Original article

Development and performance evaluation of air compressor on agricultural tractor

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Abstract

The experiment was conducted in Darmali village, River Nile State, Sudan, to design an air compressor, which will be installed in the rear of a tractor and operated from the tractor PTO shaft. An air container was added for air saving under pressure. The installation included three iron frames A, B and C in addition to flexible hoses and air pressure gauges. The compressor tests were carried out for three types of tires: 10//, 16// and 38// (three times a day, 10 am, 12 midday and 3 pm). It was compared with two air filling mechanisms, manual and in a workshop. Obtained results showed that the difference on fuel consumption between loaded and unloaded compressor was 103.2 ml/hr. Also, the results indicated that the compressor had no significant effect on fuel consumption during operation although it was significantly affected the time taken for tires air filling. The time taken for air filling for the tires 10//, 16// and 38// was (0.73 hr, 4 hr and 0.01 hr), (2 hr, 4 hr and 0.05 hr) and (7.3 hr, 4 hr and 0.12 hr) with manually, in workshop and by designed compressor, respectively.

Keyword: Development, performance air, compressor

Introduction

Agricultural mechanization is considered to be responsible for the application of engineering, mathematical and physical theories to solve some problems and increase production besides a good work environment for farmers [1]. Power source in agriculture is of great importance in determining the level of agricultural mechanization and development. In the farm there are three sources of power for carrying out operations, the human power (about 0.07–0.1 kw) for a limited amount of work which seldom exceeds subsistence level, animal power which is mainly used for draft work or transport of goods and people and mechanical power [2].

Mechanical power through tractors will continue to be an absolute necessity for agricultural production [3]. The tractor engine can be used as a prime mover for active (moving) tools or stationary farm machinery through the power take off shaft (PTO) or belt pulley [4].

Transmitting power from its source to the points of use is one of the important variables to the farm equipment designers. The selection of proper power transmission systems on mobile agricultural machinery must take into account the customer requirements, cost constraints, field usage, operator safety and reliability [5].

The primary function of the transmission member is to affect the change in speed

between the two shafts as well as in linking them. It is generally required that the transmission system should have adequate reliability, service life, simple in construction, little resistance to motion, produce little noise, offers substantial resistance to vibration and easy to control.

There are many power transmission systems used, but the most extensively used in agricultural machinery applications are V-belts [5,6] with efficiency ranges from 70 – 95% [11]. Gears and chains are also widely used for power transmission as linear or rotary motion [7-10]. Other power transmission systems included bearings, shafts and universal joints. Rotating shafts are of various lengths, diameters and types and they may be subjected to bending, tension, compression or torsion loads, acting singly or in combination with one another [7,11]. Therefore it is important to locate the PTO shaft of the tractor with respect to the draw bar because of the telescoping action of the drive member.

The compressor is a device used to increase the pressure of compressible fluid; it consists of a cylinder, piston and rod, valves and crank shaft and bearing [12]. The inlet pressure level can be any value from a deep vacuum to high positive pressure. The discharge pressure can range from sub-atmospheric levels to high values.

Therefore the main objectives of the present research work are to design an air compressor, which will be installed in the rear of tractor and operated from tractor PTO. Air compressor was evaluated and tested for its fuel consumption, time consuming in tires air filling and cost of constructing and repairing.

Materials and methods

The study was carried out in Darmally village, 13 km north of Atbara city and 325 km north of Khartoum city. A Massey Fergeson (290) tractor of 74.8 hp (maximum PTO) was used as a source of power, technical specifications shown in (Table 1). A compressor and air container were used with their technical specifications shown in (Table 2, 3 and plate 1). Other materials and tools used to carry out the installation included iron sheets, iron angles, iron flanges, fixing bolts, nuts, shims, pulleys and other workshop equipment in addition to flexible hoses and pressure gauges. The main frame made of steel was constructed for locating the compressor and air container. The main frame was consisting of three parts; frame A, B and C. All designing criteria were considered when fixing the frame strongly with fixing bolts. Frame A was designed to fix the air container and the compressor to the tractor body (Plate 2 and Fig 1). Assembly of frame B and C were for compressor locating and they were used as an adjustable base to make tension of the belts (Plate 3 and Fig 1).

The following calculations were carried out to have an optimum speed (rpm) and required horse power from the tractor PTO shaft to the compressor. Tractor PTO shaft speed was approximately 500 rpm.

