PROTOTYPE DESIGN AND TEST ANALYSIS OF A BEANS PARTICLE SEPARATING MACHINE

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ABSTRACT

The initial stages of the design, fabrication and performance analysis of a prototype beans particle-separating machine are discussed in this work. The working principle of the machine is based on the difference in aerodynamic properties as the basis for separation of beans and associated foreign particles, mainly chaff and stones. To achieve this pneumatic principle, the archetypal design necessitated the incorporation of two blower fans at various tilt angles to the horizontal plane. The results of the performance analysis of the separator showed that maximum efficiencies were 95% at 40^0 tilt angle for the first fan and 90% at 0^0 tilt angle for the second fan.

Key Words: *Prototype design, Beans particle, Aerodynamic separation, Performance analysis.*

1.0 INTRODUCTION

Notable research works have been done on the separation of cowpeas (commonly known as beans) from unwanted materials. Feller, [4], worked on the effect of oscillating screen motion on the passage of particles through perforations. Some physical and aerodynamic properties relevant in destoning some grain crops were also studied [5]. Other relevant and applicable works include bean production without irrigation, dry bean production and works relating to applied geophysics [9]. The common process by which foreign particles or unwanted particles are removed from beans prior to consumption is majorly that of separation by hand picking. This method is time consuming and inadequate when large quantity of beans is needed for consumption.

To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem [7]. Also the process of design is essentially an exercise in applied creativity [8]. Based on these stated principles, the objective of this work is to design and fabricate a beans particle pneumatic separating machine that can be operated by a single operator, capable of separating unwanted materials from large quantity of beans within a short time prior to cooking and consumption. However, the design of a machine for separation of foreign unwanted particles from large quantity of beans would probably be difficult without the study of the physical and aerodynamic properties of beans. These properties include: size, shape, angle of repose, static coefficient and terminal velocity of which the terminal velocity is the main criterion for the design of the beans particle separating machine. The machine was designed such that a fan blows the chaffs which has terminal velocity between 7.0 - 9.0m/s, while the second fan blows the beans with an average terminal velocity of 13m/s. As part of the initial design processes, the two fan blowers were tested after construction by allowing mixtures of beans and unwanted particles to fall through their air streams and the best angles of tilt with maximum performance determined for both fans.

2.0 DESCRIPTION AND OPEARTION OF MACHINE

2.1 Machine Parts

The main components of the beans/particles separating machine at this first design stage are shown in figure 1. They are: (i) The Frame; This forms the skeleton on which all other components of the machine hangs and also withstands the vibrations, stresses and the strains on the machine during operation. (ii) The Hopper; this part is used as a means of introducing and regulating the feed rate of the unclean beans into the machine. (iii) The Inclined Plate; this plate is inclined at a predetermined angle based on the angle of repose and static coefficient of friction of the beans. This is to ensure the smooth fall of the unclean beans into the air flow lines of the fans. (iv)The fan Blowers; these are two centrifugal fans made up of the fan housing shafts and blades. The free air inlet and duct outlet principle was adopted for the fans because of its moderate efficiency and stability. (v) Grain Collector; this is made from wood material to reduce cost and noise of impact of grains as they fall into it. It is partitioned into two for the collection of heavier stones and lighter clean beans. (vi) Electric Motor; This is used to drive all moving components of the machine through the pulley belt system.

2.2 Machine Operation

The bean particle-separating machine uses the air separation method with the aid of two identical blowers to separate foreign materials from bean seeds, which is finally collected at the base of the machine in the grain collector. An electric motor, which has a double groove pulley, is used to power the machine with the aid of two 'A' type flat belts. One belt connects the electric motor to the first blower and the other joins the motor to the second blower (blower closer to the ground).

