PERFORMANCE ANALYSIS OF PNEUMATIC SEPARATORS FOR A BEANS/PARTICLE SEPARATING MACHINE

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Abstract

The initial stages of design, fabrication and performance analysis of a prototype beans/particle-separating machine have been carried out in this work. The working principle of the machine is based on the difference in aerodynamic properties of beans and associated foreign particles, mainly chaff and stones as the basis for separation. This design principle therefore necessitated the incorporation of two pneumatic separators (blower fans) for optimum performance. Performance analysis carried out on the two blower fans at various tilt angles to the horizontal plane showed that the maximum efficiencies were 88% and 90% at 50° and 0° tilt angle to the horizontal plane for the first and second blower fans respectively.

Key Words: Bean Separation, Pneumatic Separators, Performance Analysis.

Introduction

A lot of research works have been done on the separation of cowpeas (commonly known as beans) from unwanted materials. Feller and Faux (1975) worked on the effect of oscillating screen motion on the passage of particles through perforations. Some physical and aerodynamic properties relevant in destonmg some grain crops were also studies by Koya and Adekoya (1994). Other relevant and applicable works include bean production without irrigation (Brandon, 1943), Dry bean production (Anderson, 1955) and works relating to Applied Geophysics (Seriff, 1976).

The common process by which foreign particles or unwanted particles are removed from beans prior to consumption is majorly that of separation through hand picking. This methods is time consuming and in adequate when large quantity of beans is needed for consumption.

The objective of this work is therefore 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 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 relevant to beans. These properties include: size, shape, angle of repose, static coefficient of friction 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 the first 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 13 m/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 determined for both fans.

Description and Operation of Machine Machine Parts

The main components of the beans/particles separating machine at the present design stage are as shown in Figure 1. They are

1. The Frame.
2. The Hopper.
3. The inclined plate.
4. The Fan Blower.
5. Grain collector.
6. Electric motor.

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 single 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 the first blower 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 bean, stones and chaff drops directly on the inclined plate and rolls down though the air stream of the first blower. The first fan blows of the chaff at this point, since the air velocity at that outlet is slightly higher than the terminal velocity of the chaff. The beans and stones continue to fall in the line of free fall and are unaffected by the first blower because the velocity of the blower is less than the terminal velocity of the beans and stones. The second fan which has a velocity slightly higher than the terminal velocity of beans further blows the beans from the path of free fall into a different compartment allowing the stones to fall separately.

Principles of Machine Design

Dabor, (2001) on the prototype design of the beans/particles separating machine, gave basic consideration to the design of fan belts, shafts, keys and bearings. However the design considered in this paper has been limited to that of fans, being the most critical. In addition, the design for power transmitted based on the belt drive tensions are also presented in this section.

Fan Design

The two fan blowers were designed based on the equation used in determining the terminal velocity (fan outlet air velocity) that can be produced from a given fan design specifications. This equation as presented by Osborne (1966) is given as

$$V_t = \frac{0.4\, d_2 b_2 P_m}{60 A_o D_f} \quad \text{.................(1)}$$

The respective terminal velocities (V_t) for the first and second blowers are 8 m/s and 13 m/s which corresponds to those of chaff and beans respectively (Koya and Adekoya, 1994). The diameter of the fan impeller from peripheral centre (d_2), the impeller width (b_2) and the diameter of the driving pulley (D,,,) are chosen within design limits (Dabor, 2001; Owowalo and Aigbokhai, 2002). The speed of the driving pulley (Nm) is determined based on speed and diameter active being constant for driving and driven pulleys. Ao is the cross-sectional area of fan outlet while the diameter of driven pulley D_f is the critical design parameter for the fan blower and is obtained from equation (1).

Belt Drive Design

Power Transmitted by Belts of Fans

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 centre distances.

Angle of Wrap

The equations employed in determination of angle of wrap for belts 1 and 2 as shown in Figure (3) are given as (Allen et al, 1982):

$$aa^1 = 180° - 2\sin' \frac{(R - r)}{Ca} \quad \text{.......................................(2a)}$$

$$aa'' = 180° + 2\sin^1 \frac{(R - r)}{Ca} \quad \text{.. (2b)}$$

Where R is radii of larger pulleys; r is radii if smaller pulleys; Ca is centre distances from the two pulleys being considered; cca' and oca" are the warp angles of the two pulleys with respect to the belt being considered. However the belt design is governed by the load carrying capacity of the pulleys which is depicted by the pulley with a smaller value of. The coefficient of friction / for leather on cast iron is used while oc is as determined in equation 2a and 2b in radians.

Belt Tensions and Power Transmitted

After the determination of the pulleys that controls the belt designs the following equations were used to obtain the belt tensions.

T, = Sbt .... (3)

M = btp .... (4)

$$\frac{T1 - Mv^2}{T2 - Mv^2} = e^{f\alpha} \quad \text{--------- (5)}$$

Where T1 is belt tension in tight side of belt
T2 is belt tension in loose side of belt
S is maximum allowable stress b is belt width t is belt thickness p is density of leather M is mass per unit length of belt v is line speed of pulley given as

$$v = \frac{2IINR}{60} \quad \text{--------- (6)}$$

where N is speed of pulley governing design
R is radius pulley governing design

The Power (P) transmitted between the pulley being considered is given as P = (T1 - T2)------------(7)

Performance Test

The two pneumatic separators for the beans/particles separating machine were designed constructed and assembled so as to make the alteration of the tilt angles to the horizontal level possible. The best angle of tilt at which the machine will be most effective was thereafter determined.