Table 1. Technical specifications of the tractor Massey Furgeson (MF290)

Technical specifications	MF 290
Machine type	Perkins/ A 248
Rated engine power	82 h.p.
Max engine torque	(260)/b.ft
Max P.T.O. h.p.	74.8h.p.(55.7kw)
Wheel and tire front/ rear	7.5X16, 18.4X30
Rear type Ballast	Water ballasted
Total weight	2585kg

Table 2. Technical specifications of the compressor

Technical specifications	Air compressor
Model No	R-2y-0067
H.P	2 hp
RPM	1000 rpm
Air filling	60 lb/m
Weight	5 kg
Length	24 inches
Diameter	7.5 inches
Full capacity	60 lb/m
Material (frame)	Steel
Steel chickens	0.25 inches

Table 3. Technical specifications of the air container

Technical specifications	Air container
Length	24 inches
Diameter	7.5 inches
Full capacity	60 lb/m^2
Material	Steel
Steel chickens	0.25 inches

Power calculation:

The following formula was carried out to have designed power for the air compressor [11].

Design power = Service Factor × Transmitted powerOverload service factor

Transmitted power = 2 hp (Table 2).

Overload service factor (Table 4).

Design power = 1.3 × 2 = 2.6 hp (selected 3 hp).

Table 4. Overload service factor

Overl-oad %	0	25	50	75	100	150
Service factor	1	1.1	1.2	1.3	1.4	1.5

Pulley selection:

The drive and driven pulleys may be selected as follows [5]:

$$\frac{PDr}{PDn} = \frac{(rpm)r}{(rpm)n} \quad \dots (1)$$

Where:

PDr = pitch diameter for the driver pulley (inch).

PDn = pitch diameter for the driven pulley (inch), proposed 5 inch (Fig. 2).

(rpm)r = driver pulley speed (rpm), 500 rpm available from the tractor PTO shaft.

(rpm)n = driven pulley speed (rpm), 1000 rpm was required for the compressor.

Then:

$$PDr = \frac{1000 \times 5}{500} = 10 \text{ inch} \quad \dots. (2)$$

V-Belts selection:

For V-belts design and selection the computations made follows the methodology mentioned by Shigley and Mischke [11]. The center distance between drive and driven pulleys was 40 inch and

this was found to fulfill the following equation:

$C < 3 (d + D)$ …. (3)

Where:

C = center distance.

D = large pulley diameter.

d = small pulley diameter

Therefore from Table (5), a V- belt section A- was selected.

The pitch length of the belt calculated as follows:

$LP = 2C+1.57 (D+d) + (D–d)\ 2 /4C$ ... (4)

Where:

C = center distance.

D = pitch diameter large pulley.

D = pitch diameter small pulley.

Lp = pitch length of belt.

$Lp = (2\times40) + 1.57 * 15 + (25/4\times40) =$ 103.7063 inch

The inside circumference is calculated using (Table 6). The conversion quantities shown are in inches and are to be added to the inside circumference to get the pitch length.

Pitch length = Lp – 1.3 = 103.7063 – 1.3 = 102.41 inch.

The nearest standard size of V-belt from (Table 7) is A-105 V-belt.

The angle of contact of the small pulley Øs was found as follows:

$$Øs = \pi - 2\sin^{-1}\frac{(D–d)}{2c} \quad \text{….(5)}$$

Where:

D = pitch diameter for large pulley (inch).

d = pitch diameter for small pulley (inch).

c = center distance (inch).

Øs = contact angle for small pulley.

$$Øs = \pi - 2\sin^{-1}\frac{(10-5)}{2\times40} = 173^{o}$$

The rated horsepower (Hr) was calculated as follows:

$$Hr=\frac{[(C1–C2–C3(rd)2–C4\log(rd)](rd)+C2r(1–1/ka)}{d} \quad ...6$$

Where :

r = rpm of high-speed pulley, divided by 1000.

Ka = speed ratio factor (Table 8).

d = pitch diameter of small pulley.

C1, C2, C3, C4 = constants (Table 9).

$0.8542 - (1.342/5) - 2.436(10)-4\times25 - 0.1703\times0.7\times5 + 1.342(1- (1/1.1106) =$ 1.43 hp

Hr = 1.43 hp

The rated horsepower was corrected according to the contact angle by the following equation:

$H\,p = k1k2Hr$ …7

Where:

Hr = corrected power rating.

K1 = correction factor of angle of contact (Fig 3).

K2 = correction factor for length of belt (Table 7).

Hp = rated horsepower.

$H\,p = 1.1\times0.97\times1.43 =$ 1.53 **hp**

Since the designed horsepower of the compressor is 2.6 hp and the calculated hp is

1.53 hp, therefore the number of belts = 2.6/1.53 = 1.7 (≈ 2 belts).

Then two V-belts of A-105 were used between drive and driven pulleys.

