Research on Reliability Life Evaluation of Torque Motor based on Performance Degradation

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Abstract. The torque motor problem of reliability. The reliability evaluation of torque motor under the condition of accelerated degradation test is studied. Firstly, the failure mechanism of torque motor is studied, the performance degradation parameters are determined, then the theory of accelerated degradation test is described, the type of accelerated degradation model and the conditions of accelerated test are described. The method and procedure of product reliability analysis using accelerated degradation trajectory method under accelerated degradation test are studied. Finally, the reliability of a torque motor is evaluated and the average life value above 0.9 is calculated.

1. Introduction
Torque motor is the most common power equipment in equipment. Its function is to convert electrical energy into mechanical energy and provide power for the system. Accurate prediction of motor residual life is an important premise to ensure the system function perfect, reasonable maintenance decision and avoid failure loss. In order to accurately predict the life of torque motor, it is necessary to collect its fault sensitive data. However, in practice, the difficulty and high cost of fault data collection make it difficult to obtain the data. If the degradation data of torque motor can be collected instead of the fault data, the cost of data collection will be greatly reduced. According to the operating environment of a torque motor, temperature is the main environmental stress factor affecting its performance degradation. By applying stepping stress, its performance degradation parameters are monitored, so as to effectively evaluate the life of the torque motor.

2. Study on failure mechanism of torque motor and selection of performance degradation parameters
2.1. Working principle and failure mechanism of torque motor
Torque motor is a permanent magnet DC torque motor, which adopts a brush structure to convert electric energy into torque output and drive servo mechanism for two degrees of freedom operation of pitch and azimuth. Its interior is mainly composed of electric brush, collector ring, permanent magnet stator, armature rotor and bearing, as shown in Figure 1. The failure of torque motor can be divided into mechanical fault and electrical fault, the mechanical fault mainly includes rotor fault and bearing failure (1). Electrical faults are mainly divided into stator winding faults, sensor faults and inverter faults, etc. These faults will affect the performance parameters of torque motor and may cause performance parameters degradation or direct faults.
2.2. Selection of performance degradation parameters

By studying the working mode and failure mechanism of torque motor, it is found that the performance degradation is mainly manifested in the flowing speed, the starting voltage parameter drift and the peak blocking torque failure. Since these parameters can be detected in real time and degrade significantly with the increase of working time, the performance degradation indexes are selected as follows: no-load rotating speed (shun), no-load starting voltage (shun), peak blocked torque (shun), no-load starting voltage (inverse), peak blocked torque (inverse).

3. Principle and method of accelerated degradation test

3.1. Conditions of use for accelerated degradation

For products with slow performance degradation, stronger stress is often used to force the product to fail as soon as possible. This method is called accelerated degradation test, or ADT for short. However, the products to be tested for accelerated degradation shall meet the following conditions:

1) Product degradation exists;
2) The degradation of the product can be accelerated.

Therefore, in order to ensure the accelerated degradation performance of the test product and to ensure the smooth performance of the accelerated degradation test, the test product shall meet the following conditions:

1) Ensure that the failure mechanism of test products can remain unchanged under different accelerating stress conditions;
2) Ensure the regular acceleration process between the life characteristic quantity of test product and the test stress;
3) Ensure that the degradation process of the test product is subject to a homogeneous random process under various accelerated stress conditions, that is, when the test stress conditions change, the product degradation only changes the process parameters, but the random process does not change.

3.2. Classification of accelerated degradation models

In the accelerated degradation test, the corresponding accelerated degradation model should be established. By establishing the relationship between the characteristic quantity of performance degradation and the stress level in the accelerated degradation model, the value of the characteristic quantity under the normal stress level can be inferred. The common accelerated degradation models are mainly as follows [6-9]: Arrhenius model, inverse power law model, Erin model, etc.

By analyzing the failure mechanism of the torque motor, it can be considered that the relationship between its performance degradation parameters and test temperature conforms to the Arrhenius model, and its acceleration model is as follows:

$$\varepsilon = Ae^{\frac{E}{KT}}$$  \hspace{1cm} (1)
Then $\varepsilon$ is the performance degradation of the product, $T$ is the degree kelvin (K), $e$ is the constant and equals 2.718.

Take the logarithm of both sides and transform it into:

$$\ln \varepsilon = A + \left( \frac{E}{K} \right) \ln T \quad (2)$$

3.3. Types of methods for accelerated degradation tests

The accelerated degradation test can be divided into three types: constant stress accelerated degradation test, step stress accelerated degradation test and sequential stress accelerated degradation test. The following are three design schemes for accelerated degradation tests:

1) Accelerated degradation test with constant stress

Constant stress accelerated degradation test is also called by degradation test, a certain number of test samples selected from the test m, and it divided into n groups, Each group of samples was subjected to accelerated degradation test at the test stress level such as $S_1, S_2, \cdots, S_n$ higher than the normal stress level $S_0$. After the test was carried out for a period of time, the performance degradation parameters of each sample were measured, and the test was stopped until the specified test time or the performance degradation parameters of the samples reached the specified degradation standard.

