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Design and Development of an Instant Amala Making Machine with Control System Integration

Dr. S. P. Ayodeji, Gbadamosi-Adeniyi Temilola, Faboyin Olanrewaju Tope, Adekoya Oluwaseun Abiodun
Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria

ABSTRACT

The most important factor in food production/processing is safety and quality in terms of hygiene and nutritional value. Processing of unripe plantain into a finished product of Amala conventionally is laborious and unhygienic. This project named Design and development of an instant Amala making machine with control system integration was designed and fabricated to make Amala preparation an easy one and remove the fatigue usually experienced during manual preparation. The machine was designed for small scale use and it is capable of processing 15 fingers of unripe plantain pulp for 10 people. It has two compartments; the cooking/pounding and the electric motor/water reservoir. The machine was designed using Solidworks CAD software and computer programming using Micro C. After fabrication, the machine was tested and the result observed from the functional evaluation of the machine, shows that before implementation of control, the time recorded was 58 minutes and after incorporating control, it took 56 minutes, the overall operation time of the machine is lesser when compared to the processing of Unripe plantain into flour. It was observed that both took longer because of the thickness of the pot and the sizes to which each finger was reduced, using a kitchen knife. The machine minimizes human intervention and makes for hygienic processing of Amala. The color observed from the final product of the operation is light brown which makes it pleasant looking, instead of the darkish brown color usually observed from plantain flour. Further course of action is recommended as the machine as it is still a prototype.

Keywords: Machine design, Food processing/Engineering, Automation and control, CAD software, programming

I. INTRODUCTION

An essential factor in food production/processing is safety and quality in terms of hygiene and nutritional value. Food processing can be defined as the methods and techniques employed to transform raw food materials into food fit for human consumption. The instant Amala making machine adopts a mechanical pounding process for its size reduction, agitation, and mixing of the plantain to give the final product and also process control. The "instant" in the title of this machine is because the usual processing of unripe plantain into flour is eliminated, which takes weeks for completion, the operation of this machine takes less than an hour for completion. The electrically operated automatic machine was designed by integrating engineering techniques with the conventional method of making Amala. Improvement in technology has led to the introduction of automation and process control for systems and processes in many industries, which have made them more simplified, smooth, efficient, and cost-effective.

Process control is an integral part of modern processing industries, and the food processing industry is no exception. According to Berk (2013), the operation of the unit of food processing by the group is 'cleaning, physical separation, molecular separation, mechanical transformation, chemical transformation, and packaging.' Most food processors utilize the mechanical transformation under which there are size reduction and mixing.

The use of automation in Africa is not widespread; as such, we still depend on mechanization instead of automation. Nigeria, as a Nation and giant of Africa, should endeavor to keep up with the various change in technologies and apply this technology in day to day activities, although expensive at first, but the use of the various techniques can be justified in the long run.

The mode of movement of the food machine is defined by the process of food production, and there are four (4) main types of food machine manual control system: the transmission coordinated control system, the time control system, the travel limit control system, and the numerical program control system (Cheng, 1992). The transmission system is used to connect the drive with the working members, to link one operating mechanism with another, to transfer necessary power for food processing. The electric motor that provides power to the shaft in this machine is directly mounted.

Plantain (Musa paradisiacal) is a staple crop and an important dietary source of carbohydrate in Nigeria and the humid tropical zones of Africa, Asia, and South America" (Robinson, 1996). It is a perennial and herbaceous plant belonging to the family Musaceae and the genus Musa, which is often confused with banana. The features of the plant include long overlapping leafstalks with a stem, which is 1.22m to 6.10m high, and the leaves grow to a length of 1.83m and a width of 0.61m (Shodehinde et al., 2014). It requires an ideal temperature of 30^{0}C, an average monthly rainfall of 100mm, and a sandy loam soil to thrive (Oluwatosin, 2003) for proper growth until maturity. As stated by Anderson and Gugerty (2013), West Africa is one of the significant plantain-producing regions of the world, accounting for approximately 32% of worldwide production, plantain has much higher production and greater nutritional importance in West Africa than bananas.