Three tires, different sizes 10//, 16// and 38// were taken for compressor testing and was compared with manual and workshop air filling mechanism. Tires technical specifications are shown in (Table 10). Air compressor testing included measurements of fuel consumption and time taken for tires air filling.

Table 5. Heavy-Duty conversion V-Belt section

Belt designation	Power Range per Belt hp.	Typical Standard Pulley Sizes (inch)
Inch series		
A	0.2 - 5	2.6 up by 0.2 increments
B	0.7 - 10	4.6 up by 0.2 increments
C	1 – 21	7.0 up by 0.5 increments

Table 6. Length conversion quantities for heavy-duty conventional inch series belts

Belt designation	Size range Inch	Conversion quantity
A	26-128	1.3
B	35-240	1.8
B	240 up	2.1
C	51-210	2.9
C	210up	3.8
D	120-210	3.3
D	210 up	4.1
E	180-240	4.5
E	240 up	5.5

Results and discussion

The compressor was designed to fill tires in the farm for tractors and other machines. This is to reduce wasting time and to reduce the cost of repairing. The average fuel consumption was measured three times a day A, B and C, for the tractor with loaded and unloaded compressor (Table 11). The

Table 7. Standard length Ls and length-correction factors K2 for heavy-duty conventional English V-Belts

Ls	A	B	C
60	0.97	0.91	0.83
68	1.00	0.94	0.85
75	1.02	0.96	0.87
80	1.04		
81		0.98	0.89
85	1.05	0.99	0.90
90	1.07	1.00	0.91
96	1.08		0.92
97		1.02	
105	1.10	1.03	0.94
112	1.12	1.05	0.95
120	1.13	1.06	0.96
128	1.15	1.08	0.98

Table 8. Speed-ratio factors for use in the power-rating equation

D/d range	K_A
1.00 to 1.01	1.0000
1.02 to 1.04	1.0112
1.05 to 1.07	1.0226
1.08 to 1.10	1.0344
1.11 to 1.14	1.0463
1.15 to 1.20	1.0586
1.21 to 1.27	1.0711
1.28 to 1.39	1.0840
1.40 to 1.64	1.0972
over 1.64	1.1106

Table 9. Constants for use in the power-rating equation

Belt section	C_1	C_2	C_3	C_4
A	0.8542	1.342	$2.436(10)^{-4}$	0.1703
B	1.5060	3.520	$4.193(10)^{-4}$	0.2931
C	2.7860	9.788	$7.460(10)^{-4}$	0.5214
D	5.9220	34.72	$1.522(10)^{-4}$	1.064
E	8.6420	66.32	$2.192(10)^{-4}$	1.532

Table 10. Technical specifications of the three tires $10^{//}$, $16^{//}$ and $38^{//}$.

Tires type	Technical specifications
Rear	12-38 Rim Dw 11
Front	750 R 16 121/120 L
Minimum size	3.5-10

result showed that fuel consumption for loaded compressor in different periods of the day varies from 1089 ml/hr at 10 am to 1090 ml/hr at 3 pm and it is equal to 1 ml/hr. The difference in fuel consumption may be due to high temperature which affects air volume and pressure inside the combustion chamber in addition to the effect of temperature on the fuel quantity. This result agrees with a previous finding that the pressure, humidity and temperature of the ambient air inducted into the engine affect the air mass flow, rate of the fuel consumed and power output. Also, it is found that the average fuel consumption was 1090 ml/hr during the compressor loading and it was 1060 ml/hr when unloaded. Statistical analysis showed that there was no significant difference between the two experiments, as well as between the three periods A, B and C.

Table 11. Means of tractor fuel consumption for loaded and unloaded compressor, A: at 10 am; B: at 12 midday; C: at 3 am

Different load	Mean fuel consumption (ml/hr)			Average (ml/hr)
	A	B	C	
Loaded compressor	1089	1090	1090	1090
Unloaded compressor	1060	1060	1060	1060

Results for the time of the tire air filling (Table 12) showed that the 10// tire the time taken for complete air filling was 0.73 hr, when using manual filling; it was 4 hr for the workshop (nearest workshop to the field was at distance of 13 km) and it was 0.01 hr for the compressor filling. For the tires 16// and 38// the time taken was (2, 7.3 hr), (4, 4 hr) and (0.05, 0.12) with manually, workshop and compressor filling, respectively. It can be observed that as the tire size increased, the time required for filling was increased. It was clear that the lowest time required for air filling was recorded by the designed compressor for the 10" tire 0.01 hr while the highest time was for the workshop 4 hr. The time of the workshop was higher because of the distance between the field and workshop, approximately 13 km. Statistically, the difference between the two mechanisms, workshop and designed compressor for tire filling, was highly significant.

