat flow,

$\frac{dT}{dx}$ = Temperature gradient [K/m] and Q = Power generated [watts]

Hence, making K subject of the relation from equation (44) the thermal conductivity of the specimen (Aluminium foil)

$K = -\frac{Q}{A} \cdot \frac{dx}{dT}$, [W/mK] [6], (45)

Thus, given Current I = 0.0021A and Voltage V = 220V

Slope of graph => $S = \frac{dT}{Dx}$

Since plastic with foil melts at 130°C and heater should be set up to 200°C for effective sealing.

∴ dT = (200 + 273) – (130 + 273) K

dT = 70 K

Since the thickness of the foil is about 2mm; dx = 0 – 2 mm = - 2 mm = - 2 X10^{-3} m

Thus, $\frac{dT}{dx} = \frac{70}{-2 X 10-3}$ = - 35000 K/m

A = π r l

Where l = thickness of foil = 2 X 10^{-3} m, r = radius of foil = 0.2 m, π = 3.142 or 22/7

A = 3.142 X 0.02 X 2 X 10^{-3}

∴ A = 1.2568 X 10^{-4} m^2

Q = IV = 0.0021 X 220 = 0.462 W

From Fourier Law, using equation (45)

$K = -\frac{0.462}{1.2568\times10^{-4}} \times \frac{-1}{350000}$

∴ K = 1.05 × 10^{-3} W/mK

Thus, thermal conductivity of the aluminium foil is 1.05 × 10-3 W/mK

2.2.10 Design for the equipment frame

This frame was design in order to reduce cost and weight of the equipment. Thus, we selected mild steel angular iron (4 mm × 508 mm). In the design for frame dimensions, Ergonomics were considered [8],[9] such that we envisaged an average height person to work on this equipment. Also considered in the dimensioning are other relevant measurements taken on the rollers (A and B), gear motor, electric motor, Air tank, pneumatic cylinder, compressor, electrical panel and frame to accommodate them all.

Therefore, the necessary dimensions were taken, angle iron cut to size and shapes. They are thus joined together by welding process after necessary machining operations on the various machine tools (such as lathe, grinding and milling machines).

2.2.11 Efficiency of the machine

The efficiency of the automated adjustable-can sealing machine can be calculated using

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} \times 100\% \quad (46)$$

Power Input = Power of Compressor motor

Compressor motor of 1.1 KW rating can supply a current, I = 0.063 Amps and Voltage, V = 220 Volts

$$\therefore P = I\,V \quad (47)$$

$$P = 0.063 \times 220 = 13.36 \text{ W}$$

Pressing force required; F = PA (48)

P = pressure required to exert force P = 3 bar = 3 X 10^5 N/m^2

A = surface area of sealing head

$$A = \pi r^2 \quad (49)$$

Given r = 0.02 m

$$A = \pi (0.02)^2 = 1.257 \times 10^{-3} \text{ m}^2$$

Thus, from equation (48)

$$F = 3 \times 10^5 \times 1.257 \times 10^{-3}$$

$$F = 377.10 \text{ N}$$

Work done by can (Jar + oil content) on conveyor = weight of can × Distance covered to sealing point

$$\therefore W_k = W \times D \quad [5] \quad (50)$$

Where W_k = Work done

W = weight of can + content = 4.615Kg X (9.81)

D = Distance covered by can = 0.468 m (from design)

$\therefore$ W_k = 0.468 X 4.615 X 9.81 = 21.19 J

$$\text{Power Output} = \frac{\text{work done by sealing head}}{\text{Time of sealing}}$$

$$P_{out} = \frac{W_s}{T_s} \quad (51)$$

P_{out} = Ws/Ts

Given that the sealing time = Ts = 2.8s

Where, Ws = work done by sealing head

$\therefore$ Ws = pressing force × distance between sealing head and Jar

$$\therefore Ws = F \times D_1 \quad (52)$$

Given F = 377.10 N, D_1 = 0.08m (from design)