This project focuses on the development of an instant amala making machine from a fresh unripe plantain. The machine is electrically powered and automated; the essence of the automatic control system is to self regulate the unit operation of the machine. The "instant amala", which the machine is designed to prepare, involves slicing fingers of plantain into smaller pieces manually before pouring into the cooking compartment of the machine and further size reduction is achieved by the action of shearing forces which is applied to the plantain by mechanical agitation, the plantain is cooked at a specific temperature provided by the heating element for a specified period of time. When cooking is done, the cutting, beating, and agitation of the cooked plantain begin resulting in the formation of fine dough having cartoon-like color. The rotating impeller/stirrer shaft impacts cutting and beating action (agitation) to the boiled plantain, which transforms it into a pulp, this is made possible by the design of impeller/stirrer blades, and the electric motor provides the power for the rotation of the impeller shaft. The development of this machine would help to ease the preparation of "instant amala" whose preparations are quite laborious and traditionally unhygienic (i.e. the processing of the plantain to flour). However, the principles upon which the machine would be designed are relative to the traditional/domestic way of preparing it but physically synonymous. Automating the food preparation process would significantly help to reduce human effort, thereby leading to higher productivity, probably raise the global acceptance level of amala consumption. The introduction of control (automation) is one of the technological advancements in food processing.

A. The food- "Amala."

"Amala" is a popular Nigerian food that is widely eaten by the Yoruba speaking parts of Nigeria. It is a brownish or darkish thick dough made from unripe plantain flour. The first method is the most commonly used, while the last method is adopted for this project. Traditionally, it is prepared by mixing plantain flour with boiling water and stirring continuously with a spatula ("orogun") thoroughly to eliminate lumps in order to have a fine dough. Unripe Plantain flour (called elubo agbagba by the Yoruba speaking part of Nigeria) is made by peeling unripe plantain, washing, drying, and grinding to reduce to a powdery form. Plantain is a highly perishable crop hence the need for processing to preserve it. Amala is a staple food consumed by all, but it is consumed in large quantities, particularly by Ibadan (the largest city in Africa) people of the Yoruba speaking part of Nigerian. Amala can be eaten with a variety of soup such as Okro, Egusi, Efo-riro, Oha, Afanga, Ewedu, Ogbono, etc. There are three methods by which Amala can be obtained from unripe plantain; processing plantain into flour and then mixing in boiling water; blending sliced unripe plantain before cooking and; slicing and cooking the sliced fingers of plantain after which is blended. The indigenous method of making Amala is laborious, as it requires a lot of physical effort for stirring and mixing the plantain flour vigorous in hot water, and the pot held with feet of the person preparing it. To ease this process, the automated amala making machine was developed to reduce the time, excess energy expended in the turning as well as overcoming some constraints and some short-coming in the previously existing designs. The machine is capable of cooking and processing the cooked plantain into Amala within the same compartment, yet retaining the quality (nutritional value) of the Amala at optimum hygiene. In order to design the machine effectively, it is pertinent to have good knowledge of the manual process involved in the making of amala.

II. METHODS AND MATERIAL

The Instant Amala Making machine is designed for the domestic preparation of Amala. This design incorporates automation of all the processes involved in the making of the final product. The machine has two (2) compartments, as shown in Fig. 1 and II. The machine consists of three (3) support stand and base stand, an AC electric motor and DC electric motor, impeller/stirrer blades, cooking and mixing bowl, two electric heating element, and a water reservoir located in the upper compartment of the machine and a solenoid valve. There are four impeller/stirrer, slightly twisted blades welded to the shaft at an angle 90^0c to each other, and to facilitate the removal of the impeller/stirrer, to aid its cleaning, the coupling is used.

The machine is automated and integrated with some controls with the help of programming and some control devices. The only manual aspect of the process is the peeling and washing of the plantain. The electric motor is directly mounted on the top cover of the pot alongside the water reservoir compartment, which contains the water required for the stirring. The whole design takes into consideration the ease with which the parts are to be cleaned as it is to be used for food preparation.

B. The capacity of the Machine

The machine is designed for household use; this is taken into consideration by designing for at least ten medium hungry persons using fifteen (15) fingers of plantain. Based on the design analysis, the machine is required to be driven by a 2 hp electric motor for active mechanical agitation of the cooked plantain and into a smooth, consistent dough.

