Validation, Analysis and Design of Critical Parameters of a Standard Hosereel

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Abstract: *Hosereel. A hosereel is a an equipment that you will find on all machines-like fire trucks or drainage cleaning machines-that require to spray water with a lot of force. Even though it may not seem to complicated, it plays an important role in machines like a fire truck – basically any machine that requires a hose to be carried around and used for spraying liquids. The main function of a hosereel is to carry the hose that is used for spraying the water. The hose is wound on the hosereel when the machine is in transit and in case of a swiveling hosereel, it also helps in the orientation of the hose and nozzle. But with change in application, the size of the hose also changes as does the method of mounting. Based on these factors, the hosereel needs to be designed as per the application. A hosereel with its strength compromised may fail owing to the crushing and bending stresses on it. On the other hand, an oversized one will lead to an unnecessary increase in the weight, cost and size of the motor required to rotate it. This paper deals with the design considerations while deciding the type of hosereel so as to ensure its smooth functioning.*

Keywords: hosereel, hose, design, application

1. Introduction

With the betterment of technology and advent of modern medicine, the lifestyle and life expectancy of the average individual have improved drastically in the past century or so. Naturally, fire hazards have gone up with the increase in electrical appliances while the population explosion has set major challenges to the underground drainages to handle the huge capacity.

Fire hazards and drain clogging aren't two things you would put in the same category. But the thing that does bind them together is the method used in solving both problems – spraying water at very high pressures through a hose. The hoses are carried and maneuvered at the sight using hosereels. So depending on the application, the hosereel needs to be designed accordingly. A proper hosereel facilitates easy usability of the hose and in turn makes it easier for troubleshooting.

Hosereels used in fire trucks need to be small and light so that they can rotate at a fast RMP as time is the major factor in case of fire hazards. However, in case of drainage clogs, it is important to get the position of the hose right so that the water jet hits the area that is clogged and removes the blockage. For this, the rotaion should be slow but jerk free. Hence, the aim of this paper is to basically propose a design philosophy to ensure the correct design of a hosereel.

2. Review of Literature

The main intent of this paper is to validate the standard hosereel used by most companies and design by calculation the factors life weld thickness, shaft diameter and the bearings that are to be selected for supporting the shafts. Till now, most hosereel manufacturers have adopted the trial and error method for design. Whenever a component fails, it is usually strengthened and not much attention is given to the root cause of the problem.

This paper aims at ensuring that the design is safe to reduce the onsite failures, if not eliminate them. Whenever there is an onsite failure, the work gets hindered till the repairs take place. Besides that, it does not give a good impression on the customer. In order to avoid these situations, it is better to make sure that the product being sent out is free from potential failure, which is what this paper intends to do.

3. Theory and Basic Component Details

The basic components of a hosereel are-

- Drum
- Hose
- Discs
- Shafts
- Bearings
- Swivel

1) Drum

The drum is the part of the hosereel around which the hose is wound. A metal plate is bent into a circle and welded to the disks to form the drum. Being hollow, the weight of the drum is low. This also facilitates an entry for the hose onto the drum. One end of the hose is connected to the tank carrying the water. The other end enters the inside of the drum through a hole in the disc. The two ends of the metal plate used for the drum are not joined together so that a gap is created. The size of the gap depends upon the outer diameter of the hose being used. The hose is brought on to the drum through this gap and is then wound on it. The drum should be strong enough to carry the hose with the water inside it. The gap in the drum should be enough so that the hose can easily come through, but not so much the strength of the welded joint is compromised. A disc is welded to the drum on either side. This is where the welded joint comes into play.

2) Hose

The hose is the part that carries the water to the point of application. The nozzles at the end of the hose covert the pressure energy of the water inside to kinetic energy and water is sprayed out at a great velocity. Hoses differ in the material, inner diameter and outer diameter. The criteria for the selection for these three parameters is the pressure that is built up in the system and the pressure and velocity with which the jet is required as well as the rate of flow of the water (in cubic meters/second). The hoses usually have a wire mesh on the inside. This gives it additional tensile strength to bear the high pressure water flowing through it. The inner diameter is decided upon the required discharge. The outer diameter only decides the thickness, i.e., the strength of the hose and ultimately depends on the maximum pressure of the system.

3) Discs

The discs are the two circular plates on either side of the hosereel drum. The drum is welded to these discs. The discs keep the wound up hose within their confines and prevent it from toppling. The diameter of the discs is determined by the length of the hose that is wound on the drum, increasing the diameter unnecessarily will just add to the weight. In some cases, the discs have holes made on them to decrease the overall weight of the discs. The centers of the holes lie on a certain diameter. A small shaft is welded to the outside of each disc.