Ws = 377.10 X 0.08 = 30.168 J

Recall equation (51),

$\therefore$ P_{out} = 30.168/2.8 = P_{out} = 10.77 Watts

Hence efficiency of the machine (η)

$$\eta = \frac{\text{Power output of sealing head}}{\text{Power input by motor supply}} \times 100\%$$

$$\therefore \quad \eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (53)$$

Recall P_{in} = 13.86 W and P_{out} = 10.77 W

$$\eta = 10.77 / 13.86 = 0.777 \text{ X } 100\%$$

$$\therefore \eta = 77.74\ \%$$

$$\eta \approx 78\ \%$$

Hence efficiency of the machine is 0.78 or 78 %. This indicates that the machine is efficient. (78 %)

III. EQUIPMENT DESCRIPTION AND OPERATIONS

3.1 Description of Equipment and Sequence of production

The metals {angular irons} were welded to construct the structural frame, then the steel hollow pipe and bars were turned and machined to produce the rollers on a lathe machine. The rollers were subsequently mounted on the frame supported by the bearings at their required positions. The required seating openings and positions where the various components and sub-assemblies were calculated and hence installed. These include the conveyor belt {tensioned}, gear motor, electric motor, compressor, air tank, electrical panel and motors and measuring gauges. It must be noted that before the conveyor belt was finally mounted and tensioned, the plywood of specified dimension was screwed on the top of the frame to support the weight of cans {jars}. Also, a mixture of glue and saw dust was used to cover up minor gaps and was smoothened with abrasive paper to obtain high surface finish. The pneumatic system and fabricated mountings were coupled with adjustable knobs on the side of the equipment and well position for sealing action. The photocells were fixed in their required position to sense the presence of jars, regulate the conveyor system and also alert the pressure control of unit respectively. A connection was made to the thermocouple that will be used to plug into an external socket to generate power. Connections were made with heat resistant wire to the cartridge heater, which is seated in the machined sealing head. More so, air hose were connected from the air tank linked with the compressor via the solenoid air valve to the pneumatic cylinder to their inlet and exit ports respectively. Its sealing unit can be adjusted and sealing head replaced to accommodate cans of varying height and lip diameter respectively. The features of the equipment includes ; (1) pneumatic cylinder (2) air hose for out stroke (3) air hose for in stroke (4) adjustable frame (5) cylinder push road (6) sealing head (7) rail guide (8) adjustable knob (plastic) (9) conveyor belt (10) plywood (11) roller (12) pneumatic valve (13) air hose to pneumatic valve (14) air compressor (15) frame {angle iron} (16)electric panel (17) compressor tank link (18) air tank (19) motor stand (20) pressure switch (21) temperature control unit (22) gear motor (23) belt drive (24) pulley and (25) photocells. See fig 14 and 15 for the isomeric view and photograph of equipment respectively.

3.2 Principle of operation

The principle of operation of this equipment is automated and very simple. Once the power supply is connected to the mains; the switch is on which immediately triggers the motor connected to the compressor. The compressor builds up enough air to about 3 bar (3 X 105 N/m2) in the air tank, which is being regulated by the pressure switches and sensed by the photocells. Simultaneously, heat is been generated by the heating element (cartridge heater) and is controlled by the temperature controlling unit (TCU) to about 200°C which is enough to melt the foil on the lid of the plastic jar.

When sufficient air is stored in the air tank, the photocells alerts the air valve (solenoid valve) which allows air intake into the pneumatic cylinder via the exit port of the air tank. Immediately, the compressor, builds sufficient air in the tank, the photocells trip off (de-activate) the compressor motor and actuates the conveyor motor. The conveyor speed is regulated by the gear motor (as designed), as the Jar content moves to sealing point. As the lid of Jar gets closed under sealing head (pneumatic cylinder), the photocells sense the presence of the Jar and stop the conveyor system via the gear motor (aluminum foil is dropped on jar mouth) and actuates the sealing head to exert the pressing force required for sealing (downward stroke), simultaneously.

Once the sealing is completed in few seconds, the photocells consequently alert the solenoid valve to open the exit port of pneumatic cylinder to withdraw the sealing head and at the same time reactivate the gear motor to move the conveyor system, thus, the jar moves and are subsequently packaged as cap-less Jar or caped before packaging.

