

Dynamic Aspects Relating to the Design of a Quasi-motion Platform

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Abstract

To give a higher-quality simulator experience, a platform is constructed for the user to stand on. The platform rotates through a limited distance about two axes to give the sensation of motion. The actuators that are used to tip the platform up and down have a finite ability to generate force, and therefore must be designed to provide sufficient force, angular displacement, and angular frequency. A distance of eighteen inches between the pivot point and each actuator was chosen to satisfy these competing requirements.

Keywords

Actuator – a device which only moves up and down

Polar Moment of Inertia – resistance to angular acceleration; the higher the polar moment of inertia, the harder it is to speed up/slow down rotation

Quasi-motion – Rotational motion about two axes only; no actual translational motion, but intended to give the impression of translational motion

Introduction

In order to give a realistic feeling of motion to the user of a computer simulation, a platform is designed for them to stand on. Through the use of hydraulic actuators, the platform oscillates about a central point through a limited range of motion. This provides the user with a feeling of acceleration without significant platform motion. Thus, the

main design concerns from a mechanical standpoint are geometrical in nature and require careful consideration.

Objective

This application note is intended to provide insight and instruction into the mechanical aspects of the design of a quasi-motion platform for computer simulation use. It will cover the gross geometrical concerns as well as the dynamic considerations.

Issues

The first issue in designing a quasi-motion platform lies in the determination of the overall geometry of the platform. Although this has significant implications on the performance and weight of the platform, it is primarily a function of the application for which the platform is being designed. For the current application, which is the simulation of the pilot cabin of a tugboat, the dimensions selected were six feet front-to-back and eight feet side-to-side. These dimensions were chosen because they would allow the platform to closely approximate the dimensions of the actual tugboat being simulated.

Once the size of the footprint is decided, the spacing of the hydraulic actuators must be determined. This decision lies at the heart of the design of the motion platform. The hydraulic actuators can only produce a limited amount of force. In this application, the hydraulic actuators are Goodyear air cushion springs which have been filled with oil instead of air. Each actuator has a diameter of 4", and can handle pressures up to 100 psi. As force is equal to the product of pressure and area, the resultant force output is approximately 1250 lbs.

$$F = P * \pi * r^2$$

$$\Rightarrow F = 100 \text{ psi} * \pi * (2 \text{ in.})^2$$

$$\Rightarrow F = 1257 \text{ lbs.}$$

As a result of the limit placed on the force that the actuators can produce, a corresponding limit is also placed on the platform dynamics. The reason for this is that the rotational motion of oscillating the platform requires the application of a torque to the platform. Torque (τ) is defined as the product of force and the distance between the rotational center and the applied torque. ($\tau = F * d$)

The force is now fixed at 1250 lbs., which sets the torque at 1250*d ft-lbs. The “d” term represents the distance between the pivot point and an actuator. Here, a trade-off exists. As the actuators are spaced out further and further from the pivot point, the torque produced increases linearly. Simultaneously, the maximum amplitude of the oscillation is decreases linearly. It is desirable to maximize the amplitude, while still having sufficient torque to move the platform. Therefore, the minimum necessary torque must be determined.

Here, torque becomes $\tau = J * \alpha$, where J is the polar moment of inertia of the platform and α is the angular acceleration of the platform. α is equal to the product of the maximum angular amplitude and the square of the frequency of oscillation.

($\alpha = A * f^2$) The higher the frequency, the faster the platform will move.

To estimate the polar moment of inertia of the platform, the masses and positions relative to the center of rotation were estimated for the steering console, ceiling, floor, front wall, side wall (x2), and user (x2). Once each was determined, they were summed together to produce an estimate of the polar moment of inertia (J). The formula used for

determining the polar moment of inertia for each component was

$$\frac{\left[(\text{height of component})^2 + (\text{width of component})^2 \right] * \text{mass of component}}{12} + \text{mass of component} * \left[(\text{y dist from center of component to center of rotation})^2 + (\text{x dist from center of component to center of rotation})^2 \right]$$

The resultant estimate for polar moment of inertia was approximately 920 slug-ft², and the estimated total mass was 1300 lbs. Since the total mass is distributed between the actuators and the pivot point (which is a universal joint that acts as a structural component), the static load is not going to exceed 1250 lbs. on the actuator.