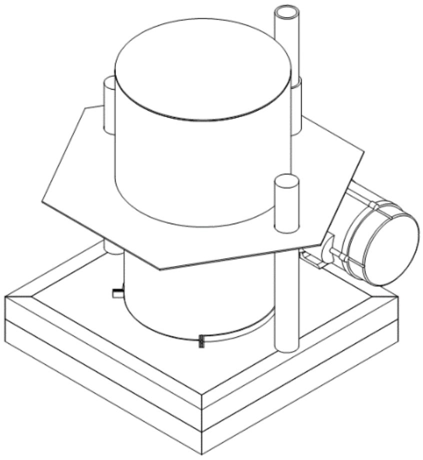


Figure 1. Isometric view of the Instant Amala making machine (SOLIDWORKS)

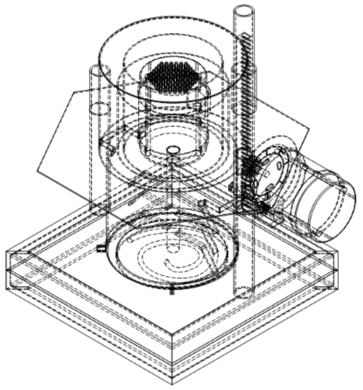


Figure 2: wireframe of the design (SOLIDWORKS)

The developed machine is integrated with the following automated functions:

1) Cooking
2) A water flow process for easy mixing/stirring to form a smooth dough
3) Slicing (determined by the stirrer edge geometry)
4) Stirring

The following parameters are considered in the design analysis, which led to the subsequent fabrication of the machine.

1) Speed (N) of the motor (which is kept constant throughout the stirring process)
2) Power developed by shaft (P)
3) Weight/Volume of the plantain

B. Material Selection Criteria

Proper material selection determines the reliability of the design and for food processing equipment/machines. Material selection is an essential process that must be carried out before any design can be fabricated. The best of designs will fail if the best material combination is not utilized. In the process of food transformation, heat is mostly required. However, the amount of heat required to process food materials, which have a significant effect on the material in which the food is being processed calls for the adoption of the knowledge of material selection in engineering. Some materials (processing containers) may react with the food during the processing which can make it unhealthy for consumption. The most important objectives, in this case, include achieving material compatibility in the design and prevention of microbial contamination of food products. In any product development, the primary aim is to achieve a piece of equipment that fulfills its engineering function such as the operating condition and capacity.

The following were considered in the material selection for the machine:

1. Mechanical stresses
2. Toxicity
3. Cost
4. Corrosion
5. Availability and the ease of manufacture
6. Fluctuations in temperature
7. Chemical properties
8. Safety

C. Operating Principle of the Machine

The unripe plantain fingers are sliced into smaller pieces using a kitchen knife after peeling the back. The required quantity of water just enough for the boiling of the unripe plantain is added. The electric heater, which provides heat to the pot, is then plugged into a socket, and the boiling/cooking commences. Once the cooking is done, the pounding process (transformation process) commences, which includes size reduction, mixing, and stirring of the cooked unripe plantain.

During these transformations, a quantity of water is added via a solenoid valve at a set time. The system incorporates process control/automation, such that after the required time for the boiling a signal is sent to the electric motor to commence rotation while the heating coil is turned off, this is when the transformation of the boiled plantain into Amala starts until a lump-free, homogenous mixture is attained. The impeller/stirrer is detached from the electric motor to facilitate the removal of the pot for easy scooping of the Amala and washing of the pot. The operation of this machine involves disintegration (subdividing larges masses of plantain fingers into smaller pieces) and mixing (agitation, homogenizing, stirring and beating.

D. Design analysis

The design parameters include:

1) The acceleration due to gravity (g) is 9.81 m/s^2
2) The density of stainless steel is 7700 kg/m^3
3) 1hp is equivalent to 746 $watts$
4) π is equivalent to 3.142

[1] Determination of Pot Capacity: The capacity of the pot is determined from the number of fingers of unripe plantain pulp it can accommodate.

