MMT Observatory

Smithsonian Institution &
The University of Arizona®

# TECHNICAL REPORT #36

## Secondary Mirrors Support:

## M2/F5 Hexapod Design Technical Report

## & M2/F5 Hexapod Test Report

ADS International s.r.l.

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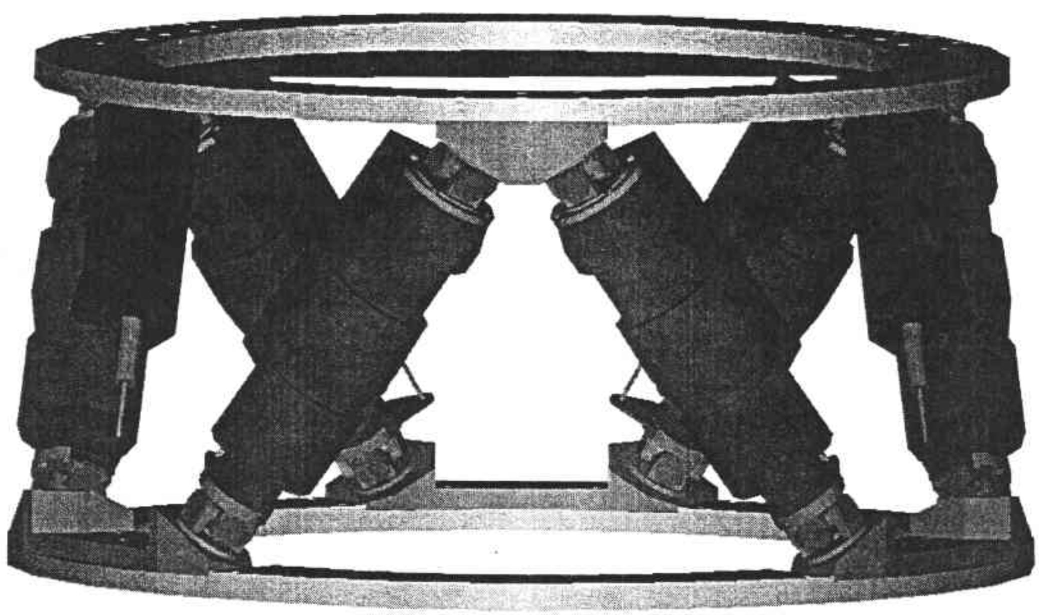
# MMT CONVERSION

## SECONDARY MIRRORS SUPPORT

## M2/F5 HEXAPOD DESIGN TECHNICAL REPORT



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## APPLICABLE DOCUMENTS AND REFERENCES

1. Statement of Work (SOW), "The f/5 hexapod positioning system for the MMT Conversion Project", March 2nd 1999;

2. W.Gallieni, R.Pozzi; "MMT Conversion – Secondary Mirrors Support – M2/f15 and M2/f9 Hexapod Design – Technical Report", Issue 3, January 1997;

3. E-mail by S. West dated 7-Feb.-2000.

## 1. INTRODUCTION

This document reports on the design of the hexapod supporting the f/5 secondary mirror.

The hexapod is designed accounting for the constraints given by the existing M2 hub and the mirror unit itself (ref. 1).

Hexapod static and dynamic analysis are studied by modelling the whole M2 hub in the f/5 configuration.

The f/9-f/15 hexapod design (ref. 2) is assumed as baseline for the f/5 development.

## 2. HEXAPOD ORIENTATION

The hexapod layout is sketched in figure 1. The gravity vector shows the hexapod orientation with respect to the telescope elevation axis.

