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Optimization Design of Structure Shape and Dimension of Anti-sway Plate in Propellant Tank of Liquid Launch Vehicle

Rui Zhang and Jian Liu***
**Land Space Technology Corp. Ltd*
101, Building H1, AVIC Plaza, BDA,Daxing Dist., Beijing, 100176, P. R. China and Zhangrui_dut@163.com
***Land Space Technology Corp. Ltd*
101, Building H1, AVIC Plaza, BDA,Daxing Dist., Beijing, 100176, P. R. China and Liujian_dut@163.com

Abstract
The characteristics of liquid propellants sloshing in flight have generated significant influence for flight stability of the large-scale liquid-propellant launch vehicles. Slight sloshing of liquid propellants may lead to the center of propellants' mass to shift, thus affecting the flight stability of the overall structure of launch vehicle. To ensure the liquid launch vehicles' flight stability, sloshing of the liquid propellant must be controlled and restrained to avoid coupling effect between the sloshing vibration of liquid propellants and the natural vibration of the whole structure. The common solution is to install an anti-sway plates in the tank. When it comes to this solution, both the structural and dimensions of the tank and the anti-sway plate will affect the sloshing characteristics of the overall structure. Based on the optimal design of structure shape and dimension of anti-sway plate in the tank of liquid launch vehicle, a reasonable tank model is obtained. This model can provide guidelines for improving the flight stability of liquid launch vehicles.

1. Introduction

Variable acceleration, which is led by variable thrust, wind shear, blast of wind, causes sloshing throughout its flight. The characteristics of liquid propellants sloshing in flight have generated significant influence for flight stability of the large-scale liquid-propellant launch vehicles, which increase the difficulty of flight stability design and flight safety, such as deviate from spacecraft trajectories even explosion of rocket. Thus, sloshing of the liquid propellant must be controlled and restrained to avoid coupling effect between the sloshing vibration of liquid propellants and the natural vibration of the whole structure. There are three ways to improve dynamic behaviour of the liquid sloshing, raising sway frequency, and decreasing sway mass and sloshing suppression. The common solution is to install an anti-sway plates in the tank. There are several forms of anti-sway damper, circular, tapered, flexible and semicircular. Semicircular anti-sway damper is prior to other anti-sway damper. In the same thickness, semicircular anti-sway has smaller area than circle anti-sway. In the same area, compared to the circle anti-sway, semicircular has higher damper with certain range.

1.1 Optimization formula

The optimization formula is as follows

$$\text{Find} \quad h(i,j), \mathrm{r}(i,j) \quad (i=1,2,\cdots,n; j=1,2,\cdots,m) \tag{1}$$

$$\text{Min} \quad W(i,j) \quad (i=1,2,\cdots,n) \tag{2}$$

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$$\text{Obj} \quad \xi(i) - a \geq 0 \tag{3}$$

$$\text{S.T.1} \quad h(i,j) < H\_1(i) - H\_1(i-1) \tag{4}$$

$$\text{S.T.1} \quad 0 < r(i,j) < R/2 \tag{5}$$

1.2 Explanation of the notations

The formulation of the optimization problem can be expressed as Eq. (1) to (5), where design variables *h*(*i*,*j*) are the distance between anti-sway plate and liquid level, *n* is the total number of liquid level concerned, *m* is the total anti-sway plate number in the iterative process. Design variables *r*(*i*,*j*) are the radius of anti-sway plate. The objective function minimize the weight of anti-sway plate and the damper of the tank is greater or equal to a constant, which is obtained by the attitude control system. Constraint function 1 represents that each anti-sway plate is located between two adjacent liquid levels. Constraint function 2 aims to illustrate that radius of each anti-sway plate is shorter than the radius of the tank (H_total).

2. Optimal flowchart and approach of each liquid level

Figure 1 is the optimal flowchart and approach of each liquid level. Firstly, some samples points are extracted from the original experimental data based on DOE, and the method of DOE is Opt LHD. Secondly, surrogate model is built by Kriging model for predicting the damper of the fuel tank with different liquid levels and anti-sway plates, which is regarded as a method of functional model of a stochastic process. If accuracy of the approximate method can meets the requirements, PSO is used to optimize the position and radius of anti-sway plates. Otherwise, some new sample points should be added into the sample points set and surrogate model be rebuilt.

