

NX Based Motion Analysis of Mass Elevating Mechanism

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Abstract: NX based motion analysis of kinematic linkages for elevating mass is undertaken to Compute the displacement and position of screw actuator and equilibrator at various angles and this paper provide required torque for elevating mass by using NX on converting CAD geometry into functioning motion analysis model. NX results are validated with a analytic calculation for kinematic linkage of elevating mass.

Keywords: NX, MATH-CAD, kinematic linkage, motion analysis.

I. INTRODUCTION

Elevating mass elevates from -5° to 75° The equilibrator and screw actuator compensates the elevation mass. Two such equilibrators are incorporated which reduces the force required by the elevation mechanism to elevate the elevating mass. The equilibrator does not require any external power for its operation other than periodically charging and maintaining the nitrogen pressure. The equilibrator is designed to compensate 95% of the elevating moment at -5° elevation and 60% of elevating moment at 75° .

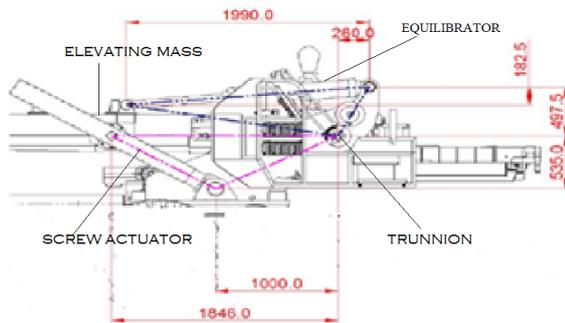


Fig. 1. Elevation Drive Kinematics

The difference in load, not supported by the equilibrator is taken by the roller screw actuator. Two roller screw actuators supports elevating mass as shown in the Fig. 1. The controlled extension and retraction of the roller screw actuator allows positioning in elevation axis. Mechanical stoppers are provided at both the limits of elevation angle.

II. ANALYTICAL CALCULATIONS

Elevating mass is elevating from -5° to 75° within 16 sec, for this maximum elevation angle (θ_{max}) is 75° and minimum elevation angle (θ_{min}) is -5° .

Total time (tt) required to elevate mass from -5° to 75° is 16 sec. At the start total accelerating time (ta) is 1 sec. Deceleration start at 15 sec and total deceleration time (td) is 1 sec.

Maximum angular velocity (ω_{max}) is calculated as,

$$\omega_{max} = \frac{\theta_{max} - \theta_{min}}{tt - 0.5 * (ta + td)}$$

Peak angular acceleration (α_{max}) is calculated as,

$$\alpha_{max} = \frac{\omega_{max}}{ta}$$

Mathcad is used for analytical calculations.

Angular acceleration equation: angular acceleration remains constant from time zero to ta equal to α_{max} and deceleration start at (tt-ta) equals to $-\alpha_{max}$

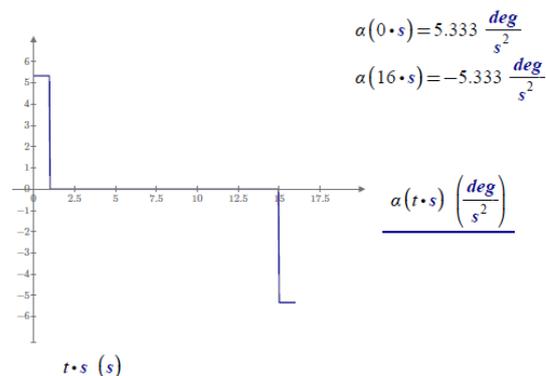


Fig. 2. Angular acceleration plot

Angular velocity Equation:

$$\omega(t) = \int_0^{tt} \alpha(t) * dt$$

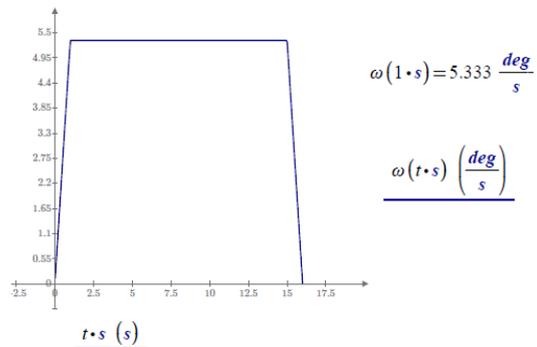


Fig. 3. Angular velocity plot

Angular Displacement Equation:

$$\theta(t) = \int_0^{tt} \omega(t) * dt$$

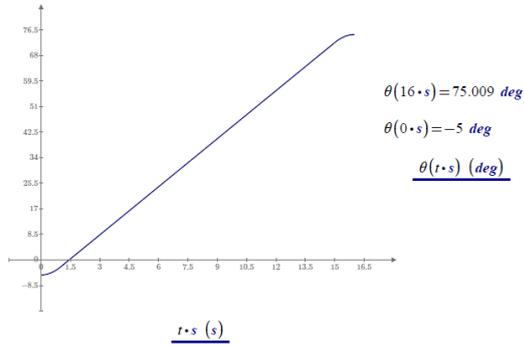


Fig 4: Angular Displacement plot

Elevating mass is elevating from -5° to 75° within 16 sec, for this maximum elevation angle (Θ_{max}) is 75° and minimum elevation angle (Θ_{min}) is -5° .

Kinematic linkages for equilibrator:

kinematic linkage layout of equilibrator is as follows,

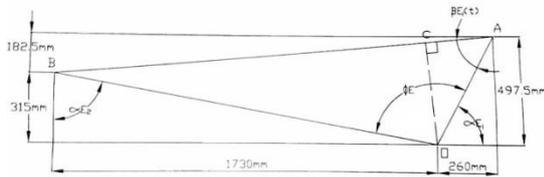


Fig.5 kinematic linkage layout of equilibrator

AB represents equilibrator link. Equilibrator extends at lower elevation angles and retracts at higher elevation angles. Kinematic triangle is used to calculate open length and close length of equilibrator. perpendicular length is used to calculate force in equilibrator.

Equilibrator length time domain

$$AB(t) = Et(t) =$$

$$\sqrt{OB^2 + OA^2 - 2 * OB * OA * \cos(\phi_E - \theta(t))}$$

Perpendicular length with respect to trunnion along the Equilibrator line of action

$$OC(t) = Er(t) = E1 * \sin \beta E1(t)$$

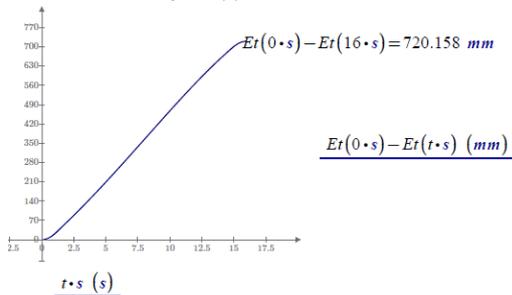


Fig 6: Equilibrator stroke length

Kinematic linkages for roller screw:

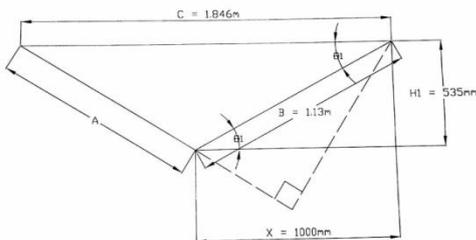


Fig 7: kinematic linkage for roller screw

The controlled extension and retraction of the roller screw actuator allows positioning in elevation axis. “A” represents roller screw link. Kinematic triangle is used to calculate open length and close length of roller screw. perpendicular length is used to calculate force in roller screw.

