

DEVELOPMENT OF A TRAVELLING SPRINKLER

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Abstract

A travelling sprinkler was designed, constructed using locally available materials and tested to ascertain its functionality. The sprinkler comprises of a sprinkler body having a water distributing apparatus (rotary sprinkler arm), adapted to be connected with a hose for supply of water under pressure. The sprinkler moves with a pair of transversely spaced drive wheels on its body for driving the sprinkler along a lawn to be sprinkled, and has a guide wheel assembly mounted in front which defines a path of driving. The machine was made to water a 1225 square meters lawn, i.e. 1/8th of a hectare. During the testing, an effective water throw of up to 5.2 m by the sprinkler's adjustable arms was recorded with a flow rate of 0.00044 m³/s from the hose, with the sprinkler moving at a linear speed of 0.040 m/s and having a drive efficiency of 40.41%. An average time of 59.6 minutes for sprinkling the test area was achieved.

Key words: gear, irrigation, sprinkler, water throw, wheel.

1.0 Introduction

Watering is one of the main components of maintaining a beautiful and healthy lawn and gardens/farms. Sprinkler systems are one of the best ways to distribute precise amounts of water to specific areas providing spray overlaps for complete lawn and bed coverage. Manual portable sprinklers are cheap but must be moved all over the garden to achieve total coverage. Automatic sprinkler systems provide outstanding coverage and, where they are used correctly, are the most efficient form of watering. At times, they operate on a computerized time clock that is fully customizable to personal requirements [1].

Sprinklers operate by pivoting on the top of a threaded nut, and impact sprinklers feature an arm that intermittently turns into the flow of the stream of water. Another type of sprinkler features a larger head that has water shooting out from underneath it. Sprinklers are made of either metal or plastic and can be set to rotate to a particular span. Some sprinklers feature a second nozzle head, which waters the area close to the sprinkler, whereas the primary nozzle waters farther distances [2].

Most existing lawn sprinklers have complex design, coupled with high cost of construction materials, it is difficult to change the location of sprinklers should various features of the area change and they are also difficult to set up [3]. In the light of the aforementioned, this paper reports an effort to provide sprinklers adapted to the peculiarities of Nigeria, and one which is of low cost, easy to set up and easy to maintain.

2.0 Design Theory and Calculations

2.1 Design Consideration and Parameters

For a successful sprinkler design, three basic requirements must be put into consideration; they are the maximum water application rate, the required irrigation period and the depth of application [1]. The maximum rate at which water can be applied will depend upon the ability of the soil to absorb it. In no case should water be applied faster than it will move in to the soil. If this rule is followed, run off and erosion from sprinkler irrigation will not occur. The depth of application and the irrigation period are closely

related. The irrigation period is the time required to cover the field with one application of water. The depth of application will depend on the amount of water that can be stored in the root zone of the soil and the efficiency of application.

For sprinklers, the water application efficiency is usually assumed to be about 70 per cent at the design stage that is to say only 0.7 parts of the supplied water is available to the plants, the remainder being lost to evaporation and other distribution losses [4].

In estimating the required depth of application, a common criterion for beginning irrigation is when the moisture level of the field reaches 55 per cent of the available moisture capacity. Thus, the effective depth of application is equal to 45 per cent of the available moisture [4]. The required period of irrigation is set so that the entire field will be completely covered before the finishing end of the field reaches the wilting point.

Another important consideration in the design of sprinkling systems is the water pressure. In this connection, the available pressure as well as the pressure losses that can be expected from friction and other sinks is considered [5]. In considering friction losses, factors like pipe diameter, pipe length, number and type of fittings used are vitally important

2.2 Description of the Machine

The designed machine has a body made up of metal plates, and consists of four major assembly parts; the sprinkler arm assembly, which has a T-shape, the worm and a worm wheel (spur gear), the hose connection; which supplies water to the sprinkler, and then the wheel which propels the sprinkler forward.

