NEW DESIGN OF POWER SCREW JACK WITH BALL BEARING

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Abstract

In the present work, a new design of power screw jack with ball bearing is presented. The Acme thread or trapezoidal thread was used which is consider the best type, since it gives high power transmission, also its simple in manufacturing compared with the other types. A computer program is developed in Quick basic language to calculates the dimensions of all parts for power screw jack (depend on the given load and materials). Revit MEP 2008 software program was used to design of power screw jack.
The validity of results is verified and shows that there is a good agreement between the results of the present solution and the correlation related to it.

Keyword: power screw, jack, ball bearing.

تصميم جديد لرافع مسنن بمحامل كروية

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الخلاصة

في هذا البحث تم دراسة تصميم جديد لرافع مسنن بمحامل كروية. تم استخدام الأسنان ذات الشكل شبه المنحرف و التي تعتبر الأفضل, حيث تعطي نقل قدرة عالي كذلك سهلة بالتصنيع بالمقارنة مع الأنواع الأخرى. تم إعداد برنامج بلغة (Quick basic) لحساب الأبعاد لجميع أجزاء الرافع المسنن بالاعتماد على الحمل المسلط و المعادن. تم استخدام برنامج (Revit MEP 2008) لتصميم الرافع المسنن. وقد أعطت هذه الدراسة تقارب كبير مقارنة بالنتائج العملية و النظرية لعدد من الباحثين.

الكلمة الدليلية: أسنان القدرة, الرافع, المحمل الكروي.

Nomenclature

Symbol

A	Area (*in^2*)
A_s	Stripping shear area (*in^2*)
A_{sh}	shear area (*in^2*)
A_{ts}	Tensile stress area (*in^2*)
C_{load}	Loading factor *(….)*
C_{reliab}	Reliability factor *(….)*
C_{size}	Size factor *(….)*
C_{surf}	Surface factor *(….)*
C_{temp}	Temperature factor *(….)*
D	Major diameter of power screw *(in)*
D_p	Pitch diameter *(in)*
D_r	Minor diameter *(in)*
d_c	Collar diameter *(in)*
E	Modulus of elasticity *(Gpa)*
e	Efficiency of a power screw *(….)*
F	Load to be moved *(Ib)*
F_a	Axial force *(Ib)*
F_n	Normal force *(Ib)*
F_1	Force on the nut *(Ib)*
$F_{1\,max}$	Maximum force on the nut *(Ib)*
$F_{1\,min}$	Minimum force on the nut *(Ib)*
I	Moment of inertia (*in^4*)
J	Polar moment of inertia (*in^4*)
ℓ	Thread pitch *(in)*
M	Moment *(Ib -in)*
N	Threads per inch
N_f	Safety factor in fatigue *(….)*
N_s	Safety factor for ductile material under static load *(….)*
P	thread pitch *(in)*
R	Reaction *(Ib)*
r	Radius *(in)*
Se	Corrected fatigue strength *(psi)*
Se'	Uncorrected fatigue strength *(psi)*
T	Torque needed to move load *(Ib-in)*
T_c	Collar torque *(Ib-in)*
T_d	Torque required to lower load *(Ib-in)*
T_{dt}	Total lowering torque *(Ib-in)*
T_u	Torque required to raise load *(Ib-in)*
T_{ut}	Total raising torque *(Ib-in)*
ν_c	Axial velocity *(in/sec)*
ν_t	Tangential velocity *(in/sec)*
W_i	(minor) area factor for thread stripping shear area *(….)*
W_o	(major) area factor for thread stripping shear area *(….)*

Greek Symbols

Symbol

α	Angle of power screw *(degree)*
γ	Weight density (*Ib/in^3*)
θ	Angle of lifting and lowering of links *(degree)*
ν	Poisson's ratio *(….)*
ν_t	Tangential velocity *(in/sec)*
ν_c	Axial velocity *(in/sec)*
ρ	Mass density (*Mg/in^3*)
σ_b	Torsional shear stress *(psi)*

$\sigma_{bearing}$	Bearing stress *(psi)*
$\sigma_{comp.}$	Compression stress *(psi)*
σ_t	Tensile stress *(psi)*
σ_{ult}	Ultimate tensile stress *(kpsi)*
σ_x	Axial stress *(psi)*
σ_{yp}	Tensile yield stress *(kpsi)*
τ	Shear stress for thread stripping *(psi)*
τ_{dir}	Mean shear stress *(psi)*
τ_m	Bending stress *(psi)*
τ_s	Direct shear stress *(psi)*
τ_{tor}	Torsion shear stress *(psi)*
τ_{xy}	Shear stress in xy-plane *(psi)*
μ	Coefficient of friction *(….)*
ω	Angular velocity *(Rad/sec)*