length of roller screw at various angle

$$\theta 2(t) = \theta 1(t) + \theta(t)$$

$$A(t) = \sqrt{B^2 + C^2 - 2 * B * C * \cos(\theta 2(t))}$$

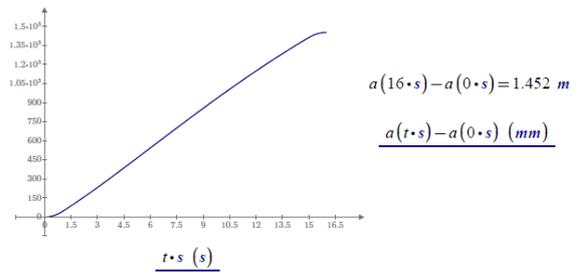


Fig 8: Roller screw stroke length

Perpendicular length with respect to trunnion along the roller line of action.

$$pr2(t) = \frac{\sin \theta 2(t) * B * C}{A(t)}$$

Dynamic gear ratio

The controlled extension and retraction of the roller screw actuator allows positioning in elevation axis.

Lead of roller screw pitch = 20 mm

Change in actuator length with respect to angle

$$a(\beta) = \sqrt{b^2 + c^2 - (2 * b * c * (\theta 1 + \beta))}$$

dynamic gear ratio

$$G(\beta) = \left(\frac{d}{d\beta} a(\beta) \right) * \frac{2 * \pi}{\text{pitch}}$$

Screw RPM:

$$Nscrew(t) = G(\theta(t)) * \omega(t)$$

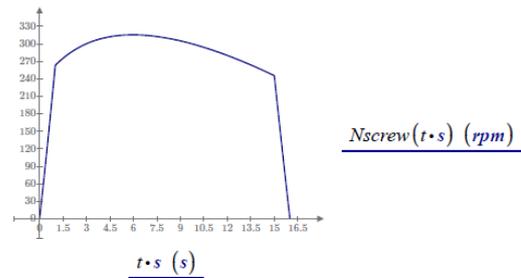


Fig 9: screw RPM

Dynamic analysis of elevation drive system:

There are two types of torques acting on the elevating mechanism about the elevation axis or main trunnion

1) torque due to Dead weight

2) torque due to inertial forces caused because of acceleration of elevating mass

T(t) is total torque due to elevating mass

Tbg(t) is torque compensated by the equilibrator.

CG of elevating mass from trunnion in X direction is $Dx = 2497 \text{ mm}$

CG of elevating mass from trunnion in Y direction is $Dy = 30 \text{ mm}$

So distance between trunnion and CG of elevating mass is

$$R = \sqrt{Dx^2 + Dy^2} = 2.497 \text{ m}$$

And angle of line joining CG and trunnion with respect to horizontal is $\gamma_1 = \tan^{-1} \left(\frac{Dy}{Dx} \right)$
Elevating mass is 6129 kg
Torque due to dead weight
Torque due to dead weight is $T_t(t) = M \cdot g \cdot R \cdot \cos(\theta(t) + \gamma_1)$

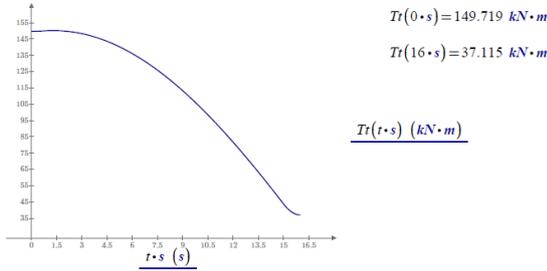


Fig 10 torque due to Dead weight

Torque balanced by Equilibrator
The Equilibrator is designed to compensate 95% of the elevating moment at -5 deg and gradual reducing to 60% at 75 deg

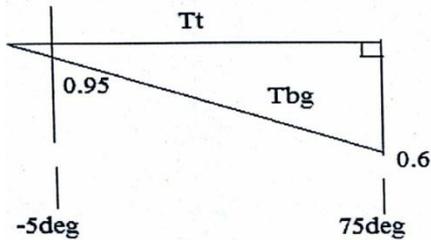


Fig 11. torque balanced by Equilibrator

$Y = m \cdot x + c$
At -5 deg torque compensated by equilibrator is 95%
At 75 deg torque compensated by equilibrator is 60%
 $0.95 = m \cdot (-5) + c \dots \dots (1)$
 $0.60 = m \cdot (75) + c \dots \dots (2)$
By solving this we get $m = 0.2506$ $c = 0.9281$
 $T_{bg}(t) = T_t(t) \cdot (m \cdot \theta(t) + c)$ this is generalize expression for T_{bg}

