FINITE ELEMENT ANALYSIS OF TIE-ROD FOR SPACECRAFTS

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ABSTRACT

This paper describes the design and mechanism for the deployment of Equipment panel of a spacecraft. For this a tie rod is designed and analysis is done in UG NX 7.5, the design analysis section provides data on linear Buckling analysis. Both the ends of the Tie rod are hinged so that the Equipment panels assembled to Tie –rod can be tilted from Horizontal condition to vertical condition. And safety of factor taken is 3.0.

***Keywords* - *Design, Mechanisms,* Linear Buckling Analysis, Tie-Rod, UG**

I. INTRODUCTION

Spacecraft consists of main structure and Equipment panels which are connected through shear webs to main structure to form a cuboid structure. Assembly, Integration and Testing (AIT) of spacecraft require number of Mechanical Ground Support Equipment (MGSE). A Tie-Rod is designed for tilting the Equipment Panel.

1.1. Tie-Rod

Tie-rod is selected as driving member for tilting the panel (along with panel mounting frame) from horizontal to vertical position and vice versa. In principal, tie-rod will have central coupler with screw rods on sides, one with left hand thread and another with right hand thread. The coupler has matching threads to accommodate these threaded tie rods. On rotating the coupler is turned, both the rods will extend or retract based on the direction of rotation of coupler. The ends of the rods are either eye or fork end type.

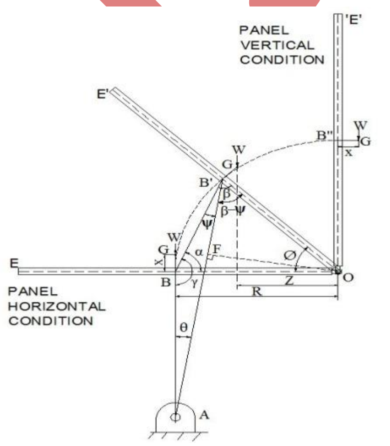

Fig 1.1 Forces acting on the Tie-Rod

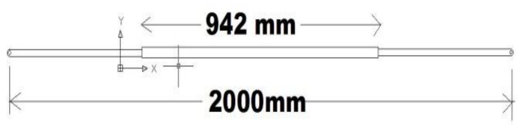

Fig 2: Tie- Rod

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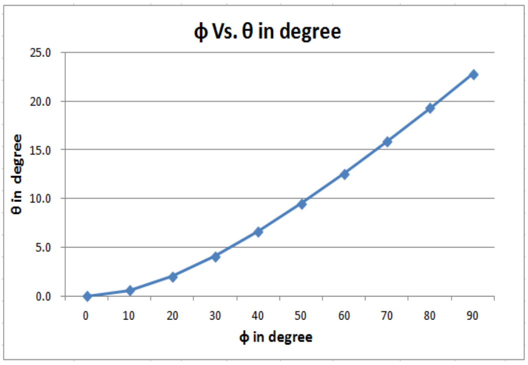
The data corresponding to panel in horizontal condition to panel in vertical condition (i.e., from 0 to 90 degrees) is presented below at an interval of 10^{o}.

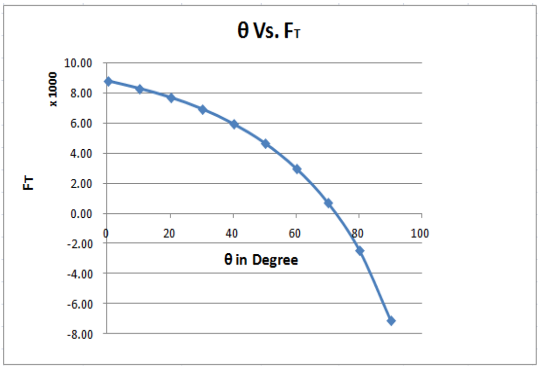
Table 1.1: Data of panel horizontal condition to vertical condition