Introduction

We observe in our daily life that the mechanical machines occupy the largest part to simplify more of our hard actions which are difficult to accomplish it by hand. Where the mechanical machines found in every place of our life as in a house, street, factory, labs, and workshops, especially in the mechanical workshops of automobiles maintenance or,(INDUSTRIAL AREA) as it is called in the public speech , where it is considered the most important part in these workshops, and the commonly and famously mechanical machine is the (JACK) which is used in many tasks, one of these is to lifting the car from one of it is sides to simplify the maintenance of it is wheels or to lift the car from the center when we want to wash the lower part of the car in the washing stations. Also, it is used to repair the buckling that is occurs in the external frame of the car during impacts accidents. Jack is also, used in building to support the buildings ceilings to replace one of it is columns. Jack has various types screwed, hydraulic and it has different sizes according to the load type (heavy or light) to be lifted, and our attention in this search will be about (SCREW JACK) which used in many applications and the most important of these applications is to lift the small automobiles ,and our search is about a new form of jack as will described in the next details, that is used to lift a car its weight is not exceed (1000kg) from one of its four sides. **Team in the Indian Institute of Technology Bombay, 2005**, computed the diameter and other parameters for screw for user defined load to be raised and effort applied by Power Screw module of E Yantra MEDO. The critical buckling load on bolt is estimated. The total error or backlash is determined. The total error is equal to the sum of axial error and twisting error. For safe rigidity condition the total error should be less than allowed error. **Team in the SRIKANT company, 2008**, studied the power screw jack having trapezoidal threads is generally used when linear motion with irreversibility is required. A motorized power screw jack consists of an electric motor driving a power screw through a gearbox. The nut translates inside a guide cylinder and provides linear motion at output. To prevent the nut from coming out of the screw there are end stops provided on the screw. **Team in the power jacks company, 2008,** studied the ball screw jacks with capacities from 25kN-200kN(metric) and 0.5-50 ton (imperial) with upright or inverted and translating or rotating screw configurations offered as standard. Ball screw jack are typically used for high speed or high duty applications. The high efficiency and positive action of the low friction ball screw and nut design provide longer life at load and require less power than machine screw jacks to achieve a specified thrust. **Team in the TSUBAKI Australia Pty Ltd., 2009,** studied the ball screw jacks with capacities from 1.96kN-196kN. JWB (Ball Screw Type) is a highly efficient jack for high speed, high frequency operations. Major components include accurate ball screw and high precision worm gear. JWB is a Non-Self-Locking design. Install a brake unit if locking is required.

The Problem

The main problem in this research is to find all the effected forces which are applied on the screw jack and calculation the stresses due to these forces on the parts of the screw jack safety factor for each part also choosing the suitable metal in design to be sure that is all considerations are taken in account and describe the features of screw jack form lifting range velocity efficiency, etc.

Assumptions

1- The jack is supported on a plane ground.
2- The analysis is separated for each link.
3- Analysis of forces and calculation are in two dimensions.
4- For average quality material work man ship and conditions of operation the coefficient of friction may be taken as (0.125) [4].
5- The coefficient of friction of collar may be taken as the same as for thread friction [4].
6- The jack is lift the load with start angle (θ=10°).
7- The final value of angle at the top is (θ=65°).
8- The load value equal (2500N = 562.05lb) as a vertical load concentrated at the upper base of the jack.

Calculations Of Motion Mechanism

The analysis and calculation are made in two dimension (x-y) plane, but the (z) dimension will increase the stability of jack. The motion mechanism of power screw jack shown in (**Figure 1**)

Range of angle
As shown in (**Figure 2**)
Maximum angle = (ϴ=65˚)
Minimum angle = (ϴ=10˚)
Length of 1st link=250mm=9.843in.
Length of 2nd link=125mm=4.9215in.

