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RESEARCH ARTICLE

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DESIGN OF WHEAT SEED DRILLING MACHINE BASED ON HORSEPOWER CAPACITY OF POWER SOURCE FOR SMALL-SCALE FARMING

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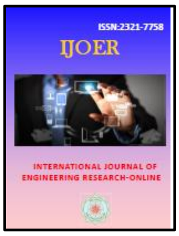

ABSTRACT

Design and improvement of wheat seed drilling machine for small-scale agriculture based on horse power such as wheeled mobile robot and two wheeled tractors were done. The design of main parts of machine such as seed and fertilizer hopper, metering unit, furrow openers and vibration controlling system being conducted.

To accommodate all the recommended seed and fertilizer plantation rates per hectare, fluted type of seed and fertilizer metering device is designed. Control of the seed and fertilizer rate is mostly achieved by the exposed length of metering device to seed. From the analysis result, it has been observed that the rate of fertilizer and seed have direct relationship with the exposed length of metering device.

Furrow opener designed for this seed drilling machine is manually adjustable for the proper placement of seed and fertilizer for different operating scenarios such as soil type, moisture content and plantation season.

Compression and extension springs are designed to achieve proper seed placement through optimized vibrations which arise due to the ground conditions in the farm.

Based on stress and strength analysis of designed parts of machine results, most of their factor of safety is more than 1.5.

Key words: Horse power, metering unit, fluted type, seed and fertilizer hoper, furrow opener, seed rate, factor of safety.

1. Introduction

Agricultural machineries are the key component to increase human productivity, work efficiency and crop productivity. There are lot of power and time-consuming operations in agriculture for instance land preparation, plantation, weeding, spraying and harvesting and these operations can be conducted by several farm machineries with ease of the operation [10].

Based on those agricultural operations, there are various power sourcesfor instance human, animal and mechanical available to pull farm implements with respect to farm operations and size of the farm implement. From the mechanical power source categories automated robotic technologies are one of the recently emerging technology [1,9].

In general, the impact of robotics is a crucial factor for any of the agricultural operations such as product enhancement of the quality and standardization, labor substitution germ free facilities, accurate provision, recording and utilization of data that has been collected while agricultural machine operation [3].

A lot of success has been accomplished, especially in the large scale automated

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agricultural machine technologies, and machineries for small scale agriculture like robotic and other small-scale farming are recently emerging technology. Specially application of robotics for some specific agricultural operations such as crop plantation [1,3,9,10].

To have improved operation performances of seed drilling machineries, improvement of main parts for instance furrow openers, depth controlling system, vibration controlling system, transporting wheels, power transmission system, seed hoppers, seed tubes and seed metering system according to the power source and condition of the farm field is important [5].

On the other hand, these seed drilling machine is improved and designed under the consideration of soil conservation scenario. To maintain less soil compaction, improve cereal productivity and farm profitability on a sustainable and environmentally sound basis but strong enough to resist the shocks due to roughness of the farm field [4,9].

Most of the successful research works related to advanced agricultural machine technologies mostly applied for large-scale agriculture for instance large-scale farm enterprises. But research on advanced small-scale machineries such as small-scale seed drilling machines that address small-scale farmers are recently emerging technologies for small-scale farmers.

To resolve the need of the small-scale farmer's agricultural machinery and improve operational performance of small-scale farm machine like for instance seed drilling machine. Improvement and design of such small-scale seed drilling machine, that can be attached to the wheeled mobile robots for automated farming or for two-wheel tractors for mechanical farming is the major statement problem for this research.

1.1. Methodology

- ✓ Assessment of literatures about small scale seed drills and its components like for instance seed hoper, seed metering device and others
- ✓ Most of the automated robots and two-wheel tractors have small capacity in draft force or horizontal component of force. To address these short comings of small scale agricultural machineries, improve the seeding machinery components as per there drought force capacity.
- ✓ Detail design of the improved seeding machinery components using three D solid works.
- ✓ Stress and strength analysis of improved components of seed drilling machine subjected to high stress force using finite element methods.