The grain mix is introduced in the hopper and regulated with the aid of the feed mechanism. The grain mix comprising mainly of beans, stones and chaff drop directly from the hopper on the inclined plate and rolls down across the air stream from the blower. The first fan located above blows off the chaff at this point. This is because the fan is designed such that the air velocity at that outlet is slightly higher than the terminal velocity of the chaff but lower than those of the beans and grains. The beans and stones continue to fall freely and at a rate unaffected by the first blower. The second fan, which has a velocity slightly higher than the terminal velocity of beans and lower than that of heavier stones blows further the beans from the path of free fall into a different compartment but allowing the stones to fall separately.

3.0 DESIGN OF SEPARATOR MACHINE COMPONENTS

3.1 Fan Design

The machine has two fans (as shown in Fig. 1) one fan is to blow off the chaff and the other is to blow out the beans from the stones. These fans are identical in shape but they are different in speed due to the differences in the terminal velocities of the chaff and beans. The design is therefore, based on finding the diameter and speed of the fan pulley that will produce the required air velocity at the fan outlet.

$$V_t = \frac{0.4 d_2 b_2 D_m}{60 A_o D_f} \qquad (1)$$

The equation presented in (1) is used to determine the diameter (D_f) of each of the fan pulleys (the driven pulleys) [6].The respective terminal velocities (V_t) for the first and second blower designs applied in equation (1) are 7m/s and 13m/s. They also correspond to those of Chaff and beans respectively [5]. The diameter of the fan impeller from peripheral center (d_2), the impeller width (b_2) as shown in Fig. 3 and the diameter of the motor (driving) pulley (D_m) are chosen within design limits [1], [3]. A_0 is the cross-sectional area of fan outlet. Also from equation (2), the driven speed of the blower fan can be calculated. Where,

$$N_m D_m = N_2 D_f \qquad (2)$$

N_m is the driving (motor speed) N_2 is the driven speed. The electric motor used based on further design (section 3.4) is a single phase 2hp with a speed of 1420 rpm

3.2 Diameters and Speeds of First and Second Bower Pulleys

The first fan is to blow the chaff and dust from the beans as they fall down from the inclined plate. The terminal velocity at this point is that of the chaff and is about 8 m/s [5]. Therefore the design is based on the pulley that will produce this velocity. Using equation (1), V_t is 8 m/s, the parameters d_2 and b_2 are based on geometry; N_m is motor speed; D_m is motor pulley diameter. The first fan pulley diameter D_f is obtained. Using equation (2), the speed of the fan pulley (N_2) is obtained. The same procedure is carried out to obtain the diameters and speed of the second fan pulley.

3.3 Design of Fan Belts

The objective of belt design is to determine the power that is transmitted by a particular type of belt with given dimensions. The flat belts were used in this design due to their high efficiencies at high speeds and ability to transmit large amount of power over long center distance. The equations employed in the determination of angle of wrap [2] for belts 1 and 2 as shown in figures (1) and (2) are given as:

$$\alpha a^{1} = 180^{o} - 2\sin^{-1}\frac{(R-r)}{Ca} \qquad (3a)$$

$$\alpha a^{11} = 180^{o} - 2\sin^{-1}\frac{(R-r)}{Ca} \qquad (3b)$$

Where *R* is radii of larger pulleys; *r* is radii of smaller pulleys; *Ca* center distances from the two pulleys being considered; $\alpha\, a^{1}$ and $\alpha\, a^{11}$ are the warp angles of the two pulleys with respect to the belt being considered. The coefficient of friction f for leather on cast iron is used while α is as determined in equation 3a and 3b in radians.

