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Joint strength analysis during vibration test of spacecrafts

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Abstract— **vibration test on spacecrafts are carried out to simulate the launch environment and measure the response of all the components of spacecraft as per the specification profile in terms of frequency range and g level that will be experienced by them during launching. To vibrate the spacecraft at required g level, vibration shakers of different capacities are used. To perform the test, the spacecraft should be rigidly mounted on top of the shaker through a fixture to transfer the same amount of force as generated by the shaker. For mounting of spacecraft different sizes of bolts can be used at different PCDs. But strength of those bolts should be enough to withstand the large force that will be encountered during vibration test. Force acting on the bolts depends on various factors such as mass of the specimen, g level, Center of Gravity (CG) height of specimen, Pitch Circle Diameter (PCD) of bolts etc. In this paper strength of joint has been analyzed to calculate the safe value of test parameters for a given shaker system. It must be noted that the numbers of bolts used for mounting are in multiples of four and are symmetric in all four quadrants.**

Index Terms— **vibration test, joint strength.**

I. INTRODUCTION

Vibration test on spacecrafts are carried out to replicate the forces experienced by the spacecraft during launching [1]. If spacecrafts survives in the test then it indicates that it will work after launching also. Vibration test includes random and sine test in all three directions and monitoring the response of all the parts like solar panels, DGRs, propellant tanks, scientific equipments mounted on the spacecraft etc [2]. If the response of all the channels is within the limit then spacecraft can survive the launch.

Spacecrafts are rigidly bolted on shaker head with help of Allen bolts and giving proper torque. Vibration is transferred through these bolts to the spacecraft. Amount of force experienced by these bolts should be less than the yield strength of the bolts to sustain the test. If forces coming on the bolts are more than the yield strength then they will yield break which may cause damage to the spacecraft. The spacecraft experiences loads along all the three axis simultaneously, but due to limitation of the facility,

Vibration tests are conducted in every axis separately covering the overall requirements. Initially tests are conducted about launch direction (longitudinally) on head expander of vibration shaker. Subsequently, the spacecraft is shifted to Slip Table for conducting tests in the transverse (lateral) axis [3].

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II. CALCULATION OF FORCES ON THE BOLTS

Input parameters

A. Mass of fixture=m(kg)
B. Acceleration of specimen at CG=g(m/sec^2)
C. CG height of specimen=H(mm)
D. Pitch circle diameter(PCD) of bolts mounted=P(mm)
E. Bolt size=M(mm)
F. Number of bolts (Nb) used

Calculation of normal load acting on each bolt due to shear (Fn)

$$Fn = \frac{m \times g}{\mu \times Nb}$$

Where μ is coefficient of friction and its value is taken as 0.3.

Calculation of tensile load acting on each bolt due to moment (Ft)

$$Ft = \frac{w \times P}{2}$$

Where w is force per unit length and it is calculated as

$$w = \frac{m \times g \times H}{2\left\{2\left(\sum_{1}^{\frac{Nb}{4}-1}(Li)\right)^2 + \left(\frac{P}{2}\right)^2\right\}}$$

Where $Li = \frac{P}{2} \times \cos\frac{2\pi i}{Nb}$

Total force = Fn+Ft

Factor of safety of the bolts (FOS) $= \frac{yield\ strength\ of\ the\ bolt}{total\ force}$

For safe operation of the test FOS must be greater than one.

III. RESULT AND DISCUSSION

In this section we have discussed the change in FOS of bolts with the mass of the specimen for various test parameters.

A. variation of factor of safety of the bolts with mass of the specimen at different g levels

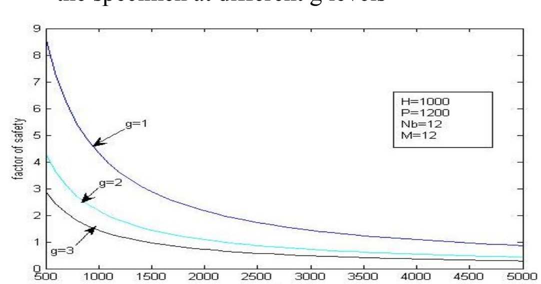

Fig.1 Plot showing the variation of factor of safety of the bolts with mass of the specimen at g level of 1, 2 and 3

Fig.1 shows the variation of factor of safety of the bolts with mass of the specimen at various g levels. It is clear that at m=500kg, FOS decreased by half (8.64 to 4.32) when g is doubled (from 1 to 2). At one g level maximum mass of the specimen that can be tested is 4300kg but as the g level goes to 3 mass of the specimen reduced to 1400kg.

B. variation of factor of safety of the bolts with mass of the specimen at different CG height of specimen

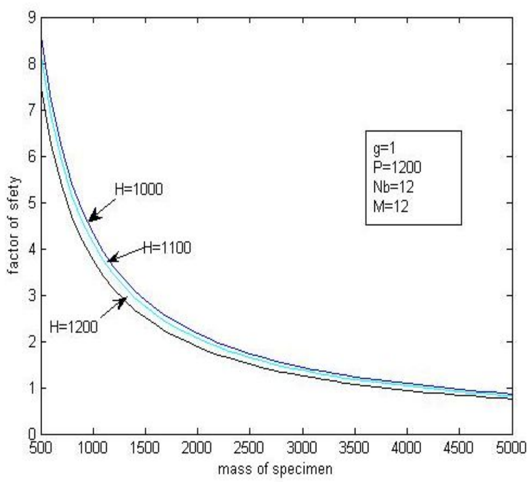

Fig.2 Plot showing the variation of factor of safety of the bolts with mass of the specimen at C.G height of 1000mm, 1100mm and 1200mm.

