

FREQUENCY ANALYSIS OF INSTABILITY OBSERVED IN A LARGE SEGMENTED SOLID ROCKET MOTOR

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ABSTRACT

During static testing of two identical large segmented solid rocket motors (SRM-3 & 4), unanticipated small amplitude pressure oscillations and consequent thrust oscillations were observed for certain duration. The purpose of this paper is to give an overview of the pressure and thrust data obtained and the frequency analysis carried out on the test data. The probable cause of the oscillations is also discussed. Frequency analysis was carried out by means of Fast Fourier Transform software. A major part of this work was carried out on frequency analysis of the data by using FFT software. The analysis revealed that the frequency of oscillations in both motors were very close, i.e., 54.29 Hz for SRM-3 and 55.17 Hz for SRM-4. The fundamental axial acoustic mode frequency is also calculated for these motors to find its matching with the analyzed frequency.

KEYWORDS: Static Test, pressure oscillation, thrust oscillation, frequency analysis

Rocket motors are to be static tested to validate the design and evaluate the margins available before going for actual flight. This is required because there are so many uncertainties with regard to performance of rocket motor, like the performance of ballistics, integrity of propellant grain, adequacy of insulation and the strength of motor case to withstand the pressure and the temperature generated inside the chamber. Although the static test is complicated, tedious and highly expensive, the same is being carried out even today all over the world to validate the design to confirm its performance meeting the set standards.

As part of the qualification programme, two identical large size segmented solid rocket motors (SRM-3 and SRM-4) have been static tested. During the static testing, both the motors exhibited unexpected minor pressure and consequent thrust oscillations for certain identical duration of burning. This oscillatory behavior has been analysed using FFT software. The main objective of this paper is to present the results of the analysis and explain the probable cause of these abnormal oscillations.

Static Test Set-Up

Each of the segmented solid rocket motors (SRM-3 and SRM-4) was static tested in horizontal configuration using a swing bench type test stand. The test stand was in

turn mounted on a concrete test bed having a thrust wall. The head end of the motor was connected to the front suspension frame through a conical adapter (Thrust frame). Between the front suspension frame and the thrust wall frame, suitable capacity load cell was assembled concentric to the longitudinal axis of the motor and perpendicular to the thrust wall. The rear suspension frame and the front suspension frame were connected by tie rods passing through the holes made on the thrust wall.

To ensure proper butting of the load cell with thrust wall frame, dead weight preload was applied to the rear suspension frame through a pulley. When the motor fires, the load cell measured the axial thrust produced by the motor in compression mode. Fig.1 describes the static test set-up used for SRM-3 and SRM-4.

Instrumentation Scheme for Pressure and Thrust

The rocket motor firing is a single shot operation. The test cannot be repeated for any deficiency in measurement of various parameters during the test. To increase the reliability, redundancy in measurements and power supply were provided in the instrumentation scheme during static testing of SRM-3 and SRM-4. Load cells were configured to give two outputs. Two pressure transducers were provided in the motor chamber port through 'Y'

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adaptor. Each output of load cell and pressure transducers was provided with separate power supply, cables, amplifiers and data acquisition system. The sensors for the other parameters like temperature, strain, displacement, etc., were divided into two groups such that locations of sensors in one group are mirror image of the other. Independent UPS power supply, cable, amplifier, recorder, etc., were provided for each group separately to have complete redundancy.

The preamplifiers kept in the Local Instrumentation Room (LIR) adjacent to the test bed were required to be rugged to withstand the vibration and sound level inside the LIR caused by the firing of the rocket motor.

Instrumentation schemes for Pressure and Thrust measurements are shown in Fig. 2 and 3 respectively.

Oscillations in Pressure and Thrust

Data obtained from both the motors during static testing showed unanticipated small amplitude oscillations in both pressure and thrust. From the Pressure Time and Thrust Time response plots of SRM-3, it is seen that the oscillations are starting at 26s after ignition of the motor and ending at 40s. For SRM-4, the oscillations are seen starting at 26s and ending at 42s. The performance of the motors was found more or less identical.

The Pressure Time Response plots of SRM-3 and SRM-4 are shown in Fig. 4 and 5 respectively. Corresponding magnified views of the pressure response of each motor for the duration when the oscillations occurred are shown in Fig. 4a and 5a.