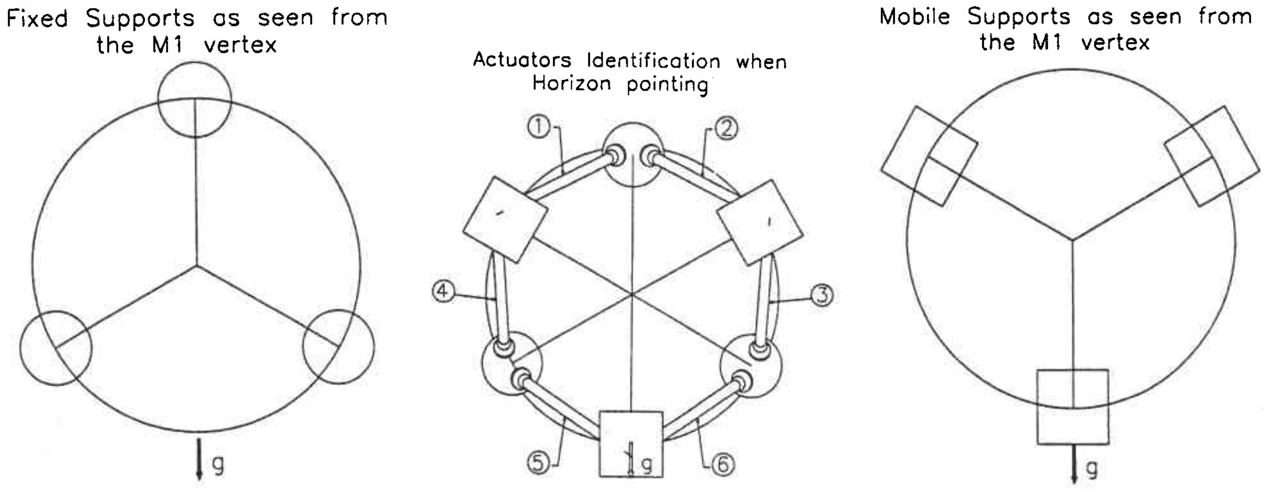


Figure 1. Hexapod orientation.

This orientation has been selected to minimise the difference between the forces in the actuators at different telescope elevations. The reverse one (with gravity upward in figure 1) leads to almost similar forces, while the 90 deg. rotated ones must be avoided.

The hexapod layout is specified to have the mirror c.o.g. placed onto the plane defined by the intersection of the six actuator axis (three pairs).

Moreover, the six hexapod axes should appear aligned on a triangle, when observed on the plan view of the hexapod wireframe (ref. 1).

## 3. KINEMATIC ANALYSIS

The kinematic model assumes the actuator length being the distance between the axis of its two joints, that is the kinematic joints is lumped on its center.

The mobile and fixed plates are defined by the kinematic joints plane.

The center of rotation is the mirror vertex. The mirror c.o.g. is centred on the plane defined by the actuators axis intersection, as specified by ref.1 – 3.2.2 .

The hexapod specifications (ref. 1) relevant to the kinematic design are hereafter reported:

- $Z = \pm 12$ mm;
- $X,Y = \pm 17$ mm;
- $TILT_{X,Y} = \pm 1.2$ deg.

The kinematic model parameters are derived from the wireframe of hexapod layout.

