A fluid transient analysis for the propellant flow with an unsteady friction in a monopropellant propulsion system

Jongwon Chae*, Cho Young Han

Communication, Ocean, and Meteorological Satellite Program Office
Korea Aerospace Research Institute(KARI)
45 Eoeun-dong, Yuseong-gu, Daejeon, 305-333 Republic of Korea
E-mail:firstbel@kari.re.kr - Web page: http://www.kari.re.kr

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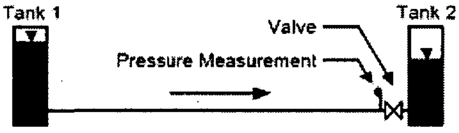
ABSTRACT

A fluid transient analysis on the Koreasat 1 & 2 pipeline system is conducted through numerical parametric studies in which unsteady friction results are compared with quasi-steady friction results and show relatively accurate prediction of the response curve with the unsteady friction. The code developed and used in this analysis has finished verification through comparing with the original Zielke model, the full and recursive convolution model and quasi-steady model as a reference. The unsteady friction is calculated by the recursive convolution Zielke model in which a complete evolution history of velocity field is no longer required so that it makes the fluid transient analysis on the complicated system possible. The results show that the application of quasi-steady friction to model cannot predict the entire response curve properly except the first peak amplitude but the application of unsteady friction to model can predict reasonably the response curve, therefore it is to know the characteristics of the propulsion system.

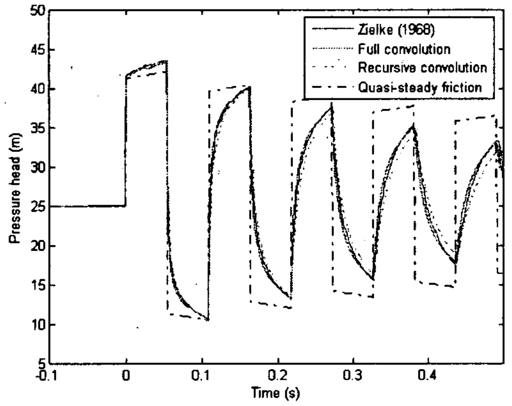
MODEL VALIDATION AND PROPULSION SYSTEM

The model validation is conducted through a comparison with results of the standard water hammer algorithms and experimental data [8]. In Fig. 1 the flow simulation details are presented. Computational results from the present models (full convolution and recursive convolution model) and the original Zielke model are compared and depicted in Fig. 2 and its FFT results that to show differences of power spectral density in Fig. 3. All of Computational results meet the result of well-proven Zielke model but the result of quasi-steady friction model agree well for only the first period of the transient (4L/a).



Laminar Flow Simulation Details
L = 36.088 m; H_2 = 25.0 m, V_0 = 0.12 m/s,
a = 1324.356 m/s; D = 25.4 mm; g = 9.81 m/s^2;
ν = 39.67×10^{-6} m^2/s; ρ = 998.2 kg/m^3, Re = 76.8

Fig. 1 Flow Simulation Details [8]



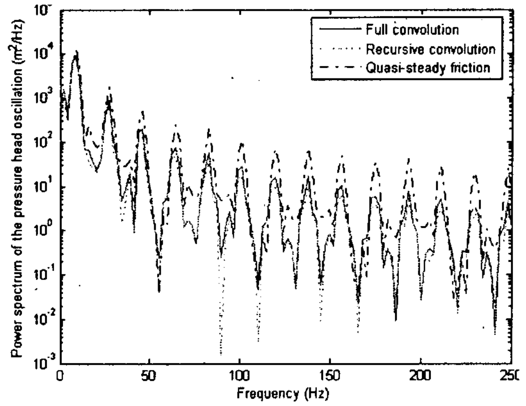
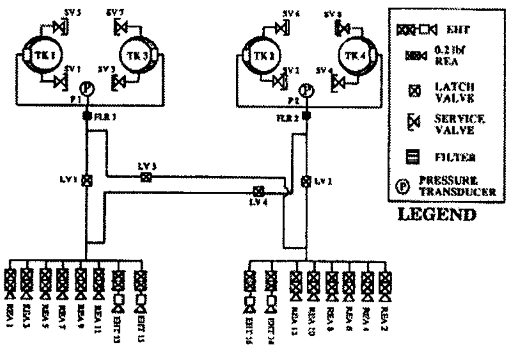


Fig. 2 Model validation: Pressure oscillation

Fig. 3 Model validation case: FFT results

It shows the schematic of propulsion system of Koreasat 1 & 2 in Fig. 4. The propulsion system composes of 50 lines and 50 junctions which are considered in a model to analyze fluid transients as shown in Fig. 5.