Putting all of the equations used so far together, the equation becomes

$d = 0.736 \text{ s}^2 \text{ ft} * A * f^2$, where A is the angular amplitude of the oscillation, and f is the frequency of the oscillation.

Conclusions

A set of frequencies from 0.1 Hz to 0.5 Hz were examined in 0.1 Hz intervals, for angular amplitudes of 1° to 15° in 1° increments. (see Table 1) All calculations were done in Microsoft Excel. This analysis showed that with a factor of safety of two, and eight inches separating the top platform and bottom platform at the pivot point, all angular amplitudes could be accommodated at a frequency of 0.3 Hz when the actuators were placed eighteen inches from the pivot point (see Table 2). This would compress one actuator to five inches and expand the opposite actuator to eleven inches. This was deemed acceptable because it would limit the expansion of the actuators to less than 50% of their nominal height. In this case, the decision was made to favor the range of motion over the speed of motion.

Table 1. Frequency v. Amplitude

	alpha	Amplitude (deg.)	Torque needed (ft- lb)			Amplitude (deg.)	Torque needed (ft- lb)
0.1 Hz	0.00689	1	6.331012526	0.4 Hz	0.110245	1	101.2962004
	0.013781	2	12.66202505		0.220489	2	202.5924008
	0.020671	3	18.99303758		0.330734	3	303.8886012
	0.027561	4	25.3240501		0.440978	4	405.1848017
	0.034451	5	31.65506263		0.551223	5	506.4810021
	0.041342	6	37.98607516		0.661467	6	607.7772025
	0.048232	7	44.31708768		0.771712	7	709.0734029
	0.055122	8	50.64810021		0.881956	8	810.3696033
	0.062013	9	56.97911273		0.992201	9	911.6658037
	0.068903	10	63.31012526		1.102445	10	1012.962004
	0.075793	11	69.64113778		1.21269	11	1114.258205
	0.082683	12	75.97215031		1.322934	12	1215.554405
	0.089574	13	82.30316284		1.433179	13	1316.850605
	0.096464	14	88.63417536		1.543424	14	1418.146806
	0.103354	15	94.96518789		1.653668	15	1519.443006
0.2 Hz	0.027561	1	25.3240501	0.5 Hz	0.172257	1	158.2753131
	0.055122	2	50.64810021		0.344514	2	316.5506263
	0.082683	3	75.97215031		0.516771	3	474.8259394
	0.110245	4	101.2962004		0.689028	4	633.1012526
	0.137806	5	126.6202505		0.861285	5	791.3765657
	0.165367	6	151.9443006		1.033543	6	949.6518789
	0.192928	7	177.2683507		1.2058	7	1107.927192
	0.220489	8	202.5924008		1.378057	8	1266.202505
	0.24805	9	227.9164509		1.550314	9	1424.477818
	0.275611	10	253.240501		1.722571	10	1582.753131
	0.303172	11	278.5645511		1.894828	11	1741.028445
	0.330734	12	303.8886012		2.067085	12	1899.303758
	0.358295	13	329.2126513		2.239342	13	2057.579071
	0.385856	14	354.5367014		2.411599	14	2215.854384
	0.413417	15	379.8607516		2.583856	15	2374.129697
0.3 Hz	0.062013	1	56.97911273				
	0.124025	2	113.9582255				
	0.186038	3	170.9373382				
	0.24805	4	227.9164509				
	0.310063	5	284.8955637				
	0.372075	6	341.8746764				
	0.434088	7	398.8537891				
	0.4961	8	455.8329019				
	0.558113	9	512.8120146				
	0.620126	10	569.7911273				
	0.682138	11	626.7702401				
	0.744151	12	683.7493528				

	0.806163	13	740.7284655
	0.868176	14	797.7075783
	0.930188	15	854.686691

Table 2. Pivot-to-actuator spacing v. torque

spacing (ft)	torque (ft-lb)
0.25	300
0.5	600
0.75	900
1	1200
1.25	1500
1.5	1800
1.75	2100
2	2400
2.25	2700
2.5	3000
2.75	3300
3	3600

References

“Quasi-Motion Tipper Platforms”

<http://www.piengineering.com/custom/quasimotion.php>, retrieved on Nov. 6th,

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