Design of portable traction mechanism for the deployment of the mobile gun sprinkler system for agricultural crops in rurals zones

Diseño del mecanismo de tracción portátil para el despliegue del sistema de aspersión móvil para cultivos agrícolas en zonas rurales

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ABSTRACT

In agricultural production, there is an irrigation process for sowing crops, where a mobile deployable gun sprinkler system is used; such system must be coupled to a tractor, then when it is deployed it must pass over the plantations that are in the stages of germination and production, satisfying the need for irrigation of the planting; due to this procedure the crop is flattened and affected in a considerable area. In this way, one (1) hectare (10,000 m2) that is one hundred percent (100%) sown loses ten percent (10%). The purpose of this research is to build a mobile prototype capable of deploying the gun sprinkler system by constructing a mobile traction mechanism that will be easy to use by the operator. The effectiveness of the project will be observed at the harvest time of the crop where there will be a significant increase per hectare or planted area in the harvest of the products and also a representative decrease in the maintenance costs of the crop, such as fuel and tractor bearings.

Keywords: Design; Aspersion; Crops; Mechanism; Traction; SolidWorks; FEA.

RESUMEN

En la producción agrícola existe un proceso de riego para la siembra de cultivos, en donde se utiliza un sistema aspersor móvil de tipo cañón desplegable; tal sistema debe ser acoplado a un tractor, luego cuando es desplegado debe pasar por encima de las plantaciones que se encuentran en estado de germinación y producción, y de esta manera satisfacer la necesidad del riego de la siembra; debido a este procedimiento el cultivo es aplanado y afectado en un área considerable. De esta forma, una (1) hectárea (10.000 m2) que es cien por ciento (100%) sembrado, se pierde un diez por ciento (10%). El presente trabajo, tiene como finalidad construir un prototipo móvil capaz de desplegar el sistema de aspersión tipo cañón mediante la construcción de un mecanismo de tracción móvil que sea fácil de utilizar por el operario. La eficacia del proyecto se podrá observar en la época de recolección del cultivo donde se generará un aumento significativo por hectárea o espacio sembrado en la cosecha de los productos y también una disminución representativa en los costes de mantenimiento del sembrado como lo son el combustible y los rodamientos del tractor.

Palabras clave: Diseño; Aspersión; Cultivos; Mecanismo; Tracción; SolidWorks; FEA.

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1. INTRODUCTION

Irrigation water sprinklers, since their creation in the 18th century, were stationary and used to irrigate small portions of crops; at the beginning of the 20th century in the United States, some devices or sprinkler mechanisms were manufactured in order to be transported from one point to another no matter how much crop was affected, having as a goal to moisten the field [1].

Since their creation they have been bulky and robust; to start the irrigation you have to unroll the hose by pulling with a tractor; once a band is finished, the drum is turned and the operation is repeated [2]. This gun-type irrigation system is one of the most used when soaking the land, especially in crops such as sugarcane, as it increases production [3][4]. A study shows that this method was adopted in Pakistan, allowing them to rationally use water in crops such as rice and wheat; in this regard, it was determined that the crops irrigated using this method increased production by 18% and reduced water consumption by 35% [5].

There are various types of engines such as: electric, that transform electrical energy into mechanical energy and combustion, that convert chemical energy into mechanical energy, both designed and constructed in order to provide a required torque and being adaptable to the needs; however, in the present study a combustion engine is suggested, because in the field where the prototype will be operating it is not available a socket to connect an AC or DC motor [6].

At present several have been adapted have been adapted and controlled in order to provide a solution and unexpected decoupling of irrigation systems as well as control of water distribution in crops, and thus take care and optimize the use of water, taking into account climate change and pollution [7][8][9][10]. Also, with the use of conventional systems reduces the contamination of crops in order to obtain healthy and toxicity-free food using conventional methods of agriculture [11].

This research begins with a search of information about irrigation systems and techniques existing in the market. Then, an experimental activity was carried out based on the knowledge of agronomists in the area, which consisted in putting into operation a mechanism to obtain the required speed and acceleration; this data allowed to perform the first calculations; later, the power required for the correct operation is calculated taking into account the different masses involved in the system and then the cable and the drum to wind the cable are also calculated [12]. Afterwards, the design of the structure is simulated through a software tool; finally, the remains of the elements are selected and assembled, and tests are carried out for its proper functioning.