$T_{bg}(t) = T_t(t) \cdot (0.2506 \cdot \theta(t) + 0.9281)$

$F_{bg}(t)$ is force in equilibrator

$F_{bg}(t) = \frac{T_{bg}(t)}{oc(t)}$

$oc(t)$ is perpendicular length with respect to trunnion along the equilibrator line of action.

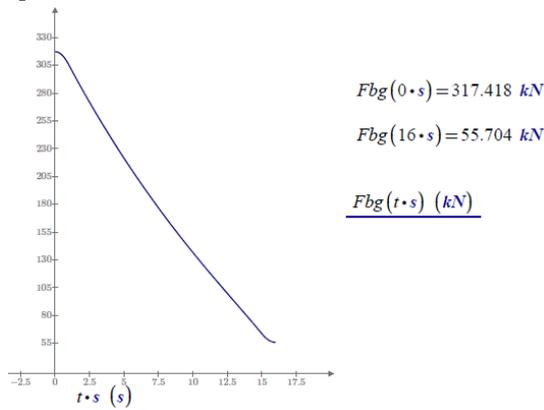


Fig 12. force in equilibrator

Torque due to inertial forces:
Moment of inertia of elevating mass is $76468205877 \text{ kg} \cdot \text{mm}^2$
Torque due to inertial forces caused because of acceleration of elevating mass.

$T_a(t) = \text{MOI} \cdot \alpha(t)$

Total torque:

Total torque is torque due to dead weight and inertial forces.

$T_1(t) = T_t(t) + T_a(t)$

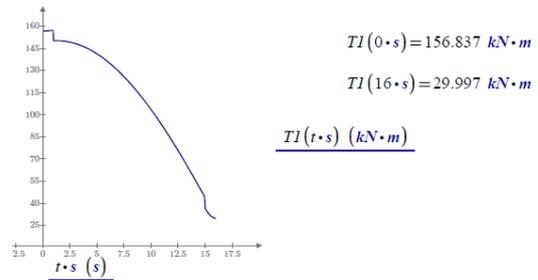


Fig.13 total torque

Torque compensated by actuator is difference between total torque and torque compensated by equilibrator
 $T_{es}(t) = T_1(t) - T_{bg}(t)$

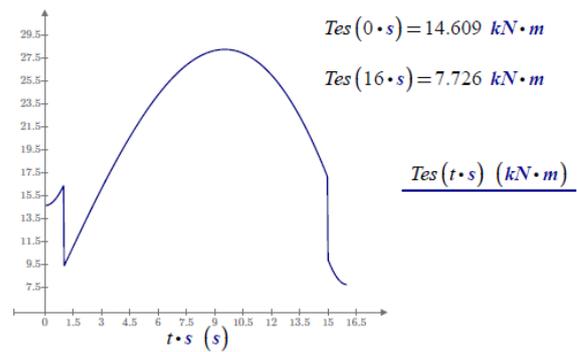


Fig.14 torque compensated by screw actuator

Load on actuator:

Force on both actuator is $F_{es}(t) = \frac{T_{es}(t)}{pr^2(t)}$

Torque at actuator input end:

Pitch=20mm

$T_{screw}(t) = \frac{F_{es}(t) \cdot \text{pitch}}{2 \cdot \pi}$

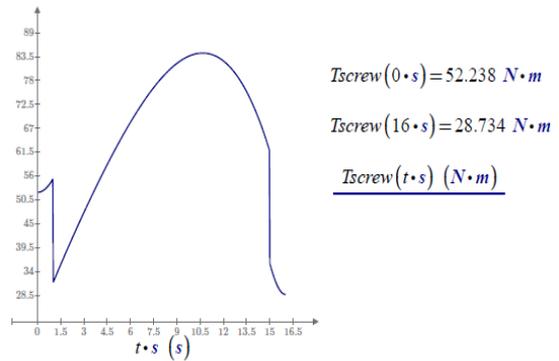


Fig.15. Torque at actuator input end

III. NX ANALYSIS OF ELEVATING MASS MECHANISM

NX based analysis of kinematic linkages of mass elevating mechanism is undertaken to Compute the displacement and position of roller screw and equilibrator at various angles.

