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Design and Development of an Electric Vulcanizing Machine

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Abstract: The present method used in vulcanizing tyre tube was studied, and the problems associated with it include the release of carbon monoxide which reacts with hemoglobin in blood, converting it to carboxyhemoglobin which reduces oxygen in the blood. An improved electric vulcanizing machine was designed and developed with temperature regulator (a thermostat), timer switch and heating element connected to the aluminum fixed plate to eliminate the effect of inhaled carbon monoxide. A performance test was carried out on four different vehicles with punctured tubes, which are trucks, cars, motorcycles, and bicycle. The test was performed three times on each vehicle tyre tube and the average time to patch each tube was found to be 12 – 20 minutes for bicycle tubes, 17 – 22 minutes for motor cycle tubes, 18 – 25 minutes for car tubes and 20 – 27 minutes for trucks according to various tube thicknesses. The machine has succeeded in reducing the time used for vulcanizing a tyre tube, improved the efficiency of a vulcanizing machine, and reduced the hazards associated with the present method of vulcanizing.

Key words: Vulcanizing, Timer, Tyre tube, Heating element and Patch.

I. INTRODUCTION

Trucks, Cars, Motorcycles, and Bicycle owners sometimes face the problem of a punctured tyre and this is as a result of bad roads, the presences of foreign materials, (sharp object) on our road surfaces and sometimes the use of inferior quality tubes (Clifford, 2003). Vulcanizing is a method of treating crude rubber with sulphur or a sulphur compound so as to make it strong, elastic and resistance to action of solvents and abrasives as well as heat and cold (Derry and trevor, 1990).

If a tyre tube has been punctured, it can be repaired with a patch. The tube is removed from the tyre to find the leak by inflating the tube and submerging in water; bubble will appear when there is a leak, the spot is marked and the tube deflated and dried (Lindenmuth, 2006).

There are two ways to patch a tube that is either by the cold patch method or by the hot patch method. With the cold patch method, the tube is cleaned, dried free from oil and grease. The area around the leak is roughed and covered with vulcanizing cement, which the allowed to dry until it is tacky. The patch is pressed into the place and rolled from the center out with the edge patch –kit can. With the hot patch method, the tube is prepared into the same way as for the cold patch. The tools used by the vulcanizers in the hot patch method include a piston or a hollow cylindrical object (e.g., engine cylinder liner), which is place over the patch; a clamp is then used to hold the piston or cylinder firmly to the tube at point where the patch is placed.

If a hollow cylindrical object is used, a little sand is poured on the patched area and fuel is poured on the sand. When the fuel is ignited, the head generate will vulcanize the patch. In a place where the piston is used crown of the piston is placed on the patched area and held firmly on the patch with a clamp. A combustible material is then placed inside the piston and ignited, as the material burns heat is generated and conducted to the patch through the piston there by vulcanizing the patch. It is obvious that hot patch method of vulcanizing described above cannot be done in an enclosed area, or inside a workshop because of the carbon monoxide and carbon dioxide gasses which are formed during combusting of fuel. The tools used in this method of vulcanizing are obsolete and it takes more time to vulcanize a tyre tube.

In automobile industry, vulcanizing is the process of cooking or curing the vulcanizing rubber by heating it to a temperature of 120°C to 150°C. A temperature of 128°C is considered best. A layer of 1.5mm for vulcanizing requires 15 to 20minutes with 5 additional minutes for each additional 1.5mm layer.

The vulcanizing tube can be heated by electric power, gas, gasoline, or steam (Francis, 1988 and Thompson, 1992). Most vulcanizing process carried out across the country (Nigeria) today is still using the obsolete tools and equipment and this involves the burning of fuel to generate heat required. This method, apart from being time consuming, it constitute a health hazard such as myocardial ischemia (a lungs disease), accompanied by angina to the person carrying out the vulcanizing process and people within the vicinity where the vulcanizing is being done; it can also lead to a fire hazard as the fuel is highly inflammable (Heinz, 1989).

In view of the above problems, the electric vulcanizing machine was designed and developed. The machine uses electricity as its primary source of power; this electric energy is then converted to heat energy which is required for the heating of patch on the tyre. The vulcanizing temperature produced by the heating element will be

conducted by the plate (housing) of the heating element to the required level automatically with the aid of a thermostat.