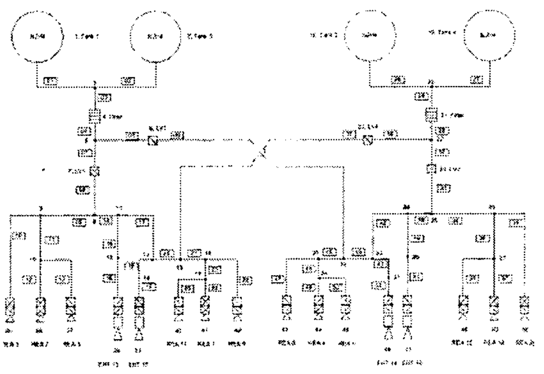


Fig. 4 Schematic of propulsion system

Fig. 5 Computational model diagram

RESULTS

The calculations are conducted for the opening and closing thruster valves of REA 5, 6, 7, and 8 (Station acquisition: East) at the operation inlet pressure ranges of 400 psia and 80 psia with quasi-steady friction and unsteady friction. But this section shows only the results of REA 8 because of similarities of the results.

It is difficult to identify the frequency components by looking at the original signal. A common use of Fourier transforms is to find the frequency components of a signal in a time domain. Converting to the frequency domain, the discrete Fourier transform of the pressure oscillation data is found by taking the 512-point fast Fourier transform (FFT).

The inlet pressure of thruster valve oscillates due to thruster valve opening/closing of 20 ms as shown in Fig. 7. On opening valve the pressure oscillation begins and then the oscillation amplitude of inlet pressure attenuates as fast as that of unsteady friction and it goes to a steady state. On closing valve the inlet pressure of quasi-steady friction oscillates but attenuates at very slow rate. Because there is no other mechanism to be considered than the pipeline friction. But the inlet pressure of unsteady friction attenuates faster than that of quasi-steady friction because the effect of unsteady friction is added. The frequency contents of quasi-steady friction and unsteady friction are shown in Fig. 8 and show clearly the difference in the power spectral densities (PSD) between quasi-steady friction and unsteady friction.

This similar patterns appears in the rest of results as shown from Fig. 9 to 12. As expected when the thruster valve opening/closing time gets short the amplitude of pressure oscillation gets higher and in 1 ms condition as a worse case it exceeds the allowable inlet pressure range. As the inlet pressure of thruster valve is reduced to 80 psia the effect of unsteady friction is still so strong that the amplitude of pressure oscillation of unsteady friction case gets attenuated faster than that of quasi-steady friction case but these results are not shown due to space limitation.

These results show that the use of quasi-steady friction cannot predict the response curve except the amplitude but the use of unsteady friction can predict the response curve reasonably and be able to be closer to the real situation.

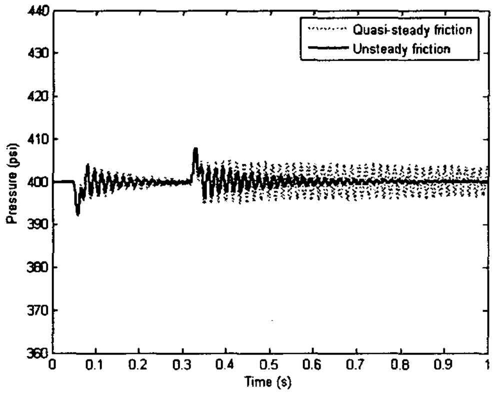


Fig. 7 Pressure oscillation of 20 ms & 400 psia.

