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Reliability test for linear induction motors*

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Abstract: Reliability is a very important target of linear induction motors. In this paper, the reliability model of the motor is established, the reliability indexes are defined, the faults' modes are analyzed and classified according to their effect and damage, the sequential sampling plan is discussed and its acceptable fault rate (ACFR) and refusable fault rate (REFR) are presented, and then, the detailed reliability compliance field test method is introduced with one case. With the method, engineers can verify the reliability of linear induction motors expediently.

Key words: Linear induction motors, Reliability test, Sequential sampling plan
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INTRODUCTION

In the past years, linear induction motors have been subjected to increased demand due to their higher horsepower, higher operating temperatures, ability to deal with more demanding duty cycles, higher starting currents, less frequent voltage transients, and ability to withstand severe environmental exposure. And among these many strong points is satisfying the requirement for long life and reliable performance (Plotkin and Moon, 2004).

The fault modes of linear induction motors are very complex (Michael, 2004), so that many people find it difficult to establish the fault evidences for reliability verification. Because the mechanism, effect, maintainability and maintenance cost of each individual fault are different, the evidences and targets are usually different for different fault mode in the reliability test.

In what follows, we consider the linear induction motor as a high reliability long-life repairable item, and in this paper the main reliability indexes of the motor is defined as the lower bound of the mean time between faults ($\mathrm{MTBF_L}$) (Lu, 1991) .

RELIABILITY COMPLIANCE TEST OF LINEAR INDUCTION MOTORS

Curve of motor's fault rate

In order to establish the distribution of the motor's life, a large-scale survey was conducted. Statistical data were used to plot the curve of motor's fault rate vs time (Yu and Fang, 2004). In this curve, the motor's life can be separated into three periods, early failure period, constant failure period, and wear-out failure period. It is estimated that worksite motors commonly operate in the constant failure period, when the motor's fault rate is constant with its life obeying single-parameter exponential distribution. The estimate is verified with an χ^2 method.

Methods for the linear induction motors' reliability compliance test

Because of the complexity of the fault modes and fault mechanism, as well as its long life, it will cost too much time and money to determine the reliability of linear induction motors with a laboratory test wherein it is very difficult to simulate the factual operation condition accurately. So that, we prefer to

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use field methods.

To verify the linear induction motors' reliability, there are two common kinds of sampling plans used, sequential sampling plans and fixed-time (fixed-fault) truncated sampling plans. Compared with the latter, the sequential sampling life test plans have some strong points. This kind of plans usually cost shorter cumulative test time, especially when the reliability of motors is very high or very low (The compared curve of the text time between two methods is illustrated in Fig.1) (Lawless, 1982). Next, a sequential sampling plan is introduced.

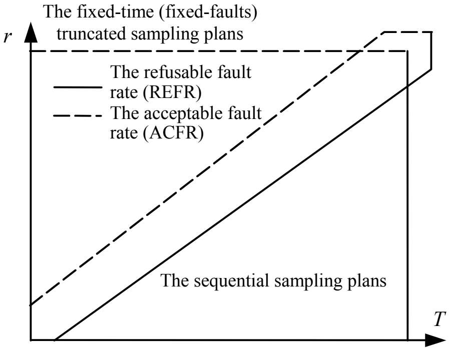

Fig.1 Comparison between the two methods

Derivation of the ACFR and REFR

To find out whether the motor reliability is qualified with a sequential sampling plan or not, the accumulated operation time between two faults must be observed. If the time is long enough (longer than the ACFR), the motor is in conformity. If the time is very short (shorter than the REFR), the motor is not. If the time is between ACFR and REFR, the test must be continued. By using classical computational methods of probabilistic statistics, we can get the ACFR and REFR as follows:

Let the producer's risk be α, consumer's risk be β, acceptable MTBF be μ_0, refusable MTBF will be μ_1. Choosing n samples from N products randomly, let the operation time be t, and the nonconformity rate be p, then the probability of the faults number will be

$$P_r = \frac{\mathrm{e}^{-np}(np)^r}{r!}. \tag{1}$$

Assuming that the sample's life obeys single-parameter exponential distribution, and letting the fault rate be λ, the accumulated operation time be T, then

$$P_r = \frac{\mathrm{e}^{-n\lambda t}(n\lambda t)^r}{r!} = \frac{\mathrm{e}^{-\lambda T}(\lambda T)^r}{r!} = \frac{\mathrm{e}^{-T/\mu}(T/\mu)^r}{r!}. \tag{2}$$

When $\mu=\mu_0$: $P_{r0} = \dfrac{\mathrm{e}^{-T/\mu_0}(T/\mu_0)^r}{r!}$.

When $\mu=\mu_1$: $P_{r1} = \dfrac{\mathrm{e}^{-T/\mu_1}(T/\mu_1)^r}{r!}$.

