Abstract—RET (reliability enhancement testing) is the most advanced technology from western countries. RET's concept, process and stress limit classification were introduced. The basic theory of RET was explained. Interference model was introduced into RET, to settle the problem that RET couldn’t be analyzed quantitatively. The failure mechanism occurred in RET was analyzed by using interference model. By analyzing the interdependence between the operating stress found in RET and the stress in actual operation environment, the formula for reliable probability was deduced. Then an example was given to explain this approach’s feasibility. RET could improve the reliability of products by improving the quality of design and manufacturing process. By using the interference model and the deuced formula, two ways of improving the reliability of products were analyzed.

I. INTRODUCTION OF RET

A. Stress Limit Classification

There are many stress limits in RET as shown in Fig 1. From low to high, there definitions are [3]:

1) Technical specification limit: determined by user or maker. Product is expected to be operated under this limit.
2) Design limit: product will not fail in design. The difference between technical specification limit and design limit is design margin.
3) Operating limit: product will not fail in actual operation environment. Working limit can be determined by RET.
4) Failure limit: this is a stress limit in which product can work and no irreversible failure appears. Failure limit can be determined by RET.
5) ESS (Environment Stress Scanning) limit: ESS is a screening process before the final product is delivered. ESS limit can be determined by RET and always within operation limit.
6) RET limit: the maximum stress in the process of RET. Obviously, RET limit will not exceed failure limit.

Operating limit is paid the most attention among various stress limit because product will not work well when this limit is exceed. Generally, there is a large distance between working limit and failure limit for a product at development stage. RET can shorten the distance by increasing the working limit and improve the reliability of products finally.

B. The Process of RET

RET applies stresses to products using step-stress and the stresses include six degree of freedom vibration, temperature, humidity and electrical stress or their combination [4]. Fig 2 is typical step-stress test schematic diagram.

The stress in Fig 2 can be vibration stress, temperature stress etc or their combination. The test begins with an initial stress (lower than technical specification limit normally), goes on by certain step and the residence time of each step changes...
from a few minutes to half an hour. Products must be real-time monitored continuously in test process and the test stress must be decreased to the last level. If the product recovers, the stress that made the product failed is the operating limit stress; if the product still can't work under the last level stress, the stress is failure limit stress. The test must stop in the following three cases: 1) any comment is failed; 2) the stress level has reached or far exceeded the needed level for the verification of durable products’ design; 3) uncorrelated failure appears with new failure mechanism at higher stress level.

For the failures in test process, test engineers and design engineers should do failure analysis together and decide take some improvements or not. The process of "test-improve-test" requires to be repeated until the product index (mainly is working limit stress) reaches the predictive value.

II. CALCULATING THE PRODUCT’S RELIABILITY

A. Analysis of Failure Reason Using Interference Model

According to the definition of operating limit stress from section I, it is known that whether the product can work well depend on the interdependence between the operating limit stress and the stress in actual operation environment. The operation will be normal when the operating limit stress is more than the stress in actual operation environment, and vice versa. Let S be the operating limit stress and E be the stress in actual operation environment, so the condition of normal operation is

$$S > E \text{ or } S - E > 0$$

In practical engineering, both the two stress are random variables. They are shown in a same coordinate (Fig 3) with the stress as abscissa against the probability density of stress distribution as ordinate. The function of $f(S)$ and $h(E)$ denote the probability density of operating limit stress and the stress in actual operation environment respectively. When the mean value of $S$ is more than the one of $E$, the situation that the operating limit stress is less than the stress in actual operation environment, namely failure, is possible to be happened in the shaded parts in the Fig which denotes the interference region [5].

B. Deducing the Formula

According to the definition of reliability, reliability $R$ can be expressed as

$$R = P(S > E) = P(S - E > 0)$$

The probability (reliability) that $S$ is more than $E$ in the interference region can be calculated according to the interference model above. As shown in Fig 4, when the stress in actual operation environment is $E_0$, the probability (reliability) that $S$ is more than $E$ is

$$P(S > E_0) = \int_{E_0}^{\infty} f(S) dS$$

The probability (reliability) that $E_0$ is in the interval $dE$ is...
Now let \((S > E_0)\) and \((E_0 - \frac{dE}{2} \leq E \leq E_0 + \frac{dE}{2})\) be two independent events, so the probability that two independent events occur simultaneously is

\[
dR = h(E_0)dE \int_{E_0}^{\infty} f(S)dS\tag{4}
\]

Considering the situation of the whole stress interval, the probability (reliability) that S is more than E is

\[
R = \int_0^\infty R = \int_0^\infty h(E)\left[\int_{E_0}^{\infty} f(S)dS\right]dE\tag{5}
\]

In practical engineering, generally, both the operating limit stress and the stress in actual operation environment accord with normal distribution. Let safety margin \(Z = S - E\), then

\[
R = P(S > E) = P(Z > 0)\tag{6}
\]