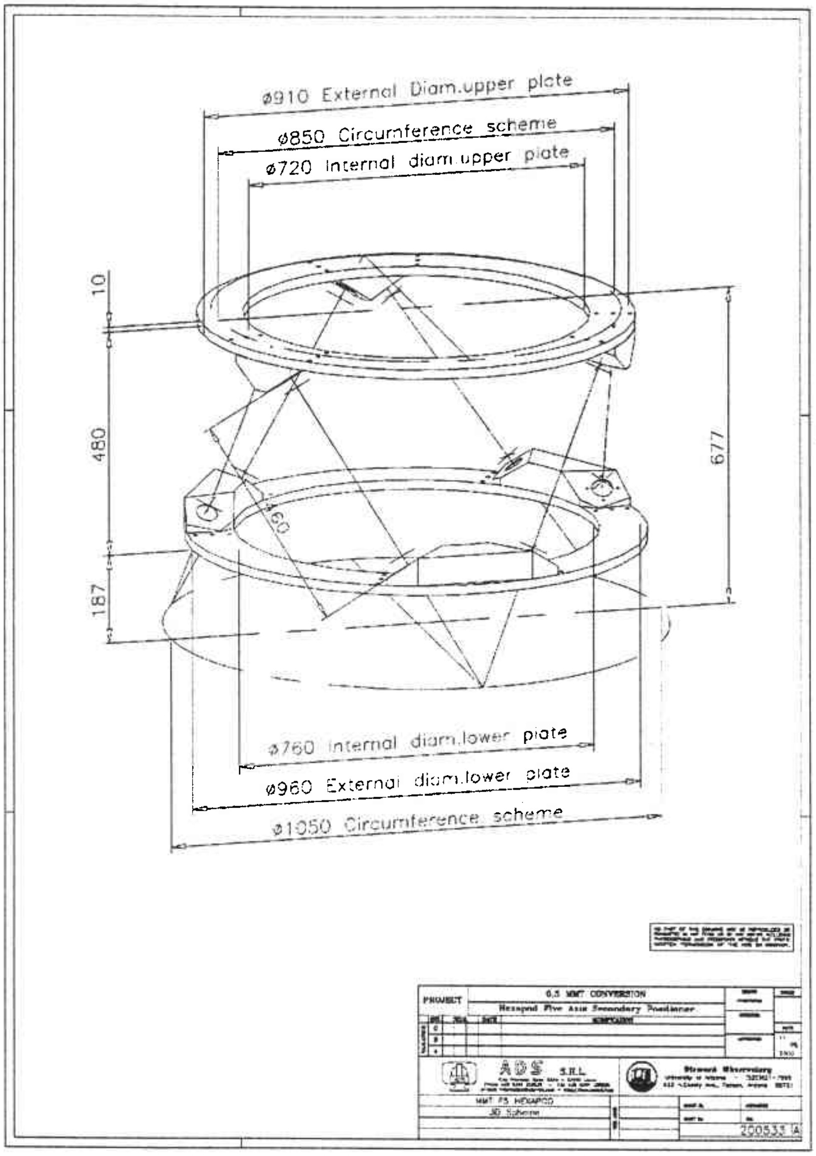


Figure 2. Hexapod wireframe.

| | |
|---|---|
| Actuator nominal length (measured between the centres of the two joints): | $L_0$ = 413 mm |
| Mobile plate joints minimum distance: | $D_{MOB}$ = 281.06 mm |
| Fixed plate joints minimum distance: | $D_{FIX}$ = 110.50 mm |
| Distance between the center of rotation (mirror vertex) and the centre of the mobile platform (mobile joints plane): | H = 365 + 71.5 = 436.5 mm |

The maximum actuator stroke is ± 25 mm. The limit switches are placed at ± 23 mm and the mechanical stops (TBD) at ± 24 mm. The joints max allowed and combined rotation is ± 6 deg.

The results of the kinematic analysis are reported in table1.

| TASK | ΔZ (mm) | ΔX, ΔY (mm) | Δθ (deg) | $\Delta L_{ACT}$ (mm) | $\Delta\theta_{JOINTS}$ (deg) |
|---|---|---|---|---|---|
| Focus | 37 | 0 | 0 | 23 | 1.5 |
| Lateral offset | 0 | 30 | 0 | 23 | 5 |
| Tip-Tilt | 0 | 0 | 3.5 | 23 | 5 |
| COMBINED | 12 | 9 | 1.2 | 23 | 3.1 |

Table 1. Kinematic analysis results.

Figure 3 shows the actuators elongation for the manoeuvre given by the following sequence:
- displace the mobile plate center by X=9mm, Y=9mm and Z=12mm;
- rotate the mobile plate by 1.2 deg around the mirror vertex;
- perform with the mobile plate the complete 360 deg rotation around the fixed plate Z axis.

Figure 4 reports the universal joints rotations during the same manoeuvre.

The kinematic analysis shows that the HP largely fulfils the individual stroke requirements.

For what concerns the worst case simultaneous combination of the specified motion the 23 mm actuator stroke limits the shift and tilt envelope.

Such limitation is automatically provided by the end stroke limit switches implemented into each actuator and then by the mechanical stops inside the actuators themselves.