Methodology

The beans was weighed before separation and 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 range of angles (0°, 10°,20°,30°,40°,50°). The average was taken for each angle and the result used to determine the efficiency of the fans at each of these angles .2.5 kilograms of beans and 0.5kg of chaff were used for the analysis.

Determination of Efficiency

The equation used for the determination of efficiency is given as

Efficiency = Wb(Af) - Wc(Af) x 100% ----- (8)

WbBf

Where Wb(Bf) is Weight of beans before separation Wc(Bf) is Weight of chaff before separation Wb(Af) is Weight of beans after separation Wc(Af) is Weight of chaff after separation

On the completion of the performance test for the blower fans, the result obtained are as shown in Tables 1 and 2 are also presented graphically in Figures 2 and 3 to give a summary of the efficiencies of the fans at various tilt angles.

Interpretation of Results

As shown in Tables 1 and 2 when the fans are at horizontal position (0°) the force produced rate of 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°, the chaff was blown away with some beans and some stones. At the first fan, increase in title angle 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° for reasons Idiscussed 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 line of free fall.

At 50° 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.

Conclusion and Recommendations

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-7.0ms, the beans 9.2m/s-12m/s while that of the stone is 14/s.

The machine was powered by single-phase 1.5KW electric motor with a speed of 1420 rpm. The first fan that blows the chaff has a terminal velocity of 8m/s, while the second fan that blows the beans has a terminal velocity of 13m/s. Efficiencies of the machine were determined based i on the angle of tilt of the fan blower.

The air velocity at the outlet of the fan blowers is paramount in accomplishing successful separation of the grains. The velocity of the fan blowers can be regulated by tilting them to different angles. 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 a multiple speed electric motor is recommended, thereby making the separation of other grains e.g. rice, maize etc possible by regulating the speed of electric motor within the range of terminal velocities of these grains.

Fantilt Angle			1” Test		2nd Test		3rd Test		Average		Efficiency
	Wb(Bf) (Kg)	VVc(Bf) (Kg)	Wb(Af) (Kg)	Wc(Af) (Kg)	Wb(Af) (Kg)	Wc(Af) (Kg)	Wb(Af) (Kg)	Wc(Af) (Kg)	Wb(Af) (kg)	Wc(Af) (Kg)	(%)
0°	2.5	0.5	0.2	0	0.2	0	0.2	0	0.2	0	8
10°	2.5	0.5	0.7	0	0.8	0	0.8	0	**0.8**	**0**	**30**
20°	2.5	0.5	1.3	0.	1.4	0	1.3	0	1.3	0	52
30°	2.5	0.5	2.0	0	2.1	0	2.2	0	2.1	0	84
40°	2.5	0.5	2.4	0	2.4	0	2.3	0	2.4	0	95
50°	2.5	0.5	0.3	2.5	2.5	2.0	2.5	0.3	2.5	0.3	88

Table I: Performance Test Result for Fan 1

Fantilt Angle			I^s"Test		2nd Test		3rd Test		. Average	Efficiency	
	Wb(Bf) (Kg)	Wc(Bf) (Kg)	Wb(Af) (Kg)	Wc (A0 (Kg)	Wb(A0 (Kg)	Wc(A0 (Kg)	Wb(A0 OKg)	Wc(A0 (Kg)	Wb(A0 (kg)	Wc(A0 (Kg)	<%)
0°	2.5	0.5	2.2	0	2.2	0	2.3	0	2.2	0	90
10“	2.5	0.5	1.5	0	1.6	0	1.5	0	1.5	0	61
20(l	2.5	0.5	1.1	0.	1.2	0	1.2	0	1.2	0	48
30"	2.5	0.5	0.9	0.	0.8	0	0.8	0	0.8	0	32
To5	2.5	0.5	0.6	0	0.6	0	0.7	0	0.6	0	24
"MP	2.5	0.5	0	0	0	0	0	0	0	0	0

Table 2: Performance Test Result for Fan 2

References

Aigbokchai, S.O. and Awomolo, A. (2002) Design Construction and Performance Analysis of Pneumatic Separators for A Beans Particles Separating Machine. Bachelor of Science Project, Department of Mechanical Engineering, University of Ibadan (Unpublished).

Allen, S.H.; Alfred R.H.; and Herman, G.L. (1982) *Theory and Problems of Machine Design.* Singapore: McGraw-Hill Publishing Company.

Anderson, A.L. (1955) *Dry Bean Production in Eastern States.* Cambridge London: Oxford University Press.

Brandon, J.F. (1943) *Field Bean Production Without Irrigation in Colorado.* Washington DC: Government Printing Office.

Dabor, S.E. (2001) Design of Bean Particle Separating Machine. Bachelor of Science Project Department of Mechanical Engineering, University of Ibadan (Unpublished).

Feller, R. and Faux, A. (1975) Oscillating Screen Motion Effect on the Particles Passages Through Perforation. *Transactions of the AVAEW* ol. 18(5), 8.

Koya, O.A. and Adekoya, I.O. (1994) Some Physical and Aerodynamic Properties Relevant in Destoning Some Grain Crops. *Ife Journal of Technology* Vol. 4, No. 2.

Osborn, W.C. (1996) *Fan.* London: Pergamon Press.

Serriff, R.F. (1976) *Applied Geophysics.* Cambridge London: Oxford University Press.