The sprinkler arms are connected to a worm gear inside the sprinkler body. The spinning arms rotate the worm, which engages the worm wheel (spur gear). This way, the rotational force of the worm gets transmitted to the drive axle that turns the sprinkler's rear wheels, thus effecting the translatory motion of the sprinkler.

A water tap running at high pressure will be ideal for good performance and effective sprinkling. In the absence of a water supply grid, a pump capable of pumping water with a pressure of about 0.3792 to 0.6894 N/mm^2 will be needed to pump water to the sprinkler. The water accelerates as it moves through the pipe towards the nozzles, this water produces a force. As the water produces this force, an equal and opposite force is produced in the sprinkler arm. A force acts on the sprinkler opposite to the flow of motion of the water. The two arms are bent at the end so that the force pushes on each arm at an angle generating a torque. This torque on the sprinkler arm causes it to spin. The sprinkler arms are connected to a worm inside the sprinkler body, the spinning arms then rotate the worm, which engages a worm wheel (spur gear) thus converting the rotational force of the worm to the drive axle that turns the sprinkler's rear wheels.

2.3 Design Analysis and Calculation of the Machine Components

In designing components that constitute the machine, the conditions (which include forces acting on various parts of the machine, stress induced and environmental factors) under which the components will operate during their service life were considered. The equations used for designing the various components of the sprinkler are presented in table 1.

Table 1: Design Calculation and Formulae

S/No.	Parameter	Equation	Remarks	Source
1	Torsional shear stress	$\frac{\tau}{r} = \frac{T}{J} = \frac{C \cdot \theta}{l}$	τ - torsional shear stress T- torque J- Polar moment of Inertia C-modulus of rigidity θ - angle of twist l- length of shaft	[6]
2	Polar Moment of Inertia	$J = \frac{\pi}{32}(d_o^4 - d_i^4)$	d_o -outer diameter of hollow shaft d_i - inner diameter of hollow shaft	[6]
3	Head loss due to friction	$h_f = \frac{4fLV^2}{2Dg}$	f - coefficient of friction L- length of pipe D- pipe diameter V- flow velocity g-acceleration due to gravity	[7]
4	Pipe head loss at entrance	$h_i = 0.5 \frac{V^2}{2g}$	V- flow velocity g-acceleration due to gravity	[7]
5	pipe fittings head loss	$h_{fittings} = k \cdot \frac{V^2}{2g}$	g-acceleration due to gravity K- resistance coefficient	[7]
6	Power transmitted by Sprinkler arm	$P_o = T \cdot \omega_{arm}$	ω_{arm} – angular velocity of the sprinkler arm T- torque	[6]
7	Pitch circle diameter of the worm gear	$D_w = \frac{(x)^{0.875}}{1.416} = 3P_c$	x-center distance between shafts P_c - the axial or circular pitch	[6]
8	Pitch circle diameter of the worm gear in terms of module	$D_G = m \cdot T_G$	m- module T_G - number of worm gear teeth	[6]
9	Efficiency of worm gearing	$\eta = \frac{\tan \lambda (\cos \Phi - \mu \tan \lambda)}{\cos \Phi \tan \lambda + \mu}$	Φ - Normal pressure angle, μ -Coefficient of friction, and λ - Lead angle	[6]
10	Equivalent twisting moment of rear axle shaft	$T_e = \sqrt{M^2 + T^2}$	M- bending moment T- Torque	[6]
11	Equivalent bending moment of rear axle shaft	$M_e = \frac{1}{2}[M + \sqrt{M^2 + T^2}]$	M- bending moment T- Torque	[6]

Using the equations of table 1, the required material properties and other design parameters were obtained as follows:

2.3.1 Sprinkle Arm Strength

The torsional shear stress on the sprinkler arm which is a hollow shaft made of steel material and having outer diameter (d_o) of 12.70mm, inner diameter (d_i) of 12.30mm and length 330.2mm, angle of twist of 30° , torsional shear τ of 164.12 N/mm^2 . Other material parameters obtained include Polar moment of Inertia J of 306.875 mm^4 and torque T of 7931.40 Nmm.

