Method for Determining Maintenance Interval of Gear Reducer Based on Preventive Sequential Maintenance

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Abstract. With the continuous development of society, maintenance work has been paid more and more attention in the production field. As one of the indispensable components of many production equipment, the gear reducer can effectively guarantee the safe operation state and maximize the efficiency of the production process through preventive maintenance. This paper constructs a preventive maintenance strategy for gear reduction gearboxes through the analysis of preventive maintenance decisions. Compare the two methods of regular maintenance and sequential maintenance to determine a more practical method. Then the method is verified by an example and the conclusion is drawn.

1. Introduction

Maintenance is a key area of concern for the academic, engineering and business sectors and a fundamental guarantee for the life cycle of equipment. Maintenance now generally defines maintenance as two modes, regular maintenance and non-time maintenance \cite{1}. The basic concept of timed maintenance is precautionary; non-time maintenance is a repair in the event of a sudden failure \cite{2}. Previous traditional timed repairs were based on empirical time to determine their maintenance intervals. However, in actual production, such methods appear to be somewhat aging, which may lead to problems such as over-maintenance or insufficient maintenance. Therefore, when determining the preventive maintenance interval, it is necessary to calculate according to the empirical formula, and finally determine the preventive maintenance interval \cite{3}.

As an indispensable part of modern process equipment, gear reducer is widely used in electric machinery, metallurgical machinery, environmental protection machinery, food machinery, light industry machinery and so on. In the event of a failure of the gearbox in a mechanical system, the entire system may be paralyzed, resulting in economic losses. Therefore, it is necessary to determine the preventive maintenance interval of the gear reducer, so that it can be periodically preventively repaired to prevent unnecessary failure of the gearbox \cite{4}.

2. Gear reducer common fault

When an abnormal situation occurs in the gear reducer, the abnormality caused by the failure of the shaft, bearing, gear, coupling, chassis and cover is generally caused \cite{5}. Therefore, the fault inquiry of the gear reducer is to diagnose the fault of these components. The main fault types of the gear reducer

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are: severe vibration, high noise or abnormal noise, oil leakage, excessive temperature rise, etc., and the main causes of these faults are shown in Table 1.

**Table 1. Gear Reducer Failure Type.**

| Serial number | Fault type                               | cause                                                                                                                                 |
|---------------|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 1             | Noise, vibration, with abnormal noise     | 1. There is both relative rolling and relative sliding between the two meshing gears;                                                  |
|               |                                          | 2. Cyclical changes, tooth profile errors, and torque changes in the overall stiffness of the system;                                |
|               |                                          | 3. Rolling bearings in gear reducer systems produce varying degrees of shock or load fluctuations during operation;                 |
|               |                                          | 4. Passing through the shaft and bearing in the form of solid sound, and finally transmitting the noise to the box of the gearbox,    |
|               |                                          | the box will directly radiate noise into the air.                                                                                   |
| 2             | Oil spill                                | Poor sealing, seal failure, improper selection of lubricating oil                                                                   |
| 3             | The temperature of the gearbox is too high| If the lubrication between the gears or bearings that are intermeshing is not up to standard and the amount of lubricating oil is      |
|               |                                          | insufficient, the frictional heat will be excessive. If the heat dissipation area is too small, the temperature will rise.          |

3. **Preventive maintenance theory**

The strategies for determining preventive maintenance intervals include two main types, regular maintenance and sequential maintenance. Among them, the sequential maintenance strategy believes that the product failure rate gradually increases with the extension of working time, and the preventive maintenance interval is not fixed. The maintenance interval and maintenance should be based on the remaining life of the product after each repair. The number of times is adjusted appropriately and the next maintenance time is determined [6]. It is a relatively dynamic process that not only reduces the maintenance cost of the product, but also avoids the occurrence of functional failure to a certain extent and ensures the availability of the product [7]. This method has a certain degree of flexibility, which is more reasonable in terms of maintenance costs or loss of product failure.

4. **Gear reduction gearbox sequence preventive maintenance interval calculation model**

In many methods of calculating the maintenance interval, the method of calculating the maintenance cost of the gear reducer with the minimum maintenance cost rate at a given reliability can not only ensure the reliability that the gear reducer must achieve, but also ensure the maintenance cost rate. The lowest. It can ensure safe operation and achieve economic benefits.

Reliability equation:

\[
\int \lambda_i(t)dt = \int \lambda_2(t)dt = \cdots = \int \lambda_N(t)dt = -\ln R
\]  (3.1)

The cost of the gear reducer during a replacement cycle is:

\[
C_z = C_f \sum_{i=1}^{N} (\int \lambda_i(t)dt) + C_p (N - 1) + C_r = NC_f (-\ln R) + C_p (N - 1) + C_r
\]  (3.2)

The maintenance period is:
\[ T_i = \sum_{j=1}^{N} T_{j} + Nt_{j} (-\ln R) + (N-1)t_p + t_r \]  

(3.3)

The maintenance cost rate optimization model is:

\[ \min c = \frac{C_{z}}{T_{z}} = \frac{NC_{z} (-\ln R) + C_{p} (N-1) + C_{r}}{\sum_{i=1}^{N} T_{j} + Nt_{j} (-\ln R) + (N-1)t_p + t_r} \]  

(3.4)

Where \( T_{i} \) is the in-service time of the gear reducer between the \( i \)-1st preventive maintenance and the \( i \)th preventive maintenance under the sequential preventive maintenance strategy, \( i = 1, 2, 3, N \)

The value of \( N \) can be solved by Equation 3.4.

