Design of Eccentric Load Carrying Lead Screw Mechanism: An Application of Auxiliary Rolling Shutter System

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Abstract

Now days, we see rolling shutters near about in every Shop, Garage, Workshops, etc. Some of them are Automatic, some are opened by Mechanical arrangements, & most of this are manually opened. Small scale industries & shops owners can't afford the automatic shutters because of the high installation cost. Manual operation requires more manpower & more time. In this project we are going to design the auxiliary system for the opening of shutters. We providing more typeof openings in one system. In this system the shutter can be open by using mechanical arrangement, by using switches, & by using the remote control, & manual opening is also provided. This mechanism consists Lead screw, Bearing, Lead screw nut and assembly, Lead screw driving mechanism, Motor, Supporting structure, Lead screw selection. Lead screw for this application is placed on side due to this lead screw contains eccentric load. So in this research paper we design and analyse the lead screw against eccentric load.

Keywords: Automatic Shutter, Auxiliary System, Eccentric Load, Lead Screw, Rolling Shutter.

Nomenclature

A = Cross-sectional area (mm^2)

d_c = Core diameter

e = Eccentricity = 400 mm

fos = Factor of safety

I = moment of inertia of the cross-section about the neutral axis (mm^4)

l = lead

M= Applied bending moment (N-mm)

M_t=Torque required to raise the load (N-mm)

W = Load required to raise the shutter= 34.11 Kg ≈ 335N

p = pitch

P = effort required to raise the load.

σ = stress

S_{yt} = Yield Strength

σ_t = Total stress (N/mm^2 or MPa)

σ_a = Axial stress (N/mm^2 or MPa)

σ_b = bending stress at a distance of y from the neutral axis (N/mm^2 or MPa)

y = distance from the centre of axis

θ = thread angle

1. Introduction

Multiple types Opening System for Rolling Shutter is the combination of the Remote controlled, Electric Switch controlled, Mechanical and Manual operation. In this project we are going to modify old Mechanical system by this new system. This system consists of lead screw, motor, gear box, bearings, nut, electronic control panel. Motor shaft is connected to the lead screw through gear box arrangement. The gear box consists bevel gear arrangement. Bevel gear can help to transfer the torque from motor shaft to lead screw with required speed ratio in 90^o angle of an axis of lead screw.

The problem under our consideration is to design lead screw for eccentric load on it for any application like our project. The lead screw also called power screw used in machine to translate rotary motion in to linear motion. The lead screw is compact, simple in design and having large load carrying capacity. Lead screw has wide application in various mechanism so lead screw is selected for analysis purpose During loading condition, the different stress acting on lead screw produces deflection which calculated first theoretically and then checked analytically

2. Design of lead screw mechanism

This mechanism consists of following parts.

- Lead screw.
- Bearing.
- Lead screw nut and assembly.
- Lead screw driving mechanism. (Motor)
- Supporting structure

2.1. Lead Screw design

In lead screw selection process, we find out length of lead screw, material selection for screw and nut, outer or major diameter, minor diameter, pitch diameter, pitch, lead, type of thread.

2.1.1 Material selection.

Material for screw is steel (C 40 to C 55).

Material for nut is bronze or cast iron. We select bronze nut because of its high friction resistance and wear resistance. [1]

For shaft we can use 0.3 to 0.5 % C in medium carbon steel %. We can use C40, C45, C50 materials. According to local market survey EN8 is very common & cheap material for manufacturing lead screw due to availability and pricing. According to our requirement, EN8 contains 0.36 to 0.44% of C. So we go for EN8.

Tensile strength - 625-775 (MPa)

Yield strength- 385 (MPa)

Hardness – 179- 229 (HB). [2]

2.1.2 Factor of safety consideration [3]

Here, taking factor of safety is 2. Because

- Factor of safety is low due to less load is applied.
- Load does not vary in magnitude or direction with respect to time.
- Forces acting on element are precisely determined. So low fos can be selected.
- Material is made of homogeneous ductile yield strength is the criteria of failure, so fos is small.

- As fos increases, dimensions of component, material requirement and cost increases.
- Material is not operating in high temperature or corrosive atmosphere.
- Quality of manufacturing & dimensions required are less etc.