ϕ panel angle (BOB') in degree	θ in degree	F_T = Force Exerted by Tie rod (N)	Fov, Vertical Force (N)	FOH , Horizontal force (N)
0	0.000	8829.00	0	0
10	0.500	8327.00	250.78	723.05
20	2.040	7729.35	552.5	1321.79
30	4.090	6964.77	940.99	1741.19
40	6.630	5972.78	1448.02	1919.61
50	9.480	4681.42	2105.76	1793.08
60	12.580	2987.72	2956.96	1293.721
70	15.880	722.67	4066.96	339.5418
80	19.310	-2425.61	5559.03	1194.3806
90	22.850	-7113.00	7692.2604	-3556.94

Following graphs show how the values of , F_T, F and F are changing when the changes from 0^{o} to 90^{o}



Graph ϕ vs θ



Graph θ vs F_T

1.1.1 Design of Tie-Rod

Material= 30C8, Carbon Steel Yield strength= $\sigma yt = 400\ N/mm^2$

Load acting = W= (300 x 9.81) = 2943 N and Factor of safety= 3

Assuming $\sigma yt = \sigma yc = 400\ N/mm^2$ Therefore, limiting stress is

$$\sigma_c = \frac{400}{3} = 133N/mm^2$$

The diameter of the rod is determined by considering the rod in two failure cases.

1. Compression failure
2. Buckling failure

Case-1: Considering the compression failure of the rod:

Compressive strength of the rod is given by, $$\sigma_c = \frac{W}{\frac{\pi}{4} d_c^2} \quad \dots (1)$$

Substituting the values we get the diameter of rod as

$$133.3 = \frac{2943}{\frac{\pi}{4} d_c^2} \qquad d_c = \sqrt{\frac{4W}{\pi\ \sigma_c}} \quad \dots (2)$$

$$d_c^2 = 28.110mm$$

$$d_c = 5.3 \text{ or } 6mm$$

Case-2: Considering the buckling failure of the rod:

Effective length of Tie –Rod= 2000mm

For circular cross section of diameter **'d_c'**

The moment of inertia, $$I = \frac{\pi}{64} d_c^4 \quad \dots (3)$$

Cross sectional area, $$A = \frac{\pi}{4} d_c^2$$

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$$\text{Slenderness Ratio} = \frac{L}{K} \quad \ldots (4)$$

Radius of Gyration $$K = \sqrt{\frac{I}{A}} = 0.25 d_c \quad .. (5)$$

By substituting the values of radius of gyration in slenderness ratio, we get,

Slenderness ratio = $$\frac{L}{K} = \frac{2000}{0.25 d_C}$$

$$\frac{L}{K} = \frac{8000}{d_C} \quad \ldots (6)$$

Assuming the critical load should be more than or equal to design load,

$$P_{cr} = \text{Working load} \times \text{FOS} \quad \ldots (7)$$

$$P_{cr} = 2943 \times 3 = 8829 \text{ N}$$

From Rankine Formula we have

$$P_{cr} = \frac{\sigma_c \text{ x } A}{1 + a\left(\frac{L}{k}\right)^2} \quad \ldots (8)$$

Where σ_c= Crushing Stress or Yield Stress in Compression = 400 N/mm^2

a = Rankine Constant = $a = \frac{1}{5000}$

A = Cross –sectional area of Column

Substituting above values in Rankine Equation, we get

$$8829 = \frac{400\text{x } \frac{\pi}{4} d_c{}^2}{1 + \frac{1}{5000}\left(\frac{8000}{d_c}\right)^2}$$

$$d_c{}^4 - 28.08 d_c{}^2 - 359550.56 = 0$$

$$d_c{}^2 = 613.82\text{mm}$$

This is quadratic equation in $d_c{}^2$, the solution of which gives,

Therefore, $d_c = 24.77\text{mm}$

From the above two cases it is very that the bucking of tie-rod is more pronounced than the compression failure.

