Life Prediction Method of Missile Based On Environmental Load Spectrum of Shipborne Tilt Launching

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Abstract. The fault time data of missile is an important information source to reflect the reliability and life index of missile. However, most of the failure time data are used for the life evaluation of missile, and there is no method to predict the life of missile by using the data of fault time. According to engineering experience and statistical analysis of fault data, the life characteristics of missiles are closely related to the storage environment. In this chapter, the relationship between the failure time data of missile and environmental load is established, the influence of environmental load on missile life is explored, and the life index of missile is predicted according to its service history and storage environment.

Keywords: Missile, Life Prediction, Environmental Loads

1 Introduction
Most of the time the missile is stored in the warehouse. Because the temperature and humidity in the warehouse change little and the missile is placed in the storage and transportation launch box, the storage environment in the warehouse can be considered as constant. When the missile is stored outside the warehouse, the change of the natural environment makes the missile storage environment unsteady. How to predict the life information of the missile is a difficult problem to be solved. In this section, the relationship between the environmental load spectrum and the life characteristic quantity of the missile is established, and the life prediction method of the missile in the unsteady storage environment is proposed [1].

2 Analysis of Environmental Load on Duty At Sea
When the missile is on duty at sea, it is affected not only by the environmental load, but also by the swaying motion of the ship. When the ship is sailing on the sea, it is mainly affected by the sea waves and produces six degrees of freedom. Generally, the forward and backward, deflection and yaw can be controlled by the ship's control system, but the heave, pitch and roll motions are largely determined by the sea state and the ship's own factors [2].
For the analysis of the environmental impact of missile on duty at sea, its basic situation is similar to that of land transportation. It mainly considers the influence of sea wave on ships and shipboard missiles, and describes it with power spectral density function [3].

### 2.1 Representation of Wave Impact

According to the research on the characteristics of sea waves, the real waves in nature are a random phenomenon, among which the wind is the main factor causing the characteristics of sea waves. In the research, it can be assumed that irregular waves are composed of many sine waves with different wavelengths, amplitudes and phases. In fact, there are statistical rules for the random waves that appear irregularly on the surface. The frequency of waves with certain wave height and wavelength is basically the same in statistical sense. Therefore, the statistical law of waves can be expressed by wave energy spectrum [4].

The wave energy spectrum can be expressed by Bretscheider two parameter method:

\[
S_e(\omega) = \frac{1.25}{4} \frac{\omega^5}{\omega^5} H^{2.5}_e e^{-1.25(\frac{\omega}{\omega_m})^4}
\]  

(1)

Among them, \( H^{2.5}_e \) is the meaningful wave height of the sea wave. The so-called meaningful wave height refers to the average value of the largest 1 / 3 of the wave height sequence in random waves. The meaningful wave height is basically close to the visual wave height of the sea wave, which is usually expressed by the sea condition level (0 ~ 9), which is easy to express and obtain. \( \omega_m \) is the maximum possible frequency of waves [5-6].

The energy density of random waves can be expressed as:

\[
E = \rho g \sum_{i=1}^{\infty} \frac{A_i^2}{2} = \rho g \int_0^\infty S_e(\omega) d\omega
\]  

(2)

The wave height is as follows:

\[
\zeta(t) = \sum_{i=1}^{\infty} A_i \cos(k_i x_0 - \omega_i t - \varphi_i)
\]  

(3)

According to the above formula, the wave height time curve under different sea conditions can be calculated, as shown in Fig. 1 and Fig. 2. The curve can be used as the external input condition of ship motion simulation program.

Fig.1 Wave height- time curve at level 2 sea condition
2.2 Motion Model of Shipborne Missile

When the ship is sailing on the sea, the irregular swaying motion is produced by the influence of the sea wave, and finally transmitted to the shipboard missile. In order to simplify the problem, assuming that the missile is fixed on the launcher in the magazine, and the launcher is firmly installed with the ship, then the irregular wave \( \zeta(t) \) can be regarded as the input, and the ship and launcher can be regarded as the energy converter to transfer the energy of the wave to the missile, thus resulting in roll, pitch and heave motions.

Through the transformation, the amplitude frequency response function of ship rolling motion at frequency \( \omega_e \) can be calculated as follows:

\[
RAOH(\omega_e) = \frac{C_{44}}{\sqrt{(C_{44} - (I_{44} + A_{44})\omega_e^2)^2 + B_{44}^2\omega_e^2}}
\]  

(4)

The amplitude frequency response function of heave motion is as follows:

\[
RAOS(\omega_e) = \frac{\hat{F}_5 S - \hat{F}_5 O}{(PS - QR)A}
\]  

(5)

The amplitude frequency response function of pitch motion is as follows:

\[
RAOZ(\omega_e) = \frac{\hat{F}_3 P - \hat{F}_3 R}{(PS - QR)kA}
\]  

(6)

According to the theory of ship slice, Maxsurf software is used to model the ship hull, and the frequency response function of ship rolling, heave and pitch motion is simulated and calculated.

Therefore, the power spectral density functions of roll, pitch and heave of Shipborne missiles can be simulated and calculated according to the "tim-sea situation" course of ships sailing on the sea, so as to effectively describe the impact of Shipborne missiles on the sea duty environment [7].