Length of one plantain is $3 - 10$ $inches$ (Umesh, 2009)
To get an average value per length of one plantain
$= \frac{3+10}{2}$
$= 6.5\ inches = 165.1\ mm$
The diameter of one plantain is $30 - 70\ mm$ (Okafor and Okafor, 2013)
$= \frac{30+70}{2}$
$= 50\ mm$
The volume occupied by one plantain;

$$V_1 = \pi r^2 \text{h} \quad (1)$$

Where,
V_1 is Volume that will be occupied by one finger of Plantain
h is the height that will be occupied by one finger of Plantain
r is the radius of plantain that will be occupied by one finger of plantain
$= \frac{\pi d^2 h}{4}$
$= \frac{\pi \times 50^2 \times 165.1}{4}$
$= 324111.9375 mm^3\ or\ 0.000324173 m^3$
Therefore for 15 fingers of plantain pulp, from equation (1)
V_{15}=15 × 0.000324173 m^3
= 0.0048625964 m^3

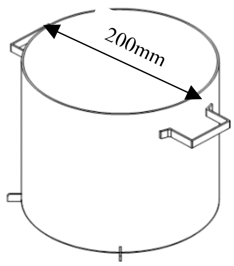


Figure 3. The Pot

As shown in Fig. III, the diameter, thickness, height of the pot used for fabrication are 200 mm, 3 mm, and 200 mm respectively. The pot was design with a buffer at the bottom sides to cushion the impact if the impeller/stirrer shaft during operation.

1) Determination of Torque Produced: Determining torque using the viscous shear involves,

$$T = \frac{\pi \mu \omega R}{2\delta} \quad (2)$$

Where,
T is the torque to be produced by the shaft in N/m
μ is the viscosity of yam flour
R is the radius of the pot in m
δ is the distance between the bottom of the pot and the impeller/stirrer blades (Fluid layer thickness) in mm
μ = 364 RVU (Ayodele et al.,)
$1\ RVU = 1\ Centipose$
$1\ Centipose = 10^{-3} pa.s$

$\omega = \frac{2\pi N}{60}$ (3)

Where,

ω is the angular velocity in rad/s

N is the speed required to rupture an unripe plantain in rpm

Assuming N = 400 rpm based on Asoegwu et al. (1998)

$$\omega = \frac{2 \times 3.142 \times 400}{60}$$

$= 41.893\ rad/s$

Therefore;

$$T = \frac{3.142 \times 0.364 \times 41.893 \times 0.1^4}{2 \times 0.05}$$

$= 0.04791\ N/m$

$= 47.91\ N/mm$

iii) Determination of Power

(7)

Recall, $power = T\omega$ (4)

From equations 2 and 3, respectively $T\ and\ \omega$ has to be determined. Therefore,

$power = 47.61 \times 41.893$

$= 2007.094\ W$

$1\ hp = 746\ W$

$$Power = \frac{2007.094}{746}$$

$= 2.690\ hp$

iv) Determination of the impeller/stirrer blades:

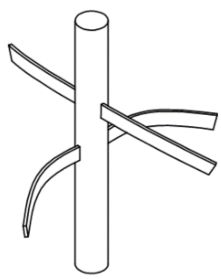


Figure 4. Impeller/stirrer shaft with the blades

l = Length of the blade = 75 mm

t = Thickness of the blade = 4 mm

w = Width of the blade = 15 mm

$V = l \times w \times t$

Where,

V is Volume of the blade, m^3

$V = 0.11 \times 0.004 \times 0.015$

$= 0.0000066\ m^3$

The density of stainless steel, ρ = 7700 kg/m^3 (Gupta, 2009)

$\rho = \frac{mass}{volume}$ (6)

From equation (6), m = □□× V

Where,

$m = Mass\ Of\ the\ blade$

$\rho = density$ of stainless steel

$V = volume$

$m = 0.0000066 \times 7700$

$m = 0.05082\ kg$

$Weight\ of\ the\ blade = m \times g$

Where,

g = Acceleration due to gravity, m/s^2

$m = Mass, kg$

$W = 0.05082 \times 9.81$

$= 0.4985\ N$

There are 4 blades welded to the shaft,

Total weight,

$W = 4 \times 0.4985 = 1.994\ N$

v) Determination of shaft diameter (Gupta, 2009):

The average weight of one plantain is 225 g (Onyejegbu and Olorunda, 1995)

The mass of 15 plantains,

$= 15 \times 225\ g = 3375\ g$

$3375\ g = 3.375\ kg$

The total weight of 15 plantains,

$F = m \times g$ (8)

Where,

m = Mass of plantain, g

g = Acceleration due to gravity, m/s^2

$F = 3.375 \times 9.81 = 33.11\ N$

Total weight on the shaft,

$= weight\ of\ plantain(15) + weight\ of\ blade$

$= 33.11 + 1.994$

$= 36.61N$

Due to the simultaneous occurrence of torsional stress on the shaft, the stress analysis of the shaft involves considering the twisting and bending moment.