Adopting the next higher standard core diameter of 26mm and pitch as 5, the nominal diameter of the Tie –rod is,

$$d = d_c + P = 31\text{mm}$$

and the mean diameter is, $d_m = d - 0.5P = 28.5\text{mm}$

It is assumed that the screw has single start thread; the helix angle is given by,

$$\tan\alpha = \frac{l}{\pi d_m} = \frac{5}{\pi \times 28.5} = 0.0558 \quad \text{… (9)}$$

$$\alpha = 3.19°$$

Assuming Maximum possible value of coefficient of friction is 0.15 (worst case)

We have, $\tan\varphi = \mu = 0.15$ ..(10)

$$\varphi = 8.53°$$

The Torque (Mt) required to raise the load is given by,

$$Mt = \frac{Wd_m}{2}\tan(\varphi + \alpha) \quad \text{.. . (11)}$$

$$Mt = \frac{2943 \times 28.5}{2}\tan(8.53 + 3.19)$$

$$Mt = 8700 \ \ N - mm$$

Now torsional shear stress is evaluated by,

$$\tau = \frac{16Mt}{\pi d_c{}^2} \quad \text{… (12)}$$

$$\tau = \frac{16 \times 8700}{\pi \times 26^3} = 2.53 \text{ N/mm}^2$$

Since the induced torsional shear stress is less than the limiting stress, the design is safe.

The condition for self locking of the screw need to checked, so that the frame should not fall off due to its own weight plus the panel weight. For this case, the efficiency of the square threaded rod should be less than 50% and is calculated as follows.

$$\eta = \frac{\tan\alpha}{\tan(\varphi + \alpha)} \quad \text{… (13)}$$

$$\eta = \frac{\tan 3.19}{\tan(8.53 + 3.19)}$$

$$\eta = 0.26 = 26.8\%$$

Since the efficiency of the rod is 26.8% which is less than 50%, the system is self-locking.

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Now the coupler dimensions are arrived by considering the proportions being used in standard design practice.

The central position of the tie rod is called coupler, the outer and inner diameter of the coupler are D and d respectively.

The inner diameter of the coupler is same as rod diameter, d = 26mm

The outer diameter of the coupler, D= 1.5d = 1.5 x 26 = 39mm

II. ANALYSIS

The FE analysis is carried out to evaluate the analytical calculations and also to validate the actual configuration and design of the tie rod which are shown below as two separate cases.

Case-1: To validate the analytical calculations.

Case-2: Actual configuration with rods and coupler

Material Properties Description

Basically two types of materials are used for assembly – plain carbon steel and cast-iron.

Table -2 Material Properties

Material	Elastic Modulus (E) in (GPa)	Poisson's Ratio (μ)	Density (ρ) in Kg/mm^3	Yield Strength (σ_y)in (Mpa)
Carbon Steel 30C8	207	0.29	7800×10^{-9}	400
Gray Cast-iron FG200	90	0.3	8000×10^{-9}	200

2.1. Element Property Description

Table -3: Element Properties

Sl. No.	Region	Element Type	Material property
1	Rod	Psolid	Isotropic Carbon steel 30C8
2	Coupler	Psolid	Isotropic Cast iron FG 200

2. 2 Boundary Conditions

Table 4: Boundary condition

Location and description		Boundary condition	Loading
A	Tie-rod hinged at base	Translations in X, Y & Z and rotation in X & Y directions arrested. Rotation in Z direction is allowed.	---
B	Tie-rod hinged to frame	Translations in X, Z and rotation in X, Y directions arrested. Translation in Y & Rotation in Z directions are allowed.	Loading in Y direction

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CASE 1. SINGLE ROD

In this case a single rod of 26mm diameter and 2000mm length is taken with ends of rod as eye end.. Material of the screw rod is Carbon Steel 30C8

Finite element Model

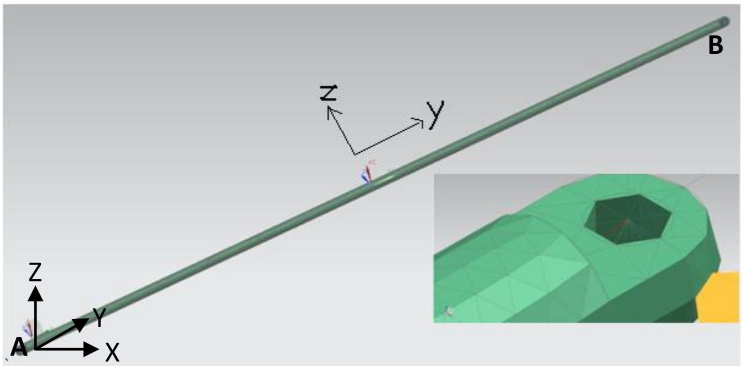

Fig 3 Finite Element Model of Single Rod

Meshing of the rod is done by 3DTETRA4 meshing, 1D Connection is applied to the rod, after applying hinged constraints to the rod ends, and the load is applied at one end of the eye end as shown in fig -3