II. DESIGN OF A VULCANIZING MACHINE

The machine consists of a heating element that converts electrical energy into heat energy, a thermostat to control the power to the machine at a pre-determined period of time. The device is constructed as a heat consumer and is fitted with an automatic temperature regulator connected to a heating element. These are attached to the upper plate of the machine. A two pole level switch is fitted in the lower part of the machine together with the timer. The necessary pressure on the vulcanizing patch of the tyre tube will be assigned through a pressure plate fastened to a reciprocating motion of a rod by means of gear mechanism controlled by the lever.

A. Design Analysis of the Heating Element

Normally, wires of circular cross section or rectangular conducting ribbons are used as heating elements. Under steady state conduction, a heating dissipates as much heat from its surface as it receives the power from the electric supply (Theraja, 2008).

B. Data used

Diameter of the heating element $d = 10\text{mm}$; Length of heating element $l = 300\text{mm}$; Voltage $v = 240\text{V}$; Current $I = 6.7\text{A}$; Resistance $R = 36\Omega$ (Cartridge and Insertion Heaters)

Now,

$$P = \frac{v^2}{R} \dots\dots\dots 1,$$

and

$$R = P \frac{l}{A} \dots\dots\dots 2$$

Where $A = \frac{\pi}{4} d^2 = 17.66\text{m}^2$. Substituting for A in equation 2

$$R = \frac{4Pl}{\pi d^2} \dots\dots\dots 3$$

Substituting for R in equation 3, into equation 2;

$$P = \frac{\pi d^2 v^2}{4\ell l} \dots\dots\dots 4$$

Where $P = 1.6 \text{ KW}$

$$\frac{l}{d^2} = \frac{\pi v^2}{4\ell} \dots\dots\dots 5$$

Where $R =$ resistance, $d =$ diameter of wire, $\ell =$ resistivity, $A =$ area, $v =$ voltage required, $l =$ length of wire.

The total surface area of the wire is given by $(\pi d) \times l$. If H is the heat dissipated per second per unit surface of the wire, then heat radiated per second is given by (Theraja, 1999).

$$P = (\pi d)lH \dots\dots\dots 6$$

From equation 5 and 6

$$P = \frac{\pi d^2 v^2}{4\ell l} = (\pi d)lH \quad \text{. Hence,}$$

$$\frac{d}{l^2} = \frac{4\ell H}{v^2} \dots\dots\dots 7$$

If 'P' is the power input it receives and it is the heat dissipated by Conduction then $P = H$ under steady state condition. From Stefan's law of radiation (Rogers, 1992), heat by a hot body is given by:

$$H = \ell \sigma A (T^4 - T_c^4) \dots\dots\dots 8$$

Where $P = H = 1.6 \text{ KW}$

And $T =$ Temperature of hot radiating material in kelvin, $T_2 =$ Temperature of Surrounding in kelvin, $\ell =$ Emissivity and $\delta =$ Stefan's radiating constant.

B. Selection of Heating Element

Dry temperature up to 40°C has little effect on rubber, but at a temperature of 181°C 240°C , rubber begins to melt and becomes sticky. It becomes completely carbonized at higher temperature. The minimum and maximum

vulcanizing temperatures for tyre are 130°C and 150°C (Eugene, 1996). In selecting the heating element for electric vulcanizing machine, the above temperature limits were considered. From table 1, the element with the least operating temperature is constantan, which was selected and has an operating temperature of 400°C. But the maximum vulcanizing temperature required is 150°C; and in order to regulate the temperature a thermostat was connected to the element and adjusted to 150°C maximum.

Table 1: Composition and Operating temperatures of elements

Element	Composition	Operating temperature
Constantan	45% Nickel, and 55% Copper	400°C
Nichrome	50% Nickel, 20% Chromium and 30% Copper	1150°C
Kautha	70% Iron, 25% Chromium, and 5% Alluminium	1200°C
Silicon carbide		1450°C

Source: Thompson (1992).