3.4 Total Power Transmitted in Belts

Before we can calculate the power transmitted we have to calculate the angle of wrap of the belts using equations (3a) and (3b). After the determination of the wrap angles, equation (4) is used to obtain the belt tension (T_1) in the tight side, *Where S* is maximum allowable stress, *b* is belt width and *t* is belt thickness,

$$T_1 = Sbt \qquad (4)$$

To determine the tension on the loose side, equations (5) and (6) are used.

$$\frac{T_1 - Mv^2}{T_2 - Mv^2} = ef\alpha \qquad (5)$$

$$M = btp \qquad (6)$$

Where T_2 is belt tension in loose side of belt, ρ is density of leather, *M* is mass per unit length of belt and *V* is line speed of pulley given as equation (7)

$$V = \frac{2\pi N R_D}{60} \qquad (7)$$

Where N is speed of pulley governing design, R_D is radius of pulley governing design. The smaller value of the pulley governs the design. The power *(P)* transmitted between the first pulley is given as

$$P_1 = (T_1 - T_2)V \qquad (8)$$

Using equations (3) – (8) the power transmitted between the motor and the first pulley P_1 and that between the motor and the second pulley P_2 are calculated. The total power P_T transmitted to the belts is the addition of the two powers as in equation (9)

$$P_T = P_1 + P_2 \qquad (9)$$

This total power obtained is the basis for selecting the electric motor used in driving the machine.

4.0 PERFORMANCE TEST

The two pneumatic separators for the beans/particles machine were designed, constructed and assembled so as to make the alteration of the tilt angles of the air flow line to the horizontal level possible. The best angle of tilt at which the machine will be most effective was thereafter determined. The beans were weighed before separation and the same was done for the chaff. The beans and the chaff were then mixed together and fed into the separating machine through the hopper at feed rate of 0.5kg/min.

The mixture was then introduced into the line of airflow of the fans. After the separation process was completed, the partially cleaned beans were collected and the chaff and beans were separated one from the other and the different weights taken again. This process was repeated three times for each angle over the results used to determine the efficiency of the fans at each of the tilt angles. 2.5 kilograms of beans and 0.5kg of chaff were used for the analysis.

4.1 Determination of Efficiency

The equation used for the determination of efficiency is given as

$$efficiency = \frac{W_b(A_f) - W_c(A_f)}{W_b(B_f)} x100\% \quad (10)$$

Where $W_b\ (B_f)$ is Weight of beans before separation; $W_c\ (B_f)$ is Weight of chaff before separation; $W_b\ (A_f)$ is Weight of beans after separation, $W_c\ (A_f)$ is Weight of chaff after separation. On the completion of the performance test for the blower fans, the results obtained are as shown in Table 1 and 2. Presented graphically in Figures 2 and 3 are the efficiencies of the fans at various tilt angles.

5.0 INTERPRETATION OF RESULT

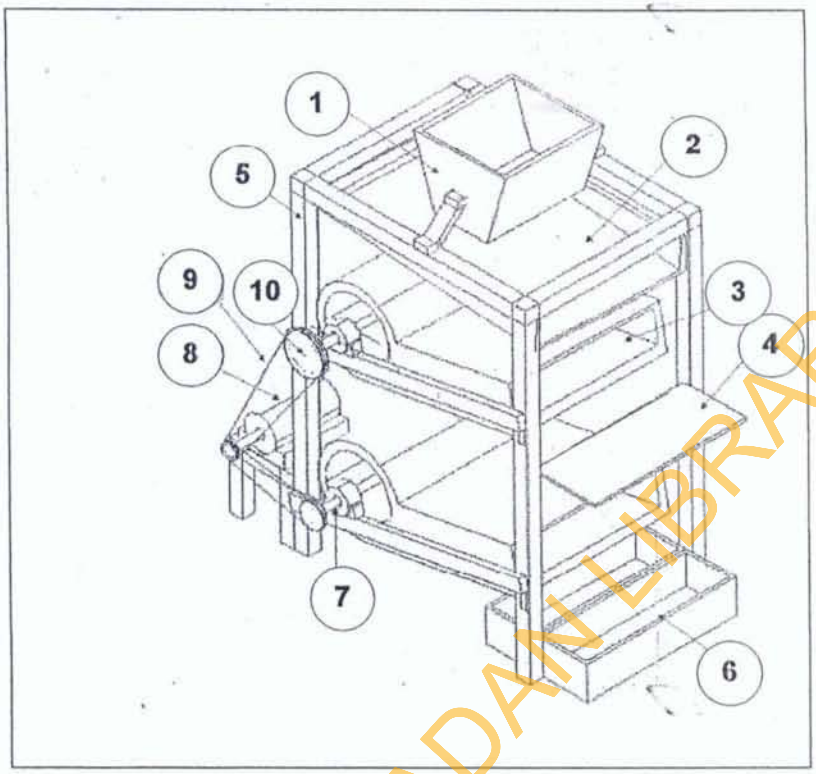
As shown in Table 1 and 2 when the fans are at horizontal position (0^0) the forces produced (rate of air flow from the fan outlet) is at maximum. However the efficiency of the first fan is reduced (from equation 8), since an appreciable amount of beans is blown off with the chaff. When the fans were both titled to 10^0, the chaff was blown away with some beans and some stones. At the first fan, increase in title reduced the intensity with which the air velocity is expelled at the outlet, thereby allowing some beans and stones get to the airflow of the second fan.