4) Shafts

Two small shafts are welded to the discs and drum assembly, one to each disc. The shafts are placed in bearings in which they rotate. The diameter of the shaft is decided by the weight of the drum and discs assembly and the bending moment acting on them. The rotational motion is provided to the entire assembly through one of the shafts. A motor is coupled to one of the shafts. The motor transfers the power to the shaft, which in turn transfers it to the discs and drum assembly. The other shaft is an idler shaft which just helps the assembly to rotate when it rotates in the bearing. The design procedure for the shaft will result in finding out the diameter of the shafts.

5) Bearings

The two shafts that are connected to the discs rotate in two bearings. The bearings provide a seating for the shafts and prevent the movement of the assembly. The force that acts on these shafts is transmitted to the bearings. The bearings that are selected for the shafts depend on the application of the hosereel. For an application like a fire truck, high speed bearings are needed whereas for other applications, low speed bearings are used. The type of bearing to be used, i.e., roller, taper roller or cylindrical, depends on the radial and the axial forces acting on it. When the force acting is only in the axial direction, cylindrical bearings are used. However, if the force has a radial component to it, taper roller bearings are preferred. If the wrong bearing is chosen, it may not be able to resist the force acting on it. A mistake in bearing selection could lead to failure of the entire assembly. This makes bearing selection a very important part of hosereel design. Depending on the force and the number of hours the bearing is expected to last, a suitable bearing is selected using the procedure for bearing design, which is described later.

6) Swivel

A hosereel maybe a fixed or swivelling type hosereel. In a fixed hosereel, the hosereel is firmly fixed to the fluid carrying tank. Its orientation cannot be changed and the vehicle has to be allgned in a particular was for ease of operation. This type of hosereel is comparatively cheap, but is inconvenient to use in applications where the jet of water may be required over a large work envelope. In case of a swiveling type hosereel, the entire assembly can be turned with the help of the swivel without having to move the vehicle. The assembly, along with the swivel, is mounted as a cantilever on the tank. In case of swiveling hosereel, it is easier to guide the hose to the point of application without much difficulty and the vehicle remains stationary. As it is mounted as a cantilever, the swivel needs to be robust as it has to bear the weight of the entire assembly. The swivel is preferred in emergency applications like fire trucks, where the hosereel is also small and light.

The following flow chart shows the steps and the order in which they were carried out.

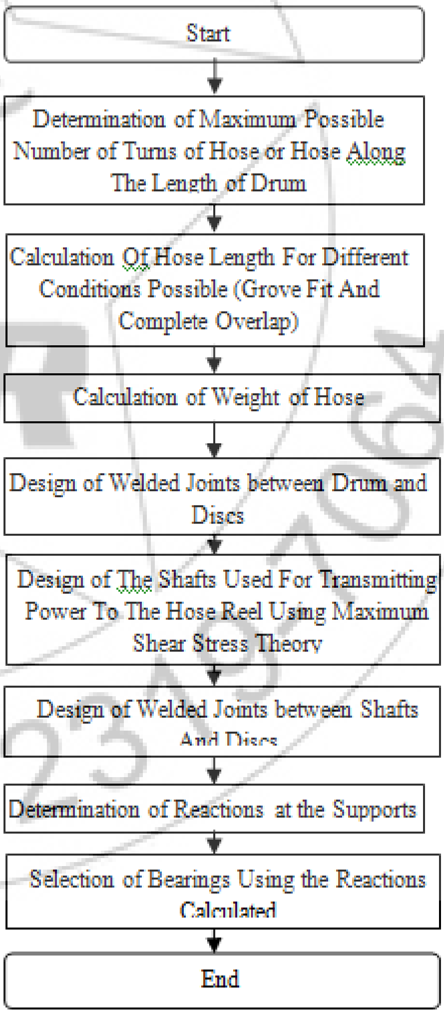

Figure 1: Process of validation and design

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Consider the hose reel assembly as shown in the diagram