2) Step stress accelerated degradation test

The step should be accelerated degradation test, also known as step plus degradation test. A certain number of test samples selected from the test will this m

Some samples first in higher than normal stress level $S_0$ of test stress level $S_1$ under the accelerated degradation test, after the test over a period of time, such as after a n hour record test the performance degradation of the sample quantity, and then increase the test stress level to $S_2$, will not exceed the prescribed amount of performance degradation of the standard sample under the new stress levels continue accelerated degradation test, so on, when to test for a specified level of the maximum stress $S_n$, after fulfilling the specified performance degradation test.

3) Sequence into stress accelerated degradation test

The sequential stress accelerated degradation test is also called the sequential degradation test. The experimental scheme of the sequential degradation test is basically the same as that of the stepwise degradation test, except that the stress level applied by the sequential degradation test rises linearly with time. The characteristic of sequential life test is that the test sample changes rapidly with the stress level, and it is difficult to accurately measure the degradation of the sample. The sequential life test is generally carried out by means of a device for controlling stress levels and a device for tracking and recording product performance changes. Will the above three kinds of loading ways of the stress of the accelerated degradation test method and test time drawn as follows, the relationship between the diagram (a) by degradation experiment test, the relationship between stress and time step (b) diagram into degradation test in the test should be relationship with time, (c) diagram sequence and degradation experiment of stress and time, the relationship between the horizontal axis in the graph, said the test time, longitudinal axis test applied stress level.
3.4. Accelerated degradation test hypothesis

Assume that under the stress level $S_i$ ($i = 1, 2, \ldots, w$), random samples $m_i$ from the product are selected for accelerated degradation test, and performance degradation is monitored at time $t_{1i}, t_{2i}, \ldots, t_{wi}$ and recorded, with total monitoring $n_i$ times and data recorded, as shown in Table 1. In Table 1, the performance degradation $y_{ijk}$ measured at the moment $t_{ij}$ of the $i$th sample at the stress level $k$ is shown.

| Stress level(s) | Sample No. | The value of the monitoring time and the performance degradation at that time |
|-----------------|------------|--------------------------------------------------------------------------------|
| $S_1$           | -          | $t_{11}$  $t_{21}$ \ldots $t_{n1}$                                           |
|                 | 1          | $y_{111}$  $y_{121}$ \ldots $y_{1n1}$                                     |
|                 | 2          | $y_{211}$  $y_{221}$ \ldots $y_{2n1}$                                     |
|                 | $\ldots$  | $\ldots$  $\ldots$ \ldots $\ldots$                                     |
|                 | $m_i$      | $y_{m_11}$  $y_{m_21}$ \ldots $y_{m_{n1}}$                                 |
|                 | $\ldots$  | $\ldots$  $\ldots$ \ldots $\ldots$                                     |
|                 | 1          | $y_{11w}$  $y_{12w}$ \ldots $y_{1nw}$                                     |
| $S_w$           | 2          | $y_{21w}$  $y_{22w}$ \ldots $y_{2nw}$                                     |
|                 | $\ldots$  | $\ldots$  $\ldots$ \ldots $\ldots$                                     |
|                 | $m_w$      | $y_{m_11w}$  $y_{m_21w}$ \ldots $y_{m_{nw}}$                                |

4. The steps and examples of accelerated degenerated trajectory method

4.1. The implementation steps of accelerated degradation trajectory method

The general steps of the degradation quantity distribution based on the degradation trajectory are as follows:

1) Collect all samples performance degradation data at the time of $t_1, t_2, \ldots, t_n$.

2) Select the probability distribution function, so that the function can fully describe the statistical law of degenerate data at each moment. At present, normal or logarithmic normal distribution is mainly selected according to statistical test.
3) Corresponding to every moment of each sample \( t_j \) \( (j = 1, 2, \cdots, m) \). Estimate \( k \) unknowns in the probability distribution function by using the degenerate data at this time point.

4) After the estimation of each parameter is obtained, the probability distribution of performance degradation data at any time can be obtained.

