Trapezoidal carjack design

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1. abstract

the car jack is a gadget used to lift the car for breakdown and maintenance for example changing tire.

2. introduction

2.1 problem statement

Design a trapezoidal car jack with input data:

m= 1000 kg, h_{min} = 180 mm, and h_{max} = 300 mm.

2.2 objectives

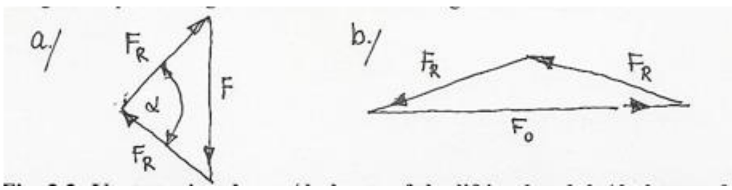
1. design a safe trapezoidal car jack.
2. calculate the stresses in the different parts and determining suitable materials for each.
3. Establish manufacturing process for each part.

3. Discussion

The used safety factor for all calculations is:

$$z = 1.5$$

3.1 Working load:



The mass of the car m=1000 kg

The load is the weight of the car:

$W = mg = 9810\ N$

Equations of equilibrium:

F_x: $F_x = 0$

F_y: $mg = 2F$

Moment around the center (point O):

M_o: $F \times b - W \times a = 0$

$$F = 4905\ N \approx 5\ kN$$

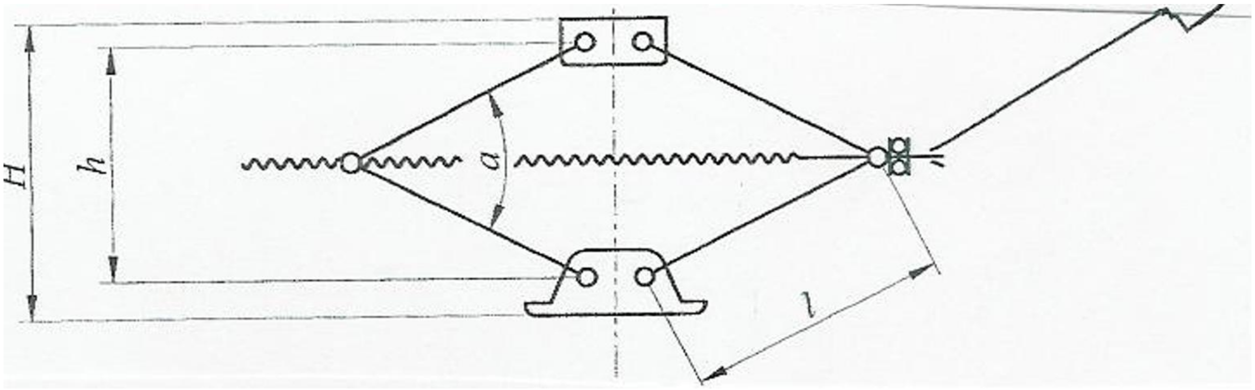
Highest stress in arms at α_{min}:

$Sin\left(\frac{\alpha_{min}}{2}\right) = \frac{F}{2F_R}$ $F_R = 4247.9\ N \approx 5\ kN$

$Cos(\frac{\alpha_{min}}{2}) = \frac{2F_R}{F_o}$ $F_o = 9810\ N \approx 10\ kN$

3.2 Lifting arms:

- **Dimensions:**



$$h_{min} = 180\ mm$$

$$h_{max} = 300\ mm$$

Considering the hinge points to be 25mm from the bottom and the top. So:

$$h_{min} = 130\ mm$$

$$h_{max} = 250\ mm$$

Also considering the angle α:

$$\alpha_{min} = 30°$$

$$\alpha_{max} = 150°$$

with the lengths L1 and L2 in the upper and lower positions respectfully:

$$L_1 = \frac{H_{min}}{2\sin\left(\frac{\alpha_{min}}{2}\right)} = 251.1\ mm$$

$$L_2 = \frac{H_{max}}{2\sin\left(\frac{\alpha_{max}}{2}\right)} = 129.4\ mm$$

The directive arm length L=130

Minimum and maximum α using L_1 and L_2:

$$\alpha_{min} = 2\arcsin\left(\frac{h_{min}}{2L}\right) = 60°$$

$$\alpha_{max} = 2\arcsin\left(\frac{h_{max}}{2L}\right) = 148.1°$$

both α's in range so L accepted.