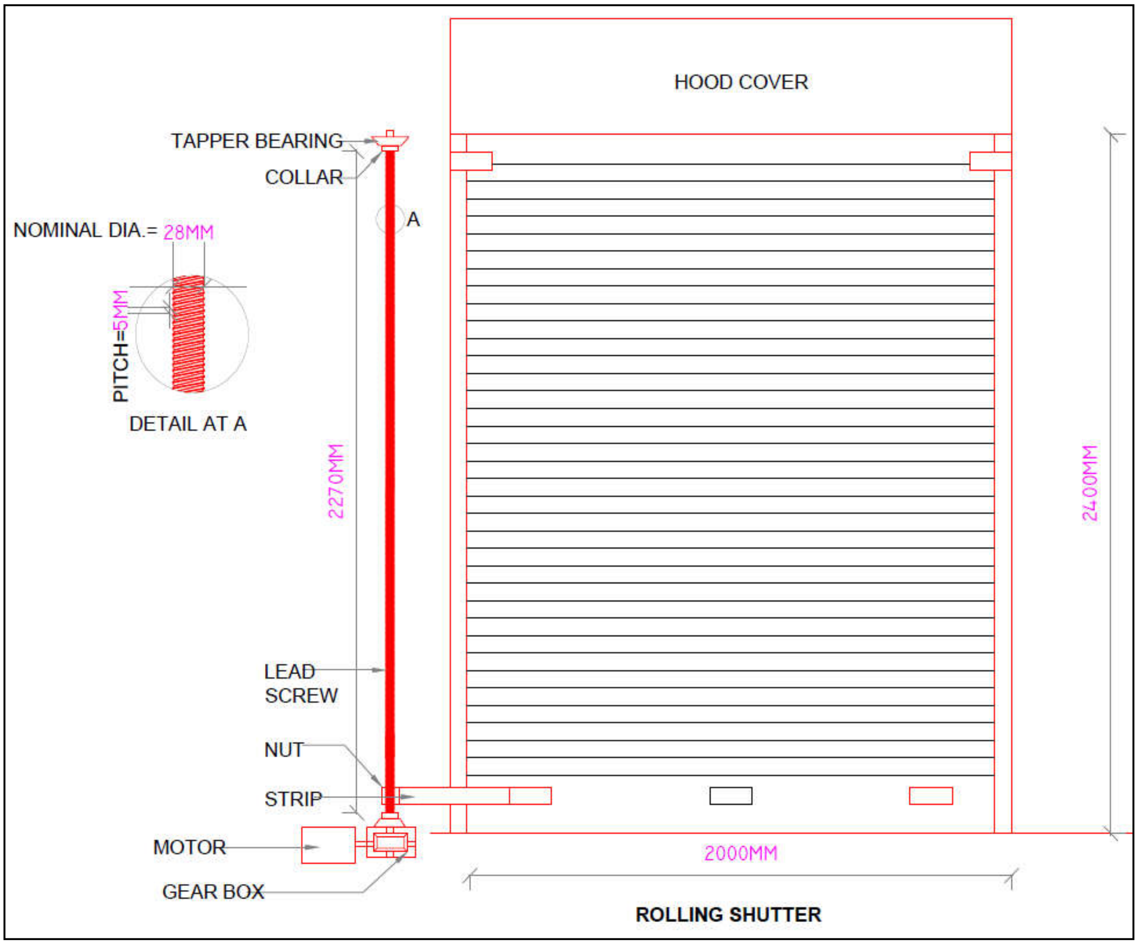

Fig.1. CAD model of rolling shutter mechanism

2.1.3 Stress calculation

Formula for stress is

$$\sigma = \frac{S_{yt}}{fos} \quad (1)$$

By using this fos we can calculate σ

$$\sigma = \frac{S_{yt}}{fos} = \frac{385}{2} = 192.5 \text{ MPa}$$

2.1.4. Selection of thread type

For selection of thread on screw, there are three different types of thread forms available.

- Square threads.
- Acme threads.
- Buttress threads.

We use trapezoidal thread because of -

- Trapezoidal threads are economical to manufacture because they are on thread milling machine. It used a multipoint cutting tool is an economical operation than single point cutting tool.

- Trapezoidal threads have more economical thickness at the core diameter than the square threads therefore screw with trapezoidal threads is stronger than square threads large load carrying capacity [4]

2.1.5. Diameter calculation

Lead screw length required is 2240 mm, because of maximum height of shutter is 2240 mm.

We also calculated load required to rise the shutter which is 335N

We are designing the lead screw for opening shutter. In this case our lead screw is placed in side, so eccentric load is applied on screw. For getting proper diameter of screw first combine the load.