<u>Results</u>

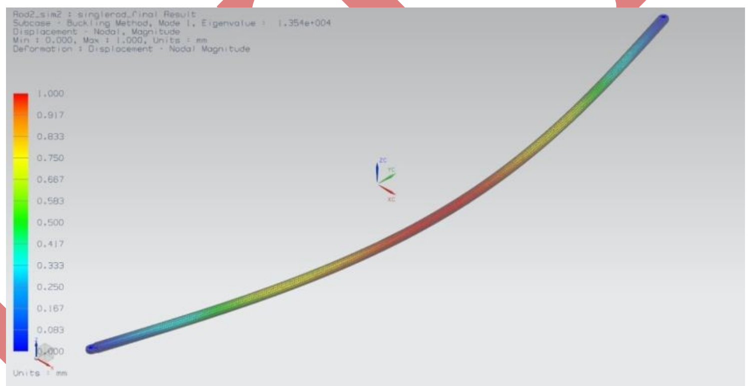

Fig-4 linear Buckling analysis

The critical buckling load as obtained from FE analysis is 13540 N as against the analytical calculation of 11265 N. The results are relatively matching with marginal difference. However, the difference may be attributed to the type of element and meshing technique used and inherent software solving issues.

CASE 2: TIE ROD

The tie rod consisting of rod is made of 26mm diameter and the the coupler of 39mm diameter , and the overall length of the tie-rod is 2000mm of which the coupler and the rod has mating distance of 50mm as shown in figure below. Other boundary conditions and loading are same as case-1.

Finite element Model

Finite element analysis is carried out in order to obtain the first mode Eigen value, which will when multiplied by the applied compressive load, gives the linear Buckling load.

Fig 5 Tie-rod mesh

The tie-rod FEM consists of 3D elements, since the material of the rod body differ, they have separate material properties in FEM. . The coupler and the rod are connected by using glue mesh mating condition so mating nodes are lined up to form a continuous mesh.

LINEAR BUCKLING ANALYSIS RESULTS

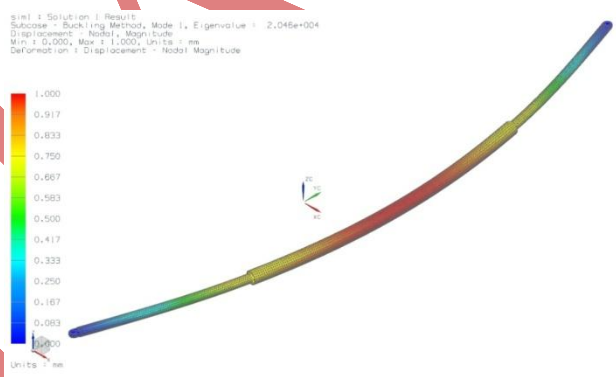

Fig -6 Linear Buckling Analysis

In this case-2 the linear analysis shows the crippling load (buckling load) obtained as 20460 N. This is due to the fact that, coupler in between the two rods adds more stiffness to the tie-rod assembly as a whole. As can be seen from the bucking equations, critical or buckling load is directly proportional to moment of inertia (MI).

Since MI of the coupler = 91129mm^4

MI of screw rod = 22431mm^4

As the MI of coupler is more than 4 times than that of the screw rod, the buckling load as obtained for the combination of screw rod and coupler (tie-rod assembly) is reasonable and justified.

III. CONCLUSIONS

In this paper, the linear Buckling analysis method for the Tie-rods is presented.

Since, the tie-rod is the main drive element for tilting of the equipment panel. It is suggested to co-relate the Analytical and FE results with experimental values.

Above results indicates that the induced stresses are within permissible limits and hence, the design is safe.

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