- **Strength checking:**

Area:

$$A = a.b - \left((a - 2c) * (b - c)\right) = 164\,mm^2$$

Compression stress:

$$\sigma = \frac{F_R}{A} = 25.9\,MPa$$

Material of arms is S235JOW Msz EN 10025-5 weather corrosion resistant. Where R_e =235 MPa.

$$z = \frac{R_e}{\sigma} = 9.1$$

$z > 1.5$ so the material answers the requirements.

- **Checking for buckling:**

Distance of center of gravity of cross section:

$$t = \frac{(2 \times 28 \times 2 \times 14) + (26 \times 2 \times 27)}{(2 \times 28 \times 2) + (26 \times 2)} = 18.122\,mm$$

Moment of inertia of cross section about center of gravity axis:

$$I = 2 \times \left(\frac{2 \times 28^3}{2} + 2 \times 28 \times (18.122 - 14)^2\right) + \frac{26 \times 2^3}{12} + 2 \times 26 \times (27 - 18.122)^2 = 13336\,mm^4$$

Radius of gyration:

$$i = \sqrt{\frac{I}{A}} = 9.02\,mm$$

Slenderness ratio:

$$\lambda = \frac{L}{i} = \frac{130}{9.02} = 14.4$$

$\lambda \ll 60$ so the part does not need checking for buckling.

3.3 Threaded shaft:

Choosing material C45E tempered carbon steel, where the yield stress Re=490MPa.

$$\sigma_w = \frac{R_e}{z} = 326.7MPa$$

since: $\sigma = \frac{F}{A}$ $\quad A_{min} = \frac{F_o}{\sigma_w} = 30.03mm^2$

$Area = \frac{\pi {d_1}^2}{4}$ so:

$$d_1 = \sqrt{\frac{4A_{min}}{\pi}} = 6.18\ mm$$

choosing thread to be: Tr8x1.5

required minimum torque:

$$T = \frac{1}{2}F_o \cdot d2 \cdot tan(\alpha + \rho) = \ 6824.4\ Nmm$$

Where: $\alpha = arctan\left(\frac{P}{d_2\pi}\right) = 0.066°$

ρ= $arctan\left(\frac{\mu}{\cos\left(\frac{\beta}{2}\right)}\right) = 0.1236°$

Since α<ρ the thread is self-locked, therefore the car does not sink under load if the required lifting load is not acting.

Stress in the threaded part of the shaft:

-tensile stress:

$$\sigma = \frac{F_o}{A} = 324.9\ MPa \approx 325\ MPa$$

-torque shear stress:

$$\tau = \frac{T}{K_p} = 145.8\ MPa \approx 146\ MPa$$

Where $K_p = \frac{d_1^3\pi}{16} = 46.8\ mm^3$

-equivalent stress:

$$\sigma_{eq}^{HMH} = \sqrt{\sigma^2 + 3\tau^2} = 411.5\ MPa \approx 412\ MPa$$

Since $R_e > \sigma_{eq}^{HMH}$ the material answers the requirements and can be used.

3.4 Nut:

- **Dimensions:**

Surface pressure between the shaft and nut (threads):

$$P = \frac{F_o}{A_p}$$

$$A_p = (d^2 - D_1^2) \cdot \pi \cdot \frac{i}{4}$$

If C22E material is chosen: $R_e = 340\ MPa$

Permitted surface stress: $P_w = \frac{R_e}{z} = 226.7\ MPa$

$$i = \frac{4F_o}{(d^2 - D_1^2) \cdot \pi \cdot P_w} = 2.53 \approx 3\ threads$$

- **Checking for bending:**

$$M_{max} = \frac{F_o \cdot k}{4} = 64991.25\ Nmm$$

Where k=26.5, is the width of the nut.

