Research on the Prediction Methods of Air Material Consumption

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Abstract. Through making an analysis of the maintenance methods of air material in some complex equipment, this paper does research on the total air material consumption rule and applies the reliability theory and probability theory to establish air material consumption prediction models. Applicability of the methods is given by way of a numerical example. The methods provide a theoretical basis for calculating reserves of air material scientifically and have the vital important guiding significance.

1. Introduction

In recent years, with the application of high-tech and information technology, equipment of formed units has become more and more complex with more and more species. Different maintenance strategies also tend to be applied for different components of equipment, making it difficult to grasp the law of air material consumption and leading to heavier workload of air material consumption forecasting. To meet the needs of equipment maintenance, it is necessary to store a certain variety and quantity of air material in advance. If the storage capacity of air material is too small, the equipment’s successful completion of the training mission cannot be guaranteed; if the storage capacity of each air material is too much, it will cause overstock which affects economic benefit of the components. To ensure that air material stored in an organization is of reasonable quantity and good quality and can timely and reliably guarantee the equipment maintenance needs, a scientific and valid method of equipment air material consumption forecasting must be given.

Many scholars have made scientific researches on air material consumption prediction. Yang Shimei proposes a combination forecasting method of air material based on least squares support vector machines and information entropy in order to achieve precision support of aviation equipment, which solves the problems of the existing methods in difficulty in accurately predicting the aviation material air material under conditions of small samples[1]. What’s more, improved models for air material consumption prediction have been developed to avoid the limitations of traditional prediction methods, utilize all the information, and improve the precision of air material consumption prediction[2]. However, through analyzing the scientific researches on air material consumption prediction, we could find that few papers have been published as of now regarding the total air material consumption rule, which is formulated by combining air material consumption rules under both corrective maintenance and condition-based maintenance.
A certain amount of condition-based replaced units should be stocked according to equipment maintenance requirement. If the stock is too small, a completed equipment maintenance task can hardly be guaranteed; if the stock is too big, the caused backlog will affect the economic benefits. Therefore, a good knowledge about the consumption rule of condition-based replaced units as well as a determination of the proper stock of condition-based replaced units are the key subjects in this paper. Based on the abstraction of above problems, a general solution is given to such kind of problems.

This paper presents methods to master the air material consumption law under condition-based maintenance. Then we could predict the number of air material consumption under condition-based maintenance in a period of time and determine a reasonable number of stored air material. The predictive precision of models applied to predict the air material consumption under condition-based maintenance can be enhanced effectively by using the information of the reliability of the units and the maintenance strategy.

2. The rule of air material consumption

Suppose the failure density function for the No. $i$ condition-based replacement unit is $f_i(t)$ and the failure density function for the total service life of $k$ numbers of condition-based replacement units is $f_{\Sigma_i}(t)$ [3]. The service life of a unit may obey the exponential distribution, the gamma distribution, the normal distribution, or the weibull distribution [4]. Figure (1) shows the graph of the exponential distribution, Figure (2) shows the graph of the gamma distribution, Figure (3) shows the graph of the normal distribution, and Figure (4) shows the graph of the weibull distribution [5].

![Figure 1. The Graph of the Exponential Distribution](image1)

When the service life of the unit obeys the exponential distribution, the fault probability function is

$$f(t) = \lambda e^{-\lambda t} = \frac{1}{\theta} e^{-\frac{t}{\theta}}$$

In Equation (1), $\lambda$ is the failure rate, and $\theta$ is the average lifespan.

![Figure 2. The Graph of the Gamma Distribution](image2)
When the service life of the unit obeys the gamma distribution, the fault probability function is

\[ f(t) = \frac{\lambda^k t^{k-1} e^{-\lambda t}}{\Gamma(k)} \]  \hspace{1cm} (2)

In Equation (2), \( k \) is the shape parameter, and \( \lambda \) is the scale parameter.

![Figure 3. The Graph of the Normal Distribution](image)

When the service life of the unit obeys the normal distribution, the fault probability function is

\[ f(t) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\left(\frac{t-\mu}{\sigma}\right)^2} \]  \hspace{1cm} (3)

In Equation (3), \( \mu \) is the average lifespan, and \( \sigma^2 \) is the variance of lifespan.

![Figure 4. The Graph of the Weibull Distribution](image)

When the service life of the unit obeys the weibull distribution, the fault probability function is

\[ f(t) = \frac{m}{\eta} \left(\frac{t-\gamma}{\eta}\right)^{m-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^m} \]  \hspace{1cm} (4)

In Equation (4), \( m \) is the shape parameter, \( \eta \) is the scale parameter, and \( \gamma \) is the location parameter.