Similarly the Thrust Time Response plots of SRM-3 and SRM-4 are shown in Fig. 6 and 7 and their corresponding magnified views for the duration of oscillations are shown in Fig. 6a and 7a respectively.

Frequency Analysis of Oscillations

To understand the characteristics of the oscillations, frequency analysis was carried out. Preliminary analysis of Pressure Time data and Thrust Time data of both the motors has indicated that the oscillations are of low frequency around 55 Hz. Hence, 100 Hz low pass filter has been used to filter out high frequency noise from the data of both the motors. Filtered data is then processed using commercially available Sigview FFT frequency analysis software. The results are presented in the following chapters.

RESULTS AND DISCUSSION

Frequency Analysis of Pressure Oscillations

Three dimensional FFT plots for the Pressure Time response of SRM-3 and SRM-4 are given in Fig. 8 and 9 respectively. Frequency Amplitude 2D plots for the Pressure Time response of SRM-3 and SRM-4 are shown in Fig. 10 and 11 respectively.

From these analyses, it is found that the frequency of oscillations in Pressure Time responses of SRM-3 and SRM-4 is 54.29 Hz and 55.17 Hz respectively. For SRM-3 the maximum amplitude occurs at $T + 32.06$ seconds and SRM-4 has the maximum amplitude at $T + 35.6$ seconds, T being the time of ignition of the motor.

Frequency Analysis of Thrust Oscillations

Three dimensional FFT plots for the Thrust Time response of SRM-3 and SRM-4 are given in Fig. 12 and 13 respectively. Frequency Amplitude 2D plots for the Thrust Time response of SRM-3 and SRM-4 are shown in Fig. 14 and 15 respectively.

Here also it is found that the frequency of oscillations in Thrust Time response of SRM-3 and SRM-4 is 54.29 Hz and 55.17 Hz respectively, thus matching with the corresponding frequency of pressure oscillations. The maximum amplitude of thrust oscillation occurs at $T + 32.06$ seconds for SRM-3 and $T + 35.6$ seconds for SRM-4 coinciding with the corresponding times at which pressure peaks occurred.

These results clearly indicate that the thrust oscillations were consequence of pressure oscillations and hence pressure oscillations are probably caused by combustion instability (Blomshield, 2006).

The frequency of oscillations seen in Pressure Time responses of SRM-3 and SRM-4 is very close to each other and low around 55 Hz. One of the causes for these low frequency oscillations may be due to acoustic modes of the chamber. The dimensions of combustion chamber of SRM motors are 1.98 meters in diameter and 7.231 meters in length. The transverse mode acoustic frequency of this size motor is likely to be more than 1000 Hz (Price, 1977).

Axial Mode Acoustic Frequency

Based on the geometry of the motor, the axial mode acoustic frequency can be determined approximately with the following expression (Price, 1977).

$$f = 1/T = 1/(2L/C) = C/2L(1)$$

$$= 1100/(2 \times 7.231)$$

$$= 76.06 \text{ Hz}$$

Where

f = Acoustic frequency in Hz

T = Natural period in s

C = 1100 m/s for speed of sound in combustion products (Price, 1977).

L = 7.231 m chamber length of SRM

This frequency is much higher than the observed ones.

As the frequency and the duration of the oscillations occurring in both the pressure and thrust are more or less same, the phenomena are probably due to combustion process and the configuration of the propellant grain in the segmented motors (Price, 1977). Recent studies made on the segmented rocket motors reveal that the probable cause of pressure oscillations is vortex shedding

(Fabignon et al., 2003). Full numerical approaches with CFD techniques are required to be used to determine the vortex shedding phenomena in such complex situations. This CFD analysis is proposed to be taken up as future work by the authors.

CONCLUSION

Static testing of two large segmented solid rocket motors revealed small amplitude oscillations for certain duration in pressure and thrust response of both the motors. Frequency analysis of test data of both the motors was carried out using FFT software. The results of the analysis revealed very close match of frequency of oscillations between the motors (54.29 Hz for SRM-3 & 55.17 Hz for SRM-4). Calculation of axial mode acoustic frequency for the geometry of the motor is found not matching with the observed frequency. Further study is proposed using CFD techniques to determine vortex shedding frequency.