3.3 Testing

- 1 litre Jar of dimensions (54×43×82mm) minimum size;

The cans were arranged on the conveyor belt of the guided by the railing, with the can having dimensions of 54×43×82mm, the machine can accommodate three cans on an operation to sealing point. The adjustable sealing frame (about 609mm height) is lowered such that the stroke of the pneumatic cylinder to the lid of the container is about 800mm. as one can passes the sealing point, another can is replaced subsequently.

- 5litres can of dimensions (233×106×314mm) maximum size;

The Jars were arranged on the conveyor belt system of the equipment guided by the railings. Owing to its dimensions, two cans can be accommodated to the sealing point. The adjustable sealing frame (about 609mm height) was increase such that the pneumatic cylinder stroke to the lid of can is about 800mm. thus, as one can passes the sealing point, another can is added subsequently.

3.4 Observations

1. Irrespective of the dimensions of the cans, the process is regulated by the photocells.
2. The pneumatic cylinder stroke is also constant; 800mm
3. The force required is also constant; about 377N
4. The minimum pressure developed by compressor is also constant; about 2.5bar or 2.5×10^5 N/m^2
5. The time of sealing 2.8s and aluminium foil melts at about 130^o C
6. The Efficiency on each operation varies in can. However, for weight of can from 3.3kg to 10kg and can dimensions not exceeding $233\times 106\times 314mm$, the equipment will be 78% efficient.
7.

3.5 Cost evaluation

From market survey carried out, the automatic can sealing machine imported into this country is sold at the rate of #2,400,000 [6490USD] including customs charges. But from the Bill of Engineering Measurement and Evaluation [BEME], the amount was calculated to be approximately #950,000; meaning that there is a saving of #1,450,000 or 60.42% cost saving of the imported one. If this equipment is produced with mass production technique (commercialization), we could be rest assured that the amount will drastically reduce further.

IV. CONCLUSIONS

The automated adjustable-can foil sealing machine is indispensable in the production industries with applications such as food and beverages, bottled water and juice, dairy products, pharmaceuticals, chemical industries, edible oils, lubricating oils, oil treatments etcetera.

This equipment has been tested after its design and construction, and it efficiency is 78 %, which can be favorably compared with the imported types, which is about 90 %. It's far productive with respect to the locally fabricated type (Manually operated).

Hence, for effective and reliable sealing, purity retention, secure packaging, easy peel off, hermetic sealing and leak proofing, this equipment will help local manufacturers achieve foil sealing of their cans {jars}.

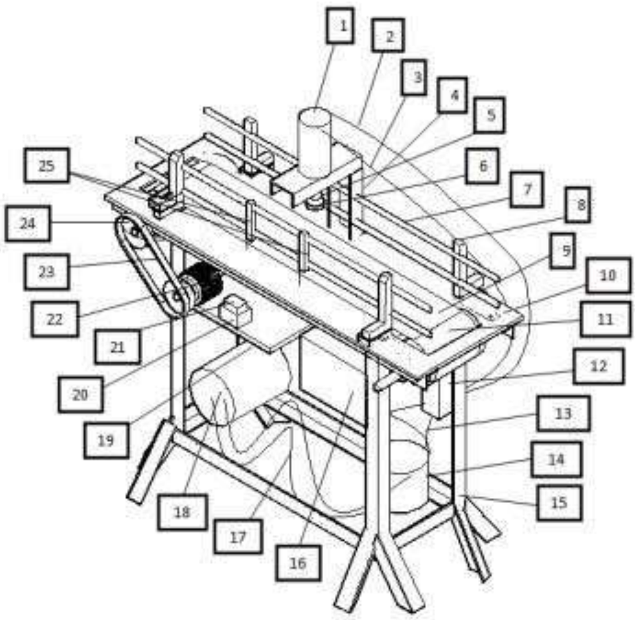

Fig 14: Isometric view of sealing machine


Fig 15: Photograph of sealing machine

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