Through a comprehensive reference on air material consumption rule of corrective maintenance within \([0,T]\) and the air material consumption rule of condition-based maintenance at \( T \) time, it can obtain the total air material consumption rule within \([0,T]\).

Suppose the air material consumption in corrective maintenance is \( y_1 \) and the total air material consumption is \( y_2 \).

The probability for air material consumption \( y_2 = k \) \((k \geq 2)\) within \([0,T]\) is

\[ P(y_2 = k) = P\left(\sum_{i=1}^{k} T_i - T_0, y_1 = k-1\right) + P\left(\sum_{i=1}^{k} T_i > T_0, y_1 = k\right) \]

\[ = P\left(\sum_{i=1}^{k} T_i - T_0, y_1 = k-1\right)P(y_1 = k-1) \]
The probability for air material consumption \( Y_2 = 1 \) within time \([0,T]\) is
\[
P(Y_2 = 1) = P(T_1 > T, Y_1 = 0) + P(T_1 > T, Y_1 = 1)
\]
\[
= P(T_1 > T) + P(T_1 > T | Y_1 = 1)P(Y_1 = 1)
\]
\[
= \int \int f_{x_1}(t_1)dt_1 + P(T_1 < T) - P(\sum_{i=1}^{k} T_i < T)
\]
\[
- \int \int f_{x_1}(t_1)dt_1 \sum_{i=1}^{k} f_{x_i}(t_i)\sum_{i=1}^{k} \mu_{i1} dt_1
\]
\[
(5)
\]
The probability for air material consumption \( Y_2 = 0 \) within time \([0,T]\) is 0.
Combining the average value of air material consumption caused by corrective maintenance within time \([0,T]\) and the average value of air material consumption at \( T \) time, the average value of air material consumption within time \([0,T]\) can be obtained:
\[
\bar{y}_2 = \sum_{k=1}^{\infty} k \left[ P(\sum_{i=1}^{k} T_i < T) - P(\sum_{i=1}^{k} T_i < T) \right]
\]
\[
+ \int f_{x_1}(t_1)dt_1 + \sum_{k=1}^{\infty} \int \int f_{x_1}(t_1) f_{x_i}(t_i) \sum_{i=1}^{k} \mu_{i1} dt_1
\]
\[
(7)
\]
After learning the consumption rule of condition-based replacement units, a proper reserve plan of condition-based replacement units can be formulated. Firstly based on equation (7), we can calculate the average stock amount of a certain condition-based replacement unit and then according to the equipment quantity and the number of units in one piece of equipment, the optimal stock amount of condition-based replacement units for all the equipment can be determined.

3. Applications
Suppose a certain organization possesses one pieces of equipment, and each piece of equipment is maintained by the combination of periodic maintenance and corrective maintenance. During the normal operation, the service life of a certain unit obeys the gamma distribution, of which the shape parameter is \( \alpha = 6 \), the scale parameter is \( \beta = 0.01/\text{h} \). Predict the spare part consumption amount of all equipment within \([0,5000\text{h}]\) and determine the stock amount of air material.

The probability for air material consumption \( Y_2 = k \) (\( k = 2,3,4, \cdots \)) within \([0,5000\text{h}]\) is
\[
P(Y_2 = k) = \int_{0}^{5000} 0.01 e^{-0.01t} dt - \int_{5000}^{80} 0.01 e^{-0.01t} dt
\]

The probability for air material consumption \( Y_2 = 1 \) within \([0,5000\text{h}]\) is
\[
P(Y_2 = 1) = 1 - \int_{0}^{0.01} e^{-0.01t} dt
\]

The probability for air material consumption \( Y_2 = 0 \) within \([0,5000\text{h}]\) is 0.
The distribution of air material consumption is shown in Figure (5).
Figure 5. Distribution of Air Material Consumption

Using MATLAB programming software, we can obtain

$$y_2 = \sum_{k=1}^{\infty} \int_0^{0.01} \frac{0.01}{\Gamma(6k)} e^{-0.01t}dt + 1 = 9.10$$

Conclusions

In this paper, through making a analysis of condition-based replacement units of certain complex equipment in a certain organization as well the simplification of related problems, using the reliability theory and probability theory, the air material consumption models under condition-based maintenance can be derived, of which the practicability is verified by an example. The methods proposed in this paper can help equipment management personnel to grasp the air material consumption rule under condition-based maintenance, and to accurately predict air material consumption amount, which provide theoretical basis for proper stock amount of air material.

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