$Moment = F \times D$
(9)
Maximum bending moment = 36.61×0.065
$= 2.5627\ Nm$
$T = \frac{60 \times p}{2 \times \pi \times N}$
(10)
$T = \frac{60 \times 746}{2 \times \pi \times 1500}$
$T = 4.75\ Nm$
Equivalent twisting moment, T_e
$T_e = \sqrt{(M^2 + T^2)}$
Where,
M = Maximum bending moment, Nm
T = Torque, Nm
$T_e = \sqrt{(2.5627^2 + 4.75^2)}$
$T_e = 13.32\ Nm$
Using the maximum Shear stress theory
$T_e = \frac{\pi}{16} \times \tau \times d^3$ (11)
Where,
τ = Ultimate tensile stress of stainless steel = 510 N/mm^2 (Aksteel, 2007)
d = shaft diameter
The choice of the factor of safety used for this design is based on the following consideration;

1) Variations that may occur in the properties of the members
2) The number of loading that is expected during the life of the machine
3) The type of failure that may occur
4) Uncertainty due to the method of analysis

Based on these considerations, a factor of safety equal to 4 was chosen.
$= \frac{510}{4}$
$=127.5\ N/mm^2$

$$d = \sqrt[3]{\frac{16 \times Te}{\pi \times \tau}}$$

$$d = \sqrt[3]{\frac{16 \times 13.32}{\pi \times 127.5 \times 10E6}}$$

d = 0.00810 m
d = 8.103 m

vi) Determination of time taken to boil plantain: The plantain used in experimenting was purchased from the Akure market from various sellers in order to get variations in their size and geometry. A heater that has 1000 $watts$ power rating was used to conduct this simple experiment. The material of the pot used is aluminum with a thickness of 1mm. The experiment was carried out three (3) times using 2, 3 and 6 fingers of plantain, respectively; table I indicates the number of plantain fingers and the time taken to cook correctly.

TABLE I
EXPERIMENTAL TIME TAKEN FOR COOKING UNRIPE PLANTAIN

NO OF PLANTAIN FINGERS	TIME TAKEN (sec)
2	1238
3	1570
6	1724

Using interpolation to determine how long it would take to cook 15 plantains based on the calculated values above:
Where;
x is the time it will take the Plantains to cook based on interpolation

$$\frac{15-2}{15-6} = \frac{x-1238}{x-1724}$$

$$\frac{13}{9} = \frac{x-1238}{x-1724}$$

$13x - 22412 = 9x - 11322$
$4x = 11090$
$x = 2772.5 secs$
$= 46\ min\ 21\ sec$
Likewise,

$$\frac{15-3}{15-6} = \frac{x-1570}{x-1724}$$

$12x - 20688 = 9x - 14130$
$12x - 20688 = 9x - 14130$
$3x = 6558$
$3x = 6558$
x =2186 sec
=36 min 43 $secs$
Recall, $P = \frac{J}{t}$ (12)

$J = p \times t$
Where,
J = Energy
p = Power, $watts$
t = time, $secs$
$p_1 \times t_1 = p_2 \times t_2$
To get the time taken if a heating coil of 1500 $watts$ was used:
Take, $t_1 = 2772.5\ secs$
$1000 \times 2772.5 = 1500 \times t_2$
$t_2 = 1848.33\ secs$
$= 30\ min\ 80\ secs$

vii) Coupling Design (Gupta, 2009): Sleeve coupling was selected for the design, therefore considering a hollow shaft as given by equation (12),

$$T = \frac{\pi}{16} \times \tau_c \times \left(\frac{D^4 - d^2}{D}\right) \quad (13)$$