Fig. 1: Static Test set-up of Large Segmented SRM

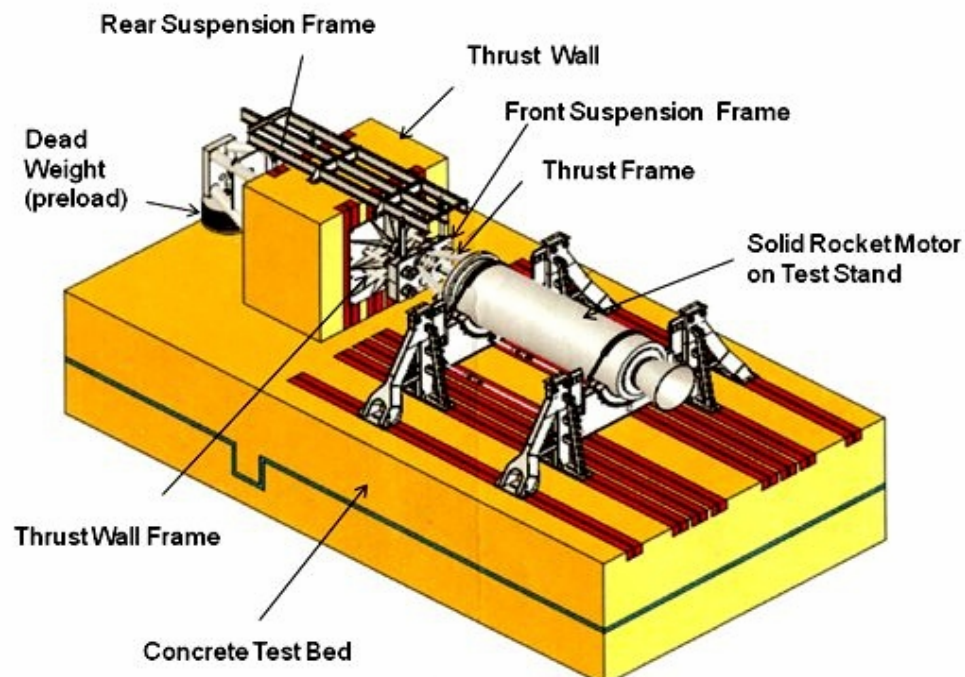


Fig. 2: Instrumentation Schemes of Pressure Measurement of SRM-3 & SRM-4

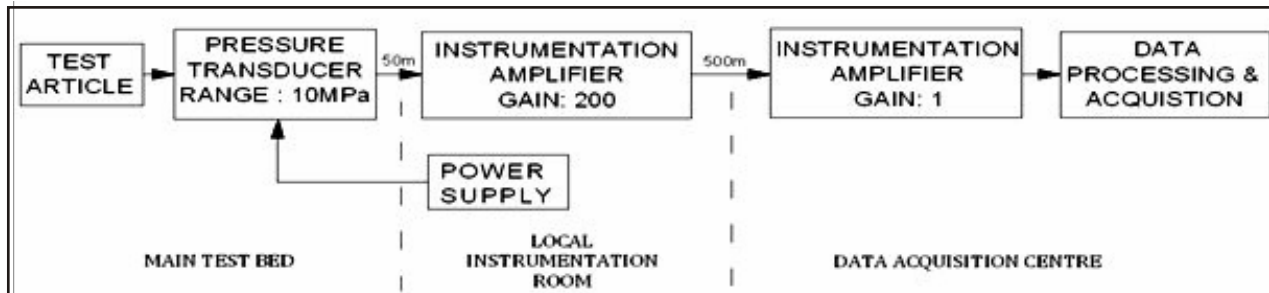


Fig. 3: Instrumentation Schemes of Thrust Measurement of SRM-3 & SRM-4

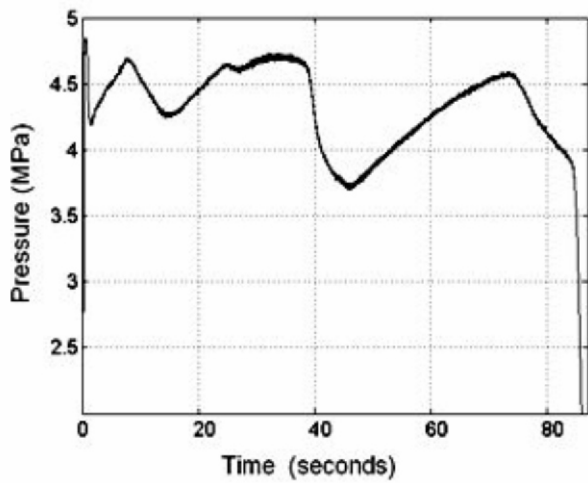
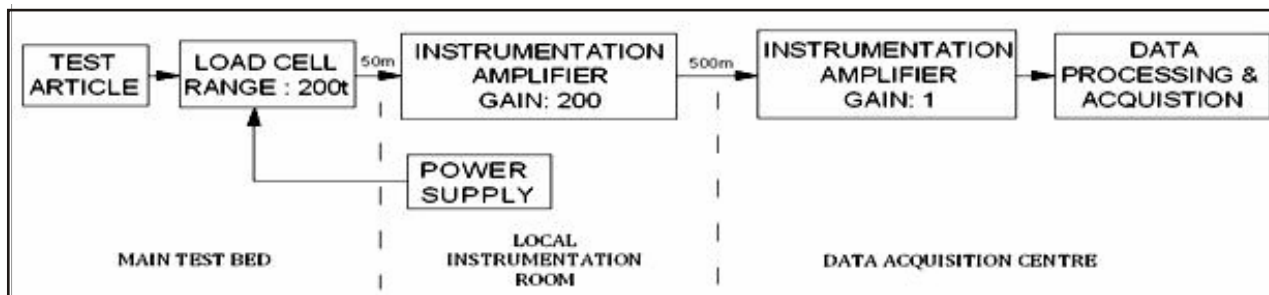