5. Case study

Check the data of the machine gear reducer to determine a number of relevant parameters, give the following gearbox parameters of the machine tool, calculate the sequential preventive maintenance interval according to the method of minimum maintenance cost under the given reliability, and get preventive Maintenance cycle. The numerical parameters are as follows:

| Shape parameter(m) | Size parameters(ŋ) | Retirement factor(a) | Failure increment factor(b) | Replacement cost (Cr/yuan) |
|--------------------|--------------------|----------------------|-----------------------------|----------------------------|
| 1.10               | 100                | 0.95                 | 1.15                        | 1100                       |
| Preventive maintenance costs (Cp/yuan) | Time required to replace repairs (tr/d) | Time required for preventive maintenance (tp/d) | Time required to replace repairs (tf/d) |
| 100                | 2                  | 6                    | 10                          |

Assume that the failure rate of the gear reducer is subject to the Weibull distribution, and the reliability is 1 when it is put into use, and it is replaced when the reliability is reduced to 0.8 or less. Assume that the gear reduction gearbox has a reliability \( R \) of 0.98, 0.95, 0.93, 0.90, 0.88, 0.85, 0.83, and 0.8 for preventive maintenance, assuming that the gear reducer is not repaired. Get the following failure rate function [8]:

\[ \lambda(t) = \frac{m \cdot \left( \frac{t}{\eta} \right)^{m-1}}{\eta} \]  

(4.1)

Where \( m \) is a shape parameter; \( \eta \) is the size parameter.

Every time the gear reducer is repaired, the failure rate will increase accordingly. According to the age-return factor retreat theory [9], the failure rate after the \( i \)-th repair is:

\[ \lambda_{i+1}(t) = b \lambda_i(t + aT_i) \]  

(4.2)

Where \( a \) is the age-return factor, \( t \) is the maintenance period, and \( b \) is the failure-increasing factor.
According to the age-return theory, it can be known that when the failure rate is \( \lambda_{aT}(t) = b\lambda(t) \cdot (aT) \), the gear reducer needs to be replaced. In the theory of life-age retreat, we can know that when the gear reducer is repaired, the failure rate will decrease accordingly, so the actual service age will increase after the repair, and the form of the increase is shown in Figure 1.

From the above figure, the influence law of the cycle can be obtained as follows:

\[
T_i = T_{i-1} + \alpha t
\]  

(4.3)

Where it is the maintenance interval without considering the age of the service. When given reliability \( R = 0.8 \), there is:

\[
\int_0^{T_1} \lambda_i(t) dt = \int_{T_1}^{T_2} \lambda_2(t) dt = \cdots = \int_{T_{i-1}}^{T_i} \lambda_i(t) dt = \int_0^1 \frac{1.1}{100} (\frac{t}{100})^{0.1} dt = -\ln R
\]

\[
= -\ln 0.8 = 0.22
\]  

(4.4)

Can find T1 = 25d, and according to the theory of life-age retreat:

T2 = 25 + 0.95 \times 25 = 49d, T3 = 49 + 0.95 \times 24 = 72d, ..., T26 = 325d.

Preventive maintenance interval is t1 = 25d, t2 = 24d, t3 = 23d, ..., t26 = 0d.

The cost of a gear reducer in a replacement repair cycle is:

\[
C_z = C_f \sum_{i=1}^{N} \left( \int_0^{T_i} \lambda_i(t) dt \right) + C_p (N-1) + C_r = NC_f (-\ln R) + C_p (N-1) + C_r
\]  

(4.5)

Maintenance cost rate:

\[
C_Z = C_p(N-1) + 1100 = 100(N-1) + 1100 = 100N + 1000
\]  

(4.6)
Replacement repair cycle is:

\[ T_z = \sum_{i=1}^{N} T_i + Nt_f (-\ln R) + (N-1)t_p + t_r \]  \hspace{1cm} (4.7)

The maintenance period is:

\[ T_z = \sum_{i=1}^{N} T_i + (N-1)t_p + t_r = \sum_{i=1}^{N} T_i + (N-1)6 + 2 = \sum_{i=1}^{N} T_i + 6N + 4 \]  \hspace{1cm} (4.8)

Optimize maintenance expense rate:

\[ \min c = \frac{C_z}{T_z} = \frac{100N + 1000}{\sum_{i=1}^{N} T_i + 6N + 4} \]  \hspace{1cm} (4.9)

Since \( N \) is a positive integer and \( N=17 \) is calculated by calculation, the expense rate is optimized to the maximum. Can be obtained, the replacement cycle is: \( T = 280 \text{d} \), the maintenance cost rate is: \( C = 6.97 \text{ yuan/d} \), the maintenance interval is: \( N = 17 \).

In actual production, the degree of wear of the gear reducer will have different effects on the failure rate of the gear reducer according to the environment of the actual production equipment and the processed products. It is necessary to clearly specify the corresponding maintenance cycle according to the actual situation.

6. Conclusion
This paper analyzes the maintenance time interval of the gear reducer. From the many maintenance decisions, sequential preventive maintenance was chosen. Establish an optimization model to determine the maintenance interval with a given reliability and minimum maintenance cost. Apply this model to the maintenance of the machine gear reducer to get the optimal maintenance interval.

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