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DESIGN AND PROTOTYPE DEVELOPMENT OF A MEAT SLICING MACHINE

A. O. ODIOR

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ABSTRACT

In an attempt to facilitate the processing of meat which is a daily nutritional food requirement of man, a meat slicing machine has been developed. The machine consists of a cutting blade, a meat feeder, a meat tray, a meat clamp, the crank mechanism and a control unit. The machine was designed to enhance the hygienic slicing of meat for both domestic and commercial consumption and it can accommodate from one to six cutting blades which are spaced 6.5mm from each other to give a meat slice thickness of 5mm per slice. It takes an average of 4 seconds to cut a slice and one hour for 2.673 tonnes.

KEYWORDS: Meat Slicing, Cutting Blade, Meat Feeder, Slice Thickness.

1.0 INTRODUCTION

Meat is the flesh of animals consumed for food and it is a very important food delicacy that has been eaten since the existence of man. The consumption of meat along with other basic food is very important as it enriches both the nutritional content of the food and also acts as important delicacies. It is a nutritious food containing some quantities of essential amino acids, in the form of proteins and also contains group of vitamins. Animal meat is composed of muscles, bones, fats and connective tissues, and the main edible and nutritional part of the meat is the muscle or lean meat (Ikekoronye and Ngoddy, 1995). Therefore the meat has to be cut into large chunks, and then into bits and pieces so as to bring out the flavour and make it in edible form.

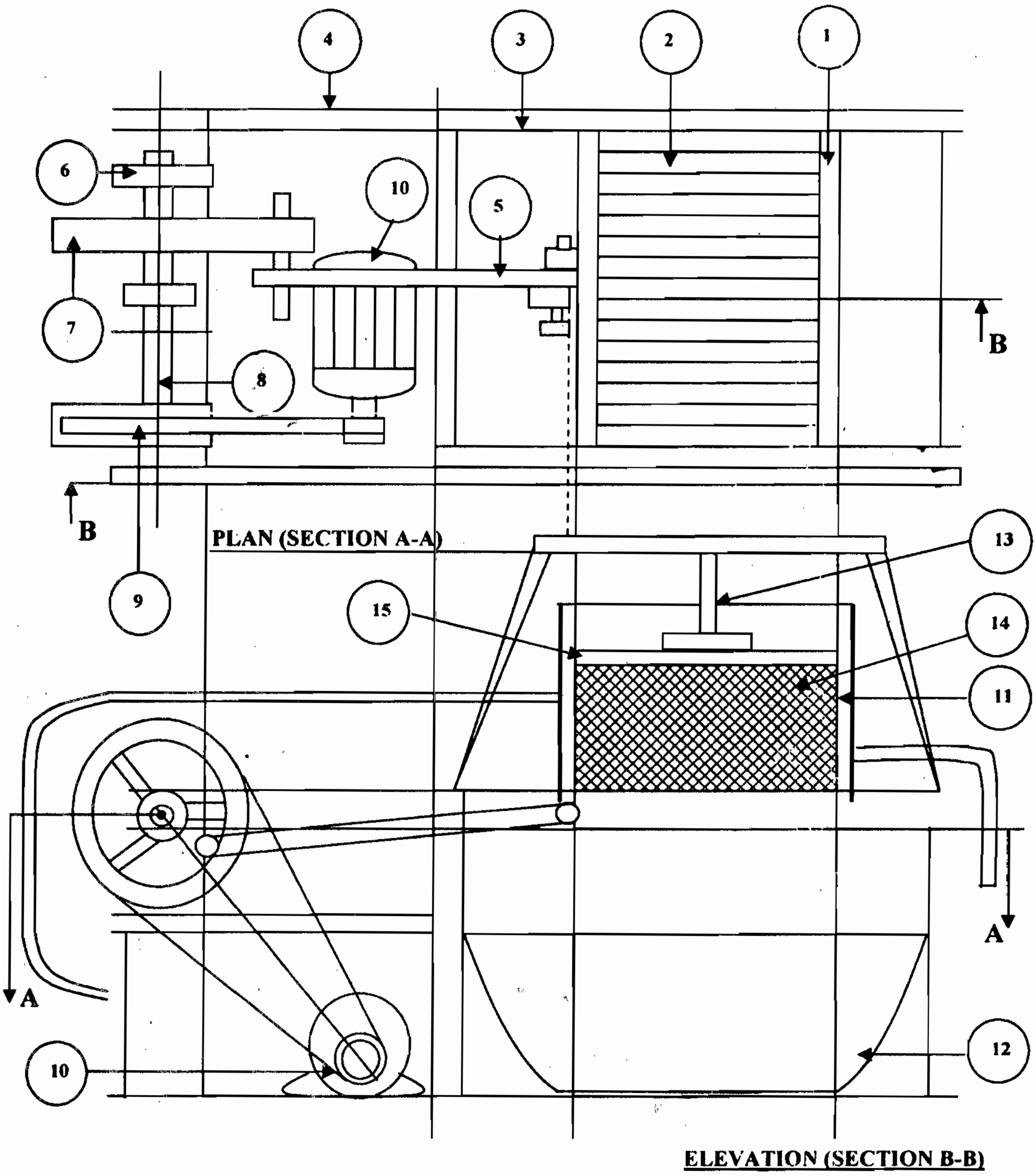
Meat is cut using various sharp instruments such as matches, knives and meat saw. These implements are only efficient in cutting the meat into chunks and de-boning but cannot cut the meat into small bits and as a result of this, different machines have been developed over time for slicing meat (Charles, 2001). The principles of slicing machine is based on the action of shearing by blades and other types of cutters with same principles as the slicing which include the impact-type cutter, the mower cutter bar and the knife drive system.