C. Upper Plate Design (Heating Element Housing)

The upper plate is a rectangular block of aluminium which was casted to size of 150mm by 220mm. the upper plate houses the heating element and the thermostat. The plate conducts the temperature of the heating body to the tyre tube being patched. Current flowing through the conducting element is derived from the power spent in the conductor (Eugene, 2001)

$$P = IV \text{ (W)} \dots\dots\dots 9$$

By Ohm's law, $V = IR$ and substituting for V in equation (9)

$$P = I^2 R \text{ (W)} \dots\dots\dots 10$$

In the electric vulcanizing machine, heat is transformed from the heating element to the upper plate by conduction. The greater the material thickness, the less the heat transfer. Heat transfer is therefore inversely proportional to thickness.

Assume the upper plate has a thickness x, and heat transfer Area A let the temperature of its faces be T_1 and T_2 respectively, and an elemental thin slice within the material of thickness δx , and the temperature full across the elemental slice = δt (Jagar et al, 1986). Then

$$Q \propto A \frac{\delta t}{\delta x} \dots\dots\dots 11$$

$$Q = -kA \frac{\delta t}{\delta x} \dots\dots\dots 12$$

Where k = thermal heat capacitance of Aluminium.

Assuming the temperature fall to be linear through the material thickness = x, equation 12 becomes

$$Q = -kA \frac{(T_2 - T_1)}{x} \dots\dots\dots 13$$

Heat transfer Q becomes

$$Q = kA \frac{(T_1 - T_2)}{x} \dots\dots\dots 14$$

D. Thermostat

The thermostat is used to control the electric vulcanizing machine so that a defined temperature is maintained. It uses the principle of bimetallic trip to bend when a defined temperature limit is exceeded by switching off itself and returns to normal shape when lower temperature has been reached. Time switch is also incorporated to cut out power supply to the machine after a specified period of time.

E. Base Plate

The base plate of the machine is made up of a mild steel of 2mm thickness. The plate is welded into a rectangular shape of 360mm by 250mm. The base plate supports the entire weight of the vulcanizing machine.

F. The Post

The post is part of the machine on which the heating element is mounted. It is made up of a rectangular pipe made up of mild steel which is welded to the base plate of the machine. The area of the rectangular pipe is given by:

$A = l \times b$.

III. GEAR DESIGN

Gear tooth design involves primarily the determination of the proper pitch and face width for adequate strength, durability, and economy of manufacture.

Guidelines for selection of minimum number of teeth of pinion are given in table 2 below.

Guideline for selection of the number of teeth on pinion

Types of Service	Minimum Number of Teeth
Heavy duty and high speed	16
Medium speed	12
Light duty and Low speed	10

Source: (Gitin, 1989)

The number of teeth of the pinion and the gear are to be chosen that a minimum value of 1:1 for contact ratio is assumed. For fast moving sets, it should be greater than 1:5 transmission ration and should not be a whole number. For the sum of the number or difference of teeth of the pinion and gear the following rules hold.

$N_p + N_g \geq 24$ for external gearing; where N_p = number of teeth of pinion, N_g = number of teeth of gear.

And $Z_g - Z_p \geq 10$ for internal gearing.

Proportion of Standard Gear Teeth.

Characteristics	14.5° composite	14.5° full depth involute	20° full depth involute	20° stub involute
Addendum	M	m	m	0.8m
Minimum dedendum	1.157m	1.157m	1.157m	m
Whole depth	2.157m	2.157m	2.157m	1.8m
Clearance	0.157m	0.157m	0.157m	0.2m

Source: Joseph (2007).

The type of gears for the electric vulcanizing machine is the involute rack and pinion gear system. The involute has the same proportions as gears but the pitch circle diameter of the rack is infinitely large. The pressure angle for the involute teeth has been standardized at 14.5° or 20°. Using an angle of 14.5° which can cause interference and gives the teeth wider root (Gitin, 1989). The number of teeth for the pinion is selected from table 3 since the gear is for light duty and low speed; a minimum of 10 teeth is required. To calculate for the module, the following formula is used.

$$OD = m(T + 2)$$

Where OD = outside diameter, m = module and T = number of teeth.

The pitch circle diameter of the pinion is given by
$$c = \frac{D\mu}{N}$$

$$\text{Center distance} = 0.5(D + d)$$

$$\text{Module} = \frac{\text{Pitch circle distance}}{\text{Number of teeth}}$$

Sum of number of teeth of pinion and wheel $= N_g + N_p \geq 24$

Angular velocity = T/t , where T = number of teeth on the rack, t = number of teeth on the pinion.