Interference Checking:

NX can solve kinematic linkages problems because it provides a true multibody dynamic solver that can compute the displacement and position of assembly components connected to springs and bodies. Additionally, NX makes it quick and easy to solve motion analysis directly within the NX environment because it can convert the CAD geometry assembly into a motion model. By using your geometry directly, we can then get a true understanding of how your mechanism will behave in its operating environment, and determine whether we need to make design changes to avoid interference issues.

Selection of driver for elevating mass mechanism:

NX can solve kinematics problems and provides torque and force in any link that specified in a motion simulation. we can provide input in form of acceleration ,velocity and displacement to kinematic link. NX converts CAD model into motion model on applying driver at any joint.

Kinematic-Simulation – The motion simulator

Creating the Kinematic-Simulation

Some pre-settings have to be done before the kinematic-simulation could be started. The assembly, which was created is loaded first. The environment is changed to kinematics through the main menu, “Start”.

The kinematics module in NX is called “Motion Simulation”

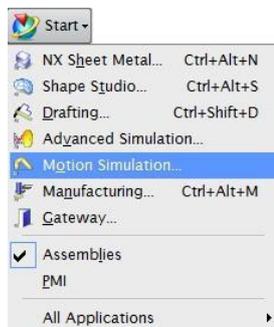


Fig.16. Motion simulation

The kinematics module in NX is called “Motion Simulation”

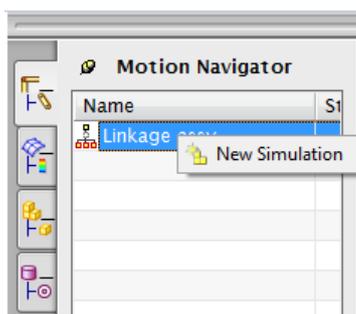


Fig.17. New simulation

Right click on the loaded assembly and select a “New Simulation”. A new window “Environment” now opens.

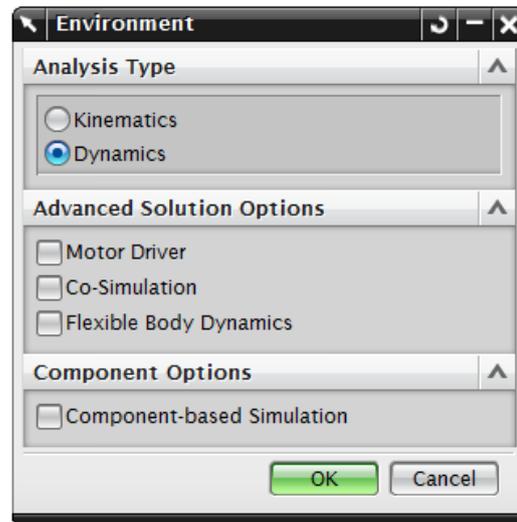


Fig.18. Dynamics analysis

The analysis type is selected in this window as “Dynamic”. The dynamic analysis type is confirmed with the “OK” button.

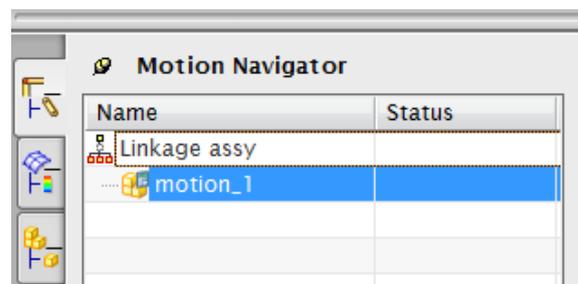


Fig.19. Motion_1

A new simulation “motion_1” is thus created as seen in the picture.

