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# AN ANALYTICAL STUDY ON THE DYNAMIC CHARACTERISTICS OF A LIQUID PROPULSION SYSTEM

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## ABSTRACT

The longitudinal instability (POGO) of the rocket should not be occurred during the whole flight time for the large class liquid propulsion system to complete a mission successfully. The longitudinal instability is caused by the resonance between the propulsion system and rocket structure in the low frequency range below 50Hz, ordinarily. Analysis on the low frequency dynamic characteristics on the liquid propulsion system with staged combustion cycle engine system was performed as a preliminary study on the longitudinal instability analysis.

*Keywords*: longitudinal instability, POGO, rocket, propulsion system, dynamic characteristic

## 1. INTRODUCTION

A rocket is the elastic mechanical system where various forms of mechanical oscillations may arise under the action of disturbing forces. From the viewpoint of the longitudinal stability problem of rockets, the interaction between the rocket structure and liquid propulsion system results in oscillating the rocket body longitudinally. If these forms of oscillations occur the rocket is distorted along the longitudinal axis. The phenomenon of the longitudinal instability of rocket (POGO) show that such forms of mechanical oscillations of the rocket are caused by pressure oscillations for the most part at the inlet of the engine system at the expense of oscillations of axial acceleration. Also, the state-of-the-art shows that the primary data for calculations of longitudinal stability of rockets is the frequency responses of the engine system represented by following equation:

$$\frac{\delta\bar{R}}{\delta\bar{p}_{o0}}k_o(i\omega),\quad \frac{\delta\bar{R}}{\delta\bar{p}_{f0}}k_f(i\omega),\quad \frac{\delta\bar{G}_o}{\delta\bar{p}_{o0}}k_{o,o}(i\omega),$$
$$\frac{\delta\bar{G}_o}{\delta\bar{p}_{f0}}k_{o,f}(i\omega),\quad \frac{\delta\bar{G}_f}{\delta\bar{p}_{o0}}k_{f,o}(i\omega),\quad \frac{\delta\bar{G}_f}{\delta\bar{p}_{f0}}k_{f,f}(i\omega) \tag{1}$$

Here, $\delta\bar{R}$ means dimensionless amplitudes of engine thrust oscillations and $\delta\bar{p}_{o0}$ and $\delta\bar{p}_{f0}$ represent dimensionless amplitudes of pressure oscillations at each pump inlet. Also, $\delta\bar{G}_o$ and $\delta\bar{G}_f$ denote the dimensionless amplitudes of oscillations of oxidizer and fuel flows at the engine system inlet. This article deals with the frequency responses of the liquid propulsion system used in the longitudinal stability problems.

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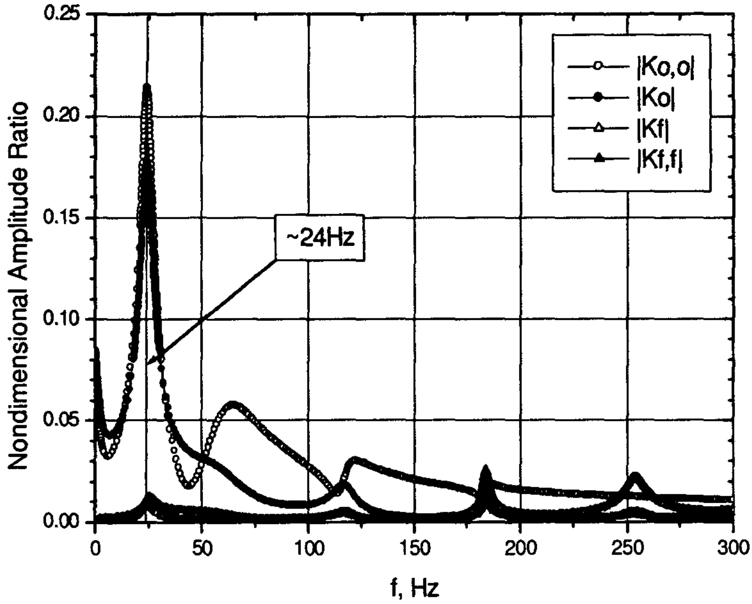


Figure 1. Amplitude-frequency characteristics ($|k_{o,o}|$, $|k_{f,f}|$, $|k_o|$, $|k_f|$).

## 2. CONSTRUCTION OF THE LINEAR MATHEMATICAL MODEL OF THE LOW FREQUENCY DYNAMICS OF THE PROPULSION SYSTEM

A staged combustion cycle engine system composed by Lee et al. (2004) with a 13tf thrust and 80 bar chamber pressure using LOX and kerosene was taken as the example for analysis on the longitudinal stability of rocket.