Range of heights of jack
Min. height = (250 sin10) +60+51.9=155.15mm=6.108in
Max. Height = (250 sin65) +60+51.9=338.5mm=13.326in
Max. Lifting =250(sin65-sin10) =183.35mm=7.218in
Slot = (250 cos10)-2(125 cos65) =140.62mm=5.536in
Center distance= (250 cos10) =246.23mm=9.694in

Nut velocity
As shown in (**Figure 3**)

$$v_t=\omega r \tag{1}$$

$$v_c=\omega\, r \tan\alpha \tag{2}$$

$$\upsilon_t = \frac{2\pi}{60}120 * 0.25 = \pi in/\sec \tag{3}$$

$$\upsilon_c = \frac{2\pi}{60} N * 0.25 * \tan(14.5) \tag{4}$$

$$\upsilon_c = \frac{2\pi}{60} 120 * 0.25 * \tan(14.5) = 0.812 in/\sec \tag{5}$$

Calculations Of Force And Reactions

The forces acting on the upper base is known and the reactions resulted due to this force as shown in (**Table 4**)

Max. Force on the Nut (θ=10)
F_1max = 1124 cot 10= 6375 Ib (6)

Min. Force on the Nut (θ=65)
F_1min = 1124 cot 65= 524.13 Ib (7)

Torque Required To Move Load

Torque to "Raise" load

$$T_u = \frac{FD_p}{2}\left(\frac{l + \mu\pi D_p}{\pi D_p - \mu l}\right) \tag{8}$$

Torque to "Lower" load/

$$T_d = \frac{FD_p}{2}\left(\frac{\mu\pi D_p - l}{\pi D_p + \mu l}\right) \tag{9}$$

Collar friction

$$T_c = \mu_c P \frac{d_c}{2} \tag{10}$$

Efficiency Of A Power Screw

$$e = \frac{Fl}{2\pi T_u} \tag{11}$$

In order to check the power screw in self lock the following condition must be applied:-

$$\mu \geq \frac{l \cos\alpha}{\pi D_P} \tag{12}$$

$$0.125 \geq \frac{0.1 * \cos 14.5}{\pi * 0.45} \tag{13}$$

$0.125 \geq 0.0685 \rightarrow$ (The power screw is in a self lock)

Calculations Of Stresses

Power screw is subjected to tensile stresses, links are subjected to compression and bending stresses, and (pins and connecting bolts) are under shear and bearing stresses. Before start to calculate the stresses of each part we must know the following information:-
The stripping – shear area (As) for one screw thread is the area of the cylinder of its minor diameter (Dr).

$$As = \pi\ Dr\ Wi\ P\ N\ \ell \tag{14}$$

For the nut stripping at its major diameter the shear area for one screw thread is

$$As = \pi\ D\ Wo\ P\ N\ \ell \tag{15}$$

(Wi, Wo):- area factors for thread stripping shear area and its value taken from (**Table 14-5**)
Wi (minor) =0.77 ----- Wo (major) =0.63}…..Thread type (ACME). [5]
The shear stress for thread stripping (τs) is then found from :-

$$\tau_s = \frac{F_{1\max}}{A_s} \tag{16}$$

The maximum nominal shear stress (τ) in torsion of the screw body can be expressed as

$$\tau = \frac{T * r}{J} = \frac{16T_{dt}}{\pi D_r^{\ 3}} \tag{17}$$

$$\sigma_t = \frac{F_{1\max}}{A_{ts}} \tag{18}$$

Pin of nut is subjected to shear bearing stresses due to 2nd link and ball bearing in the slot as follows:-

$$\sigma_{bearing} = \frac{R}{2A} \tag{19}$$

$$\tau_{dir} = \frac{R}{A_{sh}} \tag{20}$$

Stress on the pin that is connect the upper base with 1st link

$$\sigma_{bearing} = \frac{F}{2(2A)} \tag{21}$$

$$\tau_{dir} = \frac{F}{2A}$$

(22)

$$\overline{Y} = \frac{\sum AY}{\sum A}$$

(23)

$$\sigma_b = \frac{M\overline{Y}}{I}$$

(24)

Calculations Of Safety Factors

$N_S = \dfrac{\sigma_{yp}}{\sigma}$ ……. (Safety factor in static)

(25)

$$\sigma = \sqrt{(\sigma_t)^2 + (\tau_{xy})^2}$$

(26)

$$\tau_{xy} = \tau_s + \tau$$

(27)

$N_f = \dfrac{s_{se}}{\tau_{max}}$ ……..(Fatigue Safety Factor)

(28)

$Se = C_{load} C_{size} C_{surf} C_{temp} C_{reliab} Se'$ [5]
(29)

Computer Program For Power Screw Jack

In this research, the program was writing with "Quick Basic" language. Many examples applied by using this program to check the accuracy of it. The input data for this program were (load, angle of power screw jack, coefficient of friction, properties of materials, safety factor). Assuming the dimensions of power screw jack and make the calculation, if the results are accepted we can consider it the final dimensions else we change the dimensions order to get the desirable results.