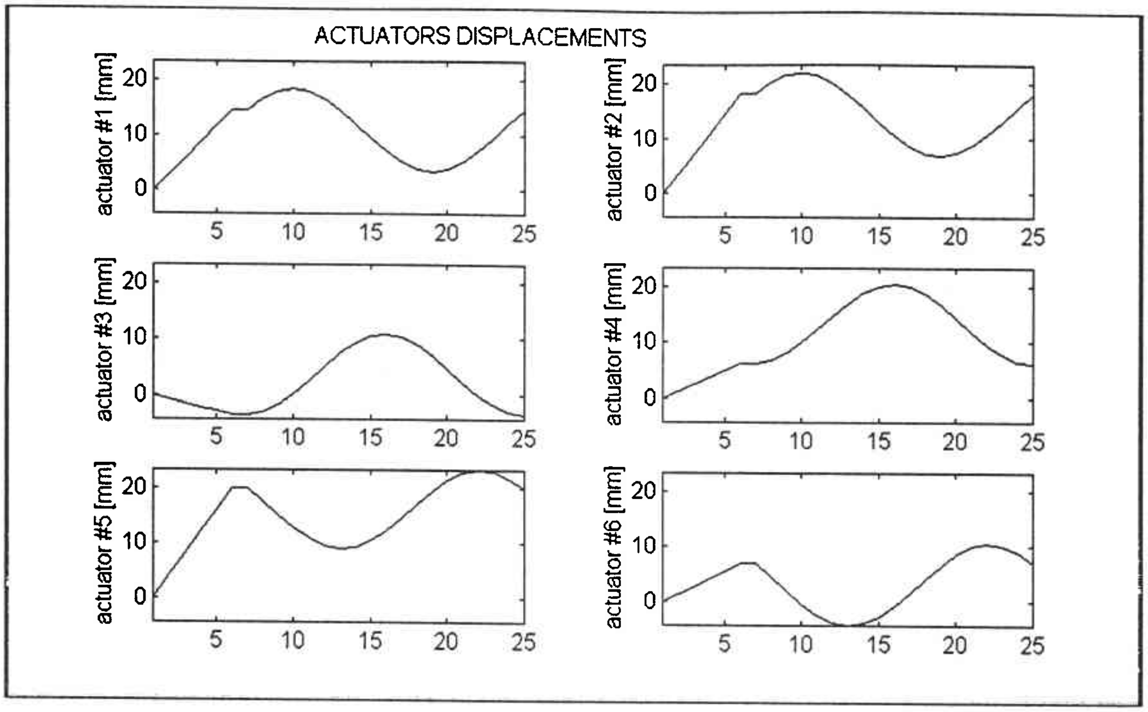


Figure 3. Actuators length variation
for 12 mm focus, 9 mm X,Y offset and 1.2 deg cone nutation.