Circular pitch = πm , tooth thickness = (circular pitch)/2

Base circle = pitch circle diameter x pressure angle and the angle is 20°

Addendum = Module m

Dedendum = 1.157m

Whole depth = 2.157m

Clearance = 0.157m

IV. PERFORMANCE TEST

The electric vulcanizing machine was tested to ensure that its working principle and its efficiency are in conformity with the reason of designing and fabrication of the machine. A punctured tyre tube was prepared and placed on the moveable plate of the machine; this plate was then raised so that it presses the tyre tube to be patched against the heating element. The machine was switched on, the temperature regulator set to vulcanizing temperature of 128°C, and the temperature timer set for 15minutes (being the minimum vulcanizing temperature for tube), and then repeated for 20minutes (being the maximum temperature for tube vulcanizing). The patched tyre was removed and tested for leakage; which was done by inflating the repaired tube and immersed in a solution of detergent with water. No air bubbles were seen, indicating no leakage on the tube. Different thicknesses of tubes were further tested to determine the temperatures for patching each tube thicknesses. The thicknesses are: 0.75, 1.5, 2.0, 2.5, 3.0, and 3.5 respectively.

V. RESULT AND DISCUSSION

Table 1: Vulcanizing tests results.

Temperature (°C)	Tube thickness (mm)	Time range (min)
128	0.75	12 – 17
128	1.5	15 – 20
128	2.0	17 – 22
128	2.5	18 – 23
128	3.0	20 – 25
128	3.5	22 – 27

From the table 1 above, it is noticeable that the time for vulcanizing varies with tube thickness. Nevertheless, the result shows that the electric vulcanizing machine provides a faster means, cleaner and faster way of vulcanizing tubes. The test also revealed that the time taken to patch a punctured tube depends on the voltage supplied at the time of the repair. In the case of the test carried above, the available voltage was between 220V and 240V which is mostly the normal temperature of appliances in Nigeria. The time to patch 0.75 tube thickness was found to be 12-17minutes.

A. Thermal Efficiency

To determine the thermal efficiency of the vulcanizing machine, the heat lost must first be determined. The quantity of heat used in heating a body is given by $Q = m \times c \times t$ (Rayner, 1987); where Q is the quantity of heat in Joules, m is the mass in kilogram, and specific heat in Joules per kilogram and (t) is the temperature rise in degrees Celsius.

Let the temperature drop of the component be $t^\circ\text{C}$, now the temperature drop = $(128 - t)^\circ\text{C}$; and temperature rise = $(t - 25)^\circ\text{C}$; where 128°C and 25°C are the room temperature of the pressing plate (Wikipedia)

Therefore Heat lost by heating element housing = $Q = (mc\theta)\text{rise} = (mc\theta)\text{drop} = 1.8 \times 921(128 - t)^\circ\text{C} = 1.9 \times 460(t - 25)^\circ\text{C}$

Now the thermal efficiency = Eff.

$$\text{Eff} = \frac{\text{Energy input} - \text{Heatlost}}{\text{Energy input}} \times 100\%$$

B. Operational Principles of the Electric Vulcanizing Machine

When the device is connected to electricity and switched on, a circuit is made immediately; and flow of electric current is allowed from the electric source to the heating element. The heating element then converts the electrical energy into heat energy. This is done when the electric current encountered resistance. A thermostat is employed in order to automatically control or maintain the temperature to a desired degree while the function of the timer is to stop the machine at a stipulated period of time once the element get heated, the prepared tube is placed on the pressing plate and adjusted linearly with the aid of bevel gear mechanism to pass the tube to the heating element (Aluminium Housing) when the tube is vulcanizing. The temperature required for the vulcanizing is ideally 128°C for a tube 1.5mm thickness in 14 – 20minutes and with each additional 5 minutes with 1.5mm thick addition.

VI. CONCLUSION

Electric vulcanizing machine was designed and developed. It drastically reduces the time spent in vulcanizing tyre tubes thereby providing an alternative way of repairing tyre tubes. The machine produced gave a new technology in vulcanizing tyre tubes and reduces the various hazards associated with local methods of vulcanizing.

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