2.3.2 Flow Parameters

Pump outlet area = $\frac{\pi}{4}(d_1)^2 = 1.140 \times 10^{-3} \text{ m}^2$, Velocity of water at the pump outlet (V_1) = 2.877m/s, Garden hose diameter = 0.0158m, Area of garden hose = $\frac{\pi}{4} \times (d_2)^2 = 1.961 \times 10^{-4} \text{ m}^2$. Velocity of water in the garden hose (V_2) = 16.725m/s and diameter (d_3) of the sprinkler arms = 0.0127m.

2.3.3 Losses in Pipes

$$\text{Pipe resistance coefficient } K_{\text{pipe}} = \frac{f.L}{D_{\text{garden hose}}} = \frac{0.0033 \times 60.96}{0.0158} = 12.732$$

Fittings resistance coefficient K_{fittings} was obtained as 3.63

$$\text{The total resistance coefficient } K = K_{\text{fittings}} + K_{\text{pipe}} = 16.362$$

Head loss due to friction within the system, given by $h_f = \frac{4fLV^2}{D \times 2g} = \frac{16.362 \times (16.725)^2}{2 \times 9.81} = 233.275 \text{ m}$.

$$\text{Head loss due to pipe entrance } h_{\text{entrance of the pipe}} = 7.128$$

$$\text{Head total } H_{\text{Total}} = h_f + h_{\text{entrance of the pipe}} = 240.403 \text{ m}$$

$$\text{Power generated by the fluid } P_o = Q \cdot \rho \cdot g \cdot H_{\text{total}}$$

$$P_o = 3.2807 \times 10^{-3} \times 1000 \times 9.81 \times 240.403$$

$$P_o = 7737.05 \text{ W}$$

Using P_o , the sprinkler arm angular velocity was calculated as $\omega_{\text{sprinkler arm}} = 235.04 \text{ rad/s}$, the diameter of the worm D_w was obtained to be 16.0712 mm.

2.3.4 Design of Worm Gear

The worm gear is a single threaded worm gear, having a lead angle (λ) of 16° . Using the specifications and the relation $\lambda = \left(\frac{N_G}{N_W}\right)^{1/3}$, the required N_G was found as 53rpm giving a velocity ratio of 42. Also, using the velocity ratio, the required number of teeth for a single threaded worm gear was determined as $T_G = 42$. The diameter of worm gear D_G was calculated to be 84.13mm and the centre distance between the mating gears C was obtained as 50.10mm.

2.3.5 Design of Axle Shaft

The rear axle shaft is mild steel having allowable shear stress (τ) of 115 N/mm^2 , allowable tensile stress (σ) of 155 N/mm^2 , twisting moment of 19512.93N/mm. The twisting moment and bending moment were gotten using a test diameter of 9.525 mm. Therefore, the equivalent twisting moment $T_e = 23530.35 \text{ N/mm}$ Using these values, the required diameter of rear axle shaft was found to be $d = 10.64 \text{ mm}$.

3.0 Construction and Testing

This section involves all processes taken to fabricate various components of the machine before it was assembled.

3.1 Construction

Due to its light weight and local availability aluminium was sand cast into cylindrical ingots for use as gear blanks in the manufacture of gears. A mould was created by placing the mixture of sand, clay and water on a plastic pattern. The plastic pattern was then removed to create a cavity that corresponds to the shape of the plastic pattern. Molten aluminium was then poured to take the form of the cavity. The gear blank was first bored and turned to the correct outside diameter with the aid of a lathe machine, and then it was mounted on an arbor (on a milling machine) which is placed between the centres of the dividing head. An arbor having a taper shank which fits the dividing head spindle was used for the gear work. The blank for the worm was first bored and turned to the correct outside diameter with the aid of the lathe machine. The pitch on the worm wheel (spur gear) was measured with the aid of a pitch gauge. Then the same pitch was selected on the lathe to cut the thread of the worm. It is a right-handed thread.