2. METHODOLOGY

Regarding the development of this research, the steps for the design and selection of elements for the construction of a portable traction mechanism for the deployment of the mobile gun sprinkler irrigation system for agricultural crops are presented chronologically. In this sense, it begins with an experimental test, in the field, to find the speed and acceleration, getting t=29.4 seconds as the time taken for the tractor to travel a distance of 10 meters; this distance was previously demarcated, and in this way unwrap the same amount of hose from the roll; in order to do this, the following equation was taken into account. With the following equations, the most important variables for the design of the machine are determined. Starting with the calculation to determine the angular velocity using the following Eq. 1:

$$v_x = w * r \qquad \text{Eq.1}$$

Where: w=0,34 rad/s

Subsequently, we calculate the angular acceleration using the following Eq. 2:

$$a_x = \alpha \times r \qquad \text{Eq.2}$$

Where: $\alpha = 0{,}01156 \ \frac{rad}{s^2}$

After having determined the required speeds and accelerations with the Equations 1 and 2, the power required for the correct operation was calculated. In this sense, the masses of all the components of the gun sprinkler were determined in the following way:

$$m_t = m_1 + m_2 + m_3 + m_4$$

Where:

m_1: Water mass

m_2: Hose mass

m_3: Drum Mass

m_4: Sprinkler barrel mass

Therefore, we have to:

$$m_t = 923{,}47\ Kg + 998{,}9\ Kg + 300\ Kg + 100\ Kg$$

$$m_t = 2322{,}37\ Kg$$

$$W_t = 22782{,}4497\ N$$

Once the total mass has been determined, the inertia that the roll has is determined through the following Eq. 3:

$$I = m_t * (r)2 \qquad \text{Eq.3}$$

$$I = 222{,}37\ kg * (2\ m)^2$$

$$I = 8889{,}48\ Kg * m^2$$

After calculating the inertia, we proceed to specify the torque with the following Eq. 4:

$T = I \times \alpha$ Eq.4

Subsequently, the sum of torques is made with the Eq. 5:

$$\sum T = I \times \alpha$$

$T = I \times \alpha$ Eq.5

Where:

$T = 8889{,}48\ Kg * m^2 * 0{,}01156 \frac{rad}{s^2}$

$T = 102{,}76\ N * m$

Then, to calculate the force we use the following Eq. 6:

$F = T/r$ Eq.6

$F_T = \frac{102{,}76\ N * m}{2\ m}$

$F_T = 51{,}38\ N$

Mass of the sprinkler gun m_4:

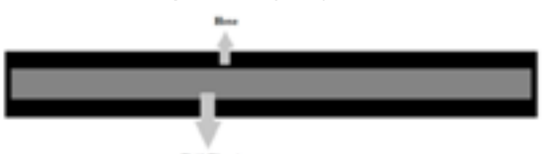
$m_4 = 100\ Kg$

$m_4 = 100\ Kg * 9{,}81 \frac{m}{s^2}$

$W4 = 981\ N$

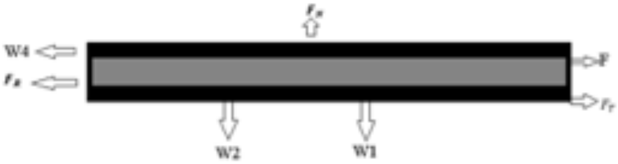
To determine the force that allows to break the inertia of the sprinkler roll, so using the kinetics, a free-body diagram is elaborated (see Figure 1 and 2).

Figure 1. Hose and fluid.
Figura 1. Manguera y fluido.



Source: [13]

Figure 2. Free-body diagram.
Figura 2. Diagrama de cuerpo libre.



Source: [13]

Solving the diagram of the free body, are obtained the following equations 7, 8 and 9. For the summation of forces in the X shaft we obtain the following Eq. 7:

$\sum_{\rightarrow} F_X = m * a$ Eq.7

F + F_T - F_R - W_4=mt* a

Then, we obtain Eq. 8 for the calculation of the friction force:

$F_R = \mu * F_N$ Eq.8

For the summation of forces in the Y shaft we obtain the following Eq. 9:

$\sum_{\uparrow} FY = 0$

$F_N - W_2 - W_1 = 0$ Eq.9

$F_N = W_2 + W_1$

$F_N = 9799{,}209\ N + 9059{,}2407\ N$

$F_N = 18858{,}4497\ N$

So, the equations are solved:

$F_R = 0{,}25 * 18858{,}4497\ N$

$F_R = 4714{,}6124\ N$

$F + 51{,}38\ N - 4714{,}6124\ N - 981\ N = 2322{,}37\ Kg * 0{,}02313 \frac{m}{s^2}$

$F - 5644{,}2324\ N = 53{,}7164\ N$

$F = 5697{,}9488\ N$

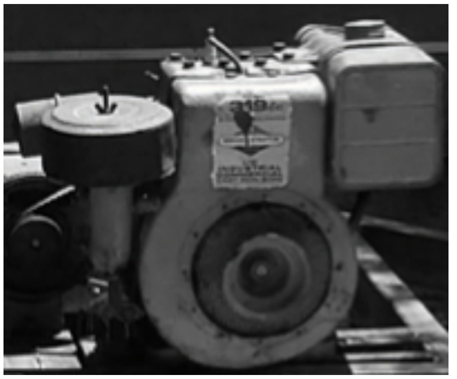
After having determined the necessary force to break the inertia of the sprinkler gun, we proceed to determine the power, taking into account parameters such as the force and the speed at which the sprinkler roll has to be deployed, as expressed below Eq. 10:

$H = F * v$ Eq.10

$H = 5{,}1938\ hp$

Being 5.1938 hp the minimum power necessary for the sprinkler mechanism to be deployed; as a consequence, a motor of 6.5 Hp was selected, which can be obtained commercially.

Figure 3. Combustion engine.
Figura 3. Motor de combustión.



Source: [13]

For the cable calculations, we proceed to establish the allowable diameter for the selection of the steel cable; for this, we select a cable with diameter d=(3/8)inches, 6×19 monitor steel, and apply a safety factor (η=3.5), allowing a more efficient operation we use the following Eq. 11 to determine the tension in the cables:

$$F_t = WT * (1 + a/g) \quad \text{Eq.11}$$

$$F_t = 1283 \text{ Lbf}$$

Subsequently, the minimum diameter of the pulley or roll is determined, as follows with the following equations 12 and 13:

$$D_{opt} = 45 * (3/8) \quad \text{Eq.12}$$

$$D_{opt} = 16{,}87 \text{ Inches}$$

Immediately, we proceed to set the wire gauge and the metal area, through the calculation using the following Eq. 13:

$$A_m = 0{,}40 * (3/8)^2 \quad \text{Eq.13}$$

$$A_m = 0{,}056 \text{ Inches}^2$$

The previous calculation allows to verify that the safety factor complies with the recommended using the following Eq. 14:

$$\eta = \frac{\nabla \text{Permissible}}{\nabla_T} = \frac{(106000 \text{ PSI})}{(22910{,}71 \text{ PSI})} = 4{,}63 \quad \text{Eq.14}$$

The next value for the factor must be greater than or equal to the given safety factor that is (η = 3.5); if so, it complies, and we can proceed to the next step. In this sense η = 4,63 it complies with the recommendation, which allows to compare the factor regarding the pulley diameter; for this procedure, equations 15 and 16 are applied.

$$\eta = \frac{\nabla \text{Permissible}}{\nabla_b} \quad \text{Eq.15}$$

$$\nabla_b = \frac{E * d_w}{D_{optimum}} \quad \text{Eq.16}$$

Where:

E = Elasticity module = 12 MPSI

η = 5,96

∇_b = 17783,04 PSI

Now, the material of the pulley is determined with the Eq. 17 presented below:

$$p = \frac{2 * F^t}{D * d} \quad \text{Eq.17}$$

Where:

F_t = Cable tension force

D = Pulley diameter

d = Cable diameter

p = 456,17 PSI

From the previous result, it is proposed that the cable roll is made of cast iron, proceeding to stipulate the cable resistance and its life expectancy, as well as the allowable tensile fatigue strength using the following Eq. 18:

$$F_f = \frac{\left(\frac{(p)}{S_u}\right) * S_u * d * D}{2} \quad \text{Eq.18}$$

Where:

F_f = Permissible force due to fatigue

S_u = Ultimate resistance = 270000 KPSI

F_f = 1285PSI

Of what it turns out that:

$$\eta = \frac{F_f}{F_f} = \frac{1285 \text{ PSI}}{1283 \text{ Lb}_f} = 1{,}00$$

After obtaining the results in terms of tension, the cable life expectancy is determined, using the following Eq. 19:

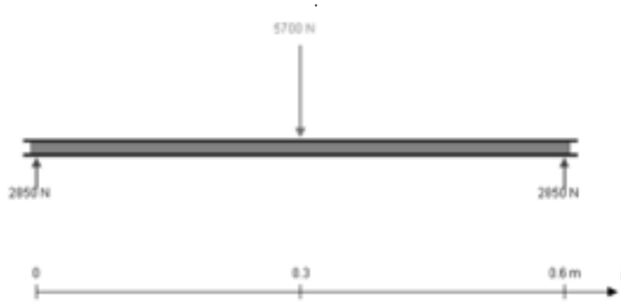
$$\text{Pressure-resistance relationship} = 1000 * \frac{P}{S_u} \quad \text{Eq.19}$$

$$\text{Pressure-resistance relationship} = 1000 * \frac{456{,}17 \text{ PSI}}{280000\text{PSI}}$$

Pressure-resistance relationship =1,62

According to Table 17-21 taken from the book Budynas [14], the cable will have or 0.5 million bends up to failure. Regarding the steel cable drum calculations and continuing with the procedure, the diameter of the roll shaft where the cable will be rolled is established by using the load diagram in the beam; in this case, a free software was used we can see in the Figures 4 and 5.

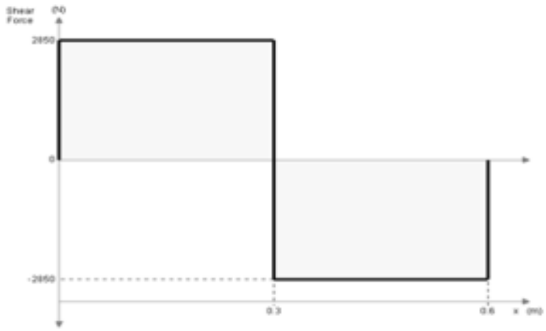
Figure 4. Beam with point load and reactions.
Figura 4. Viga con carga puntual y reacciones



Source: [13]

In Figure 4, the point load is observed along the beam; the sprinkler mechanism must support this load. Likewise, the value of the fundamental supports for the selection of the bearing was determined.

Figure 5. Shear force diagram in the beam.
Figura 5. Diagrama de fuerza de corte en la viga.



Source: [13]

In this sketch, we can see the point that supports the highest load and is useful when selecting material, either solid or hollow cylinders, and so on.

Figure 6. Moment diagram.
Figura 6. Diagrama de momento.

Source: [13]

We can see the maximum value that the shaft will have when the load is applied, in order to obtain a precise diameter. Next, the shaft diameter was determined using the following equations 20 and 21:

$$d_{shaft} = \left[\frac{16 * n}{\pi * S_y} * (4 * M^2 + 3 * T^2)^{\frac{1}{2}}\right]^{\frac{1}{3}} \quad \text{Eq.20}$$

$$d = \left(\frac{16n}{\pi}\left\{\frac{1}{Se}\left[4(K_f M_a)^2 + 3(K_{f1} T_a)^2\right]^{\frac{1}{2}} + \frac{1}{S_{ut}}\left[4(K_f M_m)^2 + 3(K_{f2} T_m)^2\right]^{\frac{1}{2}}\right\}\right)^{\frac{1}{3}} \quad \text{Eq.21}$$

Where:

d_shaft= Shaft diameter

S_y= Creep resistance

n= Security factor, by suggestion it is assumed that 1,2

M= Bending Moment

T= Torque on the shaft

A commercial diameter in inches will be sought:

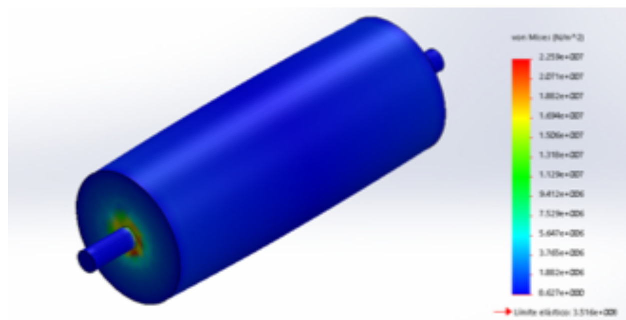
d_shaft=1,37 Inches

3. ANALYSIS AND DISCUSSION

Bearing in mind that in this shaft will be installed the drum where it will be rolled the cable that will stretch the sprinkler system, we proceed to use solidworks in order to simulate if the components are capable of resisting the torsional force, producing the following data.

In Figure 7, the von Mises stress is observed with minimum and maximum values of 8.62724 N/m^2 8.62724 N/m2 and 2.25877e^(+007) N/m^2, respectively.

