Mechanical Analysis of Failure of Projectile-Borne Vibration Sensor under High Overload

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Abstract. In view of the failure situation of the vibration sensor carried by the projectile without anti-overload treatment, two failure cases of the vibration sensor on the projectile are analyzed, and the internal structure of the vibration sensor on the projectile is simplified as the mechanical model of the fixed beam. The results show that the interior structure of the projectile-borne vibration sensor has a direct impact on its impact resistance, and the impact resistance of the projectile-borne vibration sensor placed parallel to the direction of acceleration propagation is higher than that of the projectile-borne vibration sensor perpendicular to the direction of acceleration propagation. The results can provide reference for selection and placement of vibration sensors.

1. Introduction

The unmanned reconnaissance projectile on the ground is commonly called "Eavesdropping Projectile". It usually uses large caliber artillery as the launching platform. After the sensor projectile is fired into the ground of the target area by artillery, the function of eavesdropping on the battlefield target information is realized by vibration acoustic sensor. When the sensing reconnaissance projectile reaches the opening point, the submunition is thrown from dispenser, while the deceleration parachute is opened, and speed of the submunition decreases in the deceleration parachute effect. Finally, it stabilizes and enters the working state. In this process, the projectile-borne vibration sensor should not only be able to withstand the impact overload when the artillery is fired and the projectile is opened, but also be able to withstand the impact overload when landing¹-². The intact of the projectile-borne vibration sensor has been greatly affected by the high overload environment, and may cause damage to the vibration sensor, so that the system cannot work properly.

In the paper, the internal structure of the projectile-borne vibration sensor is simplified as a fixed beam, and the maximum shear force, the maximum bending moment and the normal stress are analyzed to study the failure characteristics of the vibration sensor under high overload environment.

2. Failure analysis of projectile borne vibration sensor under impact load

At present, there are two kinds of projectile-borne vibration sensors: piezoelectric sensor and resistive sensor³-⁵. The submunitions with these two sensors are fired at shooting range. After launching the live ammunition, the failure of the vibration sensor on the projectile can be divided into two kinds under the impact of high acceleration.
(1) The vibration sensor cannot load the signal. This is due to the drop off of the solder joints between the wires and the sensor pins on the high overload environment.

(2) The vibration sensor is not working properly, and the output signal is incorrect. It is impossible to analyze the cause from the outside of the sensor, only to analyze the internal changes under the impact of high overload environment.

In order to find out the reason of the second failure of the projectile-borne vibration sensor, the recovered piezoelectric and resistive vibration sensors are opened, and their internal structure diagrams are shown in figure 1 and 2. It is found that the bolt in the resistance vibration sensor is broken and dislocated after 13,000 g, acceleration impact, and the beam in the piezoelectric vibration sensor is also broken, which resulted in the failure of the projectile-borne vibration sensor.

3. Failure characteristic analysis of projectile-borne vibration sensor under impact load

From the mechanical point of view, the bolt inside the piezoelectric vibration sensor and the beam inside the resistive vibration sensor are regarded as fixed beam, but they are not the same. The bolt in the piezoelectric vibration sensor is fixed on both sides, and the beam in the resistance vibration sensor is fixed on one side. When the projectile-borne vibration sensor is placed perpendicular to the impact acceleration, the bolt inside the piezoelectric vibration sensor can be simplified as a fixed beam at both ends, and the internal beam of the resistive vibration sensor can be simplified as a mechanical model of the fixed beam at one end, as shown in figure 3 and 4.
Figure 3. Shear force and bending moment of internal fixed beam of piezoelectric vibration sensor.

Figure 4. Shear force and bending moment of internal fixed beam of resistive vibration sensor.

The internal fixed beam size of piezoelectric vibration sensor is: length $l=25.12$ mm, width $b=7.36$ mm, thickness $h=0.10$ mm; internal fixed beam size of resistance vibration sensor is: length $l=42.35$ mm, width $b=10.48$ mm, thickness $h=0.12$ mm.

In fig. 3 and 4, the load is distributed inertia force, the size is:

$$q = \rho A a_0$$  \hspace{2cm} (1)

Among them: $\rho$ is density, $A$ is cross section area of fixed beam, $A = bh$, $a_0$ is acceleration amplitude for fixed beam.

For the internal fixed beam of the piezoelectric vibration sensor, the maximum shear force is:

$$Q_{\text{max}} = \frac{1}{2} ql$$  \hspace{2cm} (2)

Fixed end bending moment is:

$$M_{\text{max}} = \frac{1}{12} ql^2$$  \hspace{2cm} (3)

Midpoint bending moment is:
For the internal fixed beam of the resistance vibration sensor, the maximum shear force is:

\[ Q_{\text{max}} = ql \]  

(5)

The maximum bending moment of the fixed end is:

\[ M_{\text{max}} = \frac{1}{2} ql^2 \]  

(6)

Comparing the maximum shear force and bending moment of the two kinds of fixed beam, it is found that the impact resistance of the internal fixed beam of piezoelectric vibration sensor is better than that of the internal fixed beam of resistance vibration sensor.