The sprinkler frame was made from sheets of metals marked, cut and welded together to give the desired shape. The sprinkler frame has two main parts. The gear box; which houses the gears and also carries the two rear wheels and then an attachment to the gear box, which carries the front wheel.

The gear box has two parts, the main housing and a cover for the housing. The main housing was formed from a metal sheet of 290 mm X 350 mm, and the cover for the housing from a sheet metal of 290 mm X 250 mm.

The total cost of manufacturing the sprinkler in Nigerian currency NGN is 21,850. Appendix I details the cost. The various parts of the sprinkler were assembled as shown in Appendix II.

3.2 Results and Discussion

The sprinkler was tested on a 1225 square metres field. It was used for watering the test area three times during which the time t taken to complete the watering, effective water throw and total distance covered s_{total} , and the speed $\frac{s_{total}}{T}$ (m/s) were recorded as detailed in table 1 below: The table shows that the sprinkler has an average effective water throw of 5.20 metres which covers a total distance of 145 metres in 59.6 minutes.

Table 2: Test Results

Test	Total Time (minutes)	Total distance (metres)	Effective water throw (metres)	Speed (m/s)
1	63	145	5.4	0.038
2	57	145	5.0	0.042
3	59	145	5.2	0.04
Average	59.6	145	5.2	0.04

4.0 Conclusion

The travelling sprinkler was constructed and tested. It was found to be capable of watering fields effectively. It was fabricated using locally available materials. The materials were aluminium blanks, plastic, flexible tubings and metal sheets. The developed sprinkler

has an effective water throw of up to 5.2m from the sprinkler's adjustable arms and a flow rate of $0.00044 \text{ m}^3/\text{s}$ from the hose. The sprinkler moves at a linear speed of 0.040m/s and has a drive efficiency of 40.41%. It is capable of watering an area of 1225 m^2 in an average time of 59.6 minutes. The sprinkler could be used in gardens, lawns and farms. We recommend the use of indigenous sprinkler to industrialist, farmers and individuals in place of the imported ones which are expensive and difficult to assess parts for maintenance.

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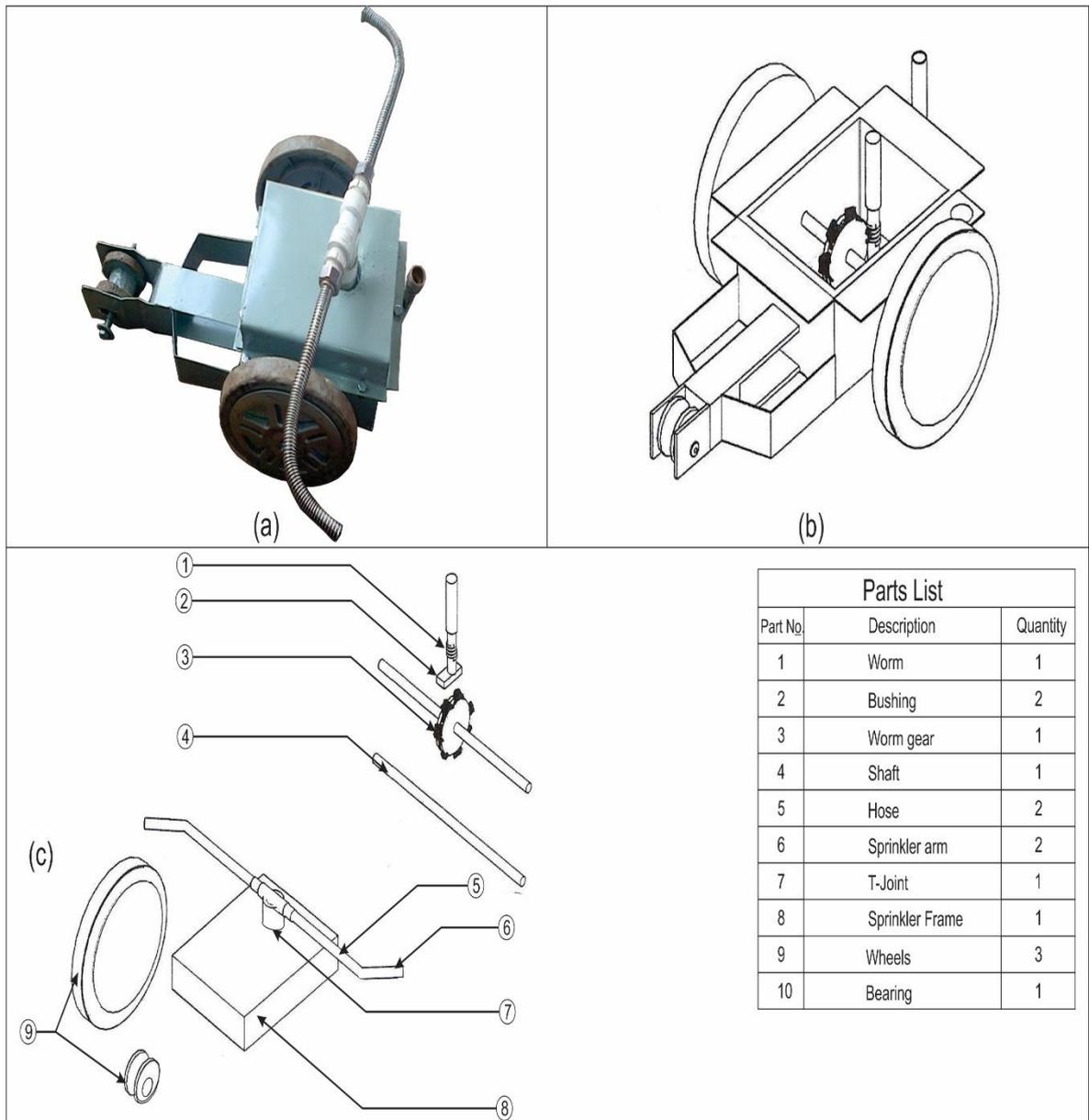
References