A number of authors have studied the principles of slicing and slicing machines. Otto Rohwedder designed and manufactured the first slicing machine that would slice and wrap bread in 1925, (Frank (2004). The first meat slicing machine was invented by an American in 1873. The machine made use of an oblique knife in a vertical sliding frame for slicing dry beef and it worked with the frame holding the meat while slicing it against the cutting blade, (Hardin, 2001). The conventional slicing machine was originally designed to slice meat into pieces of uniform thickness. It was also used for slicing cheese, vegetables, ham, onions green peppers an sandwich ingredients (Tannahill, 2003). According stated that There are basically three types of slicer; the gravity slicer, the horizontal slicer, and the bacon slicer and these three groups of slicer have their own shortcoming. The slicing machine for slicing food, such as meat, cheese, sausage and vegetable consists of a conveying device, a rotating blade and a knocking-off mechanism for transferring the slices from the conveying device to deposit area, (Ohaneche, et al., 2005). Orobor (1992) studied a vegetable slicing machine and divided the operations into four stages, consisting of material intake, material transmission, material slicing and material ejection. He also stated that the vegetable slicing machine mechanism is simply the action of shearing by the blades just like that of meat slicing machine.

2.0 PARTS AND OPERATION OF MACHINE

The developed meat slicing machine was designed to slice meat in frozen form. It can accommodate one or more cutting blades as required by the user. Figure 1 shows the assembly of the meat slicing machine which works on the principle of a normal slicing machine. It is made up of a frame on which on which are mounted, electric motor, the tray carriage, the meat feeder, the meat clamp, the slide way which carries the slider in which a set of cutting blades are arranged. The cutting blades are spaced 6.5mm from each other to give a meat slice thickness of 5mm. Figure 2 shows the cutting blades arrangement and the cross – section of the meat hopper.

A. O. Odior, Department of Production Engineering, University of Benin, Benin City, Nigeria.



(1) – Cutting Blades Cage/Slider
(2) - Cutting Blade (Φ 240mm)
(3) - Slideway
(4) - Machine Frame (600mm X 520mm).
(5) - Connecting Rod
(6) - Crank Wheel
(7) - Bearing
(8) – Crank Shaft
(9) – Crank Pulley
(10) –Electric Motor (2hp)
(11) – Machine Cover
(12) – Slice Collecting Bowl
(13) – Meat Feed Spring
(14) – Meat
(15) – Meat Hopper

Fig. 1: Plan and Front View of the Meat Slicing Machine.