The storage environment of Shipborne tilt launched missile on duty is not constant. The change of storage environment is mainly reflected in the daily change of temperature and humidity and the seasonal change of the year. Because the change of storage environment between years can be ignored, only the statistical analysis of temperature and humidity in one year can accurately describe the
storage environment of Shipborne tilt launching missile on duty [8]. The temperature and humidity data are collected by humidity sensor and temperature pressure composite sensor of missile storage and transportation launcher, and the temperature load spectrum is established according to the following steps for the collected data:

1. Taking 0 °C as the center and step size of 2 °C, the temperature interval is established, such as [-5 °C, -3 °C], [-1 °C, 1 °C], [29 °C, 31 °C], etc;
2. Count the number of times that the collected temperature values fall within each temperature range in a year (if the temperature value is odd, the counts of the two temperature ranges are increased by 0.5 times each);
3. The frequency of the collected temperature values in each temperature range is obtained by dividing the number of collected data in each temperature range by the total number of collected data in a year;

In the same way, the humidity load spectrum can also be established by taking the relative humidity interval as [30,32%], [40%, 42%]. Figure 6 and Figure 7 show the simulated temperature load spectrum and humidity load spectrum of missile respectively [9-10].

![Temperature load spectrum of missile](image)

**Fig.3** Temperature load spectrum of missile

![Humidity load spectrum of missile](image)

**Fig.4** Humidity load spectrum of missile

### 3 Reliability Model Based on Environmental Load Spectrum

Let $X_0$ be the standard environment and the failure rate under the standard environment is $\lambda_0(t_0 \mid X_0)$. From the Cox model, the failure rate under the accelerated environment $X_h$ is:
\[ \lambda_h(t_h | X_h) = \lambda_q(t_0 | X_0) \exp\left( \varphi(X_h) - \varphi(X_0) \right) \]

(7)

Where \( \varphi(\cdot) \) is the environment covariate function.

Assuming that the missile life follows a 3-parameter Weibull distribution, then the cumulative distribution function (CDF) is:

\[ F(t) = 1 - \exp \left( - \left( \frac{t - \gamma}{\eta} \right)^m \right), \quad t > \gamma, \eta, m, \gamma > 0 \]

(8)

Where \( \gamma, \eta, m \) are position parameters, scale parameters and shape parameters respectively.

The failure rate function is

\[ \lambda(t) = \frac{dF(t)}{dt} \left( 1 - F(t) \right) = m\eta^{-m} (t - \gamma)^{m-1} \]

(9)

4 Parameter Estimation and Life Prediction

The coefficients \( \mu, \sigma, \alpha, \beta \) to be determined for the spectral density function of the environmental load are first estimated. The following likelihood equation is established from equation (3-34)

\[ L(\mu, \sigma) = \prod_{i=1}^{2020} \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( - \frac{(x_{li} - \mu)^2}{2\sigma^2} \right) \]

(10)

Substitute all the collected temperature values \( x_{li} \) into the above equation to estimate \( \hat{\mu}, \hat{\sigma} \).

From equation (3-35), the following likelihood equation is established to estimate \( \hat{\alpha}, \hat{\beta} \).

\[ L(\alpha, \beta) = \prod_{i=1}^{2020} \frac{\beta^{-\alpha}}{\Gamma(\alpha)} (x_{2i})^{a-1} \exp \left( - \frac{x_{2i}}{\beta} \right) \]

(11)

The coefficients \( m, a, b, c, d \) to be determined in the conditional reliability function \( R(t | x_1, x_2) \) are then estimated. There are two methods: a rough estimate based on engineering experience, and a more accurate estimate using data from the temperature and humidity dual stress accelerated life test of the missile.

5 Simulation Examples

Assuming that a model missile has been subjected to temperature and humidity dual stress accelerated life tests, the simulation test data are shown in Table 1.

| Accelerating Stress \( x_{1,i}, x_{2,i} \) | Failure Time \( \xi_{j,k} / \text{d} \) |
|-----------------|------------------|
| 323K, 50%       | 465, 530, 560, 600(3) |
| 343K, 60%       | 320, 335, 350, 360, 380(2) |
| 363K, 70%       | 198, 220, 235, 240, 250, 260(1) |
| 373K, 80%       | 150, 155, 165, 185, 190, 190 |

The characteristic lifetime \( \eta \) of the missile varies in a pattern with temperature \( x_1 \) and relative humidity \( x_2 \) as shown in Figure 5.
Modeling the environmental load, the solution is $\hat{\mu}, \hat{\sigma}, \hat{\alpha}, \hat{\beta} = (25.160, 8.012, 2.513, 4.985)$. The reliability function of the missile in a non-constant storage environment is given by

$$R(t) = \int_0^\infty \int_0^\infty \exp \left[ -\left( \frac{t - \exp\left(1.028 + 1375.413/x_1 - 2.247/x_2\right)}{\exp\left(3.166 + 1375.413/x_1 - 2.247/x_2\right)} \right) \right] \frac{(x_2 - 25.160)^2}{128.384} \frac{(x_2 - 4.985)}{4.985} \, dx_1 \, dx_2$$

The average lifetime of the missile is $\bar{\xi} = \int_0^\infty R(t) \, dt$. Since the prediction of $\bar{\xi}$ requires 3-dimensional integration and the expression of $R(t)$ is relatively complex and difficult to solve by conventional numerical methods, the Markov Chain Monte Carlo method is used to obtain the approximate solution for $\bar{\xi} = 1168.5$.

6 Conclusion

In this paper, a non-constant storage environment missile residual life prediction algorithm related to two environmental variables is developed to achieve the life prediction based on environmental load spectrum. The problem of predicting missile residual life in a variable environment is solved by developing a 9-parameter reliability model containing environmental parameters, missile life model parameters, and acceleration model parameters.

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