2. Improvement and design of wheat seed drill machine

Seed drilling machines are one of the major agricultural implements used for seed plantation. The recommended forward speed of mechanical power source for planting or seed drilling machine is between 4km/hr-6km/hr. On the other hand, most of the mobile robot forward speeds ranged from 1 up to 100km/hr with pulling capacity of 7500N [1 &2].

2.1 Determination of horse power of power source

From recommended forward speed and draft force of grizzly robot, the following mathematical analysis being held [1,2].

$$Power = F * V \qquad 2.1$$

Where, F=drawbar force of the grizzly robot, V=forward speed of the grizzly robot

But, the draw bar horse power (DBHP) that is =60-75% of the total drawbar horse power of power source being used to operate the machine in any agricultural scenarios [2].

Therefore,

Let us take DBHP = 60%of brake horse power

$$\text{Also, } DBHP = \frac{\text{draft (kg)}*\text{speed}\left(\frac{\text{km}}{\text{hr}}\right)}{270} \qquad 2.2$$

After substituting numerical values in to equation 2.2, daft available for seed drills that is expressed in terms of mass;

The draft requirement per meter width of seed drill is considered as standard as follows;

= 150kg/m [2]

Therefore, width of seed drill=458.46kg/150kg/m = 3.06m

But, designing 3.06-meter-wide seed drilling machine is impossible to achieve required machine performance for such kind of power sources such as grizzly robot or two-wheel tractors.

On the other hand, to customize the power source for instance robot or two-wheel tractors with their implements like seed drilling machine. Seed driller machine size is defined by the number of furrow openers and distance between two consecutive furrow openers [5].

$$\text{Working width of seed drill} = \text{number of furrow openers} * \text{spacing between furrow openers}. \quad 2.3$$

2.2 Power transmission mechanisms design

In this design case the design of chain sprocket mechanism is considered. Chain and sprocket system is the most reliable means of power transmission for agricultural machineries [2, 12&13].

2.2.1 Design of sprocket and chain

Usually roller chains have high torque load resistance ability, and they provide ideal velocity by connecting slow to medium shafts [14].

Center-to-center distance *C* of the roller chain is given by

$$C = \frac{p}{8}\left[2L - N_2 - N_1 + (2L-N2-N1)2-0.81(N2-N12 \right. \quad 2.4$$

L is the length of chain in terms of the number of pitch of the chain, N1 is the number of teeth on small sprocket and N2 is the number of the teeth on the bigger sprocket.

	Pitch diameter(mm)	Outside diameter(mm)	Caliper diameter(mm)	thickness(mm)
1	103.68	113.33	91.31	11.66
2	218.6	229.2	206.7	11.66

Table 2. 1 Power transmission mechanism specification

ITEM	Pitch(mm)	Width(mm)	Minimum tensile strength(N)	Roller diameter (mm)
1	19.05	12.7	31300	11.91
2	>>	>>	>>	>>

Where, Item Number 1 and 2 is Driver sprocket and Driven sprocket respectively.

2.3 Design of seed and fertilizer box

Design of trapezoidal shape of hopper is convenient for the free flow of seeds using gravitational forces under the bottom of the hopper [1,11].

To determine length of the seed or fertilizer hopper, the length of seed box being defined as follows;

Length of seed box (Lb) =working width of seed drill-2b 2.5

Where, b is the distance between the side of seed box wall and ground wheel.

$$\text{Volume of seed box} = \frac{\text{weight of seed in the box (kg)}}{\text{bulk density of seed in the box} \left(\frac{\text{kg}}{\text{m}^3}\right)} \quad 2.6$$

$$Weight\ \text{of seed to be used within required time} = \text{seed rate (kg/ha)} * \text{field capacity} * \text{refilling time (hr)} \quad 2.7$$

Volume of seed box = $\frac{\text{weight of seed in the box (kg)}}{\text{bulk density of seed in the box }(\frac{kg}{m^3})}$ 2.8

2.4 *Design of seed drill metering mechanism*

For better quality of seed rate and uniformity determination of type of metering device, each cell shape and size are important parameters. As per the various research report on seed metering mechanisms for seed drilling machine is fluted type with cell shape of trapezoidal is the most efficient one for seed rate and uniformity [6].