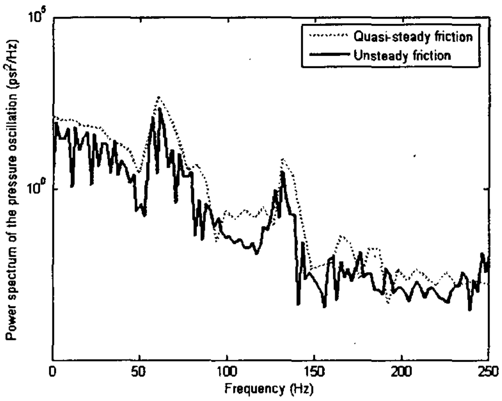


Fig. 8 PSD of 20 ms & 400 psia.

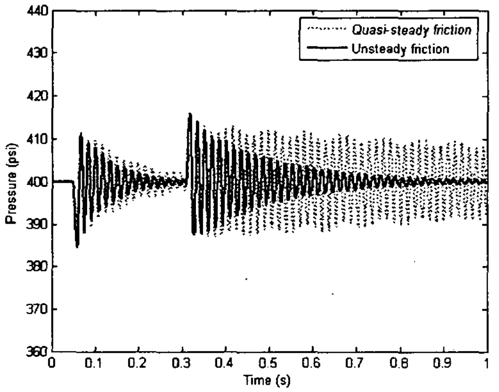


Fig. 9 Pressure oscillation of 10 ms & 400 psia.

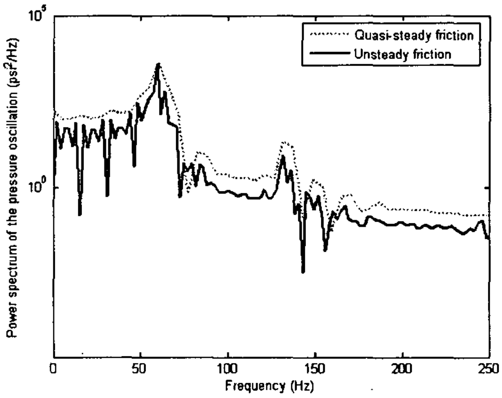


Fig. 10 PSD of 10 ms & 400 psia.

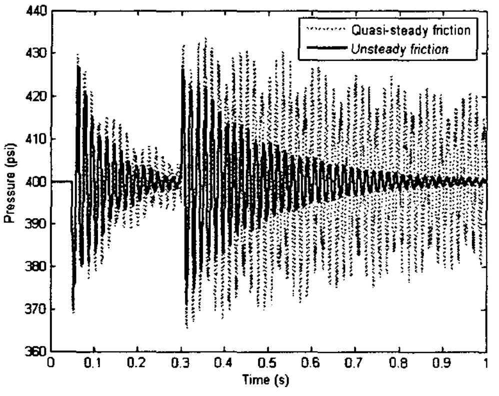


Fig. 11 Pressure oscillation of 1 ms & 400 psia.

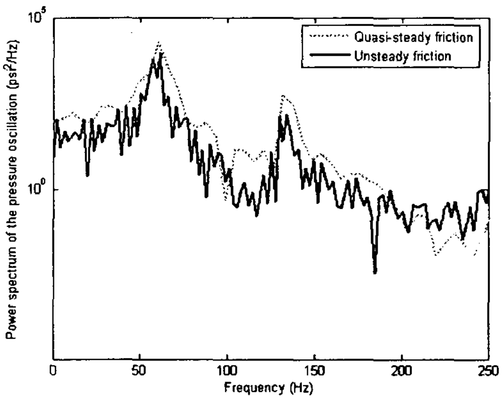


Fig. 12 PSD of 1 ms & 400 psia.

CONCLUSION

This work is done to identify fluid transient phenomena of Koreasat 1 & 2 propulsion system through numerical parametric studies in which a comparison between the quasi-steady friction and unsteady friction results is made. The valve operation time and unsteady friction are the dominant parameters to analyse the fluid transient phenomena. The results show that the shorter operation times cause the greater the response amplitude of pressure oscillation.

The results show that the use of quasi-steady friction cannot predict the entire response curve properly except the peak amplitude but the use of unsteady friction can predict the response curve reasonably.

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