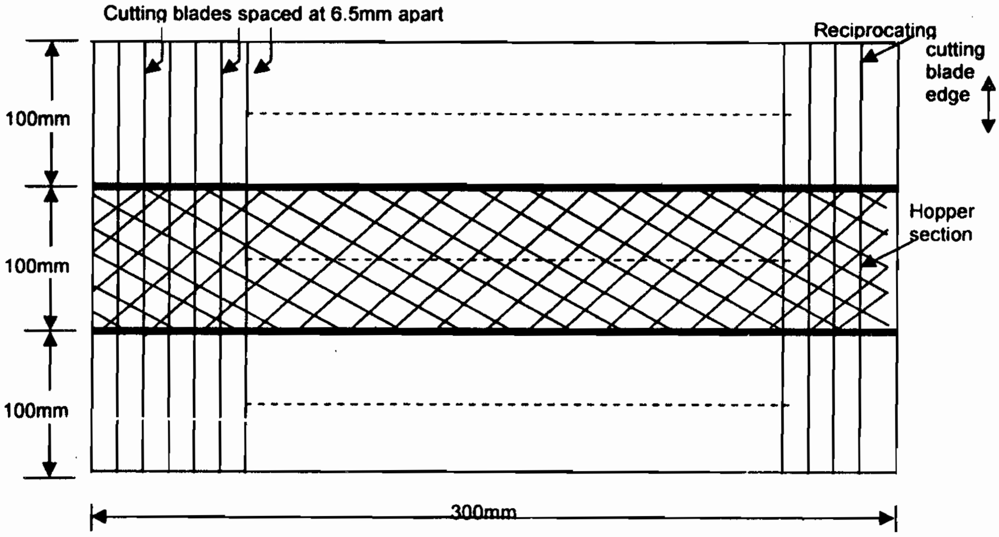


Fig. 2: Cutting Blades Arrangement and Cross – Section of Meat Hopper

The machine is designed to produce smooth and hygienic slices with a total mass of about 3.125 tonnes in one hour. This machine slicing capacity is anticipated with the assumption that the meat being sliced is boneless and in frozen form. It consists of the following main components; the rotating disc cutter, the tray-carriage, the meat feeder, the meat clamp and the control unit

2.1: The Rotating Disc Cutter

The rotating disc cutter is a flat disc made of stainless steel material. It is 240mm in diameter and is coupled to an AC electric motor. The blade rotates at a speed of about 1500 revolutions per minute and it is shown in Figure 3.

2.2: The Tray – Carriage

This is the component that carries the meat to be sliced to the slicing point. It consists of a framed part with stainless steel tray that is used to carry the meat which it moves towards the blade for slicing. It exhibits a reciprocating to and fro motion towards the blade for cutting to take place. This is shown in Figure 4.

2.3: Meat Feeder

The meat feeder feeds the meat to be sliced towards the blade by pushing the meat out of the tray towards the blade. The meat feeder consists of a pusher and threaded screw length as shown in Figure 5.

2.4: Meat Clamp

The meat clamp is a device that holds the meat to be cut in place. As the meat is fed out by the meat feeder, the clamp is activated to hold and clamp the meat for slicing. This is shown on the assembly of meat feeder, meat clamp and tray carriage in Figure 6 below.

2.5 The Control Unit

The control unit is an important component of the machine as it coordinates and controls all the other components of the machine. It is made up of step down transformer, relays, switches, capacitors and a timer which are all connected together in a circuit.

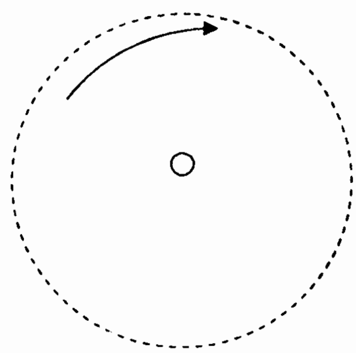
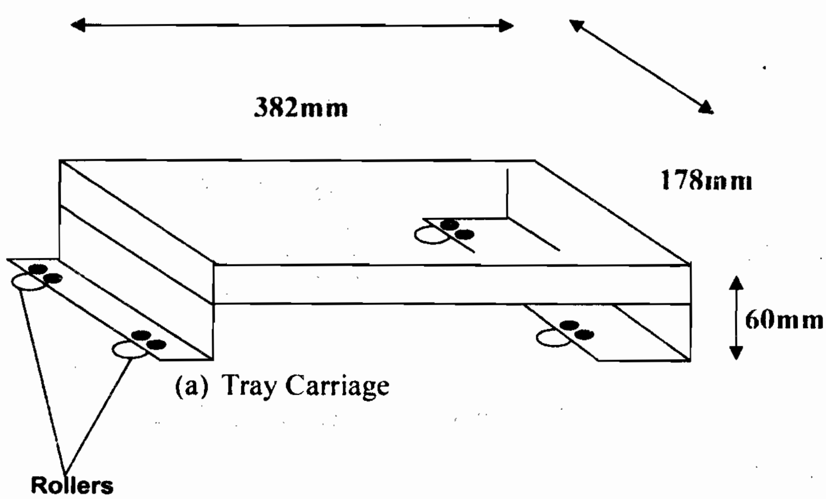
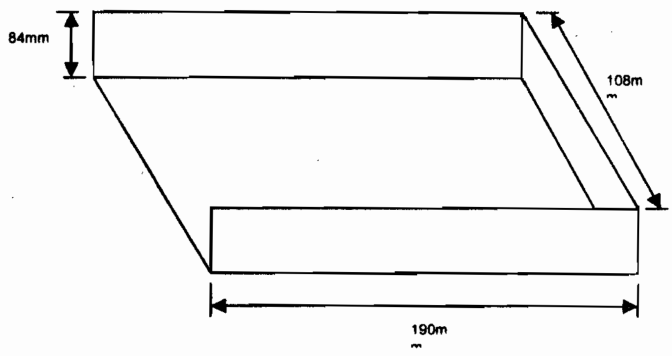