Results And Discussion

All the results due to assumptions may be change if its not acceptable by changing one or more of the primary assumptions. The maximum angle of jack is (65˚) which is selected according to the required height of lifting. Ball bearing is putted in a slot in the lower base of jack which is support the nut and to allow to move in a limited range. Using a thrust ball bearing to reduce the torque of collar. (**Table 1**) shows the materials of parts. (**Table 2**) shows the power screw properties and features. Range of angle, range of heights of jack and nut velocity are shown in (**Table 3**). (**Table 4**) shows the torque required and efficiency of power screw. (**Table 5**) shows the stresses of power screw jack. (**Table 6**) shows the safety factor. (**Figure 1**) represent the effect of angle on the height of power screw jack and maximum lifting. (**Figure 3**) represent the effect of angle of power screw jack on the axial velocity of nut. Rotation arm may be designed as in (**Figure 5**), (**6**) to reduce the rotation force and in a same result of moment. All dimensions of power screw jack with ball bearing is shown in (**Figure 5**). (**Figure 7**) represent the load on the jack and assistants is considered to be a function of height level of automobile. In starting of load lifting (car lifting).the jack will not bear all the load because of a suspension system will bear part of this load ,but the load will increase on the jack as lifting increase since the assistants part are not loaded. The stresses on a power screw and nut will be high when the height is low (in the start of lifting) this can treat by assistant part as described in the above, this yield to be the motion of rotation arm is very easy to rotate the power screw.

Conclusion

From the results of the analytical solution of the present work for design of power screw jack with ball bearing, the following conclusions are deduced:-

1. The minimum height of jack is (6.108 *in*) and the maximum lifting of jack is (7.218 *in*).
2. Length of slot is (5.536 *in*).
3. The axial velocity of nut approximately equal to (0.812 *in*/*sec*).
4. We have maximum force on the nut at minimum height (θ=10°) but we have minimum force on the nut at maximum height (θ=65°).
5. The maximum torque required to lift the car is (47.62 *lb*-*in*).
6. By using thrust ball bearing the torque required is reduced.
7. The maximum torque required to down the car is (29.42 *lb*-*in*).
8. The coefficient of friction is greater than (*tan* 14.5) then self lock the jack.
9. The stability is increased by using the ball bearing (support the nut of power screw).
10. Maximum safety factor for power screw and equal (3.57).
11. Minimum safety factor for rotation arm and equal (1.2).
12. Select the material is very important, where the material effect on the torque by friction factor and effect on the factor of safety by properties of metal.
13. In starting of lifting the load, there is no difficult in the speed of lifting, because of suspension system and the wheels of the car, i.e. the load is a function of height.
14. The stability of the jack is very high, this depends upon the width of jack base.
15. Using of ball bearing make the motion of the nut more easily, hence easy lifting.
16. Safety factor of rotation arm is done to be lowest than the other parts, to avoid the accidents during maintenance.
17. Parts of this device are easily assembling and separating, this lead to easy repair.
18. Using a thrust ball bearing to reduce the torque of collar.

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Table (1) Materials of Parts

Name of Part	Type of Material	σ_{yp}	σ_{ult}	$\sigma_{comp.}$	Elongation over 2 *in*	Brinell Hardness
Power screw	Steel (SAE/AISI number 4130 Q & T @ 400°F)	212 *Kpsi*	236 *Kpsi*		10%	41 *HB*
Nut	Cast Iron (Ductile Iron 65-45-12)	48 *Kpsi*	67 *Kpsi*	53 *Kpsi*		147 *HB*
Links	Steel (SAE/AISI number 1030 Q & T @ 800°F)	84 *Kpsi*	106 *Kpsi*		23%	302 *HB*
Pins	Steel (SAE/AISI number 1010 cold rolled)	44 *Kpsi*	53 *Kpsi*		20%	105 *HB*
Rotation arm	Steel (SAE/AISI number 1020 cold rolled)	57 *Kpsi*	68 *Kpsi*		15%	131 *HB*