Fig. 4: Pressure Time Response of SRM-3

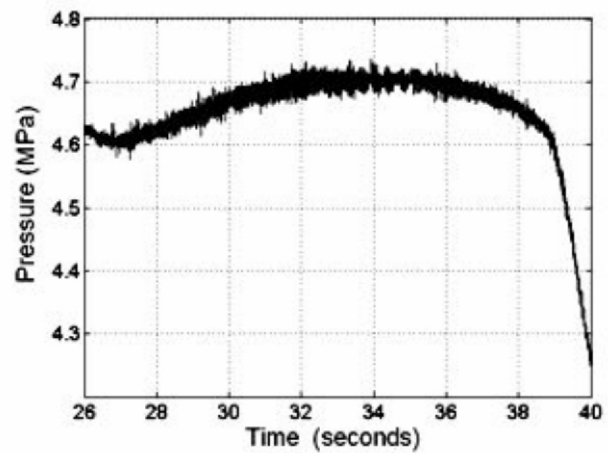


Fig. 4a: Magnified Pressure Time Response Of SRM-3

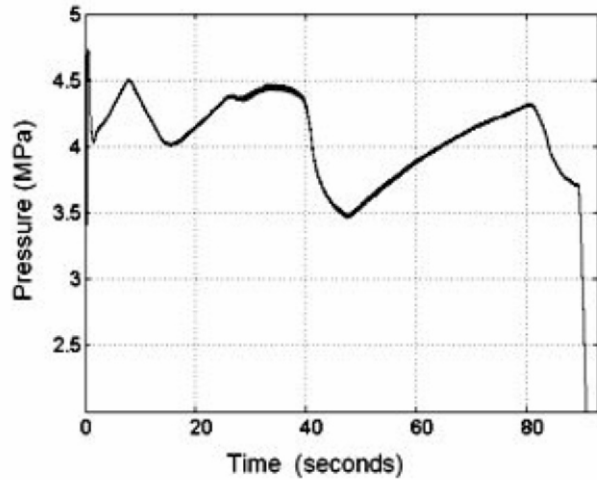


Fig. 5: Pressure Time Response of SRM-4

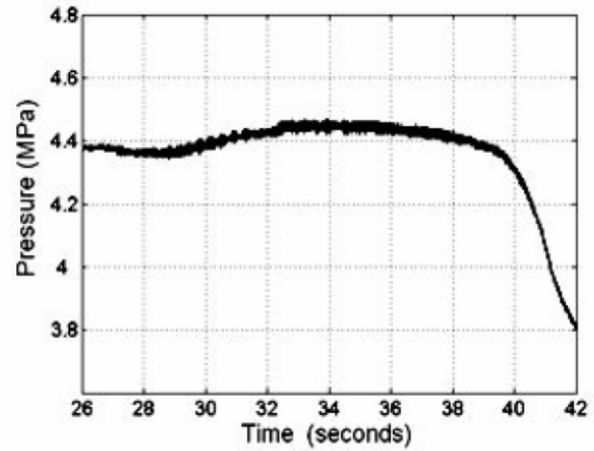


Fig. 5a: Magnified Pressure Time Response of SRM-4

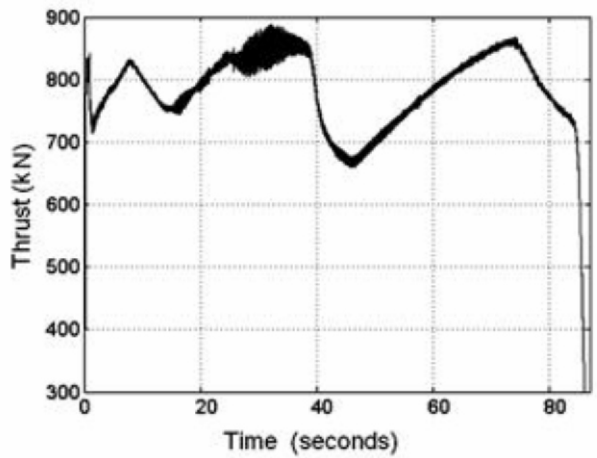