Using following mathematical analysis important parameter of the fluted roller seed metering device such as number of slot and length of slot determined [2]:

The transmission ratio between metering device shaft and ground wheel is 2.12

The area covered by the seed drill in one revolution=π*0.381*0.22=0.264m^2

Therefore, for one hectare the required revolution will be=10000/0.264=37,976rev

So, the metering roller revolution will be=37976/2.12=17,914rev as speed ratio between driving and driven wheel is 2.12

The rate of seed=100kg/ha and it is 17914rev/ha

So, for dropping of 1 kg of seed, we require=17914/100rev

And seed dropped in one rev=100/17914=5.6gm

To change this value in terms of volume we can use bulk density of the wheat crop that is 1120kg/m^3

=5.6*1000000/ (1120*1000) =5cm3

Thus, volume of fluted roller slot is =5/2 = 2.5cm^3

2 represents number of rows for seed drilling machine, because we already decided to design two row seed drill. And the shape of the slot is already decided to be trapezoidal for optimum seed distribution.:. Volume of one groove(slot)=area*length

So, number of the grooves will be = of one fluted roller/volume of one groove (slot)

And the clearance between two grooves(slots) is 4.281mm

Periphery of the roller =πD Where, D is the diameter of the fluted roller metering device

= No. of flutes*pitch

Table 2. 2 Specifications of the designed grizzly wheeled robot drawn wheat seed and fertilizer drilling machine

1	Working width of drill	440mm
	Number of furrow openers	2
	Spacing between furrow openers(adjustable)	220mm
	Draft requirement	6.708hp
	Field capacity	0.141ha/hr
2	Bottom width of seed box	130mm
	Top width of seed box	220mm
	Height of seed box	13mm
	Angle of repose	75^0
	Thickness of seed box	3mm
	Type of material	Sheet metal or PVC
3	Type of seed metering	Fluted type
	Number of slots/roller	12
	Length of roller	60mm
	Diameter of roller	31mm
	Radius of curvature of slot	17.49mm
	Top width of the groove	4mm
	Bottom width of the groove	2mm
	Depth of the groove	1.25mm

Where, 1, is the wheat seed drilling machine 2, is the seed and fertilizer hoper3, is the seed and fertilizer metering device

The following mathematical model is being used to evaluate influence of parameters on seed rate [7]. And performance of metering mechanism, specially related to exposed length of metering unit.

A=ρ×N×L×S×10000/(0.22×π×d×i) 2.9

Where,

A is the wheat seed rate (kg/ha)