However at this angle the second fan does not blow the beans and the stones indicating that the intensity of the air velocity from the second fan is not enough to terminate the beans from the line of free fall. To increase the air velocity of the second fan, the fan is tilted back to 0^0 for reasons discussed earlier. The second fan at this angle starts to work as desired and it is of note that it is at only this angle that the second fan can effectively blow the beans from the lines of free fall.At 50^0 the efficiency begins to drop again, since air velocity at the outlet has fallen a little below the terminal velocity on the chaff. This causes some chaff to be carried over to the second fan, which is undesirable.

6.0 CONCLUSION AND RECOMMENDATION

The main objective for which the machine was designed is to accomplish the separation of the beans and chaff using the principle of Terminal Velocity. The terminal velocities of the particles considered are as follows, the chaff 5.0m/s, the beans 9.2m/s while that of the stone is 14 m/s. The machine was powered by single-phase 1.5 KW electric motor with a speed of 1420 rpm. The first fan that blows the chaff has an air velocity of 8m/s, while the second fan that blows the beans has an air velocity of 13m/s, efficiencies of the machine were determined based on the angle of tilt of the fan blower.

The air velocity at the outlet of the fans blower is paramount in accomplishing successful separation of the grains. The velocity of the fan blowers can be regulated by tilting them to different angle. The air velocity can also be varied by changing the size of the driving pulley. For easier regulation of the air velocity the use of multiple speed Electric Motors is recommended, thereby making the separation of other grains like rice, maize among others possible by regulating the speed of electric motor within the range of terminal velocities of these grains.



ITEM	DESCRIPTION	MATERIALS/CAPACITY	QUANTITY
1	Hopper	Metal Sheet	1
2	Inclined Plate	Metal Sheet	1
3	Fan Blower	Metal Sheet	2
4	Grain Separator	Metal Sheet	1
5	Frame	Angle Iron	4
6	Grain Collector	Metal Sheet	5
7	Impeller Shaft	Mild Steel	2
8	Electric Motor	2HP	1
9	Belt	Leather	2
10	Pulley	Cast Iron	4