Defining links:

As the first step in motion analysis, the “Links” must be defined. Defining the links allows to set which parts of the assembly should have movement. This is one of the important requirements to construct the motion model

On clicking “Link” option opens a new window. objects selected from the assembly. If more than one component is selected as a link, they always move together in the simulation.

While defining link if you want to fix the link. Then click on “fix the link”

In this model saddle is fixed

Defining joints:

The subsequent step is to define “Joints”, which simulates a rotating motion in between these links. A joint describes the relative movement of bodies, relative to the other.

A mouse click on the “Joint” button opens a new window.

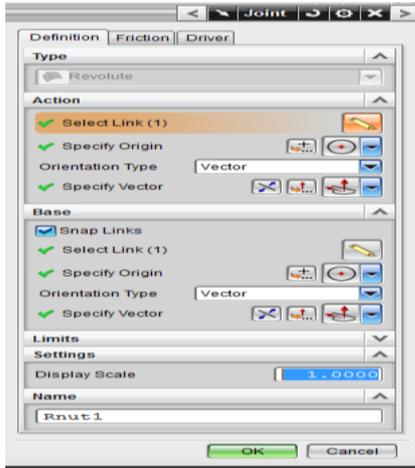


Fig.20. Defining joints

Under “Action” menu, the connecting body movements have to be defined. The body has to be selected as a whole.

Under the Menu “Base”, the base link has to be selected. The base link has to be connected with the “Joint”, which is created in the first step. The appropriate link is selected, The same is step is repeated for the other links too. Hence joints are created.

While specifying origin, origin must be same for the both links. And vector directions should be in same direction.

Defining driver for model:

The motion simulator now requires a “Drive”. Gravity can be a driver at the first instance. The acceleration due to gravity can be simulated and for this purpose, the direction of the gravity must be input. This is done as follows

Preferences > Motion > Gravitational constants and input the value $G_z = -9806.65$, for defining the acceleration due to gravity in the negative “Z” direction.

Defining driver for mass elevating mechanism:

mass is elevating from -5 to 75 deg in 16 sec. we know angular acceleration plot for 16 sec at various angle conditions. Elevating mass is rotating about trunnion so angular acceleration is applied at trunnion joint as driver. Screw RPM is calculated by taking plot at joint Rnut.

Driver is changed from trunnion to screw .

Solution:

The button “Solution” (Which is a command in the motion menu) is clicked upon. The following information window opens:

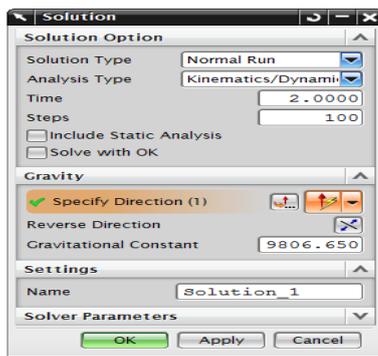


Fig.21. Solution

As solution type, the “Normal Run” is selected and as the Analysis type, “Kinematics/Dynamics” is chosen.

As an example, the “Time” is input as 2 seconds and the number of “Steps” is defined as 100. All parameters are confirmed with “OK”. The motion navigator in the model tree will now have a new entry “Solution_1”, with relevant sub-entries.

With the command (button) “Solve” the entries are calculated. An information window appears indicating the redundant degrees of freedom (or constraints). A redundant constraint means that the degree of freedom of the system is over-determined. The over-determination of complex assemblies can lead to conflicts. To make sure that we arrive at a conflict-free solution, these provisions are eliminated automatically by the motion analyser.

IV. VALIDATION OF RESULTS

NX can provides torque and force in any link that specified in a motion simulation. we can provide input in form of acceleration ,velocity and displacement to kinematic link.