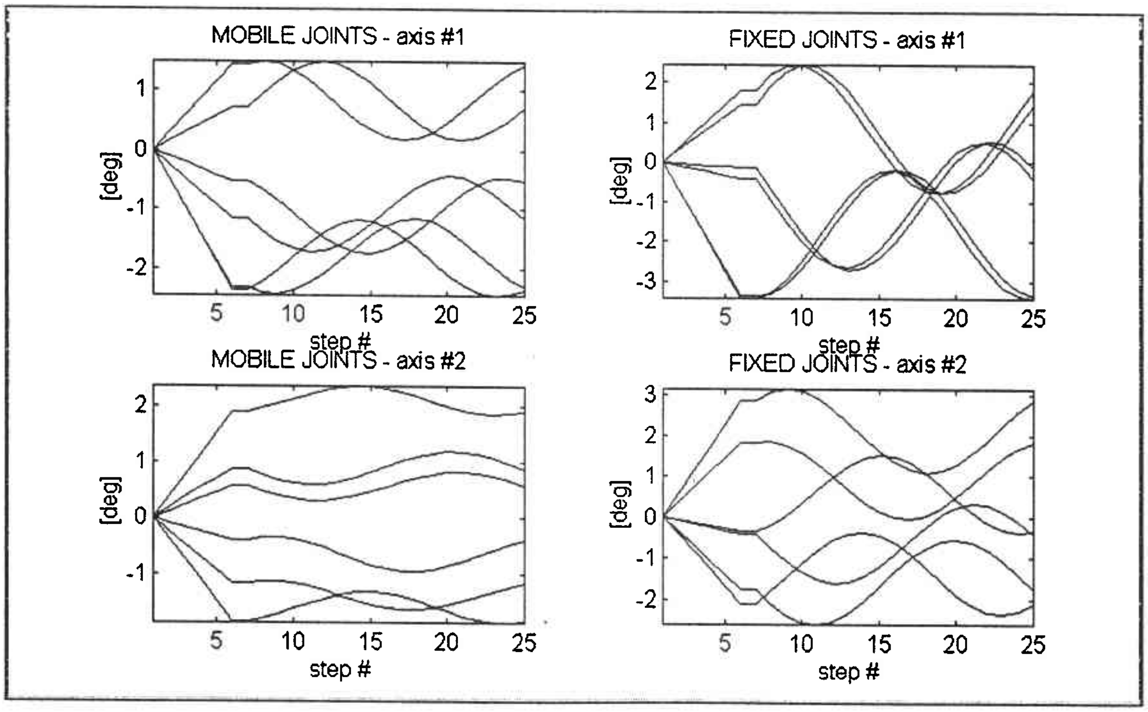


Figure 4. Joints angles variation
for 12 mm focus, 9 mm X,Y offset and 1.2 deg cone nutation.

## 4. JOINTS DESIGN

According to ref.1, the weight of the f/5 secondary mirror system is 6000 N.

The estimated mass of the hexapod, included the fixed and mobile plates, is about 170 Kg.

Actuators axial loads when zenith pointing:

**1 = 2 = 3 = 4 = 5 = 6 = + 1300 N**

Actuators axial loads when horizon pointing:

**1 = 2 = + 4121N**
**3 = 4 = - 4028 N**
**5 = 6 = - 93 N**

Figure 5 reports the actuator axial loads as function of telescope elevation.