Figure 1: Isometric view of The Archetypal Beans/Particle separating Machine

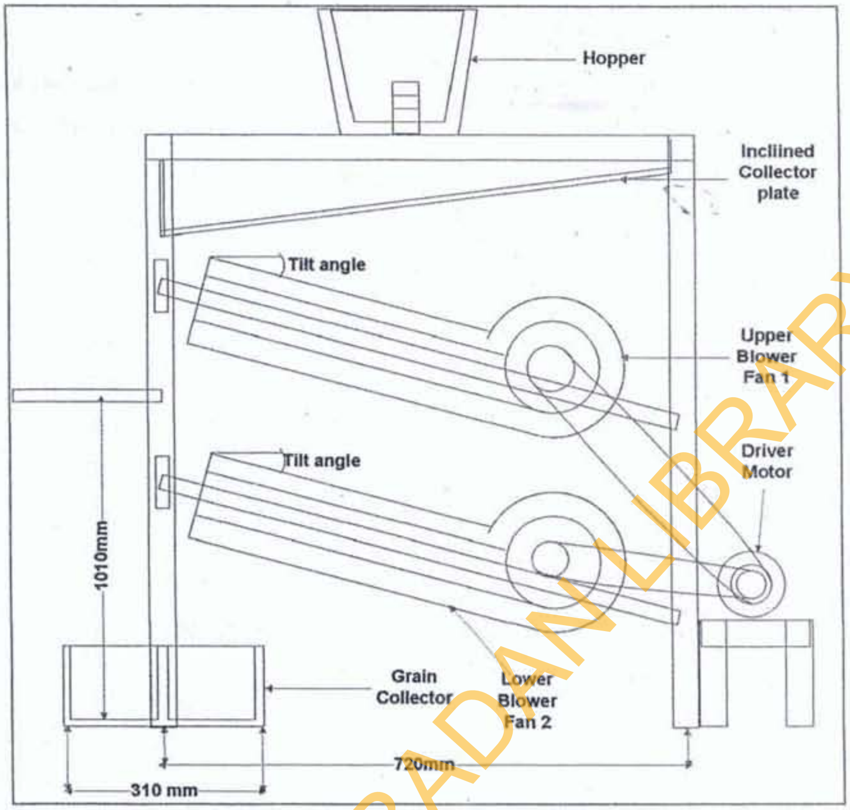


Figure 2: Set up of blower fans at tilt angles during testing

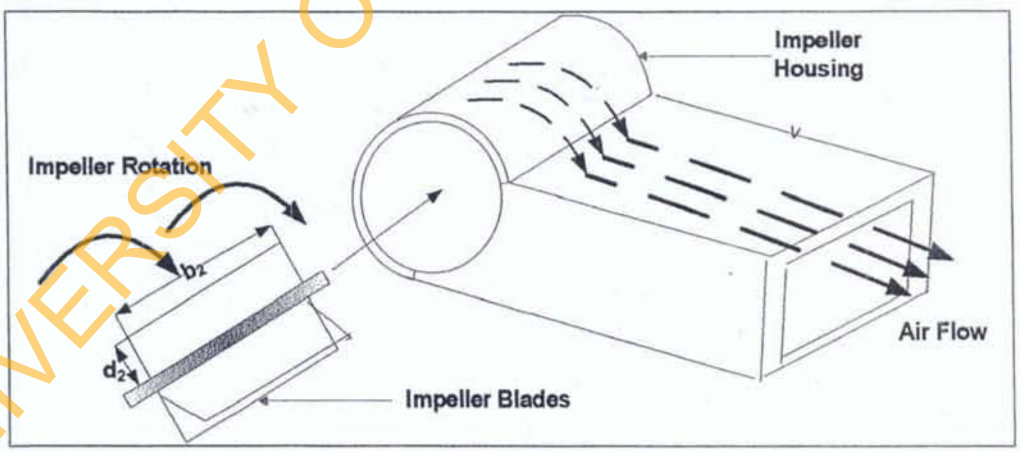


Figure 3: Impeller blade design parameters and its positioning

Table 1: Performance Test Result for Fan 1

Fan tilt Angle	Initial Weights Before Tests		1st Test		2nd Test		3rd Test		Average	
	$W_b(B_f)$ (Kg)	$W_c(B_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)
0^0	2.5	0.5	0.2	0	0.2	0	0.2	0	0.2	0
10^0	2.5	0.5	0.7	0	0.8	0	0.8	0	0.8	0
20^0	2.5	0.5	1.3	0	1.4	0	1.3	0	1.3	0
30^0	2.5	0.5	2.0	0	2.1	0	2.2	0	2.1	0
40^0	2.5	0.5	2.4	0	2.4	0	2.3	0	2.4	0
50^0	2.5	0.5	0.3	0	0.3	0	2.5	0	2.5	0