Fig. 6: Thrust Time Response of SRM-3

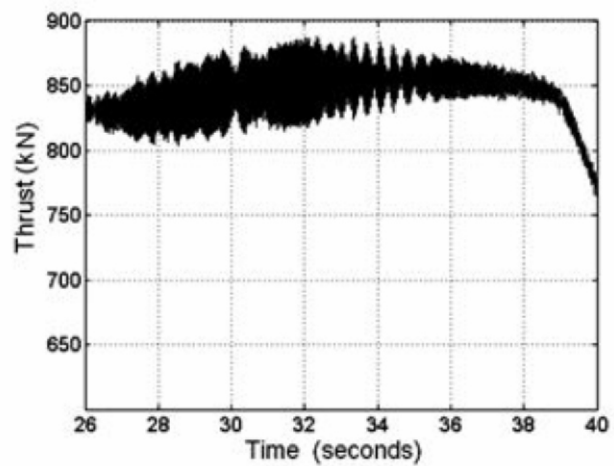


Fig. 6a: Magnified Thrust Time Response of SRM-3

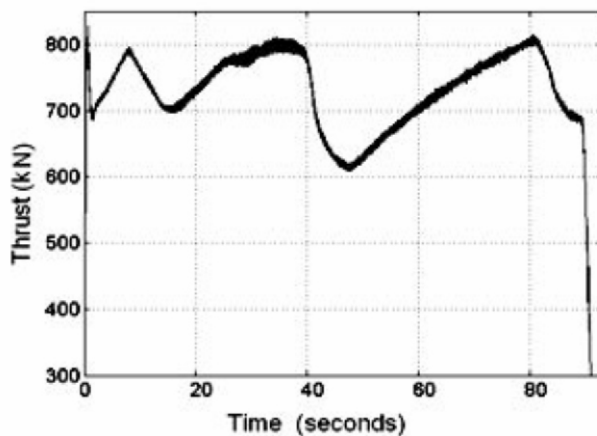


Fig. 7: Thrust Time Response of SRM-4

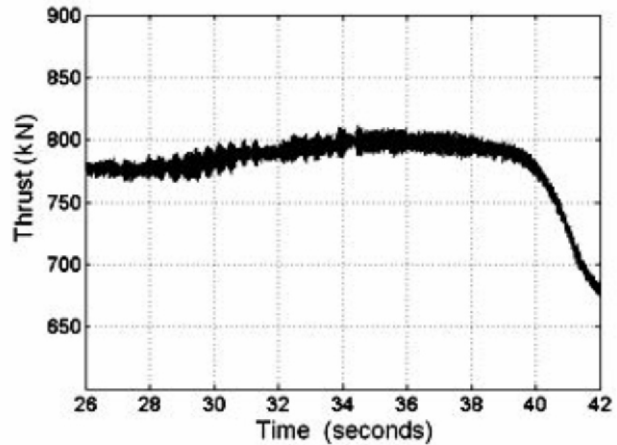


Fig. 7a: Magnified Thrust Time Response of SRM-4

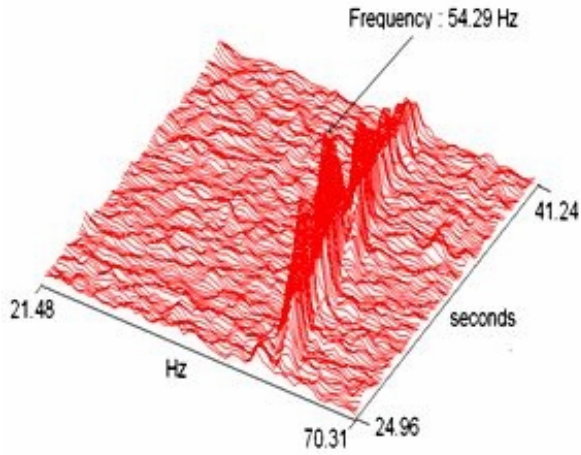