Fig.3: Cutting Blade



(a) Tray Carriage



(b) Meat Tray.

Fig. 4: Tray Carriage and Meat Tray

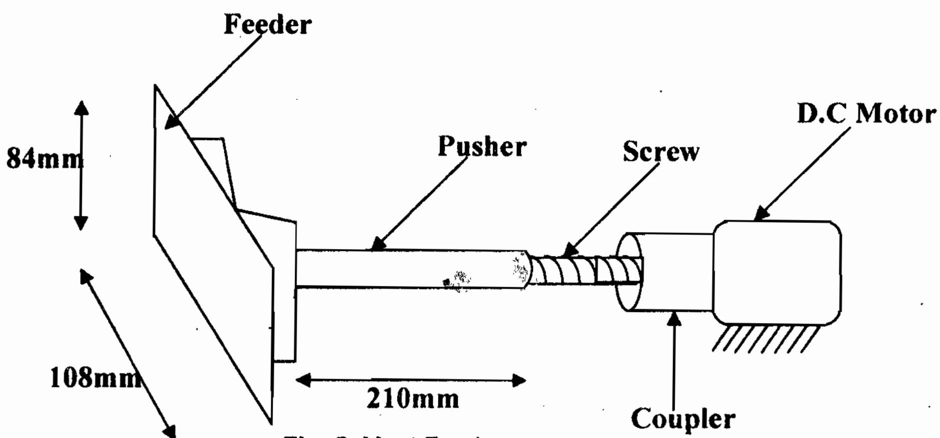


Fig. 5: Meat Feeder

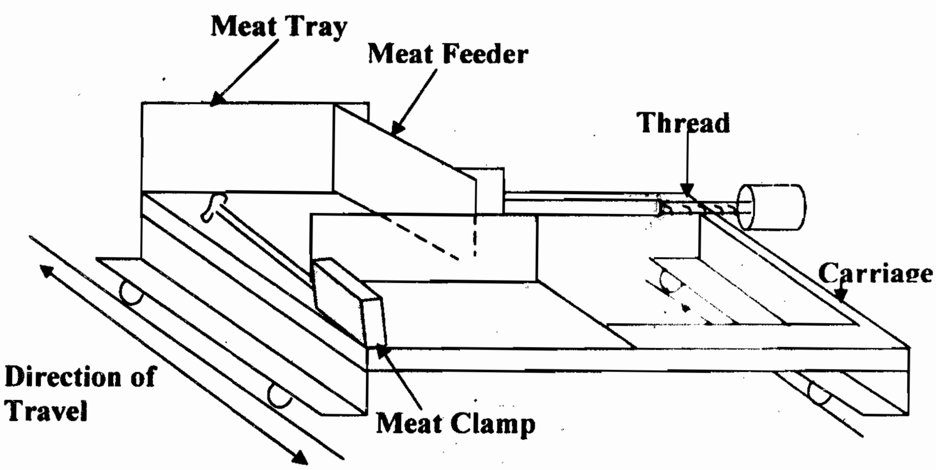


Fig. 6: Assembly of Meat Feeder, Meat Clamp, and Tray on The Carriage

2.6 Operation of the Machine.

The meat to be sliced is loaded on the tray placed on the tray-carriage which moves the tray with the meat towards the blade for cutting. The meat feeder then moves the meat through a pre-set distance before the meat clamp is activated to hold the meat in position for cutting. When the power source is switched on, the cutting blade begins to rotate while the required size of the meat to be cut is selected for the slicing. The meat feeder then feeds the selected size of the meat towards the cutter and stops automatically

A signal is then set to the meat clamp to hold the meat to be sliced and the tray mechanism moves quickly to the rotating blade which then cuts the meat into the pre-set slice sizes. After that the tray returns to its original position and as it stops, another signal is set to the meat clamp to release the meat by pushing it towards the blade. It takes on the average about 4 seconds to cut a slice. The process continues until the whole meat is completely cut into the required slices.