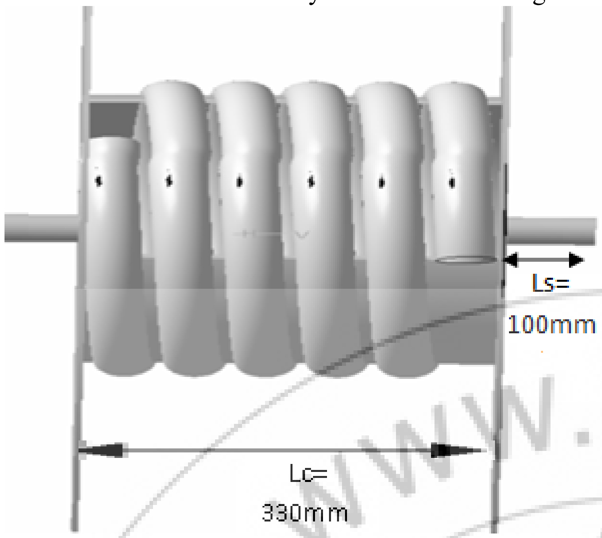

Figure 2: Hosereel assembly (Front view)

The hosereel being considered for validation in this paper is the one shown above. This is a standard hosereel used by the company's manufacturing drain cleaning machines.

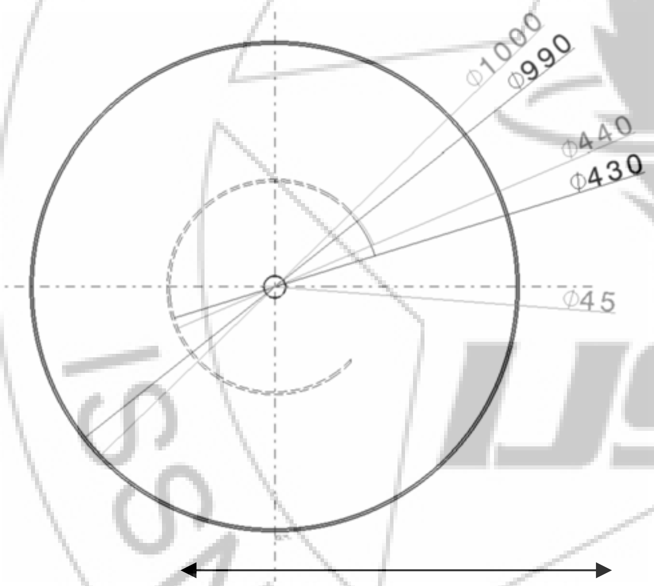

Figure 3: Hosereel assembly (Side view)

Dimensions of the most commonly used hosereel in the drain cleaning industry

D_D = 1000 mm

D_C = 440 mm

D_P = 48 mm

Lc = 330 mm

N = number of turns of the hose on the drum

1) Hose length calculation

The diameter of the hose was obtained from the Trellborg – Calkner catalogue. The hoses used in these machines are standard hoses. [3]

Number of turns that the hose can make along the reel length (N):-

$N = L/D_p = 330/48 = 6.875$

$\therefore N = 6$

Actual length of drum covered = 6 x 48 = 288 mm

Clearance = 330 – 288 = 42 mm

Since there are 5 gaps between 6 turns,

∴ Clearance between two turns = 42/5 = 8.4 mm

Length of hose for one set of turns around the drum or cylinder (lp)

$= \pi\,(Dc+Dp)*N$

$= \pi\,(440+48)*6$

∴ lp= 9.1986m.

(a) Consider the case that the next set of turns of the hose is in the groves of adjacent turns of the previous set of turns.

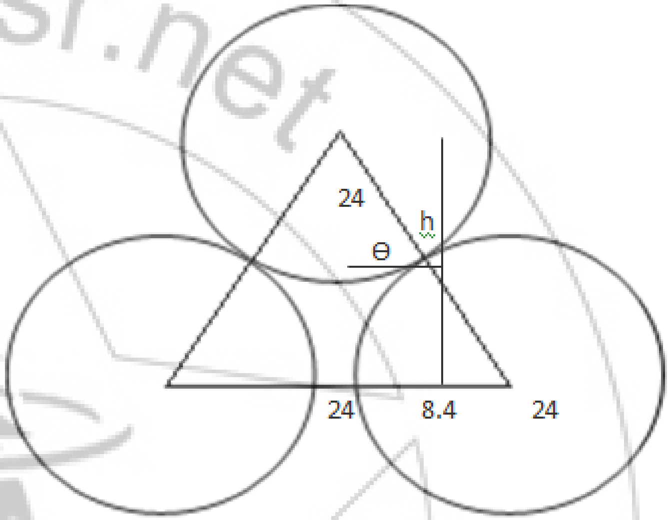

Figure 4: Placement of adjacent layers of the hose

As shown in the figure, the net height 'h' gained by the next set of turns is 24sinΘ.