Fig. 8: FFT (3D) plot: Pressure Time Frequency (SRM-3)

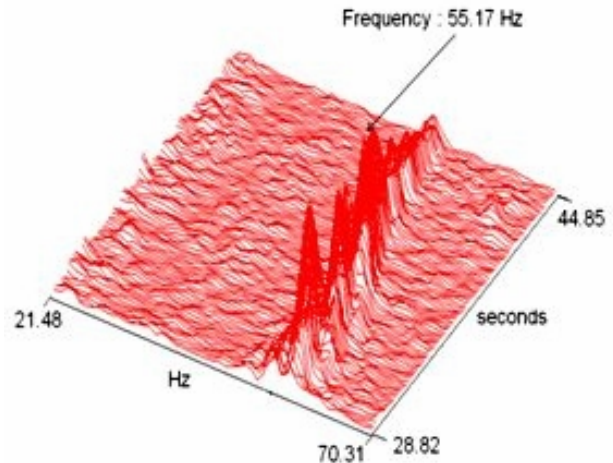


Fig. 9: FFT (3D) plot: Pressure Time Frequency (SRM-4)

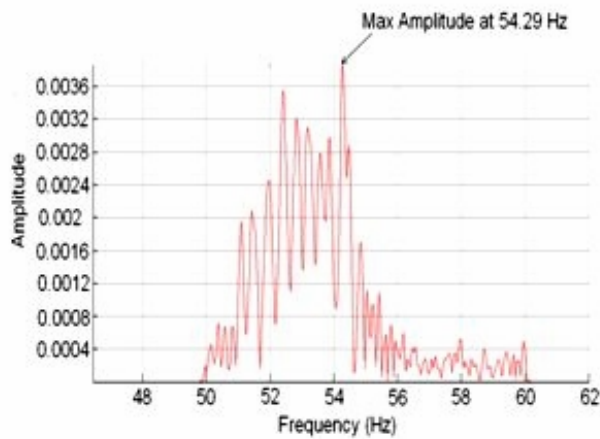


Fig. 10: FFT (2D) plot: Frequency Amplitude (SRM-3 Pressure)

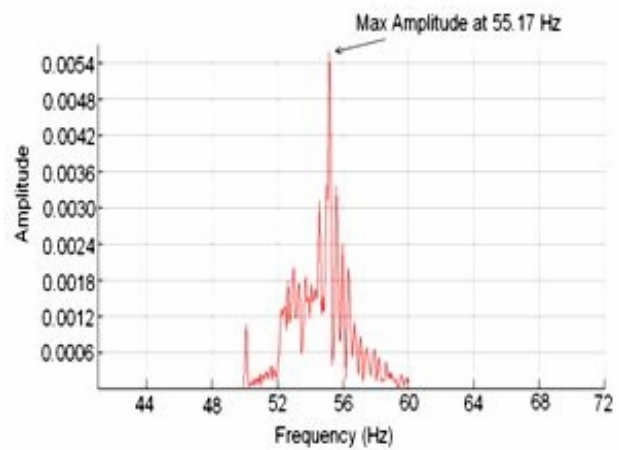


Fig. 11: FFT (2D) plot: Frequency Amplitude (SRM-4 Pressure)