The designed compressor under this study was found to be very effective and useful in saving time, increasing the efficiency of the tractor and reducing the time and cost of preparing. The cost of the compressor installed and its accessories was approximately 5200 SDG which includes construction and preparing of the compressor, air container, workshop and labor, flexible hoses and pressure gauges, pulleys and V-belts and fasteners, and shim, angles (Table 13).

Table 12. Average time taken for air filling by different types of filling mechanisms for the three tires 10", 16" and 38"

Tires size inch	Time for air filling by different types (hour)		
	Manual	Workshop	Compressor
10"	0.73	4.00	0.01
16"	2.00	4.00	0.05
38"	7.30	4.00	0.12

Table 13. Cost of the compressor and modified design parts

Items	Cost (SDG)
Compressor	2500
Air container	2000
Fasteners, shim, angles etc.	100
Workshop and labor	500
Pulleys corner	100
Total	5200

Conclusions

In developing countries, where services are not within the economical easy reach of farmer and agro tractors and machinery owners, tractors mounted and operated compressor is most effective method for increasing efficiency and reducing cost. To reach the optimum benefit from the tractor PTO shaft compressor, several modifications may be done such as: modifying the speed ratio between PTO shaft and compressor, change pulleys diameter from (10,5) inch to (15,5) inch, substitute A V-belt with B V-belt, choosing the air container of high capacity approximately 120 bounds etc.

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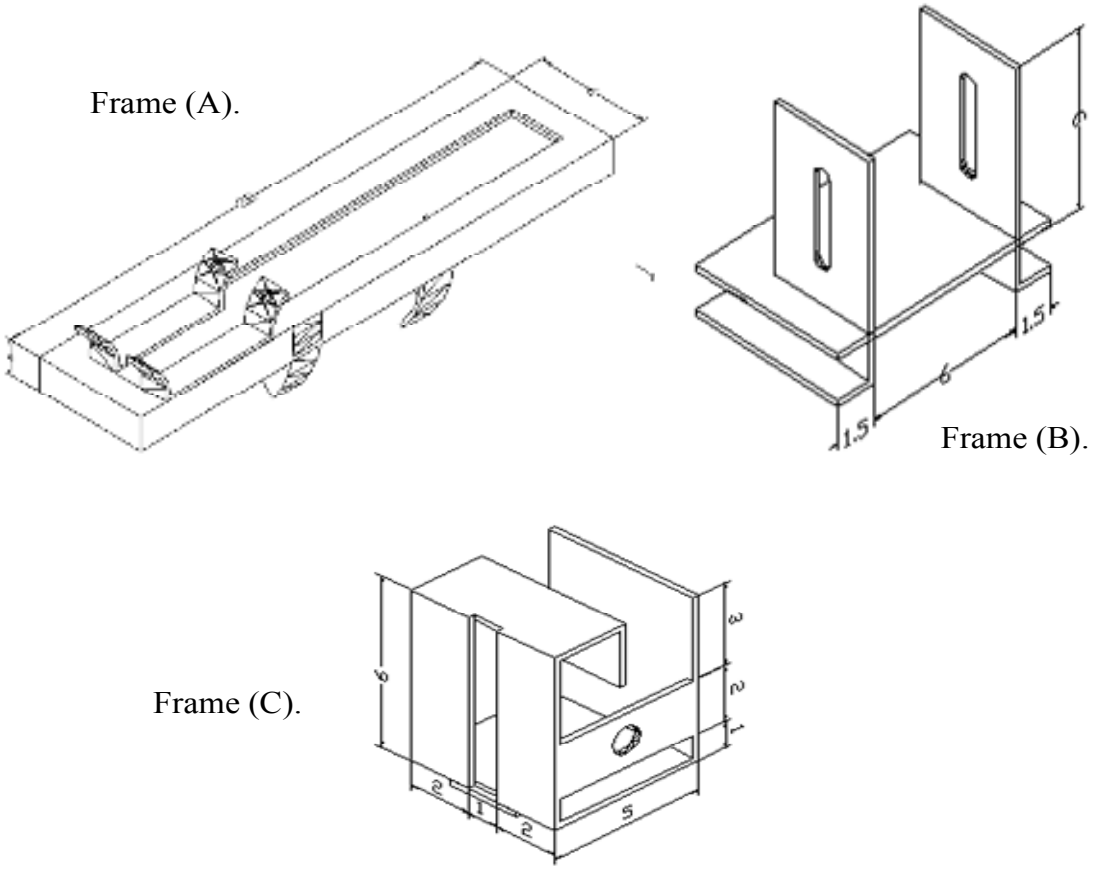