$\therefore \cos\Theta = (24+4.2)/48$

$\cos\Theta = 0.5875$

$\Theta = 54.02^0$

$h = 24\sin\Theta$

$\therefore h = 19.4213mm$

In this case of hose accumulation in groves, 'n/2' sets of turns will contribute 'Dp' to the total height of the hoses while the remaining 'n/2' sets of turns will contribute h+Rp to the total height.

$\therefore Dd-Dc = n/2*Dp + n/2*(h+Rp)$

$\therefore 1000-440 = n/2*(48+19.4213+24)$

$\therefore n = 12.251$

∴ Max 12 set of turns are possible.

∴ Total length of hose = n*lp

∴Lp=110.382m

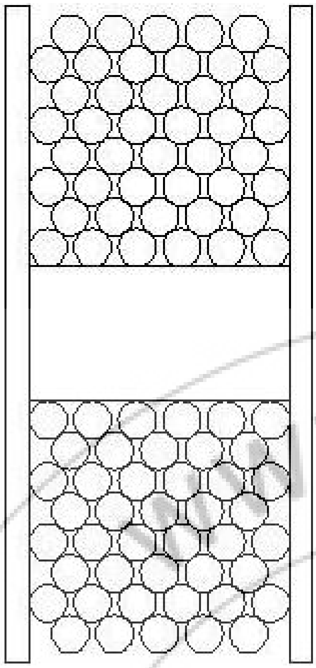

Figure 5: Wounding of the hose on the hosereel when adjacent layers sit in the groves

(b) Consider the case that the next set of turns of the hose is exactly on top of an initial turn. In this case, the height gained per turn (h) = D_P = 48 mm

Total No. of turns that can fit on the drum or cylinder (n) = (Dd-Dc)/Dp

= (1000-440)/48 = 11.67
∴ n=11
∴Total length of hose=n' * lp
∴Lp'=101.184m

Since Lp>Lp', we will consider the maximum length of hose that can be wound on the drum as Lp.

Considering a standard hose, the mass per length of which is 1.19243kg/m,

Mass of hose (mp)=ρ*Lp
∴mp=131.623kg

2) Design of welded joints
The discs have been welded to the drum using annular fillet joints. The discs have also been welded to the shafts in a similar way. The welded joints have been designed to not only to withstand the bending moments but also against torsion. The throat thickness has been found out in each case.

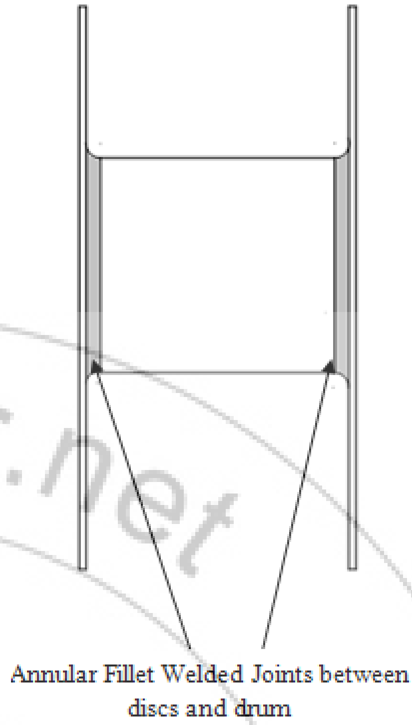

Figure 6: Welded joints between the drum and discs

(a) Direct primary stress (τ_d)

$A = (2\prod D_C)/2 \times t = \prod D_C \times t$
Assuming static load in an annular fillet weld-
$\tau_{all} = 80\ N/mm^2$
$\therefore \tau_D = (W_P + W_C)/2A$

$W_C = P_C \times M_C \times x \times g$
$\therefore W_C = 7850/4 \times [\ \pi x\ D_C^2 \times L - \prod(D_C - t_C)^2 \times L\ ] \times 10^{-9}$
$= 7850/4 \times \pi x\ L \times [\ D_c^2 - (D_c^2 - 2D_C.t_C + t_c^2)\ ] \times 10^{-9}$
$= 7850/4 \times \pi x\ 330\ [\ 2D_C.t_C - t_C^2\ ] \times 10^{-9}$
$= 7850/4 \times \pi x\ 330\ [\ 2 \times 440 \times 5 - 5^2\ ] \times 10^{-9}$
= 8.901 kg