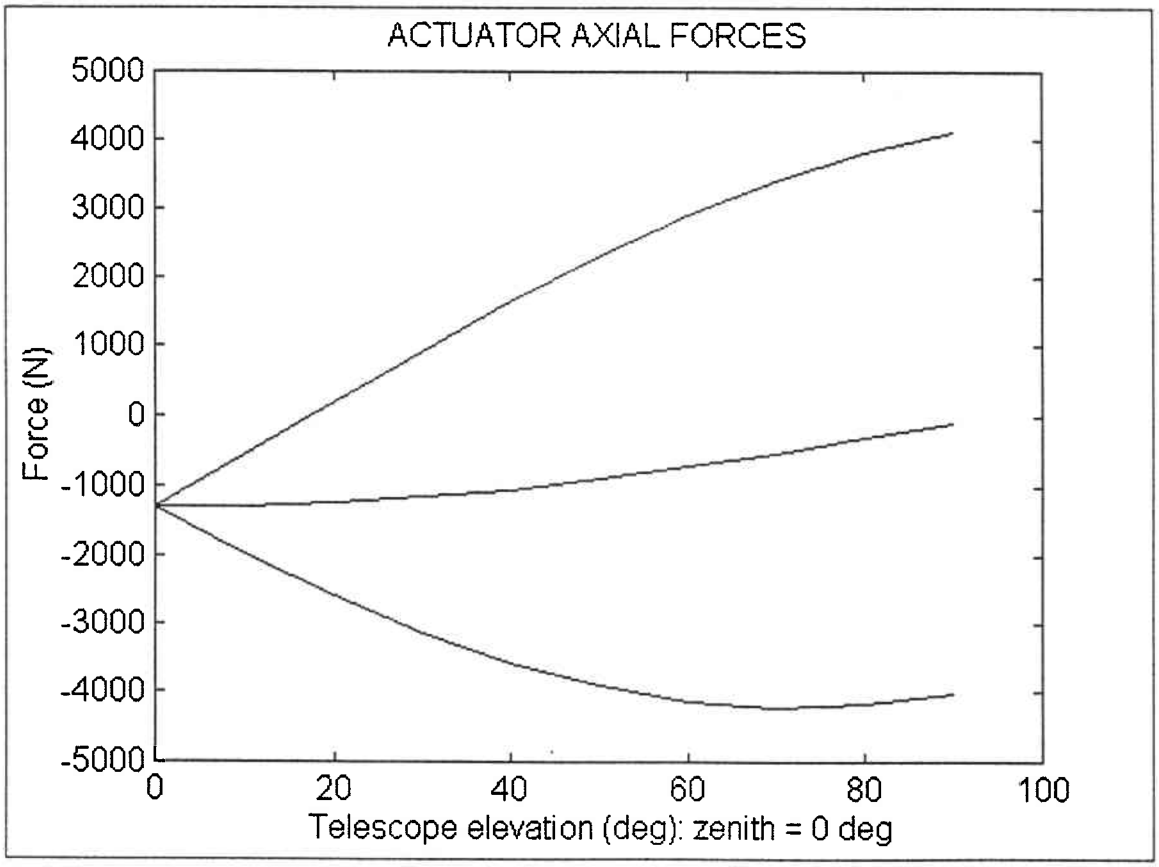


Figure 5. Actuators loading.

Each joint is made by three components: the central cross pinion and two U-shaped flanges carrying the two bearings pairs.

<u>The design axial load is 4500 N.</u>

The bearings are FAG B7000E.T.P4S.UH with a max static loading of 2400 N. Each bracket carries two bearings, thus loaded by 2250 N (static load).

The pin diameter is 10 mm and the bearing height is 8 mm; the minimal flange section at the bearing interface is 2x(9x4.5) = 81 mm$^2$.

Thus, assuming an actuator max axial load of 4500 N, the max structural stress into the joint flange is $\frac{2250}{81}$ = 28 N/mm$^2$. The bearing pressure is $\frac{2250}{10 \times 8}$ = 28 N/mm$^2$.

The bearings come already preloaded to assure that the universal joint does not introduce play into the hexapod structure. Moreover, further preload is introduced by a flange fixed on the bracket by four screws in order to increase bearing's stiffness with respect to its nominal value.

Figure 6 reports the stress pattern into the universal joint when the 4500 N is applied in the rotated configuration (6 deg on both axes).

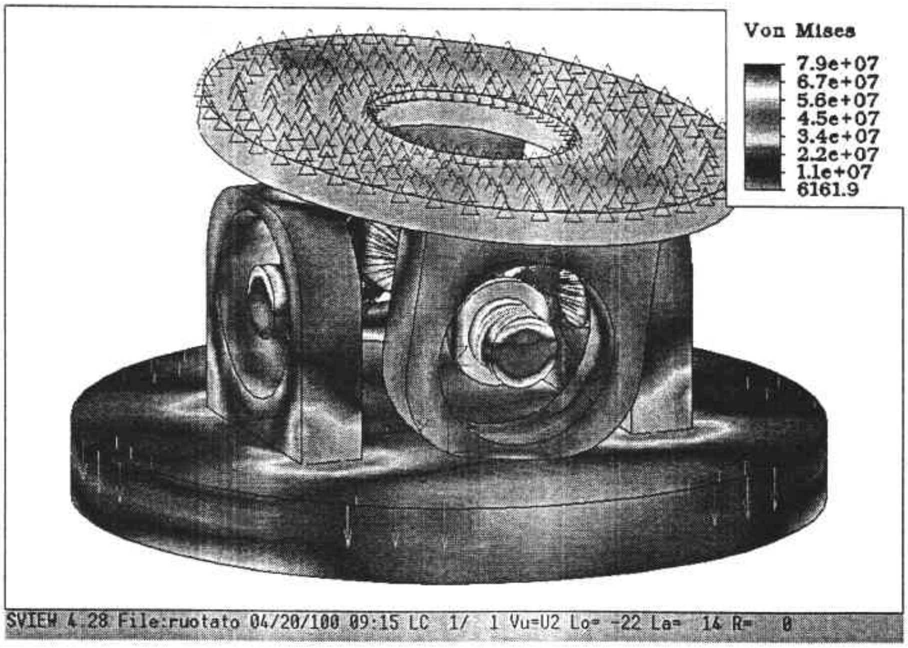


Figure 6. Universal joint stress pattern under 4500 N load.