Table (2) Power Screw properties and features

Type of Power Screw	Single start acme (0.5-10)	
Name	**Symbol**	**Dimensions**
Tensile stress area	A_{ts}	0.142 *in*
Major diameter	D	0.5 *in*
Pitch diameter	D_p	0.45 *in*
Minor diameter	D_r	0.4 *in*
Thread pitch	ℓ	0.1 *in*
Thread per inch	N	10
Angle of power screw	α	14.5°

Table (3) Motion Mechanism properties

Range of angle	**Maximum angle**		**Minimum angle**		
	65°		10°		
Range of heights of jack	**Min. height**	**Max. height**	**Max. lifting**	**Slot**	**Center distance**
	6.108 *in*	13.326 *in*	7.218 *in*	5.536 *in*	9.694 *in*
Nut velocity	v_t		v_c		
	3.14 *in/sec*		0.812 *in/sec*		

Table (4) Torque required and efficiency of a power screw

Symbol	
T_c	22.62 *lb-in*
T_u	25 *lb-in*
T_d	6.8 *lb-in*
T_{ut}	47.62 *lb-in*
T_{dt}	29.42 *lb-in*
E	36%

Table (5) Stresses of power screw jack

Part	τ *(psi)*	τ_{dir} *(psi)*	τ_s *(psi)*	τ_{tor} *(psi)*	σ_b *(psi)*	$\sigma_{bearing}$ *(psi)*	σ_{comp} *(psi)*	σ_t *(psi)*
Power screw	3791.4		18611.3					4489.4
Pins of nut		53094				18972		
Pins of link		9219.82				5943.8		
Pin of upper base		2305				2971.925		
Large link					49685.8 *comp.* 249212.6 *ten.*	11887.7	1725	
Small link					49630 *comp.* 30229 *ten.*		824.65	
Fork		198.4				501.2		
Rotation arm		27215.45		17543.8				

Table (6) Safety Factor

Part	N_s	N_f
Power screw	3.57	1.7
Links	1.364	
Pins	2.7	
Nut	2.2	
Rotation arm	1.2	