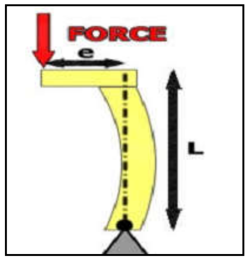

Fig 2: Eccentric loading diagram

∴ Combine loading (Axial +Bending) [5]

$$\sigma_t = \sigma_a + \sigma_b = \frac{P}{A} + \frac{M.y.}{I} \quad (2)$$

$$= \frac{P}{\frac{\pi}{4} \times dc} + \frac{P \times e \times \frac{dc}{2}}{\frac{\pi}{64} \times dc^4} \quad (3)$$

$$\therefore \sigma_t = \frac{4P}{\pi dc^4} + \frac{32 \times P \times e}{\pi \times dc^4}$$

$$\sigma_t = \frac{S_{yt}}{fos} = \frac{385}{2} = 192.5 \text{ MPa}$$

$$\sigma_t = 192.5 \text{ MPa}$$

Using (3)

$$:\sigma_t = \frac{4P}{\pi dc^2} + \frac{32 \times P \times e}{\pi \times dc^3}$$

$$192.5 = \frac{4 \times 335}{\pi dc^2} + \frac{32 \times (335 \times 400)}{\pi \times dc^3}$$

$$d_c = 19.25 \approx 20 \text{ mm}$$

Table 1:Properties of ISO metric trapezoidal Thread [6]

Nominal diameter (mm)	Pitch (mm)
10	2
12	3
14, 16	4
24, 28	5
32, 36	6
40, 44	7
48, 52	8
60	9
70, 80	10
90, 100	12

We require nominal dia. for design lead screw (d),

$$d_c = d - p \quad (4)$$

According to standard table for d_c=20 mm 'p' should be 5

$$d = d_c + p = 20+5 = 25 \text{ mm}$$

But from standard Table 1 next nominal diameter should be 28 mm

$$\therefore d=28 \text{ mm}, p = 5 \text{ mm}$$

$$d_m = d - 0.5p = 28-(0.5\times5)$$

$$d_m = 25.5 \text{ mm}$$

2.1.6. Lead calculation (l).

Here, we select 2 start, because

- we required less time & more speed for opening & closing the shutter.
- Also require more efficiency.
- But we can't go for 3 start due to over halving problem & torque requirement is more.
- Also manufacturing is difficult. [7]

$$l = n \times p \,(5) = 2 \times 5$$

$$l = 10 \text{ mm} \quad d_m = 25.5 \text{ mm}, \; 2\theta = 30° \quad \theta = 15°$$

2.1.7. Helix angle of thread,

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{10}{\pi \times 25.5} \quad (6)$$

$$\tan\alpha = 0.1248 \,,\; \alpha = 7.11528°$$

Now, for safety purpose & better failure free results, increasing load by 50%

$$\therefore W = 335 \text{ N to } 500 \text{ N}$$

2.1.8. Calculation of coefficient of friction (μ):

The coefficient of friction steel screw & bronze nut is normally taken as 0.1 the maximum possible value of coefficient of friction is 0.18 this occurs when, friction occurs maximum on account of poor lubrication we will consider the worst condition where the operator is careless about the lubrication of the screw.

$$\mu = 0.18°, \theta = 15°, \text{(Tr)}, \emptyset = 10.20°,$$

$$\mu \sec\theta = \frac{\mu}{\cos\theta} = \frac{0.15}{\cos 15} = 0.18635 \quad (7)$$

$$\emptyset > \alpha, \text{ Screw is self-locking.}$$

2.2 Torque calculation

$$M_t = P \times \frac{d_m}{2} \quad (8)$$

$$P = \frac{W \times (\mu\sec\theta + \tan\alpha)}{(1 + \mu\sec\theta \tan\alpha)} \quad (9)$$

$$= \frac{500 \times (0.18635 + 0.12428)}{(1 + 0.18635 \times 0.12428)}$$

$$P = 151.799939 \approx 152 \text{ N}$$

$$M_t = P \times \frac{d_m}{2} = 152 \times \frac{25.5}{2} = 1938 \text{ N.mm}$$

$$M_t = 1938 \text{ N.mm}$$

Total torque required to raise the load we are using the threats bearing so torque required negligible but we have to calculate it.

The torque required therefore the bearing for raise the load is in between 0.01 to 0.02. Assume higher coefficient of friction 0.2 and bearing on shaft is newly manufactured so Uniform pressure theory is applicable.

$$(M_t)_c = \frac{\mu_c \times W}{3} \times \frac{{D_o}^3 - {D_i}^3}{{D_o}^2 - {D_i}^2} = \frac{0.02 \times 500}{3} \times \frac{35^3 - 25^3}{35^2 - 25^2} (10)$$

$$(M_t)_c = 151.31 \text{ N.mm}$$

Upper bearing has no load, but we consider same amount of load while lifting the load.