## 5. MECHANICAL DESIGN

This paragraph reports the selection of the most relevant actuator mechanical components.

Screw: ROLLVIS Satellite Roller Screw RVR 25 x 1

Nominal diameter $d_0$ = 25 mm

Lead = 1 mm

Dynamic load rating = 12.2 KN - Static load rating = 18.9 KN

Nut stiffness = 605 N/μm

Screw stiffness (length 20 mm) = $\frac{21000\times 10^7 \times \pi(0.025/2)^2}{0.020}$ =5152 N/μm

Lead angle = $\varphi = arc\tan\left(\frac{P}{d_0\pi}\right) = arc\tan\left(\frac{1}{25\pi}\right) = 0.73$ deg

Efficiency (%) results smaller than min values, min val. used:

$\eta_1$= (0.68) → 0,71 - force direction opposite to movement
$\eta_2$ = (0.58) → 0,61 - force direction toward movement

Preload design:

Max Axial loads on the screw nut = 4500 N
Minimum preload to be applied to the nut = $F_{pr}$ = 4500 / 2,83 =1590 N

Selected preload value = 2000 N

Torque due to preload = $\frac{2000\times 0.001\times(\frac{1}{0.9\times 0.71}-0.61)}{2\pi}$ =0.30 Nm

Max torque for braking: $C_{BRK} = \frac{F_{MAX}\times P}{2\pi}\times \eta_2 - C_{PRE}$ =

= 4500 *0.001 / 6.28 *0.61 – 0.30 = 0.14 Nm

WARNING: for brake verification it is assumed a null preload torque:

Max torque for braking = 4500 *0.001 / 6.28 *0.61 = 0.44 Nm
Backdriving force:

$$C_{BCK} = \frac{F_{BCK} \times P}{2\pi} \times \eta_2 = C_{PRE} \rightarrow F_{BCK} = 0.30 \times 6.28 / 0.001 = \mathbf{1884\ N}$$

Demanded torque for lifting:

$$T_{lif\ max} = \frac{4500 \times 0.001}{2\pi \times 0.71} = 1.01\ \text{Nm}$$

Demanded torque for lowering:

$$T_{low\ max} = \frac{4500 \times 0.001 \times 0.61}{2\pi} = 0.44\ \text{Nm}$$

Demanded torque for accelerating the rotating masses:
considering the extremely small value of the specified axial speed 0,5 mm / sec = 30 rpm of the motor, the angular acceleration is very small and the accelerating torque can be neglected in the balance of the max. torque demanded to the motor.

**Total demanded torque: $C$ = 1.01 + 0.3 = 1.31 Nm**

<u>Motor: Inland Brush servomotor QT Series, type 2603</u>

| | | |
|---|---|---|
| Motor Constant | = 0.28 lb ft / sqrt(W) | = 0.38 Nm/sqrt(W) |
| Peak Torque | = 5 lb ft | = 6.78 Nm |
| Inertia | = $4 \times 10^{-4}$ lb ft $s^2$ | = $1.09 \times 10^{-4}$ Kg $m^2$ |
| Weight | = 3.5 lb | = 15.6 N |

<u>Brake: Electroid Failsafe brake EFSB Series, type EFSB35</u>

| | | |
|---|---|---|
| Rated static torque | = 35 lb in | = 3.95 Nm |
| Inertia | = 0.127 lb $in^2$ | = $3.5 \times 10^{-5}$ Kg $m^2$ |
| Weight | = 2.7 lb | = 12 N |

<u>Encoder: Heidenhain Incremental Encoder type ERO 1324</u>

| | |
|---|---|
| angular resolution | = 5000 line counts /rev (x 4) |
| resolution on 1 mm pitch screw | = 0,05 $\mu$m/cts |