Estimation and Reliability Evaluation of Weibull Distribution Parameters of CNC Gear-hobber Machine Based on Computer

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Abstract. The development of computer brings great computing and operation convenience to the mechanical industry, but also provides a new research mechanism for equipment operation and safety evaluation. In this paper, the Weibull distribution model is briefly introduced, and based on this, the operating parameters and reliability of the independent components of CNC gear-hobber machine are evaluated by computer program.

Keywords: Computer, CNC Hobbing Machine, Weibull Distribution

1. Introduction

CNC gear hobbing machine is widely used in industrial engineering. With the improvement of product reliability, the fatigue life of individual components is also required. Weibull distribution is a continuous distribution model, based on the system weakest link model or series model, so it can fully reflect the raw material defects and structural stress concentration on the fatigue life of the product. It is often used to describe the distribution of fatigue life data of mechanical system and its related parts. So we can use Weibull distribution to process the data of CNC hobbing machine and analyze the fatigue life. The parameter determination of Weibull distribution is more complicated. The traditional Weibull distribution parameter determination methods include graphical method and analytical method [1]. The traditional graphical method parameter estimation results vary from person to person, and the accuracy is difficult to guarantee; the analytical method includes maximum likelihood estimation, point estimation, etc. The solution process is more cumbersome. The traditional parameter estimation method is difficult to obtain accurate parameter estimation results when the data sample is small. In the actual working process, the spring fatigue fracture data is mostly small sample data. It is necessary to consider the processing method of spring fatigue data under small sample size [2]. In this paper, the support vector machine theory is combined with the traditional graph estimation method to
develop the processing program of Weibull distribution parameter estimation, to process the fatigue data of different sample sizes, and to verify the effectiveness of the developed program in the process of NC hobbing machine data processing.

2. Establishment of Weibull distribution model

2.1. Fault distribution curve
During the service life of mechanical equipment, the incidence of failure is related to the age of use. Failure rate function is a function that changes with time t equipment is in different service periods, and its failure rate is also different. Figure 1 curve reflects the fault distribution of the whole period of the equipment, including the early fault period. The accidental fault period and the wear fault period, because the overall shape is like the bath, which is called the bath curve [3-4].

![Figure 1. Fault distribution of equipment in full cycle](image)

2.2. Weibull distribution model
Weibull distribution [5-6] is one of the most widely used models in the reliability analysis of equipment life in recent years, which can describe the whole bathtub curve as a whole.

The failure distribution function of Weibull distribution is

\[
f(t) = \frac{B}{\theta} \left( \frac{t - \gamma}{\theta} \right)^{\beta-1} \exp \left[ - \left( \frac{t - \gamma}{\theta} \right)^{\beta} \right], \quad t \geq \gamma
\]

Fault density function be represented by

\[
f'(t) = \frac{B \theta^{\beta-1}}{\alpha^2} \exp \left[ - \left( \frac{t}{\alpha} \right)^{\beta} \right]
\]

The cumulative failure distribution function is

\[
F(t) = 1 - \exp \left[ - \left( \frac{t}{\alpha} \right)^{\beta} \right]
\]
\[ F(t) = \int_{\gamma}^{t} f(t) \, dt = 1 - \exp \left[ - \left( \frac{t - \gamma}{\theta} \right)^{\beta} \right], t \geq \gamma \]  

(3)

Reliability function is

\[ R(t) = 1 - F(t) = \exp \left[ - \left( \frac{t - \gamma}{\theta} \right)^{\beta} \right] \]  

(4)

If the position parameter of the Weibull distribution \( \gamma = 0 \), the three-parameter Weibull distribution is simplified to the two-parameter Weibull distribution, and the formula (3) becomes

\[ F(t) = 1 - \exp \left[ - \left( \frac{t}{\theta} \right)^{\beta} \right] \]  

(5)

Constant transformation of formula (5), arranged

\[ \ln \ln \left( \frac{1}{1 - F(t)} \right) = \beta \ln t - \beta \ln \theta \]  

(6)

\[ x = \ln t, \quad y = \ln \ln \left( \frac{1}{1 - F(t)} \right), \quad B = - \beta \ln \theta \]  

(7)

Bring (7) into formula (6) and you can get the following formula

\[ \gamma = \beta x + B \]  

(8)