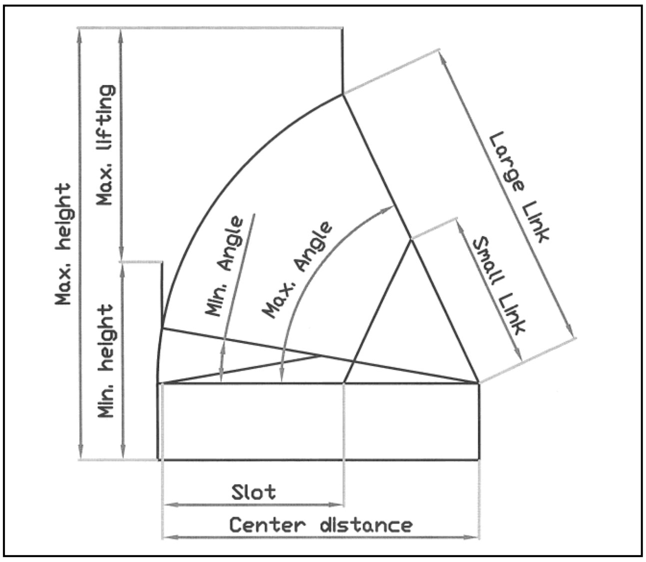

Figure (1) motion mechanism of power screw jack

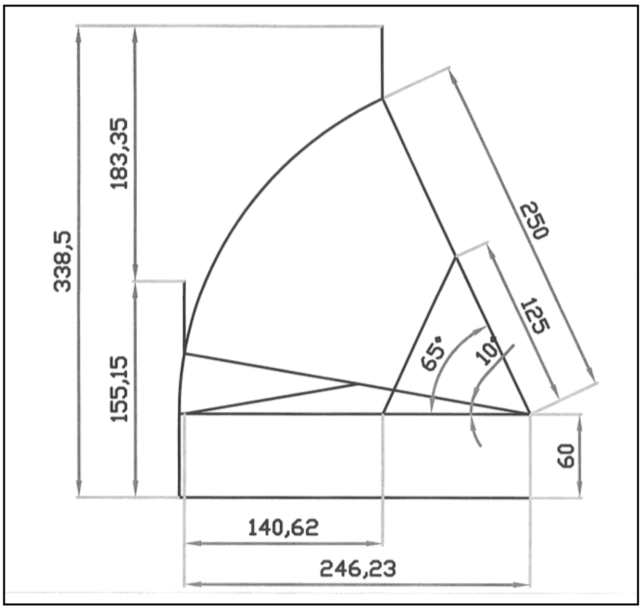

Figure (2) range of angles and heights of jack

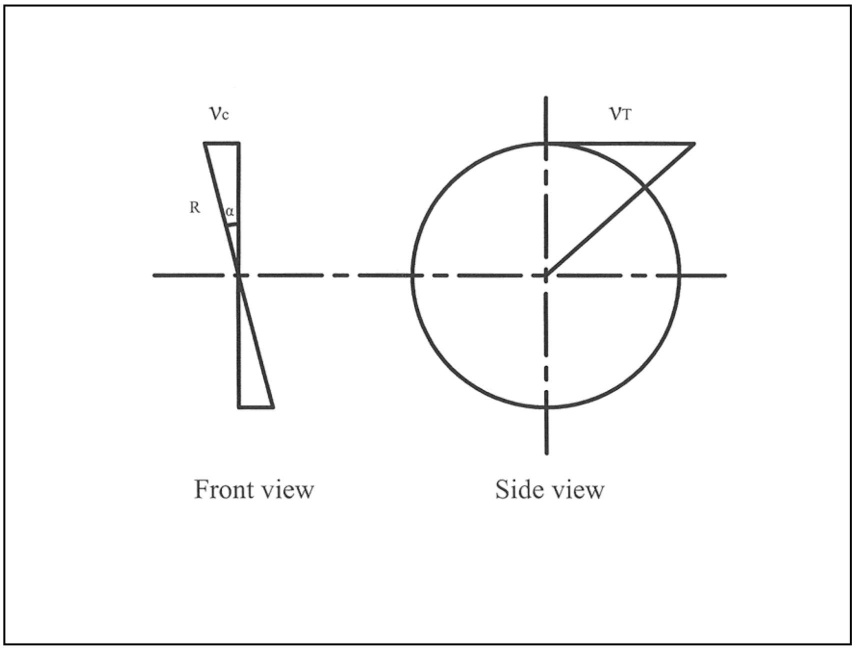