ρ is the bulk density of wheat seed=1120kg/m^3

N is the Number of slots on metering device = 12

L is the exposed length of the metering device =0 to 0.2m

S is the area of the one slot = 0.00018m2

Ground wheel diameter = 0.381m

i is the transmission ratio between driving and driven sprocket=2.12

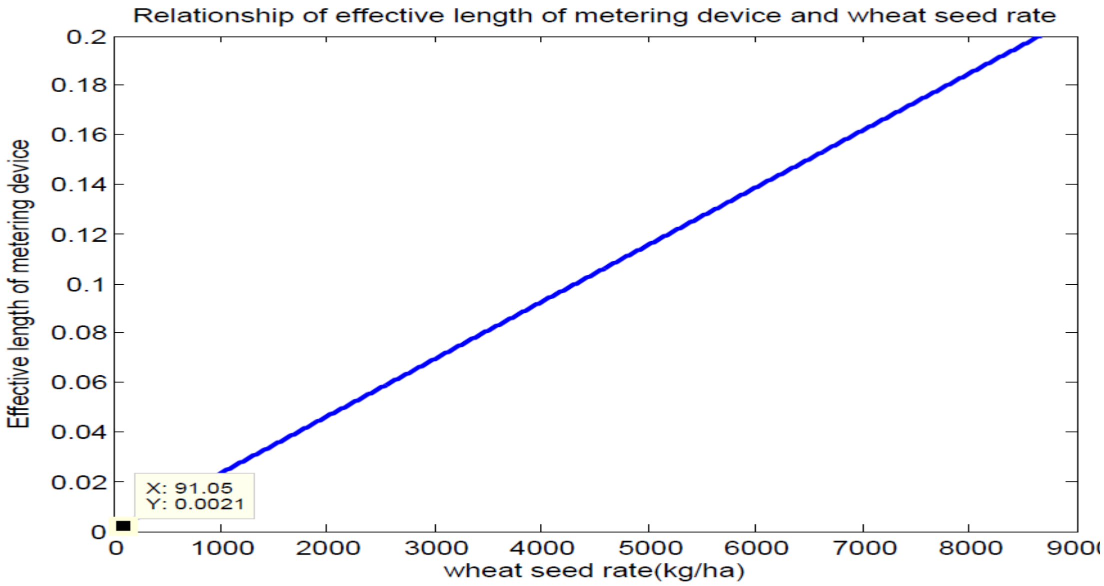

Fig 2. 1 Relationship of wheat seed rate and exposed length of metering device

3.Static force analysis

3.1 Vertical and horizontal force analysis

Conducting of static force analysis on some of the improved seed drilling machine components are required to conduct stress and strength analysis for those stress load subjected parts.

With the consideration of semi-static condition, all the external forces applied on seed drilling machine defined by the following mathematical model written in the X and Y direction respectively [1].

$F_x = D_x + G_x + B_x + P_x$ 3.1

And Y direction forces,

$F_y = D_y + G_y + 2B_y + P_y - W$ 3.2

Where, Fxis the total draft force from power source, D_x, G_x, B_x, P_x are frictional forces at disc, gauge wheel, seed delivery and ground wheel (press wheel), respectively.

F_y is the total vertical force from power source to push seed drill down ward from disc plough, Gage wheel, and furrow openers. D_y, G_y, B_y, P_y are normal reaction forces that applied on disc, gauge wheel, furrow openers (for fertilizer and seed) and ground wheel respectively W is the weight of the seed drill including seed.

3.2 Analysis of extension spring force:

Usually vibration loads applied on the seed drilling machine through soil contacting parts such as disc plough, gage wheel, furrow openers and pressing wheel. Two types of springs being considered for this seed drilling machine such as compression to reduce vibration loads from the disc plough, gage wheel and furrow openers, extension springs for vibration coming from the pressing wheel.

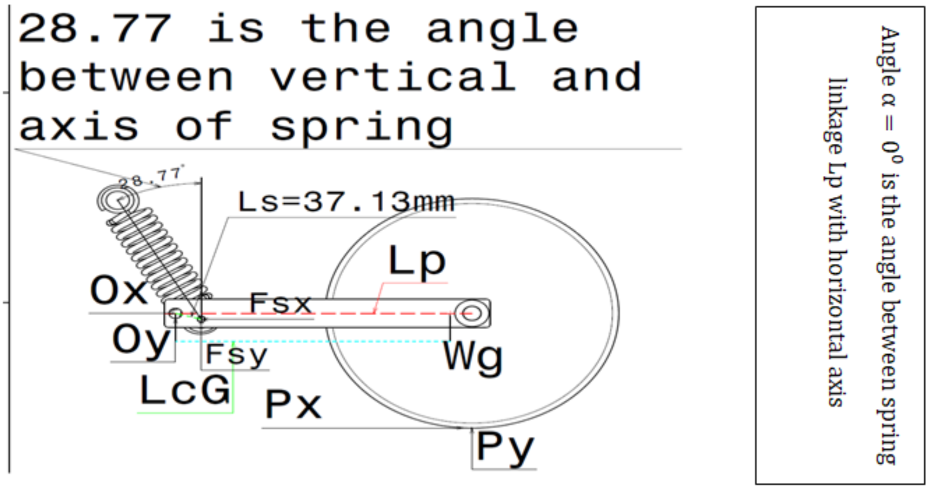

Fig 3. 1 Schematic view of pressing wheel and its linkage to determine force on extension spring

Where, Px and Py are the reaction forces on the pressing wheel from soil.