Where,
T is Torque transmitted from the motor which is = 10.18 Nm
τ_c is Shear stress, N/m
d is the inner diameter of the Sleeve which is equal to the diameter of the shaft =25 mm
D is the outer diameter of the Sleeve Coupling

$$D = 2d + 13mm \quad (14)$$

D = 63 mm

$$10.18 = \frac{\pi}{16} \times \tau_c \times \left(\frac{63^4 - 25^4}{63}\right)$$

τ_c□□□□□□□□□□□mm^2

Since induced shear stress muff (Stainless steel) is less than the permissible shear stress of 15 N/mm^2, therefore, the design for muff is safe.

Design for Coupling Bolt,
Torque transmitted to bolt is given by:

$$T = \frac{\pi^2}{16} \times \mu \times d_b^{\ 2} \times \sigma \times n \times d \quad (15)$$

T is Torque transmitted which is 10180 Nmm
Using a factor of safety 0f 3: $T = 30540\ Nmm$
Where,
□□is the coefficient of friction between the muff and shaft surface which is 0.7
□□is permissible tensile stress for bolt = 70 MPa =70N/mm^2
d_b is Diameter of the bolt
n is numbers of bolts which is equal to 2
d is shaft diameter which is 25mm

$$30540 = \frac{\pi^2}{16} \times 0.7 \times d_b^{\ 2} \times 70 \times 2 \times 25$$

$d_b = 4.494mm$
Therefore, the bolt diameter of 6mm (M6) is chosen as a standard.

viii) Determination of time taken to boil water: It is essential to know the time taken for the reservoir water to boil appropriately in order for the whole process to be appropriately controlled. The water is required to be at 60^o, considering the electric motor, which is in the same compartment as the water. 1 $litres\ of\ water$ is needed for the operation.
1 $litres\ of\ water = 0.001\ m^3$
m = □□$\times V$
□□$is\ density$ of water which is equal to 1000 kg/m^3
V is the volume of water in m^3 which is 0.001 m^3
m is the mass of water
$m = 1000 \times 0.001$
$m = 1\ kg$

$$Q = m \times c \times \theta \quad (16)$$

Where,
$\theta = temperature\ change = T_2 - T_1$
Q is the amount of energy in J
c = Specific heat capacity
T_2 is the required temperature of the water = 60
T_1 is room temperature of the water = 25
$\theta = 60 - 25$
$\theta = 35$
$Q = 1 \times 4200 \times 35 = 147000$

$$Q = P \times t \quad (17)$$

P is the power rating of the boiling ring to be used, which is 250 $watts$.
From equation 16,
t = Q/P

$$t = \frac{147000}{250}$$

$t = 588\ sec$
$t = 9.8\ minutes$

E. Description of the Automatic Control System

The design of the control system requires the knowledge of programming and digital techniques, the control variable for this machine is time. A control circuit for the automated instant Amala making machine was developed using Proteus Design Suite which is a software tool used primarily for electronic design automation. The control system of the machine consists of the following devices shown in Fig. V are listed below and their various functions:

i) Microcontroller: This is for the sequential operation of all the devices at the preprogrammed time. The main function of the microcontroller is to energize each relays controlling the corresponding devices.

ii) Relays: Each control device consists of five (5) relays, which are energized by the microcontroller to allow the flow of current which actuates the necessary device based on the sequence.

iii) Diodes: This is to ensure the single directional flow of electricity to avoid backflow which can cause damage to the devices. There are diodes before each control device and a bridge of diodes after the transformer which aids the conversion of the $230\ v\ to\ 12\ v\ and\ 5\ v$ respectively.

iv) Complementary metal-oxide semiconductor (CMOS) battery: This is connected to the microcontroller to store operation that has been performed by the microcontroller. The memory is a permanent one so that when there is no supply of electricity it retains operations performed previously.