3.0: DESIGN ANALYSIS.

3.1: Power Required for Slicing Operation.

In cutting processes, Boothroyd (1985). The required for slicing is

$$P_m = P_e \eta_m \text{ ------------ } (1)$$

$$\text{or } P_m = P_s Z_w \text{ ------------ } (2)$$

$$\text{while } Z_w = f_e a_c v \text{ ------------ } (3)$$

where P_m = cutting power.

P_e = electric motor rating,

η_m = overall drive system efficiency,

P_s = specific cutting energy

Z_w = material removal rate,

f_e = feed per stroke of cutter,

a_c = undeformed meat thickness,

v = cutting speed.

3.2: Cutting Speed

The cutting speed required for slicing is given by,

$$V = \frac{\pi D n}{60} \text{ ------------ } (4)$$

Where V = cutting speed of blade,

n = rotational speed of blade (rpm),

D = cutter diameter.

The speed of cutter is obtained from equation (4) as,

$$n = \frac{60V}{\pi D} \text{ ------------ } (5).$$

3.3: Crank Mechanism of the Tray-Carriage.

Figure 6:shows the crank mechanism which produces the reciprocating motion of tray-carriage that carries the meat and moves to and fro relative to the disc cutter. The displacement, velocity and acceleration of the slider are evaluated as follows (Mabie and Ocvik,1978).

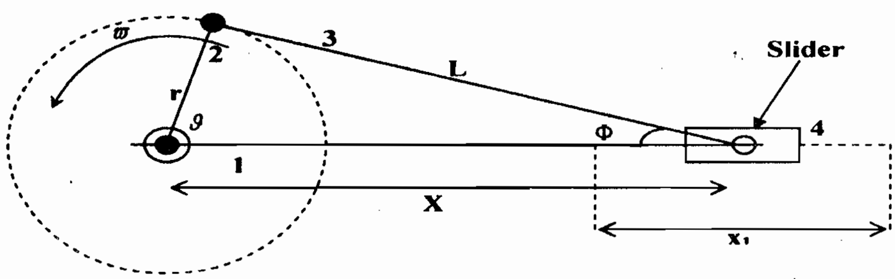


Fig.6:Crank Mechanism for the Tray Carriage

$$x = R(1 - \cos\theta) + \frac{R^2}{2l}\sin^2\theta \text{ ------------ } (6)$$

$$v = \frac{dx}{dt} = R\omega(\sin\theta + \frac{R}{2l}\sin 2\theta) \text{ ------------ } (7)$$

$$a = \frac{d^2x}{dt^2} = R\omega^2(\cos\theta + \frac{R}{l}\cos 2\theta) \text{ ------------ } (8)$$

where x = distance moved from maximum end of dead centre,

v = velocity,

a = acceleration

l = length of connecting rod,

R = crank length,

ω = angular velocity of the crank,

θ = crank angle,

ϕ = connecting rod angle.

3.4: Turning Moment and Axial Load on Meat Feeder.

The turning moment and axial load on the meat feeder is obtained from the relationship,

$$T = w[r_m(\frac{\tan\alpha + \frac{f}{\cos\theta}}{1 - f\frac{\tan\theta}{\cos\theta}}) + f_c r_c] \text{ ------------ } (9)$$

Where T = torque applied to turn the meat feeder,

w = load parallel to screw axis,

r_m = mean thread radius,

r_c = effective radius of rubbing surface,

f = coefficient of friction at collar,

α = helix angle at mean radius,

θ = angle between tangent to tooth profile and a radial line.

4.0 THE THROUGHPUT OF THE MACHINE

The machine capacity is determined from the mass of the sliced meat per unit time. From the performance of the machine, the time taken for the carriage to move to and from the blade is 4 seconds and the thickness of each slice is 5mm, while the length of the slice is 108mm. Thus the cross – section of the meat sliced by the blade is

$$A_m = 10.8 \times 0.5 \text{ cm}^2 = 5.4 \text{ cm}^2.$$

The stroking rate of the to and from the blade is S_r = 15 strokes per minute, The feed rate of cutting the meat is f_m = 0.5 cm /stroke.