Wg is the weight of the pressing wheel including its link and determined by the Catia load analysis.

LcG is the length between Wg and load applied by spring.

Lp is the length between reaction forces from the X and Y direction and load applied by spring.

Ox and Oy are the reaction forces coming from extension spring on pressing wheel.

Forces from the X direction

$$P_x - O_x - F_s \sin\theta = 0 \qquad 3.3$$

And forces in the Y direction

$$P_y - O_y - W_g + F_s \cos\theta = 0 \qquad 3.4$$

Where, Fs is the down ward force of extension spring.

And from the momentum equilibrium equation at Point O, where point O is the point of reaction force being applied and, it's the point of rotation of the press wheel link (Lp).

$$F_s\left(\sin(90-\theta)\times L_x - \cos(90-\theta)\times L_y\right) + W_g LcG - L_p \times P_y - P_x \times D_p/2 = 0 \qquad 3.5$$

$$P_y = \frac{F_s\left(\sin(90-\theta)\times L_x - \cos(90-\theta)\times L_y\right)}{L_p} + \frac{W_g L_{CG}}{L_p} - \frac{Px\times Dp/2}{L_p} \qquad 3.6$$

Force of spring defined as:

$$F_s = K(S - S_o) \qquad 3.7$$

Where, K is the constant of spring, S is the length of extension spring after deformation and S_o is the length of extension spring before deformation.

Maximum load on the extension spring expressed as in terms of the initial pre-load (F_i) and optimum force (F_{opt}) of the extension spring mathematically expressed as follows [8].

$$F_{max} = F_i + F_{opt} \qquad 3.8$$

Where, F_{max} is the maximum load being applied on the extension spring

$$F_i = \frac{\pi \tau_i d_s^3}{8D_s} \qquad 3.9$$

The range of preferred torsional stress load τ_i caused by initial tension load on extension spring can be expressed as follows [8].

$$\tau_i = \frac{33500}{\exp(0.105C)} \pm 1000\left(4 - \frac{C-3}{6.5}\right) \text{psi} \qquad 3.10$$

The determination of the extension spring coil turns(Nd) and free length with hooks (Lo) of the extension spring. By applying the following mathematical model [8].

$$L_o = (2C - 1 + N_b)d \qquad 3.11$$

Length of the spring L without hooks determined as follows [16].

$$L = N_a p + 1.5 d_s \qquad 3.12$$

3.4 Compression spring design (part No 39)

Main purpose of the springs is to store and release elastic energy when it necessary. There are various springs are available depending on application area. For Operating scenario such as static and steady working conditions compression spring is the most suitable or relevant one [15,16].

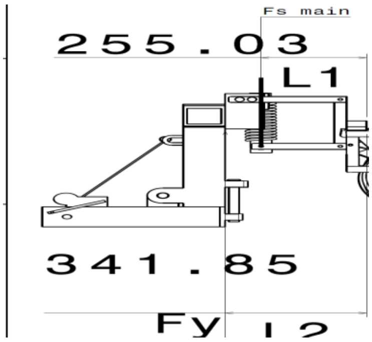

Fig 3. 2 Free body diagram of compression spring for force analysis

$F_y L_2 = F_{spring} L_1$ 3.13

Where Fy is the total vertical force from the disc plough and furrow openers that is = 1232.64N

L1 is the length from the spring to the disc and gage wheel =255.03mm

L2 is the length from the total vertical force from the robot to the disc and gage wheel that is = 341.85mm.

4. Stress and Strength analysis of the parts of seed drilling machine

Stress and Strength analysis applied to verify where the maximum stress and maximum displacement on the designed and improved seed drilling machine parts.