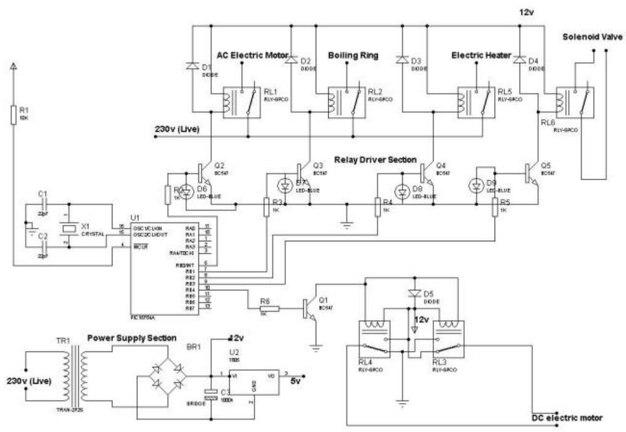
v) Capacitor: A $22\ \mu f$ capacitor connected in parallel to the microcontroller to smoothen the waveform

vi) Transformer: This is to convert $230\ v\ to\ 12\ v\ and\ 5\ v$ respectively.

vi) The main part of the system is the microcontrollers and the relays. Micro C Professional 4.0 was used to develop the programming codes and compile into machine, PIC16F84A microcontroller. Any PIC16F84X Series could also be used because they are a very useful and versatile tool as applicable to many electro-mechanical controlled projects, usually cheaper in comparison to microprocessor, optimize the speed of work, simplicity, code compactness, saves times and space. The control was synchronized according to the unit operation sequence of the process which includes the devices to be controlled such as; electric heater, AC motor, boiling ring, solenoid valve, stirrer, and DC motor. The synchronized operation was allowed to run for several minutes in order to determine its efficiency and the effectiveness of the control system.

F. The control Circuit (Electrical System)

The electrical system consists of a relay, capacitor, AC to DC converter, microcontroller, oscillator, resistor, linear voltage regulator, transformer, and PCB. Figure 5 shows the circuit diagram developed for the control system



C. Figure 5. Circuit Diagram for the Control System

G. Development Process of the Automatic Control System

The initial stage of the development of the control system was to ascertain the number of units required to be controlled and to analyze the necessary control devices required for the units. Proteus Design software has the facility to simulate and display the configuration of the components on board. This virtual displayed component placement serves as a guide during the Printed Circuit Board (PCB) preparation and the development of the Printed Circuit Board Assembly (PCBA). PCB is used to mechanically support and electronically connect electronic components using conductive pathways or etched from copper sheets laminated onto a non-conductive substrate to avoid the scattered connection of wires. The stages involved in PCB production include:

a) patterning (etching)
b) drilling
c) testing
d) Printed circuit assembly and;
e) Circuit performance test.

The designed PCB was transferred onto the copper clad using etch-resistant inks to protect the desired copper traces. The etching process removed the unwanted copper surface. The etch-resistance ink was removed from the remaining copper surface by scrubbing it with sandpaper.

H. Material Selection for the Control System

The components that make up the integrated circuit of this control system were selected from the Proteus library, based on the calculated values. This is to ensure that the components remain secured on loads.

III.RESULTS AND DISCUSSION

A. Performance Evaluation

The device was tested when fabrication of the machine was completed on 4-runs manually, a constant power supply was ensured to be available before carrying out the experiment and the power rating of the electric heater used was 1800 $watts$, although an electric heater of 1500 $watts$ was used for design analysis in section 3.6.6 eventually 1800 $watts$ was used for the design. The pot was filled with diced pieces of fresh unripe plantain together with water and allowed to cook using the electric heater. Immediately the plantain was observed to have finished cooking; the AC motor was turned on to provide rotation to the impeller/stirrer shaft to begin the pounding process. The pounding process continued until the cooked unripe plantain formed into a homogenous paste. The evaluation was carried out at first to determine the time taken for the cooking by using 2 fingers, 3 fingers, 4 fingers, and 6 fingers of plantain and also to know the exact volume of water that would boil the plantain successfully; both parameters were recorded. To check the effect of the sizes of the plantain cut on the cooking time and the pounding process, for the first two runs of the experiment, a finger of plantain was cut into small pieces subsequently, for the remaining runs of the experiment, a finger of plantain was cut into 3 pieces. By so doing it was observed using a stopwatch to record the time taken that the shorter the sizes of the fingers of plantain, the lesser the cooking time because it absorbs more heat faster than when the sizes were big. All these parameters are measured and shown in Table II below:

TABLE II
THE VOLUME OF WATER USED AND TIME RECORDED FOR MANUAL OPERATION

No of unripe plantain finger	The volume of water used (ml)	Time is taken to boil plantain (seconds)	Time taken to prepare the dough (seconds)	The overall time taken for the total operation (seconds)
2	350	1823	300	2123
3	350	1845	330	2175
4	450	2025	420	2445
6	1350	2716	600	3316
10	1800	2880	600	3480

The result from the test conducted on the machine as compared to the experiment carried out earlier shows that the plantain cooked for a longer time, this is due to the thickness of the pot and the material used, in comparison to the aluminum material and thickness of the pot used initially in carrying out the experiment. After the performance of the cooking process was tested, the pounding operation (size reduction, stirring, and agitation) began with the pounding of 2, 3, 4, and 6 fingers of plantain, respectively. It was discovered that the machine could not pound 2 and 3 plantain fingers effectively as there were still visible lumps showing after the pounding, and this was due to the size of the pot, but 4 and 6 fingers formed into a light brown thick fine homogenous paste, smooth to touch.

Plate 1. Final Product from the Machine

E. Result Obtained After Implementing The Control

The test was also carried out after the complete integration of the machine with the various control devices and microcontroller, the machine was also tested with 10 fingers of plantains, and constant power supply was ensured to be available to avoid interruption during operation. The same procedure observed for the manual experiment as in the above was also carried out automatically, after the overall operation a gear reduction motor mated to a rack and pinion connected to the upper part of the machine lifts it to facilitate the easy removal of the paste from the pot. This significantly reduces fatigue on the machine operator as the main electric motor is located on the lid and the following result was recorded with a stopwatch.

TABLE 2. TIME RECORDED AFTER IMPLEMENTING CONTROLS.

Device	Unit Operation	Start time (Delay)	Duration of operation
Stepper motor for Rack and pinion	Release the gear to close the top compartment	2 sec	55 min
Electric Heater	Cook the plantain	30sec	44 min 30 sec
Boiling ring	Boil the water needed for stirring	40 min 03 sec	5 min 0sec
Electric motor for stirrer	Paddling the plantain	46 min 14 sec	10 min 0sec
Solenoid valve	Release the hot water into the pot	50 min 02sec	55 min
Stepper motor for the plunger	Open the tray	56 min 0sec	----------

Table 1 above shows the start time, delay, and end time for each unit operation of the machine. From the flow chart and programming codes respectively, it was observed that the control system performed as expected. The overall time taken for the automatic operation of the machine is $56\,minutes$ approximately $1\,hour$, while for the manual process on the same amount of unripe plantain fingers took $58\,minutes$. This is faster than the typical duration of operation of the machine observed without the controller; this is because there was no human intervention causing delays. The color and texture observed produced similar to those produced during the manual operation. The time taken for the machine is lesser in comparison with the overall process necessary to make Amala flour.

IV. CONCLUSION

The Instant Amala making machine was designed with materials sourced locally; it is simple to operate and requires little or no particular skill. The machine components are assembled to permit ease of disassembly and maintenance. The fabrication of the machine followed special requirements such as the materials used, design and characteristics of both compartments. The machine is reconfigurable to an extent as it can be used for other food products other than unripe plantains, such as yam, cocoyam, and cassava. The machine was also integrated with a control system to further reduce human effort on the machine. The machine minimizes human intervention and makes for hygienic processing of Amala. The color observed from the machine makes it pleasant looking instead of the darkish brown color usually observed.

A. RECOMMENDATION

The significant challenges faced in the development of this machine is the inability to vary the speed of the AC electric motor and the weight of the machine. The time taken for the operation of the machine and the eventual outcome from the operation of the machine which is the Amala can be improved upon by carrying out more research. Hence the following recommendations are made:

1. An electric motor whose speed can be varied should be employed.
2. The machine should not be used below capacity; that is, it was observed it could not pound 1-4 fingers of plantain. Improvement should be made on the machine so that it will be able to process any number of plantain pulp.
3. Lighter materials should be used for the machine, as the material used made it heavy.
4. The thickness of the pot should be reduced to increase heat transfer.
5. Rack and pinion used should be replaced with a hydraulic or pneumatic system

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