Validation of NX motion analysis with analytical calculations:

Angular acceleration of elevating mass:

Plot is taken at trunnion joint

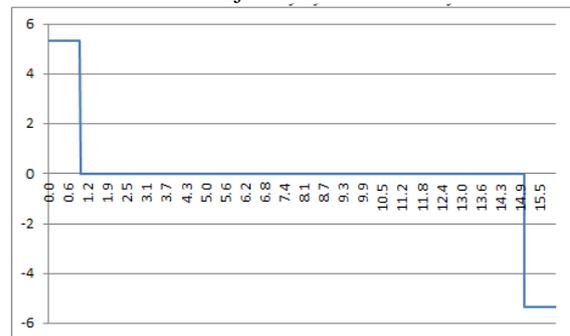


Fig 22: Angular acceleration(m/s^2) vs time(sec)

Angular velocity of elevating mass:

Plot is taken at trunnion joint

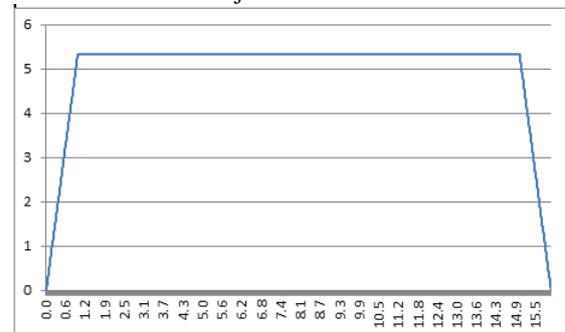


Fig 23: Angular velocity(m/s) vs time(sec)

No deviation in analytical and NX motion result

Angular displacement of elevating mass:

Plot is taken at trunnion joint

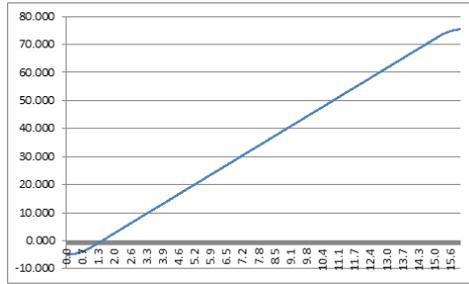


Fig 24: Angular displacement vs time

Elevating mass is elevating from -5° to 75° as per requirement. no deviation in analytical and NX motion result.

Equilibrator stroke length:

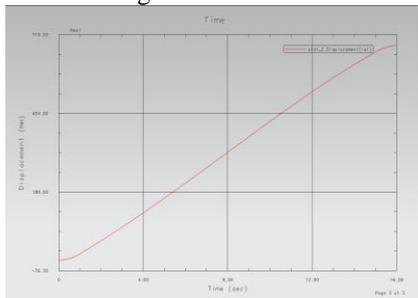


Fig 25: Equilibrator stroke length

Equilibrator is working with in described limit. no need to make design changes. no interference issue with equilibrator.

Roller screw stroke length:

Roller screw is working with in described limit. no need to make design changes. no interference issue with Roller screw.

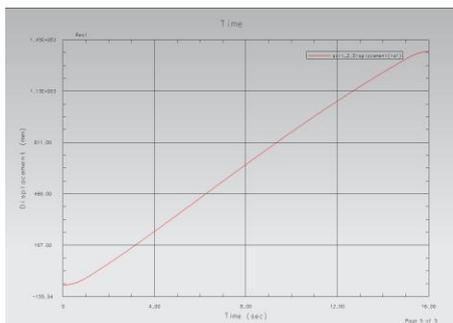


Fig 26: Roller screw stroke length

Screw RPM:

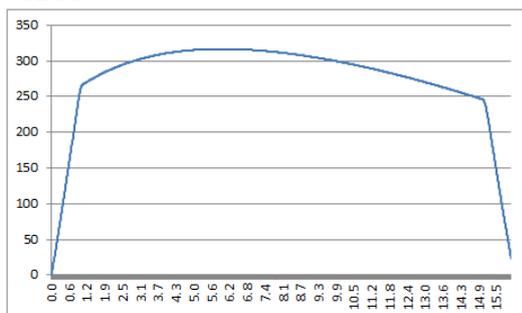


Fig 27: screw RPM vs time(sec)