Therefore, the height of meat cut in one minute is $H_m = S_r \times f_m$ = 7.5 cm.

Thus, volume of meat sliced in one minute is

$$V_m = A_m \times H_m = 40.5 \text{ cm}^3.$$

The density of meat (at 75 percent moisture content), ρ_m = 1100g/cm³.

Thus, the mass of the meat cut per minute,

$$M_m = V_m \times \rho_m$$
$$= 40.5 \text{ cm}^3 \times 1100 \text{ g/cm}^3$$
$$= 44550\text{g}$$
$$= 44.55 \text{ kg per minute.}$$

The mass of meat sliced in one hour,

$$M_m = 44.5 \times 60 \text{ kg.}$$
$$= 2673 \text{ kg or } 2.673 \text{ tonnes.}$$

5.0 CONCLUSION

Over the year, the traditional process of slicing meat has always been slow, tedious, boring, time consuming and in some cases unhygienic. The possibility of mechanism the process of meat slicing becomes very necessary. A meat slicing machine was therefore designed to mechanize the process of slicing meat for both domestic and commercial consumption.

The manufacture of the meat slicing machine involves the design and fabrication of some principal components which include the tray-carriage, the disc cutter, the meat feeder, the meat clamp and the control unit. Each part was carefully designed to meet the functional requirement of the machine, and different sizes of slices are obtainable by activating the meat feeder to give the desired sizes of sliced meat. The efficiency of the machine is quite encouraging as very smooth and hygienic slices are obtained and it takes on the average, about 4 seconds to cut a slice, while the mass of meat sliced in one hour is about 2.673 tonnes.

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flux-linkage into components. Instead it fits the total flux-linkage data using equation (10) directly and the coefficients, so generated, are used for the prediction of static torque.

The result of fitting the flux-linkage data shows that the total discrepancy using a root error squared routine as compared to the measured flux-linkage data at the motor rated current of 15.0A is 0.37% for the separate fitting and 0.29% for the composite fitting methods, meaning that the later approximates the flux-linkage data more accurately than the former.

For the prediction of static torque/rotor angular position, the discrepancy using the average root error square routine when compared with the average holding torque at the motor rated current of 15.0A are 3.35% and 2.27% for the separate and composite fitting methods respectively, while the percentage of the root of the average error squared as compared to the holding torque at the particular current is displayed in Figure 6. This again shows the superiority of composite fitting over the separate fitting method. The superior accuracy of the composite fitting method over the separate fitting variant shows that permanent magnet mmf varies with the hybrid motor stator excitation. Hence, the algebraic summation to produce the current-dependent flux-linkage as implemented elsewhere (Pickup and Russell, 1979) will lead to loss of accuracy of prediction.

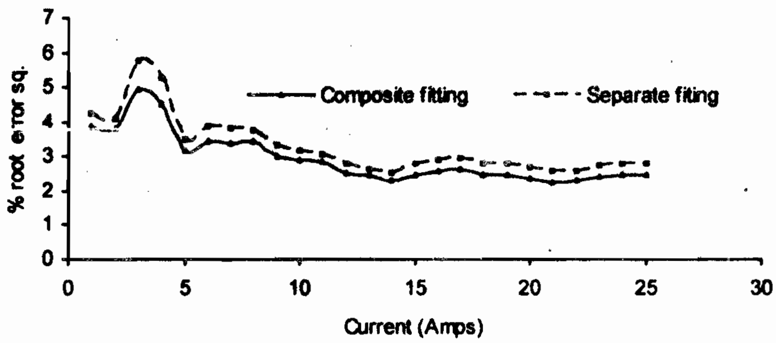

Fig. 6: Percentage of the Root of the average Error Squared as compared to the holding torque at the particular current

CONCLUSION

A new theoretical method of predicting static torque/rotor angular position characteristics of hybrid stepping motors based on measured flux-linkage data has been presented. This method uses the principles of an existing method (Pickup and Russell, 1979) but differs in the way it handles the flux-linkage data. While the original method separated the flux-linkage data into permanent magnet and current-dependent components and handles them separately, the new method handles them compositely. The analytical (composite fitting) method fits the total flux-linkage data and calculates the $T(i,\theta)$ characteristics with less discrepancy than the analytical (separate fitting) method. The high accuracy of prediction displayed by the composite fitting method gives it an edge over the separate fitting method (Pickup and Russell, 1979) and is highly recommended for this class of motors.

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