To solve the stability problems, it is sufficient to describe low-frequency dynamic characteristics of the system for small deviations from an equilibrium position, that is, a set of linearized equations in the neighborhood of the stationary mode of operation. The equations obtained by Lee et al. (2004) are composed of a set of linear differential equations with retarded arguments and constant coefficients and may be represented as following matrix form:

$$W(\omega) \cdot \delta\bar{x} = d \cdot \delta\bar{y} \tag{2}$$

Here, $W(\omega)$ and $\delta$ are the matrix of complex coefficients for the components of the liquid propulsion system and gain coefficients of disturbing actions, respectively. And $\delta\bar{x}$ and $\delta\bar{y}$ denote the column-vector of dimensionless internal variables and external variables such as $\delta\bar{p}_{o0}$ and $\delta\bar{f}_{o0}$, respectively.

## 3. RESULTS

With the help of the mathematical model formed the calculations of above frequency responses (eq. (1)) were conducted. Figures 1 and 2 show a strong dependence of the dimensionless amplitude ratios on frequency in the whole frequency range of our interest (for longitudinal stability problems it may be limited by range from 0 to 50 Hz). The amplitude-frequency characteristic has a pronounced

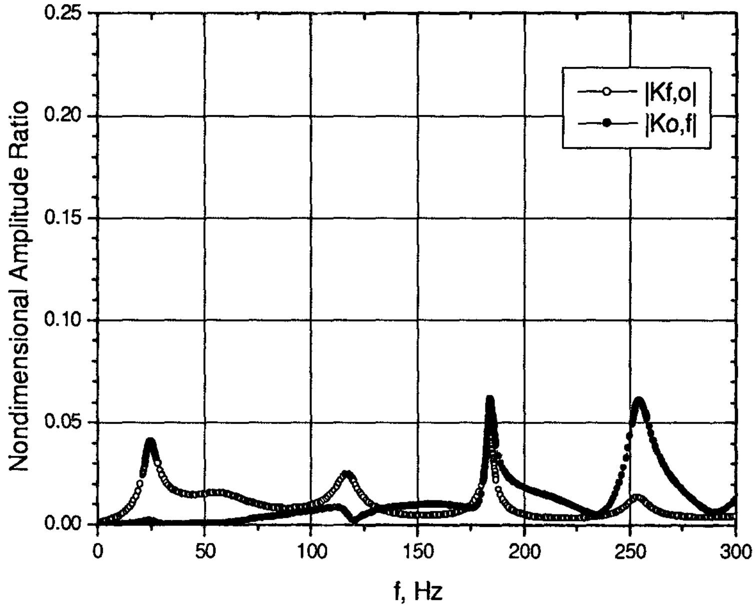


Figure 2. Amplitude-frequency characteristics ($|k_{o,f}|$ and $|k_{f,o}|$).

resonant maximum also. The coefficient $|k_{o,o}|$ has the maximum value (Figure 1) at 24 Hz frequency. Also, Figure 1 shows oscillations of the fuel flow are more strongly affected by pressure oscillations at the oxidizer pump inlet than by those at the fuel pump inlet. Figure 2 shows that the influence of pressure oscillations at the fuel pump inlet on those of the oxidizer flow oscillations (the coefficient $|k_{o,f}|$) is insignificant (in particular, in the range 0 to 50 Hz) for the propulsion system at hand. Also, we can find that the value of $|k_o|$ is much more than that of $|k_f|$ from Figure 1.

Oscillations of the pump inlet pressure and the flow of that propellant which has the longer pipeline exert a governing action on longitudinal stability. In this case, that is the oxidizer line and the characteristics $k_o$ of $k_{o,o}$ and are more important. This fact is confirmed form Figures 1 and 2, that is, the magnitudes of amplitude maxima of these parameters are higher than those of others.

## 4. CONCLUSIONS

The frequency responses necessary for solution of the longitudinal stability problem were calculated with the help of the mathematical model for low-frequency dynamics of the propulsion system. The analysis on the frequency responses such as $k_o$, $k_f$, $k_{o,o}$, $k_{o,f}$, $k_{f,f}$, and $k_{f,o}$ represented by eq. (1) shows that the main characteristics which may exert some action on rocket longitudinal stability are $k_c$ and $k_{o,o'}$ (the characteristics in the oxidizer line).

## REFERENCES

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