$$\text{Total load of bearings} = 2 \times (M_t)_c$$

$$(M_t)_c = 302.77 \text{ N.mm}$$

Total torque required to raise the load,

$$M_t = (M_t)_t + (M_t)_c = 1938 + 302.77$$

$$M_t = 2240 \text{ N.mm}$$

2.3 Stress calculations for checking design is safe or not

Shear calculations $\tau = \frac{16 M_t}{\pi {d_c}^3} = \frac{16 \times 2240}{\pi \times 23^3}$ (11)

$$\tau = 0.9376 \ N/mm^2$$

Compressive stress calculation

$$\sigma_c = \frac{W}{(\frac{\pi}{4} \times {d_c}^2)} = \frac{500}{\frac{\pi}{4} \times 23^2} (12)$$

$$\sigma_c = 1.2034 \ N/mm^2$$

$$\sigma_b = \frac{32 M_b}{\pi {d_c}^3} = \frac{32 \times (500 \times 400)}{\pi \times 23^3} (13)$$

$$\sigma_b = 167.43 \ N/mm^2$$

Our load is eccentric so as stress high in bending.

So chances are more failure occurs in bending, therefore we neglecting compressive stress determined by us & considering the effect of combination of torsional shear stress and bending stress determined by equation (8) & (10) respectively.

$$\tau_{max} = \sqrt{(\frac{\sigma_b}{2})^2 + \tau^2} = \sqrt{(\frac{167.43}{2})^2 + 0.9376^2} \quad (14)$$

$$\tau_{max} = 83.72025 \text{ N}/mm^2$$

Factor of safety is given by,

$$(f_s) = \frac{S_{sy}}{\tau_{max}} = \frac{0.5 \times S_{yt}}{\tau_{max}} = \frac{0.5 \times 385}{83.7205} \quad (f_s) = 2.299 \approx 2.3$$

$$\therefore f_s \text{ more than } 2$$

Double start trapezoidal thread of 28 mm diameter & 5 mm pitch is suitable for our requirement.

Tr30×10(P5) LH

3. Selection of bearing

We selected taper roller bearing because,

- The line of action of the resultant reaction makes an angle with the axis of bearing. This reaction can resolve into radial and axial component "Tapper roller bearing is suitable for combined axial and radial loading."
- The conical surface of each roller is suitable to pressure, which acts to the normal to the surface therefore "If the external force acting on the bearing is purely radial it induced a thrust reaction within a bearing to avoid the separation of cup from cone. This thrust traction must be balanced by equal and opposite force. This is balanced by at least two taper roller bearings on the same shaft, so we are using same bearing for both ends.

We select the bearing No.32005X from standard bearing catalogue specs. of that bearing as follows, [8]

Table 2: Dimension(mm), Dynamic Capacities(N), and calculation factor for single row taper roller bearing

D	D	B	C	Designation	E	Y
25	47	15	25500	32005X	0.43	1.4

4. Decision regarding selection of motor

Total length of shutter fully opened condition = 2270 mm

Our load we calculated, Lead = 10 mm

Revolutions required to open the shutter

$$= \frac{length\ of\ shutter}{lead} = \frac{2270}{10}$$

$= 227$ revolutions

Considered Time period required to open the shutter = 30 seconds

Revolutions per second (RPS)

$$= \frac{227}{3} = 7.566 \text{ RPS}$$

Revolutions per minute (RPM) = $7.566 \times 60 = 454$ RPM

From design data book we select motor according to our power, torque requirement and rpm value. Power, rpm and other values of selected motor are given bellow. Basic dimensions of motor are given in fig.3.

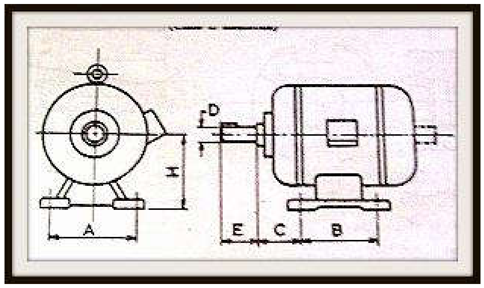

Fig. 3: Basic dimensions of lead screw driving motor.

Power rating: 0.37kW, Motor rpm: 1000rpm, Frame no: 80, H (Tol-0.5): 80mm. A = 125mm, B = 100mm, C = 50mm, D = 19j6, E = 40mm, Bolt size = M8. [9]

RPM can be reduced in gearbox according to requirement.

5. Results

Design of lead screw mechanism for rolling shutter is done and from stress calculation our design is quite safe.

6. Conclusion

The design and development of lead screw mechanism for rolling shutter is completed and it is safe to be implement in project for opening and closing shutter. This method of designing lead screw is useful for load is acting apart from the axis of lead screw. Using this calculations, we can conclude that it is possible to design lead screw in optimum way if it is in eccentric loading.

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