Considering the failure of inertia force, the failure position is located at the maximum bending moment and shear force. For a piezoelectric vibration sensor, the maximum bending moment \( M_{\text{max}} \) is fixed at the fixed end, the size of which is:

\[ M_{\text{max}} = \frac{1}{12} ql^2 \]  

(7)

The internal bolt of piezoelectric vibration sensor is made of quartz, it has high mechanical strength and its yield limit stress \( \sigma_s \) is equal to 1000MPa. Because quartz is a brittle material, when the Eq. (9) is established, the internal fixed beam of the piezoelectric vibration sensor fails.

\[ \sigma_{\text{max}} \geq \sigma_s \]  

(9)

According to Eq. (8) and Eq. (9), the maximum acceleration that the fixed beam of a piezoelectric vibration sensor can withstand is:

\[ a_0 = \frac{2h\sigma_s}{\rho l^2} = \frac{2 \times 0.1 \times 10^{-3} \times 1000 \times 10^6}{2.65 \times 10^3 \times 25.12^2 \times 10^{-6}} \]

\[ = 1.22 \times 10^4 \text{ g}_n \]

Because the fixed beam is very thin, the influence of shear stress is small, and the principal stress is consistent with the direction of horizontal normal stress, so the normal stress can be used as the strength control condition. Therefore, when the fixed beam of the projectile-borne vibration sensor is placed perpendicular to the impact acceleration direction, if the external load reaches 13,000\text{g}_n, the internal fixed beam of the piezoelectric vibration sensor will be damaged, similarly, the internal fixed beam of the resistance vibration sensor will be damaged in this case, the result will cause the projectile-borne sensor to fail.

When the placement direction of the projectile-borne sensor is parallel to the impact acceleration direction, the internal fixed beams of the piezoelectric vibration sensor and the internal fixed beam of the resistive vibration sensor can be simplified as the mechanical model shown in figure 5.
Piezoelectric sensor  Resistive sensor

Figure 5. Mechanical model of projectile-borne sensor placed parallel to acceleration.

The maximum normal stress of the internal fixed beam structure of the resistance vibration sensor is at the fixed end, and the size is:

$$\sigma_{\text{max}} = \rho a_0 l$$  \hspace{1cm} (10)

The internal fixed beam of piezoelectric vibration sensor is statically indeterminate, and the relative deformation of the two fixed ends is zero. Solve the following deformation compatibility equation,

$$\Delta l = \frac{\rho a_0 l^2}{2E} - \frac{R l}{E A} = 0$$  \hspace{1cm} (11)

The reaction force at the end is obtained, it is:

$$R = \frac{1}{2} \rho a_0 l A$$  \hspace{1cm} (12)

The maximum stress is:

$$\sigma_{\text{max}} = \frac{R}{A} = \frac{1}{2} \rho a_0 l$$  \hspace{1cm} (13)

At this point, the maximum stress in the fixed beam structure of the piezoelectric vibration sensor is also smaller than that in the fixed beam structure of the resistance vibration sensor, so the former can withstand higher impact.

Comparison of Eq. (13) and Eq. (8), the ratio n is:

$$n = \frac{\rho a_0 l}{2} \left( \frac{\rho l^2 a_0}{2h} = \frac{h}{l} \right)$$  \hspace{1cm} (14)

Because $h/l$ is far less than 1, the shock resistance of the shock sensor placed in parallel with the impact acceleration is much higher than that of the vertical position.

4. Conclusion
(1) Under high impact, the solder joint at the junction of the lead and the sensor pin may drop off, the result will cause the projectile-borne sensor to fail.

(2) When the placement direction of the projectile-borne vibration sensor is perpendicular to the impact acceleration direction, if the external load exceeds the bearing limit of the fixed beam inside the sensor, the bolts inside the piezoelectric vibration sensor and the beams inside the resistance vibration sensor will break, resulting in the failure of the projectile-borne vibration sensor. In contrast, piezoelectric vibration sensor has better impact resistance than resistive vibration sensor.

(3) The impact resistance of the projectile-borne vibration sensor placed parallel to the impact acceleration direction is higher than that of the projectile-borne vibration sensor perpendicular to the impact acceleration direction. Therefore, when the projectile-borne vibration sensor is arranged, the
The orientation of the projectile-borne vibration sensor should be parallel to the impact acceleration direction as far as possible.

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