$$I = I_A - I_B$$

$$I_A = \frac{r^4}{2}\left(\varphi - \frac{1}{4}\sin(4\varphi)\right) = 12174.14\ mm^4$$

Where:

$$\varphi = arcsin\frac{b}{2r} = 0.819\ rad$$

$$I_B = \frac{ab^3}{12} = 6859\ mm^4$$

$$I = 5315.14\ mm^4$$

$$\sigma = \frac{M \cdot e}{I} = 229.2\ MPa$$

Where:

$$e = \frac{b}{2} = 9.5\ mm$$

$\sigma < \sigma_w$ so the nut is alright for bending.

3.5 Nut pin:

- **Dimensioning:**

Surface pressure on nut:

$$P = \frac{F_R}{2dv}$$

Required diameter:

$$d_{min} = \frac{F_R}{2vP_w} = 6.34\ mm$$

Where working surface pressure:

$$P_w = \frac{R_e}{z} = 167.4\ MPa$$

Therefore selected diameter d=16mm answers the requirments.

- **Shearing:**

$$\tau = \frac{4F_R}{d^2\pi} = 21.13\ MPa$$

For material C22E: $R_e = 340\ MPa$

$$\sigma_w = 242.8\ MPa$$

$$\tau_w = \frac{\sigma_w}{2} = 121.4\ MPa$$

As $\tau < \tau_w$ the pin is alright for shearing.

3.6 Threaded shaft head

-stress from F_o:

$$\tau_{\parallel} = \frac{F_o}{4(L-a)a} = 53.1\ MPa$$

-stress from T:

$$\tau_{\perp} = \frac{T}{d_2 \cdot 2a(L-a)} = 23.5\ MPa$$

-comparative stress:

$$\sigma_c = \sqrt{\sigma_{\parallel}^2 + \sigma_{\perp}^2 - \sigma_{\parallel}\sigma_{\perp} + 3(\tau_{\parallel}^2 + \tau_{\perp}^2)}$$

Since there is no normal stress $\sigma_{\parallel} = 0$ and $\sigma_{\perp} = 0$

$$\sigma_c = \sqrt{3\left(\tau_{\parallel}^2 + \tau_{\perp}^2\right)} = 100.6\ MPa$$

$$z = \frac{R_e}{\sigma_c} = \frac{490}{100.3} = 4.87$$

Since z > 1.5 the material of the shaft answers the requirements for the shaft head.

3.7 Thrust ball bearing:

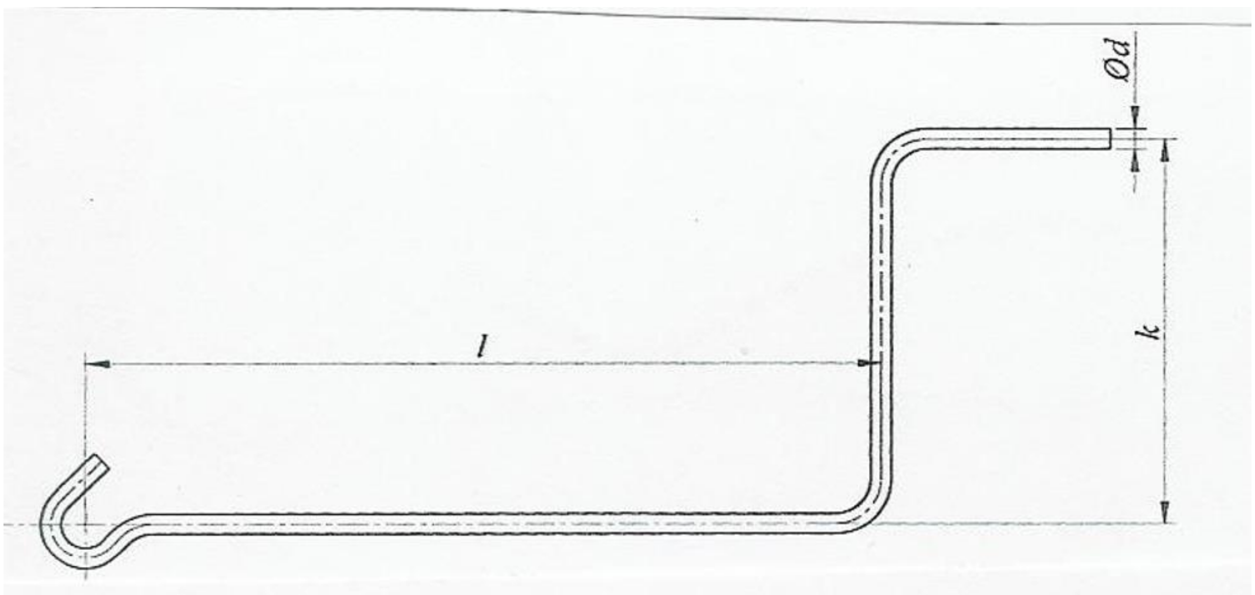
The selected bearing serial number from SKF: 51100. Where static load rating C_o=14000 N.