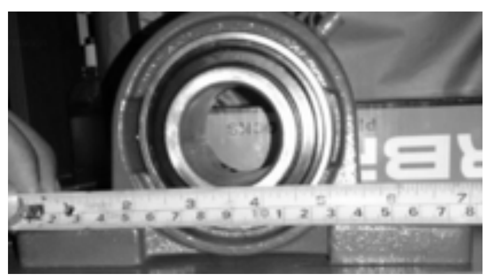
Figure 7. Von Mises tress analysis of the roll.
Figura 7. Analisis de Von Mises del cilindro.



Source: [13]

As it is visualized, the maximum value that has deformation, is below the elastic limit the material has. Once the shaft diameter was obtained, a SKF pedestal bearing was selected for a diameter of 1 1/2 inches for both ends, which was capable of supporting an approximate 3000 N load, we can see the Figure 8.

Figure 8. Roll bearing.
Figura 8. Cojinete del cilindro.



Source: [13]

To transport the mechanism that has an approximate distributed load of 2000 N, a SKF pedestal bearing was selected for a diameter of 1 1/4 inches, for both wheels, we can see the Figure 9.

Figure 9. Wheel bearing.
Figura 9. Rueda del cojinete.

Source: [13]

Regarding the wheel selection, it was taken into account that each one was capable of supporting a load of 1100 N, so one was commercially found that supports 1300 N, we can see the Figure 10.

Figure 10. Wheel.
Figura 10. Rueda.

Source: [13]

In the next Figure 11, regarding the design of the structure that the prototype will have using the solidworks software, a frame with some fastening characteristics was proposed, in such a way that in the system startup, it would be more practical to transport it.

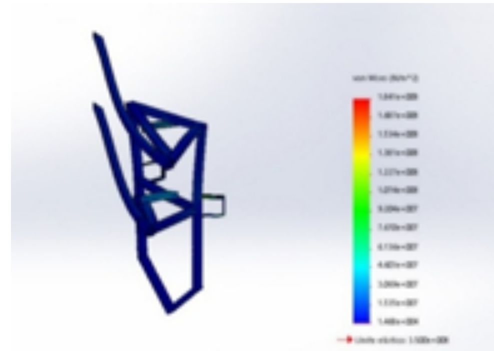
Figure 11. Isometric view of the structure.
Figura 11. Vista isométrica de la estructura.

Source: [13]

The next step consisted in simulating the structure in the software, placing loads in all the constituting points and thus being able to identify which will be its maximum resistance to stresses. To carry out this activity, a structure capable of supporting the loads to which it will be subjected was designed; in this step, the mechanism support points were taken into account as well as the place where the force affects it directly [15][16].

Likewise, a free body analysis was performed where the cable was wound and the forces for the supports were obtained; in this sense, the frame was subjected to the greatest force with a value of 4500 N. For the procedure, a fine meshing was done in order to obtain the most realistic results possible, ensuring its support of external loads [17][18][19][20]; in such a way, the tension structure was analyzed, subjecting it to von Mises stress, handling minimum and maximum parameters between $14681.6\ N/m^{2}$ and $1.84065e^{(+008)}\ N/m^{2}$ respectively, having an elastic limit of $3.500e^{(+008)}\ N/m^{2}$ that, as shown in Figure 12, it is above the elastic limit.

Figure 12. Elastic limit of the structure.
Figura 12. Limite elástico de la estructura.



Source: [13]

Finally, and taking into account the parameters determined through the calculations, the prototype was assembled, putting together the whole structure and mounting in it the traction system.

4. CONCLUSIONS

According to the field tests carried out for the prototype assembly, it was possible to demonstrate that the prototype works efficiently in terms of speed and force of the deployment in the irrigation, which will guarantee that during its use it will not be affected.

In this sense, the proper design of the traction system guarantees a good selection of all the mechanical parts, which are able to fulfill their objective and costs are reduced. Likewise, the machine has a drag capability that is around 6000 N at a speed of 0.68 m/s; however, the drag capability could be much higher if the cable diameter is increased.

Furthermore, the use of an internal combustion engine guarantees the operation of the mechanism in any place of a seeding, unlike the implementation of an electric motor which should have strategic location points and would not guarantee operation in another plantation.

Bearing in mind that the speed reducer is totally mechanical, it ensures that all the load offered by the motor is delivered to the drum where the cable will be wound.

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