$\therefore W_C = 87.32\ N$
$W_P = M_P \times g$
= 1291.22

$\therefore \tau_D = (1291.22 + 89.32)/(2 \times \pi x\ 440 \times t)$
$\therefore \tau_D = 0.4986/t$

Moment induced secondary shear stress:
$M = (W_p + W_c)/2 \times L/2$
$T = My/I_{xx}$
$I_{xx} = \prod R_c^3 t$
$= \pi x\ (440/2)^3 \times t$
$= 33.452t \times 10^6\ mm^4$ $y = R_c = 220$ mm

$T_b = (113.72 \times 10^3 \times 220)/(33.452t \times 10^6) = 0.7479/t$

$T_{eff} = \sqrt{}(\tau_D^2 + \tau_b^2)$
$= \sqrt{}\ (o.4986/t)^2 + (0.7479/t)^2$
= 0.8989/t
∴ 80 = 0.8989/t
∴ t = 0.011 mm in bending

(b) Shear stress in torsion

$J = I_{xx} + I_{yy}$
$= \pi R_c^3 t + \pi R_c^3 t$
$= 2\pi R_c^3 t$
$= 2\pi \times (220)^3 \times t$
$= 66.903 \times 10^6 t\ mm^4$

$\tau = TR_c/J$

$\therefore \tau = (340 \times 220 \times 10^3) / (66.903 \times t \times 10^6)$
$\therefore \tau = 1.118/t$
$\therefore 80 = 1.118/t = 0.0139$ mm
$\therefore$ Since the calculated thickness is very low, the thickness of the welded joints is taken as the minimum thickness possible. [5]

Min thickness=0.5* Base Tube thickness
$\therefore t = 0.5 * tc$
$\therefore t = 2.5$ mm

3) Design of Shaft

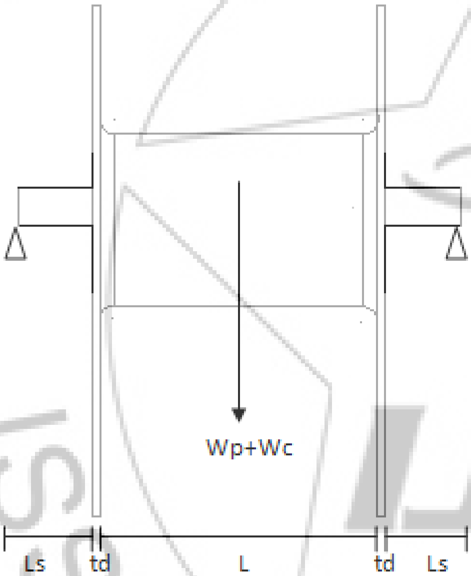

Figure 7: Free body diagrams of shafts

$L_s = 100$mm
$L_c = 330$ mm
$L_p = 5$ mm

$H_A = H_B$
$V_A + V_B - W_P - W_C - 2W_D = 0$
$\therefore V_A + V_B = W_P + W_C + 2W_D$

Since loading is symmetric, $V_A = V_B$

$\sum M_A = -(W_P + W_C) \times (L_c/2 + t_D + L_S) - W_D \times (t_D/2 + L_S) - W_D \times (L_S + t_D + L + t_D/2) + V_B \times (L + 2L_S + 2t_D) = 0$

$V_B \times 540 = (372.206 + 30.998 + 132.207) \times 10^3$

$V_B = 991.687$ N
$\therefore V_A = 991.687$ N
$W_D = P_D \times \pi \times (1000^2/4) \times 5 \times 9.81 \times 10^{-9}$

$W_D = 7850 \times \pi \times (1000^2/4) \times 5 \times 9.81 \times 10^{-9}$

$W_D = 302.417$ N

Maximum bending moment $= (V_B \times L_{total})/2$

$M = 267.759 \times 10^3$ Nmm

For the application under consideration, the Parker Motor catalogue suggests a motor having a torque output of 340 Nm [4]

Torque = 340 Nm

$T_e = \sqrt{[(K_b M)^2 + (K_t T)^2]}$

Considering a rotating shaft with sudden load with sudden load with minor shock
$K_b = 2$, $K_t = 1.5$ [6]
$T_e = \sqrt{[(2 \times 267.759)^2 + (1.5 \times 340)^2]}$
$T_e = 739.513$ Nm

By using maximum shear stress theory,

$T_{max} = 16T_e / \pi D_S^3$

Taking $T_{max} = 50$

$50 = 16 \times 739.513 \times 10^3 / \pi \times D_S^3$
$D_S = 42.23$ mm = 43 mm = 45 mm