Safety factor:

$$S_o = \frac{C_o}{F_o} = 1.43$$

The minimum safety factor according to SKF is S_o=0.5 for static load (no dynamic shocks). So the chosen bearing is suitable.

3.7 Driving arm:



Required torque to operate car jack as calculated before:

$$T = 6824.4\ Nmm$$

Maximum force by hand:

$$F_{max} = 130\ N$$

Minimum arm length k_{min} :

$$k_{min} = \frac{T}{F_{max}} = 52.5\ mm$$

For comfortable operation k taken to be:

$$k = 150\ mm$$

If material C22E is used:

$$\tau_w = 124\ MPa$$

So

$$d_{min} = \sqrt[3]{\frac{16 \cdot T}{\tau_w \cdot \pi}} = 6.5\ mm$$

d taken to be:

$$d = 10\ mm$$

And

$$l = 320\ mm$$

4. Manufacturing

As the jacks are made in mass production, the production technology of the elements is selected accordingly.

Part No.	Product	The manufacturing process	The material
1	Base	Produced from atomspherical corrosion resistance steel plate by shearing to proper form by bending	MS2 EN 10025-5 S235Jow Corrosion resistance steel R_e=235MPa R_m=360-510MPa
6, 15	Distance ring	Produced by shearing and bending process from corrosion resistance steel plate	MS2 EN 10025-5 S235Jow
3, 12	Lifting arm	Produced by shearing process to get the proper form by cold bending	MS2 EN 10025-5 355Jow, R_e=355MPa R_m=360-510MPa
2, 14	Pin	Made from carbon steel bar semi product by cutting to size and riveting during assembly	MS2 EN 10083-1 C22 R_e=240MPa R_m=430MPa
13	head	Produced from atomspherical corrosion resistance steel plate by shearing to proper form by bending	MS2 EN 10025-5 S235Jow C40E
8	Thrust ball bearing	From stock	SKF 51202
11	Driving ear	Made by shearing from atmospherical corrosion resistance steel flat bar	MS2 EN 10025-5 S235 Jow
7	Threaded shaft	Turned from steel bar semi-product of tempered carbon steel by cutting to dimension and by thread rolling or turning	MS2 EN 10083-1 C45 R_e=490MPa R_m=700MPa
9	Compensator	Produced by turning from carbon steel	MS2 EN 10083-1 C25
10	Dust protector ring	Sheared and deep drawn from zinc plated steel plate	MS2 EN 10139 R_e=310MPa R_m=310-540MPa
4	Nut	Produced from tempered carbon steel semi-product bar by chip formation	MS2 EN 10083-1 C22E R_e=340MPa R_m=500MPa
5	Cross piece (Non-threaded nut)	Produced from tempered carbon steel semi product bar by chip formation	MS2 EN 10083-1 C45 R_e=490MPa R_m=700MPa
17	Driving arm	Made from carbon steel bar by chip formation and cold bending	MS2 EN 10083-1 C25 R_e=230MPa R_m=440MPa

5.References

BME machine elements 1 carjack design aid.