Then

$$P_{r1}/P_{r0} = \mathrm{e}^{-(\mu_1^{-1}-\mu_0^{-1})T}(\mu_0/\mu_1)^r. \tag{3}$$

Let $A=(1-\beta)/\alpha$, $B=\beta/(1-\alpha)$, then, if $P_{r1}/P_{r0}\ge A$, it will be refused; if $P_{r1}/P_{r0}\le B$, it will be accept; and if $A>P_{r1}/P_{r0}>B$, the test will be continued. Thus, the condition of continuing test is

$$B < (\mu_0/\mu_1)^r \mathrm{e}^{-(\mu_1^{-1}-\mu_0^{-1})T} < A, \tag{4}$$

$$\ln B < r\ln(\mu_0/\mu_1) - (\mu_1^{-1}-\mu_0^{-1})T < \ln A,$$

$$\frac{-\ln A + r\ln(\mu_0/\mu_1)}{\mu_1^{-1}-\mu_0^{-1}} < T < \frac{-\ln B + r\ln(\mu_0/\mu_1)}{\mu_1^{-1}-\mu_0^{-1}}. \tag{5}$$

Let

$$h_0 = \frac{-\ln B}{\mu_1^{-1}-\mu_0^{-1}},\ h_1 = \frac{-\ln A}{\mu_1^{-1}-\mu_0^{-1}},\ s = \frac{\ln(\mu_0/\mu_1)}{\mu_1^{-1}-\mu_0^{-1}},$$

then

$$-h_1+sr<T<h_0+sr. \tag{6}$$

It means that, up to the number r fault happening, if $T\ge h_0+sr$, the products will be accepted, and if $T\le -h_1+sr$, the products will be refused.

To avoid too long test time, we define a fixed-fault number r_0, stipulate that if the time up to number r_0 fault happen is shorter than h_0+sr_0, the test will be stop and the products will be refused.

Test plan of linear induction motors

For linear induction motors, their reliability compliance test can be sorted into two classes: the finalized test and maintain test. The former is used to define the product's reliability level and the latter is used to confirm the product's reliability level be not lower than before. Usually we choose lower α and β ($\alpha=\beta=0.1$) in the former and higher α and β

($\alpha=\beta=0.3\sim0.4$) in the latter to balance the precision and expense.

In this paper, the faults of linear induction motor were classified into the following three classes (Fang *et al*., 1999):

(1) Class A: The critical faults caused by the inherent weakness failures of the electric insulation system or the main structural parts (except the easily replaced parts). We usually consider the kind of faults as the failure criterion of motors.

(2) Class B: The major faults causing a minor failure or causing less damage to the operation of the motors and can be repaired by replacing some parts. For repairing these faults, less time and less cost are required.

(3) Class C: The other faults, such as misuse faults and secondary faults will not be taken into account.

Next, the class A and class B faults will be examined. Apparently, we must set different reliability indexes for both of them according to their different criticality. For linear induction motor, we usually choose the index $MTBF_{\text{classA}}=2MTBF_{\text{classB}}$.

We define the $D_{\text{m}}=\mu_0/\mu_1$ as discrimination ratio. For small induction motor, we usually choose $D_{\text{m}}=1.5\sim5$.

For example: The design $MTBF_{\text{classA}}$ of one series of linear induction motor is 10 years, and it operates 11 month every year. So that

$$MTBF_{\text{classA}}=10\times11\times30\times24=79200\approx80000\text{ h},$$
$$MTBF_{\text{classB}}=0.5\times MTBF_{\text{classA}}=40000\text{ h}.$$

If the test is a finalized test for $MTBF_{\text{classB}}$, $\mu=MTBF_{\text{classB}}$, $\mu_1=40000$ h, and let $D_{\text{m}}=2$, $\alpha=\beta=0.1$. According to Eqs.(1)~(6), we can get

$$A=B=0.1/(1-0.1)=0.1111,$$
$$h_0=\frac{-\ln(0.1111)}{\mu_1^{-1}-(2\mu_1)^{-1}}=4.395\mu_1=175786,$$
$$h_1=\frac{-\ln(0.1111)}{\mu_1^{-1}-(2\mu_1)^{-1}}=4.395\mu_1=175786,$$
$$s=\frac{\ln(2\mu_1/\mu_1)}{\mu_1^{-1}-(2\mu_1)^{-1}}=1.386\mu_1=55452\text{ h}.$$

Thus, the accept line will be

$$T=(175786+55452r)\text{ h},$$

and the refuse line will be

$$T=(-175786+55452r)\text{ h}.$$

Up to now, we have got full sequential sampling plans for the reliability compliance test of small induction motors as shown in Fig.2 and Table 1.

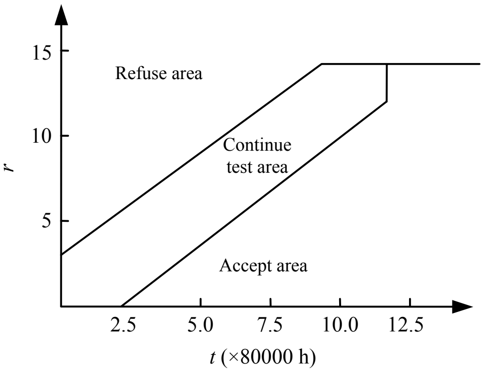

Fig.2 The sampling plan of the finalize test for the $MTBF_{\text{classB}}$ of linear induction motors

Table 1 Data table of the sampling plan

Number of faults	Accumulated test time (h)	
	*Refuse ≤	Accept ≥
0	–	176000
1	–	231200
2	–	287200
3	28000	342400
4	83200	397600
5	139200	453600
6	194400	508800
7	249600	564000
8	305600	620000
9	360800	675200
10	416000	730400
11	472000	786400
12	527200	824000
13	582400	824000
14	637600	824000
15	693600	824000

*Refuse if the number of faults>15

CONCLUSION

How to determine the reliability of linear induction motor is a very complex problem. In this paper, the detailed test method and sampling plan are introduced by using one case, including the data tables. With the proposed method, engineers can verify the reliability of their products expediently.

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