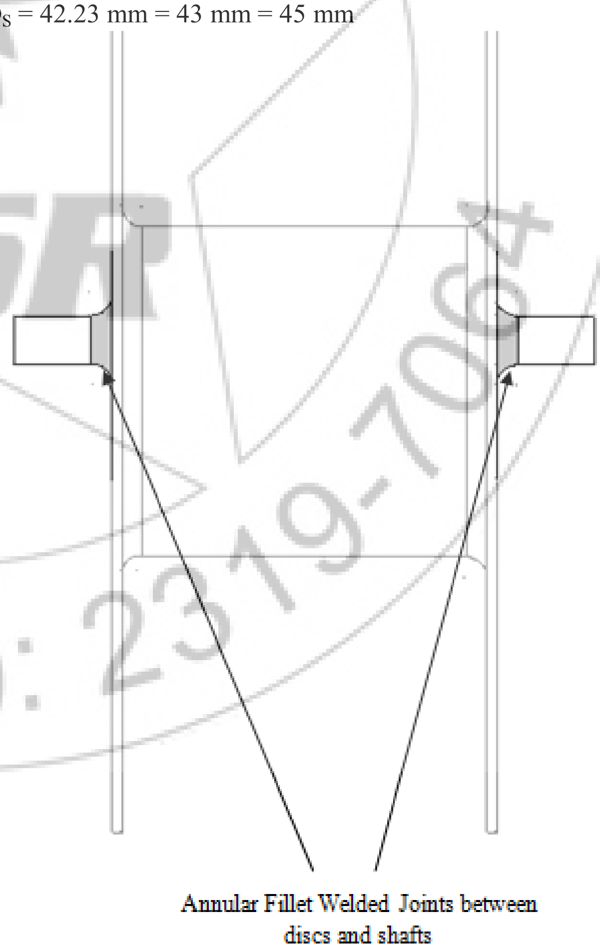

Figure 8: Welded joints between the discs and the shafts

Considering welded joints,

1) Direct primary shear stress-
$A = \pi \times D_S \times t$
$A = \pi \times 45 \times t$

$\tau_{all} = 80$ N/mm
$\tau_D = [\ (W_P + W_C)/2 + W_D]/A$
$\tau_D = [\ 991.687N/45\ \pi\ t]$
$\tau_D = 7.0147/t$

2) Secondary shear stress-
$M_S = M = 267.759 \times 10^3$ Nmm
$I_{XX} = \pi \times R_S^3 \times t$
$= 35.785 \times 10^3 \times t$ mm^4

$\tau_b = My/I_{XX}$ $y = R_S = 225$
$\tau_b = 267.759 \times 10^3 \times 22.5/35.785 \times 10^3 \times t$
$\tau_b = 168.354/t$
$\tau_{net} = \sqrt{(\tau_a^2 + \tau_b^2)}$
$80 = 168.500/t$

$T = 2.106$ mm

Torsion
$J = I_{XX} + I_{YY} = 2I_{XX} = 2 \times 35.785 \times 10^3 t$ mm^4
$\tau = TR_S/J$
$80 = (340 \times 10^3 \times 22.5)/(2 \times 35.785 \times 10^3 \times t)$
$80 = 106.889/t$
$T = 1.336$ mm $h = \sqrt{2}t = \sqrt{2} \times 2.100 = 2.978 = 3$mm

4) Selection of bearings
Considering the hose reel as a machine used for short periods or intermittently
$L_h = 8000$ hours [6]
$L_{10} = (L_h \times 60 \times n)/10^6 = (8000 \times 60 \times 5)/10^6 = 2.4$ million revolutions

$F_A = F_B = F_R = 991.67$ N
$L_{10} = (C_A/P_{eA})^3$
$P_{eA} = K_a \times F_R$
$= 1487.55$

$2.4 = (C_A/1487.55)^3$
$C_A = 1991.629$ N

Considering extra light bearing no. 6009 from SKF catalogue (single row deep grove ball bearing)
$C_0 = 14.6$ kN
$C = 20.8$ kN

4. Conclusion and Remarks

- The process used above validates the design already in use. The dimensions of the components are within the safe limits as shown by the calculations.
- The process also suggests the parameters like weld thickness, shaft diameter and the bearing to be used to avoid failure.
- This paper shows the process only for a certain type of hosereel, but it can be generalized and used for any hosereel.

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