4.2. Pseudo-accelerated life data analysis method

As a result of the previous analysis is under a stress level of degradation path and data, this article adopts the method of used above normal stress level, assuming that the stress level \( S_k \) under \( k \) unit test, which \( q \) is accelerated stress on the number of levels \( k = 1, 2, \cdots, q \), under the stress \( S_k \), the performance of the unit \( i \) in the time \( t_{ijk} \) for measurements \( y_{ijk} \), in \( j = 1, 2, \cdots, m_j \) which for the \( i \) units under the stress level measurement \( S_k \). The pseudo-life value at the accelerated stress level \( S_k \) can be obtained by using the pseudo-life method of degraded data \( \hat{t}_{ik}, \hat{t}_{2k}, \cdots, \hat{t}_{nk} \), and the product reliability can be estimated by using the method of accelerated life data analysis.

Assume linear degradation \( y_i \) has an initial value \( y_0 \), The accelerated degradation equation of change is

\[
\frac{\Delta y}{y_0} = At^n \exp \left( -\frac{E}{KT} \right)
\]  

Which \( \Delta y \) Is the change of the degradation quantity with time \( t \). Then the above formula is linearized and obtained

\[
\ln \left( \frac{\Delta y}{y_0} \right) = \beta_1 + \beta_2 \ln t
\]

Which \( \beta_1 = \ln A - \frac{E}{KT} \), \( \beta_2 = B \).

If the failure criterion is defined as \( \frac{\Delta y}{y_0} \geq y_c \), Pseudo-life values at different temperatures can be obtained

\[
\hat{t} = \exp \left[ \left( \ln y_c - \hat{\beta}_1 \right) / \hat{\beta}_2 \right]
\]

That is, the life value at the temperature level \( T \) can be expressed as

\[
t = \left( \frac{y_c}{A} \right)^{\frac{1}{B}} \exp \left( \frac{E}{KBT} \right)
\]

4.3. Normal distribution test

As mentioned earlier, the distribution test can be used to verify whether the fitted distribution is a normal distribution function. This section will introduce the normal distribution test method. Currently, the distribution test is specially designed for normal distribution, including chart test, partial kurtosis test, Shapiro-Wilk test, Epps-Pulley test, etc., among which, Shapiro-Wilk test can be used when it is in \( 3 \leq n \leq 50 \) use. This test is based on sequential observation values, and the specific test steps are as follows:

1) Arrange the samples from small to large as sequential statistics

\[
x_{(1)} \leq x_{(2)} \leq \cdots \leq x_{(n)}
\]
Find out the corresponding value of \( n \) according to the coefficient table \( \alpha_{k,n}, \ k = 1, 2 \ldots, l \) Among them

\[
l = \begin{cases} 
\frac{n}{2}, & \text{if } n \text{ is even number} \\
\frac{n-1}{2}, & \text{if } n \text{ is odd number}
\end{cases}
\]  

(8)

3) Calculation of test statistics

\[
Z = \frac{\sum_{k=1}^{l} a_{k,n} \left[ x_{n+1-k} - x_k \right]^2}{\sum_{k=1}^{n} \left[ x_k - \bar{x} \right]^2 / (n-1)}
\]  

(9)

4) The critical value of \( Z_\alpha \) can be obtained by looking up \( Z \) in the table according to the significance level \( \alpha \) and \( n \).

5) Make a judgment: if \( Z \leq Z_\alpha \), refuse \( H_0 \); Otherwise, accept \( H_0 \).

4.4. Example

In the actual test, the trend chart of the actual speed change will be obtained. In order to facilitate calculation, the data will be fitted to obtain the speed degradation track, as shown in Figure 3 and Figure 4.

**Figure 3.** Trend chart of no-load speed (clockwise) change

**Figure 4.** Fitting diagram of no-load speed (clockwise) variation tren

In normal distribution test (Shapiro-Wilk test), the failure threshold is lower than 600r/min. As calculated by formula (9) above, the test statistic \( Z = 0.8496 \). When the significance level \( \alpha = 0.01 \) and the sample size \( n = 8 \), \( Z_\alpha = 0.749 \). Because \( Z \geq Z_\alpha \), a solid satisfies a normal distribution.

At the temperature of 80°C, according to the linear degradation model, it can be known that the distribution type and distribution parameters of pseudo-failure time are: the distribution model is normal, with a mean value of 35115h and a standard deviation of 8864.9.

5. Conclusion

1) By studying the reliability evaluation method under the condition of accelerated degradation test of torque motor, the failure mechanism of torque motor is understood and its performance degradation parameters are determined.
2) According to the theory of accelerated degradation test, the method and procedure of using accelerated degradation trajectory method for product reliability analysis under the condition of accelerated degradation test are defined.

3) Through the analysis of the case, the reliability of a certain type of torque motor is evaluated, and the average service life of the torque motor above 0.9 is calculated as 35115h.

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