4.1. Frame for assembly of disc plough holder (part No 31)

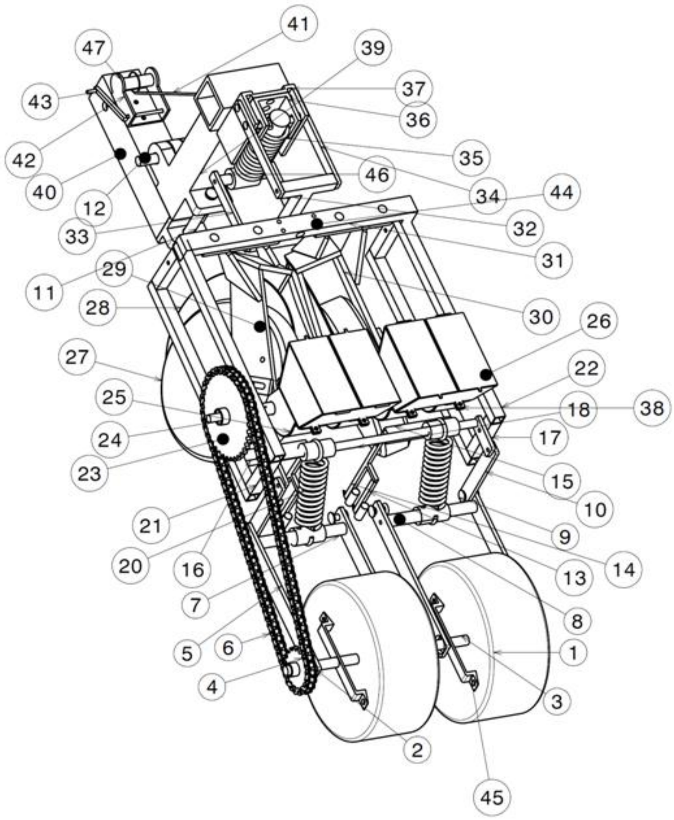

Fig 3.3.Detailed drawing of some of the seed drilling machine and parts

Table 4. 1 Coordinate axis forces and moments on part no 31

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Components	AppliedForces	Reactions	Residual	Relative Magnitude Error
Fx (N)	3.0222e-013	4.2023e-009	4.2026e-009	4.8500e-012
Fy (N)	-5.5375e+002	5.5375e+002	8.5538e-010	9.8716e-013
Fz (N)	-3.2554e+003	3.2554e+003	-8.1322e-008	9.3850e-011
Mx (Nxm)	5.2685e+001	-5.2685e+001	1.1716e-009	2.0789e-012
My (Nxm)	1.0587e+003	-1.0587e+003	3.0024e-008	5.3272e-011
Mz (Nxm)	-1.8008e+002	1.8008e+002	6.2462e-010	1.1083e-012

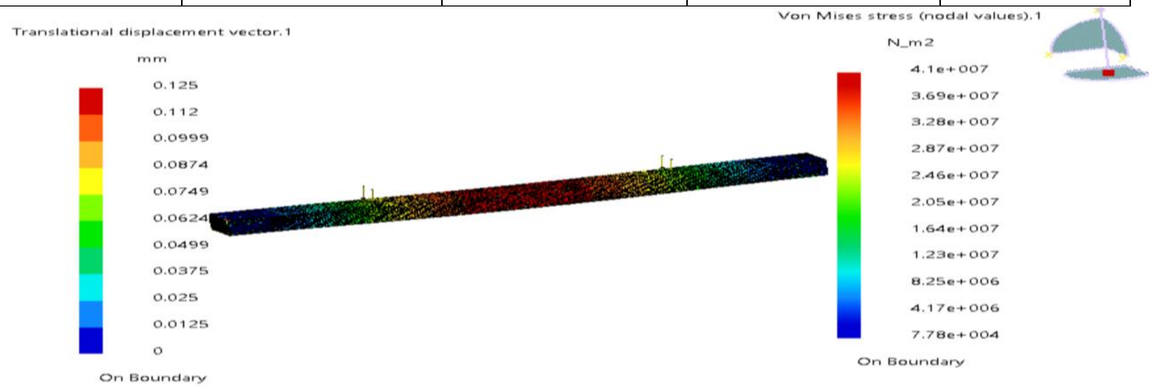

Fig 4. 1 Static Case Solution. - Von Mises stress (nodal values) and displacement deformation.

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