Figure (3) nut velocity diagram

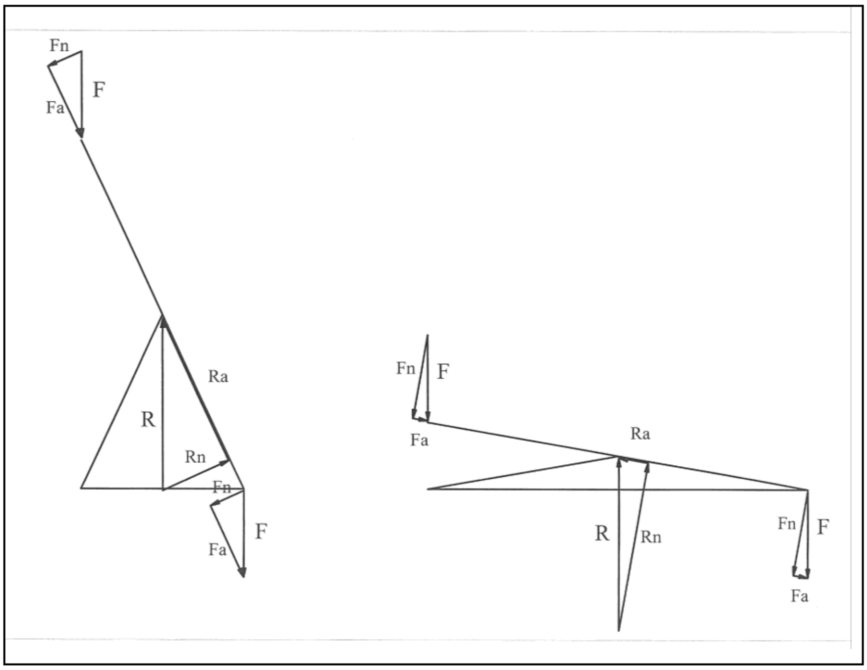

Figure (4) force diagram

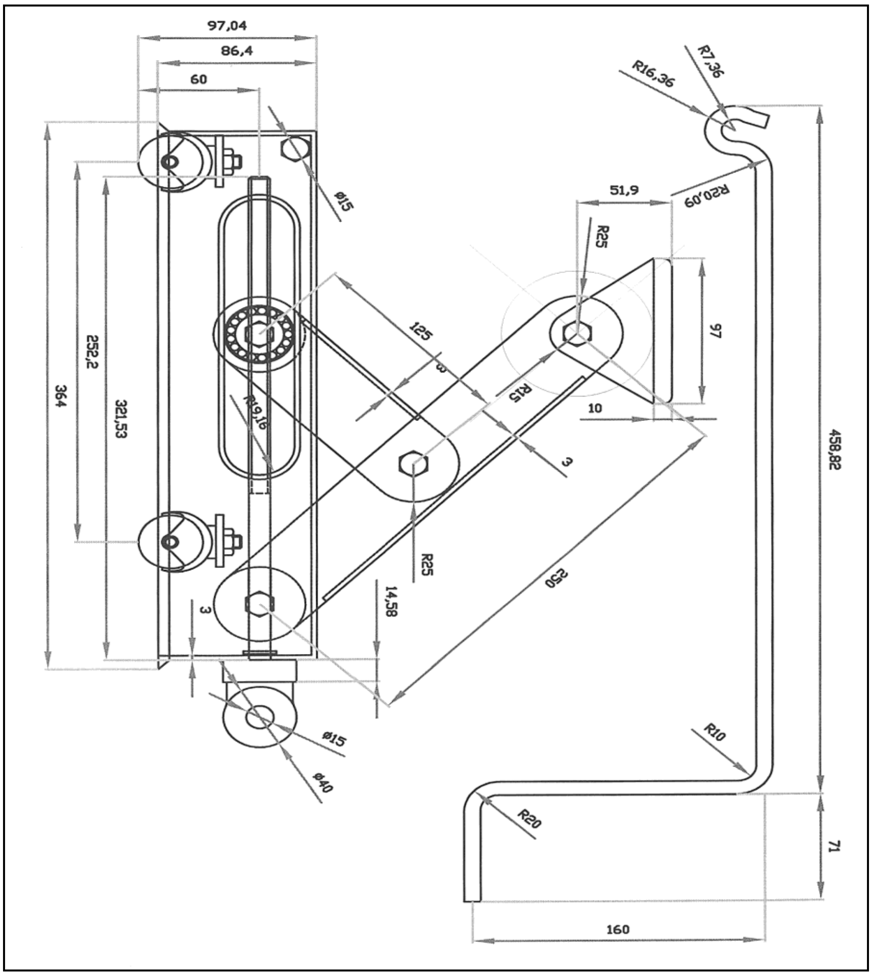

Figure (5) parts and dimensions of power screw jack with ball bearing