Figure 1. Frames A, B and C; All dimensions in inches

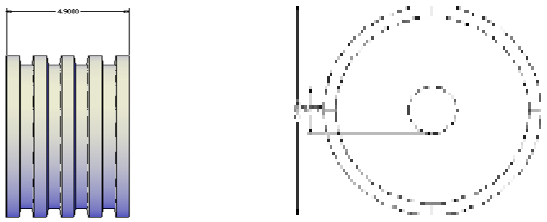


Figure 2. Pulley driven

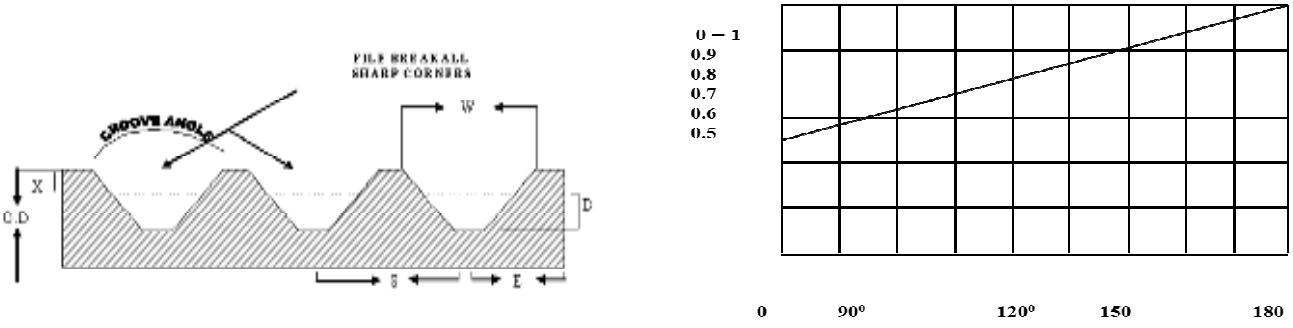


Figure 3. Correction factor K1 for angle of contact to 180^0.\ Angle of contact, Ø.

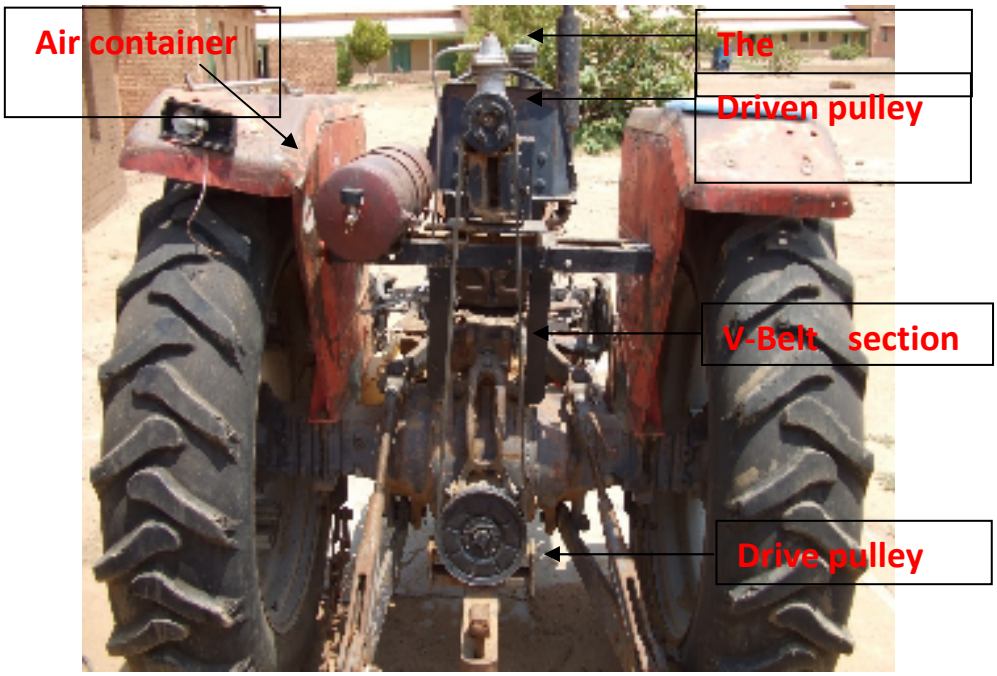


Plate 1. Parts of the designed compressor installed on the tractor.



Plate 2. Frame A .



Plate 3. Assembly of frame B and C