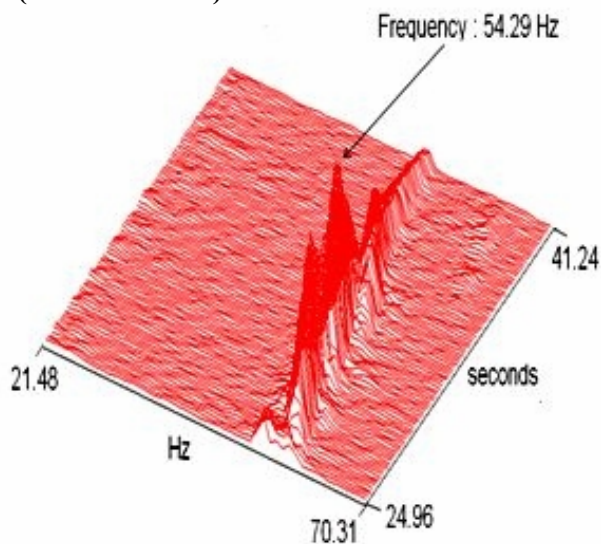


Fig. 12: FFT (3D) plot: Thrust Time Frequency (SRM-3)

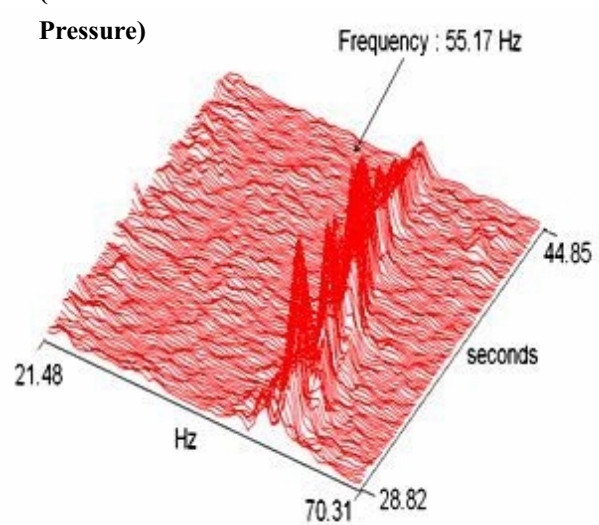


Fig. 13: FFT (3D) plot: Thrust Time Frequency (SRM-4)

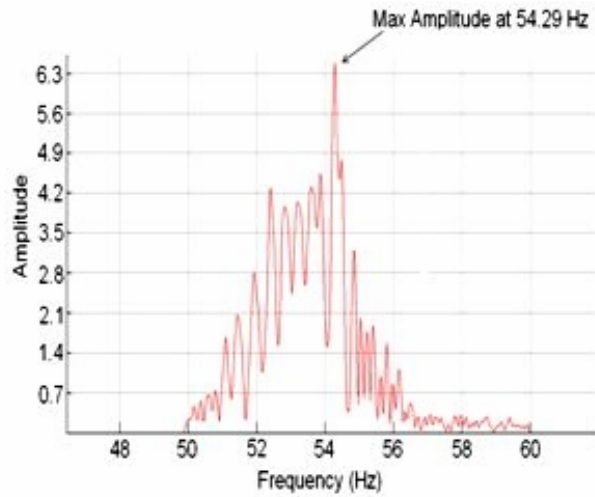


Fig. 14: FFT (2D) plot: Frequency Amplitude (SRM-3 Thrust)

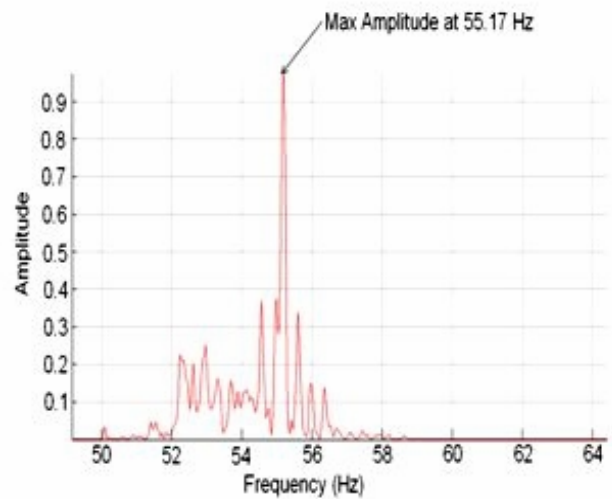


Fig. 15: FFT (2D) plot: Frequency Amplitude (SRM-4 Thrust)

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