1. Howard, N. and Robbins, J.A. (2009). *Equipment Selection and Sizing for Sprinkler and Drip Irrigation*. University of Idaho.
2. Tyson, J. (2013). History of Lawn Sprinklers. Retrieved on 4/4/2013 from <http://www.ehow.com>.
3. Adebayo, V. O. (2014). Design, Construction and Testing of a Travelling Lawn Sprinkler. B. Eng Project, Department of Mechanical Engineering, Modibbo Adama University of Technology, Yola, Nigeria.
4. Glen, O. S and Frevert, R. K. (1985). *Elementary Soil and Water Engineering 3rd Ed.* John Wiley and sons, Singapore.
5. Kith, B .E. (1981). *Modern Plumbing*. The Goodheart-Willcox Company, Inc., Illinois, US.
6. Khurmi, R.S and Gupta, J. K (2010). *A Textbook of Machine Design*. Eurasia Publishing House (P) Ltd, Ram Nagar, New Delhi.
7. Rajput, R.K. (2008). *A Textbook of Fluid Mechanics and Hydraulic Machines in SI Units*. S. Chand and company Ltd., Nagar, New Delhi.

Appendix I: Cost Estimate

S/No.	Component	Material	Quantity	Cost per unit (NGN)	Sub-total cost(NGN)
1	Worm	Aluminium	1	1,000	1,000
2	Bushing	Cast iron	2	650	1,300
3	Worm gear	Aluminium	1	1,000	1,000
4	Shaft	Aluminium	1	150	150
5	Hose	plastic	2	50	100
6	Sprinkler arm	High Tensile steel	2	250	5,00
7	T-joint	Plastic	1	100	100
8	Sprinkler frame	Metal sheet	1	2,500	2,500
9	Wheels	Plastic	3	533.33	1600
5	Bearing	Cast iron	1	100	100
11	Labour			9,500	9,500
12	Overhead cost			4,000	4,000
Total					21,850

Appendix II: Sprinkler Views



(a)-Pictorial, (b)-Isometric and (c)-Exploded views