Maximum screw RPM is about 312 in both analytical and NX result. no deviation in result

Dynamic analysis of elevation drive system:
Force in Equilibrator

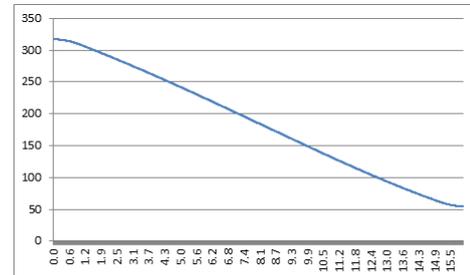


Fig 28: force in equilibrator (kN) vs time(sec)

At starting force in equilibrator is 317kN and decreases to 54 kN at the end.

Force in equilibrator is getting near about equal to analytical calculation

Total torque is due to elevating mass and moment of inertia.

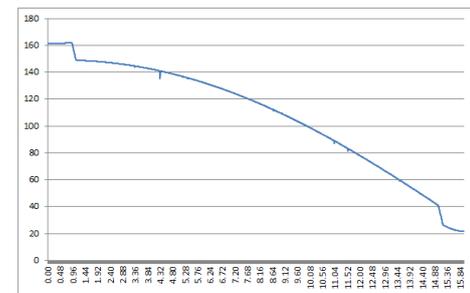


Fig 29: Total torque (kN*m) vs time(sec)

Total torque at starting in analytical calculation is 156.83kN*m and Total torque at starting in NX result is 161 kN*m. difference is due MOI. while analytical calculation MOI is considered as constant. But in NX motion simulation change in MOI is considered

Torque compensated by Roller screw

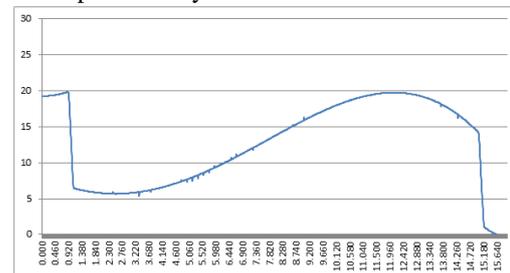


Fig 30. Torque compensated by roller screw (kN*m) vs time(sec)

Torque compensated by Roller screw is difference between total torque and torque compensated by equilibrator. Torque compensated by Roller screw at starting in analytical calculation is 14.60kN*m and Torque compensated by Roller screw at starting in NX result is 19.89 kN*m. difference is due to difference in Total torque.

Torque at roller screw input end:

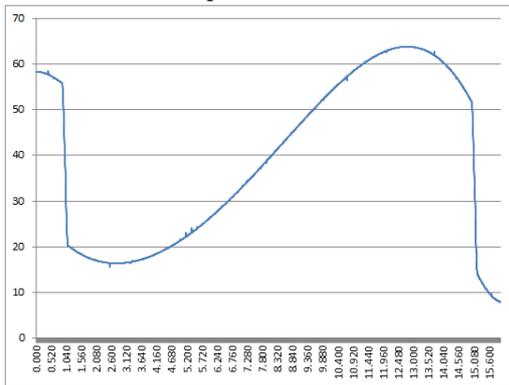


Fig 31. Torque at roller screw input end (kN*m) vs time(sec)

This is required torque to be applied at roller screw to elevate mass from -5° to 75° without considering any type of efficiency

V. CONCLUSION

NX motion analysis were performed for interference checking and to calculate required torque at roller input end to elevate mass from -5° to 75° .

Equilibrator and roller screw are working within given stroke limit. no need to make design changes and there is no interference issue. To elevate mass from -5° to 75° the required input torque is calculated. Maximum required torque is $63.70\text{kN}\cdot\text{m}$. The equilibrator is compensating 95% of the elevating moment at -5° elevation and 60% of elevating moment at 75° .

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a DMII, Università degli Studi Guglielmo Marconi, Roma 00193, Italy
- [5] 4,012,986 Mar. 22, 1977 Raimond Germershausen, Kaarst; Wilfried 'Becker, Duesseldorf, both of-Germany.