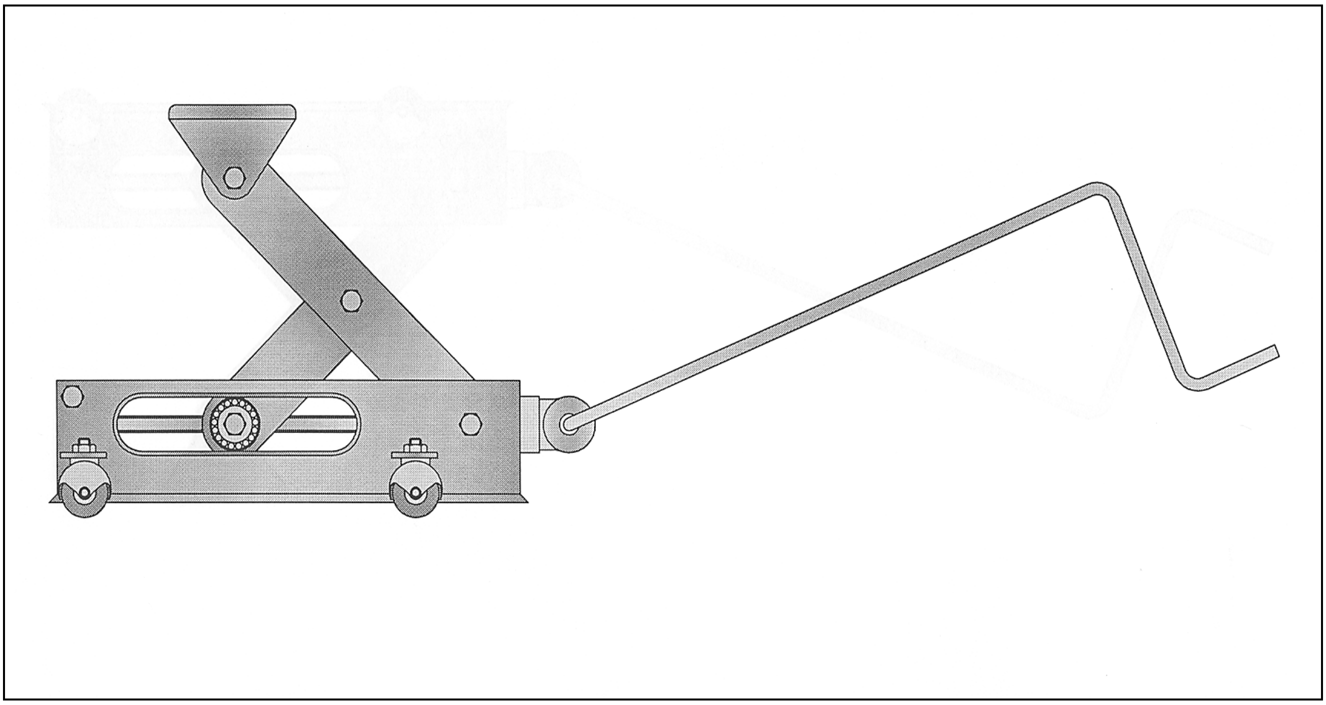

Figure (6) sketch of power screw jack with ball bearing

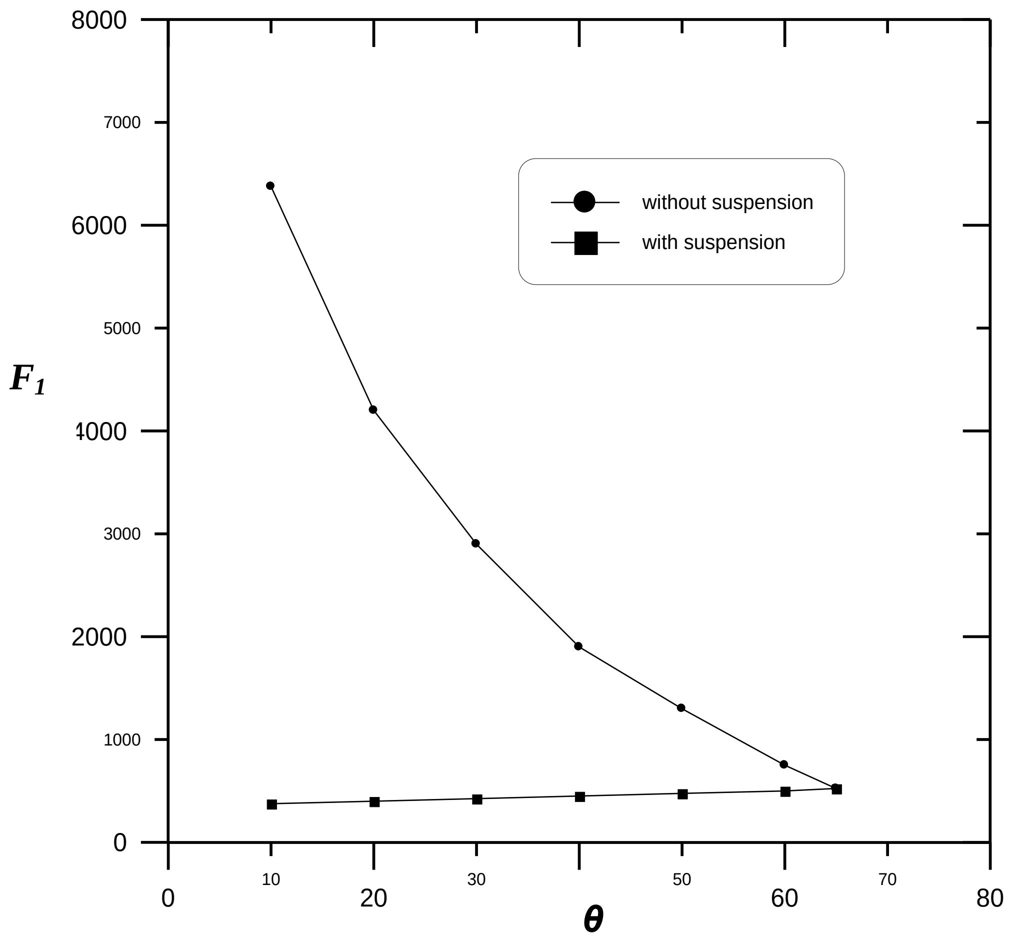

Figure (7) Effect the suspension on the nut force