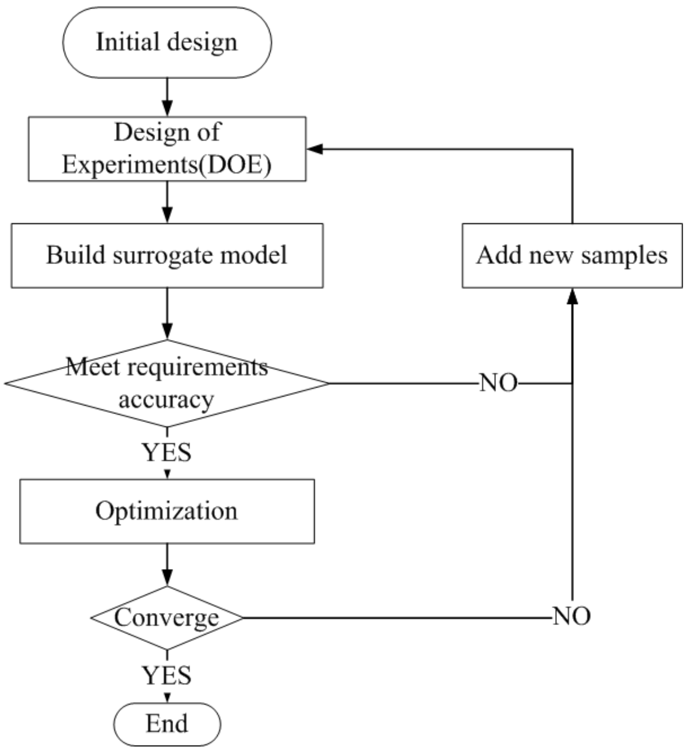

Figure 1: Flowchart of the optimization process

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$$\%\text{RMSE} = 100\frac{\sqrt{(1/n)\sum_{j=1}^{\text{time\_total}}\left(\xi_j - \hat{\xi}_j\right)^2}}{(1/n)\sum_{j=1}^{\text{time\_total}}\xi_j} \quad (6)$$

$$\%\text{AvgErr} = 100\frac{\sqrt{(1/n)\sum_{j=1}^{\text{time\_total}}\left|\xi_j - \hat{\xi}_j\right|}}{(1/n)\sum_{j=1}^{\text{time\_total}}\xi_j} \quad (7)$$

$$\%\text{MaxErr} = \text{Max}\left[\frac{100\left|\xi_j - \hat{\xi}_j\right|}{(1/n)\sum_{j=1}^{\text{time\_total}}\xi_j}\right] \quad (8)$$

Table 1: Anti-sway plate number vs. anti-sway plate position

r=0.618	
Anti-sway plate number	Anti-sway plate position(m)
1	9.03
2	8.49
3	7.80
4	7.23
5	6.68
6	6.13
7	5.70
8	5.01
9	4.30
10	3.62
11	3.04
12	2.36
13	1.79
14	1.10
15	0.71

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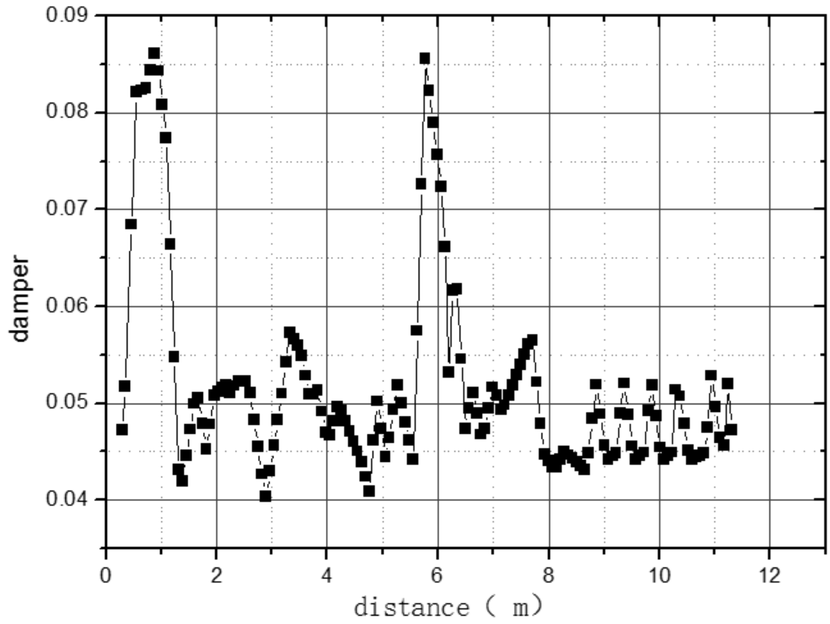

Figure 2: The relation between anti-sway plate number and anti-sway plate position

The numerical example illustrates the advantage of the proposed method over experiment both from the cost of time, money to accuracy. This optimization can provide guidelines for improving the flight stability of liquid launch vehicles.

References

[1] Bauer H f. fluid oscillation in the containers of a space and their influence on stability[R],NASA TR-187,1964
[2] The Damping Factor Provided by Flat Annular Ring Baffles for Free Fluid Surface Oscillations , Banuer ,H .F.
[3] Optimizing Latin hypercube designs by particle swarm, Ray-Bing Chen.
[4] Multi-objective optimization of coronary stent using Kriging surrogate model Kriging approximate method, Hongxia Li.
[5] Particle Swarm Optimization, Eberhart