The plot shows that with increase in the CG height of specimen factor of safety reduces. It can be seen from the graph that as the mass of specimen goes above 3700kg the FOS is less than one for CG height of 1200mm and that specimen cannot be tested at parameters given in the plot but if the CG height reduces to 1000mm then mass of specimen can be increased up to 4300kg.

C. variation of factor of safety of the bolts with mass of the specimen at different PCD of bolts

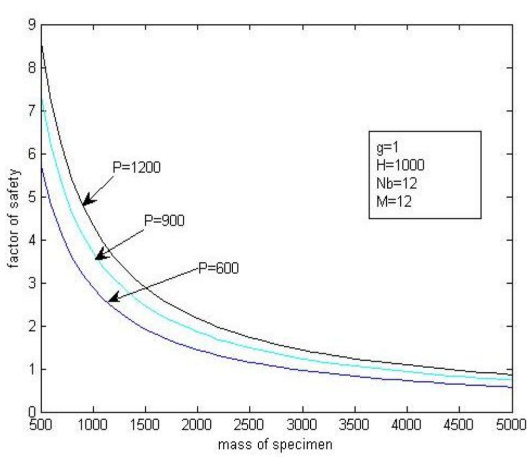

Fig.3 Plot showing the variation of factor of safety of the bolts with mass of the specimen at PCD of 600mm, 900mm and 1200mm

It is clear from Fig.3 that by increasing PCD of bolts used for mounting of spacecrafts with vibration shaker FOS of bolts increases. For 500kg specimen FOS is 5.76 at 600mm PCD and it goes to 8.64 at 1200mm PCD. FOS reduces to half when mass of the specimen is doubled. It can also be seen that at PCD of 600mm only 2800kg specimen can be tested but as the PCD increased to 1200mm, specimen mass can be increased to 4300kg.

D. variation of factor of safety of the bolts with mass of the specimen for different number of bolts

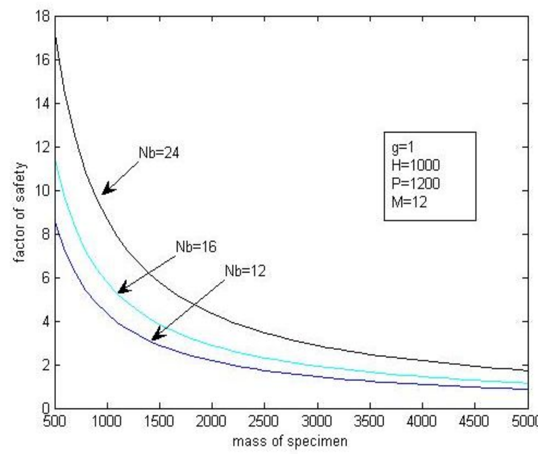

Fig.4 Plot showing the variation of factor of safety of the bolts with mass of the specimen for 12, 16 and 24 number of bolts

The plot shows the change in FOS of bolts by changing the mass of specimen for 12, 16 and 24 number of bolts used for mounting. It can be seen from plot that for 12 numbers of bolts used for mounting specimen mass can go up to 4300kg and using 24 bolts specimen mass can go up to 5000kg with FOS of bolts equal to 1.7.

E. variation of factor of safety of the bolts with mass of the specimen for different sizes of bolts

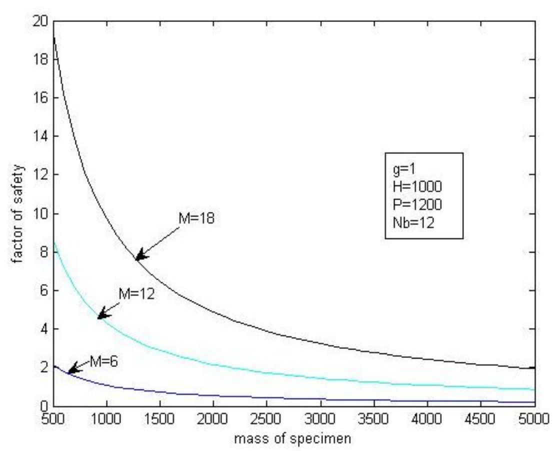

Fig.5 Plot showing the variation of factor of safety of the bolts with mass of the specimen for bolt size of 6mm, 12mm and 18mm

Various sizes of bolts can be used for mounting of specimen on the shaker system. Fig.5 shows the change in FOS with respect to mass of specimen for bolt size of 6mm, 12mm and 18mm. it is clear from the plot that for 500kg specimen, FOS varies from 2.16 to almost 20 as size of bolt increases from 6mm to 18mm. it can also be seen that for 6mm bolt size

1000kg specimen mass can be tested safely and as the bolt size changed to 12mm mass of specimen increased to 4300kg.

CONCLUSION

In this paper we have analyzed the variation in FOS of bolts used for mounting the specimen on shaker system and mass of the specimen for different parameters like g level, CG height of specimen, number of bolts used, PCD of bolts. It is found that FOS of bolts reduces to half by doubling mass of the specimen, g level, Center of Gravity height of specimen and Pitch Circle Diameter of bolts.

Different diameter of bolts and Number of bolts used for mounting of specimen on the shaker is a very important criterion for vibration tests. Increases in number of bolts or increase in size of bolts increases the total moving mass of the system, which affects the g level achieved and FOS of bolts. Therefore these parameters must be verified correctly before vibration test of any specimen is commenced.

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