Because that both S and E accord with normal distribution, according to the properties that the sum(difference) of two normal distribution still follows normal distribution, \(Z\) also follows normal distribution:

\[
f(Z) = \frac{1}{\sqrt{2\pi}\sigma_Z} e^{-\left[\frac{Z - \mu_Z}{\sigma_Z}\right]^2}\tag{7}
\]

Where \(\mu_Z = \mu_S - \mu_E\) \(\sigma_Z = \sqrt{\sigma_S^2 + \sigma_E^2}\)

Reliability is

\[
R = P(Z > 0) = \int_0^\infty f(Z)dZ = \int_0^\infty \frac{1}{\sqrt{2\pi}\sigma_Z} e^{-\left[\frac{Z - \mu_Z}{\sigma_Z}\right]^2} dZ\tag{8}
\]

Transfer the formula above to the standard normal distribution:

\[
R = \int_0^\infty f(Z)dZ = \int_0^\infty \frac{1}{\sqrt{2\pi}\sigma_Z} e^{\frac{1}{2}\left[\frac{Z - \mu_Z}{\sigma_Z}\right]^2} dZ\tag{9}
\]

\[
Z = \frac{Z - \mu_Z}{\sigma_Z} \quad Z_0 = -\frac{\mu_Z}{\sigma_Z} = -\frac{\mu_S - \mu_E}{\sqrt{\sigma_S^2 + \sigma_E^2}}
\]

Where

\[
\beta = -Z_0 = -\frac{\mu_Z}{\sigma_Z} = \frac{\mu_S - \mu_E}{\sqrt{\sigma_S^2 + \sigma_E^2}}
\]

Let

\[
R = \int_0^\infty f(Z)dZ = \Phi(\beta)\tag{10}
\]

Because restricted by the thrust of test equipment, generally, RET is only applied on the products which are small and light, such as boards and modules [6]. And the distributed parameters of the operating limit stress \(S\) such as mean value and variance can be estimated according to test data because the test samples of these products are plenty. Furthermore, the distributed parameters of the stress in actual operation environment also can be estimated due to the analysis of the application environment. The probability that \(S\) is more than \(E\) in interference region can be calculated based on formula (10) and then the estimation of product's reliability can be obtained.

C. Example Analysis

It is analyzed that a certain product's main failure reason is vibration. Because the vibration stress of application environment approximately follows normal distribution \(N(20, 5^2)\), so the vibration stress is chosen to be tested. 20 samples are chosen and the test conditions for them are the same. The vibration operating limit stress for each sample through RET is as follows (rms, unit: \(\text{m/s}^2\)): 26.3, 38.7, 27.1, 31.0, 34.1, 36.5, 45.4, 44.7, 38.8, 35.6, 30.2, 32.2, 26.6, 32.8, 32.2, 45.5, 39.5, 35.4, and 33.2.

Population mean can be estimated by sample mean:

\[
\hat{\mu} = \bar{x} = \frac{1}{20} \sum_{i=1}^{20} x_i = 35.0
\]

Using sample variance to estimate population variance:

\[
\hat{\sigma} = s^2 = \frac{1}{20-1} \sum_{i=1}^{20} (x_i - \bar{x})^2 = 5.8
\]

Combined with the distributed parameters of the stress in actual operation environment, according to formula (10):

\[
\beta = \frac{35 - 20}{\sqrt{5^2 + 5.8^2}} = 1.9588 \quad R = \Phi(\beta) = 0.975
\]

III. TWO WAYS OF IMPROVING RELIABILITY BY RET

The basic principle of improvements for product's reliability by RET is: excite defects through higher test stress, analyze the failure reasons, take measures and then heighten the operating limit stress and failure limit stress (mainly is operating limit stress), thus improve the reliability of product.

It is known from the analysis above that the possibility of failure is related with the area of the interference region in
In Fig 5, broken line express the distribution condition of operating limit stress after improvement. Fig 5a is corresponding to the condition of increasing the mean value and Fig 5b is corresponding to the condition of decreasing the variance. There are two main failure origins in RET: the design of product and the manufacturing process. For design problems, improving the design can increasing the mean value of the distribution of operating limit stress. And for process problems, improving the process and the consistency in production process can reduce the variance of distribution.

IV. CONCLUSIONS

In overseas, RET is applied in various industrial sectors successfully after it was put forward and remarkable effect was achieved. But the intensive study is not comprehensive by now at home. This paper introduced the interference model in to RET, deduced the formula for reliable probability according to interference theory, settled the problem that RET couldn’t be analyzed quantitatively by introducing quantitative analysis to RET. This paper also discussed the basic principle of RET intuitively and vulgarly by using the model. And two ways of improving the reliability of products were analyzed. This will be beneficial for the popularization and application of the new technology.

REFERENCES