Table 2: Performance Test Result for Fan

Fan tilt Angle	Initial Weights Before Tests		1st Test		2nd Test		3rd Test		Average	
	$W_b(B_f)$ (Kg)	$W_c(B_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (kg)	$W_b(A_f)$ (Kg)	$W_c(A_f)$ (Kg)
0^0	2.5	0.5	2.2	0	2.2	0	2.3	0	2.2	0
10^0	2.5	0.5	1.5	0	1.6	0	1.5	0	1.5	0
20^0	2.5	0.5	1.1	0	1.2	0	1.2	0	1.2	0
30^0	2.5	0.5	0.9	0	0.8	0	0.8	0	0.8	0
40^0	2.5	0.5	0.6	0	0.6	0	0.7	0	0.6	0
50^0	2.5	0.5	0	0	0	0	0	0	0	0

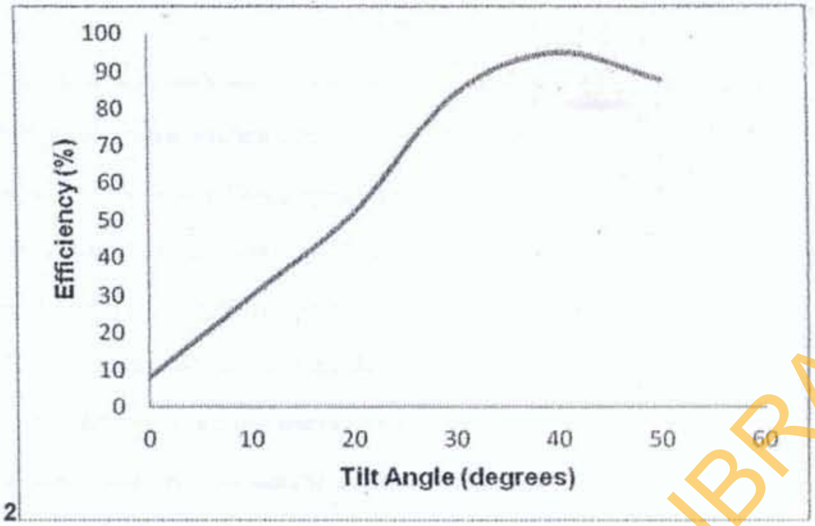


Figure 4: Effeciencies at various tilt angles for fan blower 1

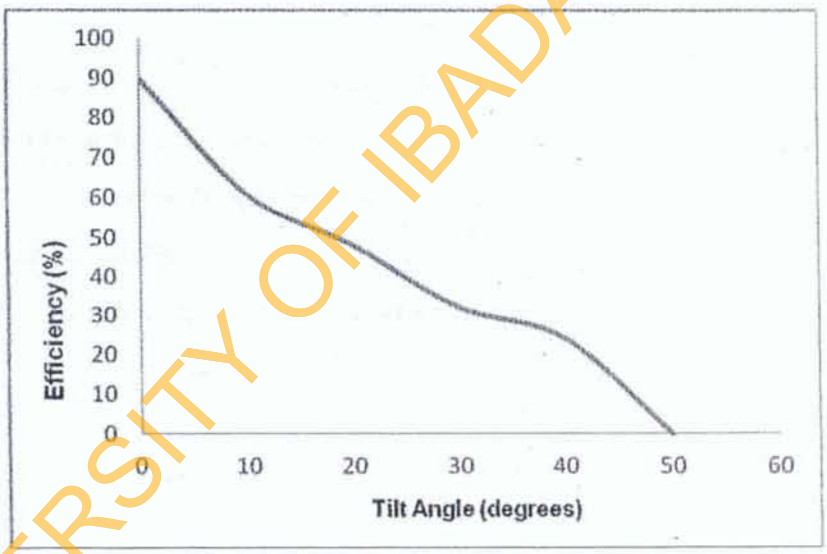


Figure 5: Effeciencies at various tilt angles for fan blower 2

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