The fatigue data \( (t_{i}, F(t_{i})) \) is drawn on the Weibull probability paper. If we obey the Weibull distribution and the position parameter \( \gamma = 0 \), the data will be approximately linear. When \( \gamma \neq 0 \), we cannot directly use regression analysis to solve the Weibull distribution parameters. If the \( \gamma \) is determined, the three-parameter Weibull distribution can be transformed into two-parameter Weibull distribution to solve the problem. Take the position parameter as the independent variable. In \([0, t_{\text{min}}]\) interval generates the sufficient quantity of the \( \gamma \) value which obeys the uniform distribution, causes the maximum correlation coefficient between the \( x \) and the \( y \) value, then calculates separately, according to the given list drawing point, will approximate to the straight line form, uses the regression analysis to calculate the Weibull distribution parameter.

3. Computer Weibull distribution parameter assessment

3.1. Design principles and processes for parameter evaluation

The data of NC hobbing machine can be normalized and preprocessed to accelerate the convergence of data training and eliminate the difference of fatigue data. The value of the Weibull distribution position distribution parameter \( \gamma \) is between \([0, \ t_{\text{min}}]\), and the position parameter is taken as the independent variable. In this interval, a sufficient quantity of \( \gamma \) values subject to uniform distribution is generated, and the linear correlation coefficient of \( x-y \) under different values is calculated. The largest linear correlation coefficient is the position parameter value. The position of obtaining the maximum value through the correlation coefficient is used to determine whether it obeys the three parameter distribution. The three-parameter Weibull distribution is transformed into
two-parameter Weibull distribution. The flow chart is shown in in Figure 2.
CNC gear hobbing data

Data analysis and processing

Weibull distribution type

Is the three parameter Weibull distribution?

Determine position parameters

Estimation method selection

Parameter solution

Results show
3.2. Introduction to the parameter assessment procedure

Computer software has powerful mathematical operation ability, can complete complex calculation, and has great advantages in graphical interface development. At the same time, it is necessary to consider the compatibility between the developed program and the spring fatigue testing machine. Therefore, the hybrid programming technology is used to develop the spring fatigue data processing software program with graphical interactive interface. The program interface design includes data input area, parameter selection area and result display area.

4. Reliability evaluation of CNC gear hobbing machine

4.1. Reliability growth evaluation model

First, we illustrate the modeling method of the reliability growth process of an independent part of CNC hobbing machine by an example, and also illustrate the role of engineering judgment in the modeling process. An independent component starts the reliability growth test at zero time, the test is carried out until the equipment fails, the test is continued after the equipment is improved (e.g. improved process, material, design, etc.), the time is broken again, and the test is put back into the test after the improvement, the test t3 stop at the moment. The final reliability level (or failure rate) of the device is now evaluated based on the above test data. If you rely only on the experimental data above, different people may draw different conclusions. The main reason is that based on the above test data and different engineering judgments can build completely different statistical models, and based on different models will lead to different evaluation results. According to the following four different engineering judgments, four different models can be obtained respectively.

(1) The two improvements completely eliminated the original failure mode and the two improvements did not add new failure mode. (2) Two improvements can not completely eliminate the original failure mode and these two improvements may add new and potential failure mode, but the improved part will not exceed the original failure rate. The first improvement completely eliminated the original failure mode without adding new failure mode. The second improvement measures can not completely eliminate the original fault mode. And this improvement may also add new failure mode, but its improved failure rate will not exceed the original loss of efficiency. (4) The first improvement measures can not completely eliminate the original failure mode, and the new failure mode is added, but the improved failure rate will not exceed the original failure efficiency; the second improvement completely eliminates the original failure mode without adding the new failure mode.

4.2. Fatigue reliability life prediction

For industrial machines, the fatigue reliability of parts will decrease gradually with the increase of service life. The probability that the fatigue life is greater than the given design life is measured by calculating the safety of the parts in terms of fatigue. The task of reliability prediction of fatigue life of parts is to calculate the reliability of fatigue life or the corresponding reliability index, so as to master the running reliability of CNC hobbing machine. Figure 3 is the reliability curve under fatigue condition of different age.
5. Conclusion
According to the data collected in the field, the distribution model of Weibull is established. The least square method is used to realize the linearization of the distribution function, and the empirical distribution function is obtained by combining the average rank order method. Comparing this method with previous methods, the results show that from the fitted regression line, it can be seen that more accurate parameter estimation and reliability evaluation are obtained, which has higher accuracy and achieves very good results.

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