A Practical Method for Automotive Accelerated Life Test

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Abstract

Accelerated life test is a viable method for identifying failure modes, incorporating design changes on an on-going basis during the early stages of automotive development program. The information from tests at high stress levels is extrapolated to obtain estimate of life at normal stress levels. This paper presents a practical method for accelerated life test to achieve a specified accuracy in estimating life at a design stress. Recommended and optimum plan are presented and the plans are illustrated with a simulated test data for the automotive power element example.

I. Introduction

Accelerated life test program is one which utilizes all development testing to find reliability problems. Testing may include functional testing, environmental testing, safety testing, performance testing, as well as mobility testing. Through the test, reliability improvement becomes integral and visible part of the development process and follows a strategy of a constant striving to make the system better.

The basic process in which reliability is improved is the same as in testing and improving any measurable characteristic, consisting of test, detect failures, redesign and retest. However, the test program must be managed in order to be successful. Important factors in a successful test program are that data are collected upon which actions can be taken, how that information is used, who the information is available to, and how to plan for reliability improvement. This requires coordination and cooperation of management as well as testers, data collectors and evaluators. Figure 1 describes the development test process as it has been applied to automotive components under development.

At the start of a development program a reliability test plan should be established to provide a measure of system performance that meets customer expectations, and should include the test conditions under which these objectives have to be met. These test conditions are based on the knowledge of customer usage and environment for a specific component, system or vehicle.

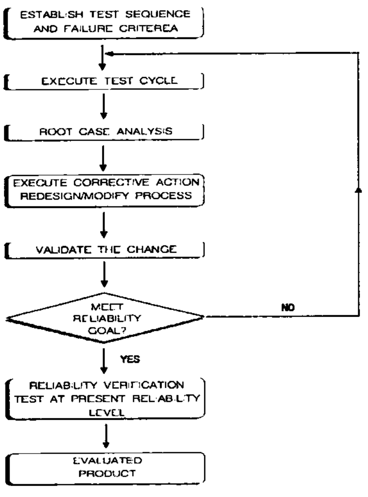

Figure 1 Development test process

Accelerated testing consists of a variety of test methods for shortening the life of products or hastening the degradation of their performance. The aim of such testing is to quickly obtain data which, properly modeled and analyzed, yield desired information on product life or performance under normal use. Such testing saves much time and money. The purpose of this research is to provide practitioners with easy to use, a practical statistical model, test plans, and data analyses for accelerated tests.

In recent years engineers and statisticians have developed much statistical methodology for accelerated testing applications. Books with chapters on statistical methodology for accelerated tests include Lawless[2], Mann, Shafer, and Singpurwalla[3], Jensen and Petersen[1] surveys statistical theory for accelerated testing. Nelson[5] presents the essentials of applied statistical methods and models for accelerated testing.

II. The model

The Arrhenius life relationship is widely used to model product life as a function of temperature. Applications may include electrical insulations and dielectrics, solid state and semiconductor devices, battery cells, and plastics, etc. For the most chemical reaction theory suggests testing at various accelerated stresses (temperature) and fitting the straight line to the relationship between the logarithm of the time to failure and reciprocal of absolute temperature. According to the Arrhenius rate law, the rate of a simple chemical reaction depends on temperature as follows

$$Y_1 = b_0 + b_1 X_i + E_i \qquad (1)$$

where Y_i = Log(time to failure)

X_i = 1/(t+273)

E_i = random error for i^{th} test unit

It is assumed that the Y_i follows a distribution with location parameter

$$U(X) = b_0 + b_1 X \qquad (2)$$

scale parameter S and a probability

distribution such as an extreme value distribution for the Y_i corresponding to a Weibull time to failure distribution.

If T(time to failure) at a constant stress follows a two parameter Weibull distribution with scale parameter. A and B. Then $Y= Log(T)$ follows a smallest extreme value distribution with location parameter,

$$U= Log(A) \tag{3}$$

and scale parameter, $S=1/B$. Also, the probability that a unit tested at stress X_i will fail by time t is

$$P(T< t) = @[(Log(t) - U)/S] \tag{4}$$

where $U= b_o + b_1 X_i$ and $@[z] = 1 - \exp[-\exp(z)]$ which is the cumulative distribution function of standardized smallest extreme value.
For the standardized stress X_i'

$$X_i' = (X_i - X_d)/(X_h - X_d) \tag{5}$$

where X_d and X_h are design and high stress conditions. Also, the P-th fractile of the smallest extreme value distribution at a stress X can be obtained from equation (2) and (4) as

$$Y_p(X) = U(X) + U_p S = bo + b_1 X + U_p S \tag{6}$$

The median(P=0.5) is commonly used as a fractile life approximately the 0.63 fractile.

III. Optimum plan

A required value to determine the test plans are guess values for the failure probability P_d and P_h by time t at the design and high stress conditions. Specification of stresses, these value uniquely determines the failure probability by time t at all stresses. William Q. Meeker and Gerald J. Hahn [4] provide table for the probabilities P_d and P_h and the expected number of failures $E(R)$ as well as the optimum standardized low stress X_L'. Works on optimum plans show that more units should be tested at low test stresses than at high ones, even when the test is terminated before all units fail.

The optimum test plan uses just two test stresses. They minimize the large variance of the ML estimates $Y_p(X_d)$ of a given extreme value fractile at the design stress X_d. The fractile of test units at X_L are

$$X_L = X_h + (X_d - X_h) \times X_L' \tag{7}$$

where $X_L' = (X_L - X_d)/X_h - X_d)$ is a standardized stress so that $X_d' = 0$ and $X_h' = 1$. For the example, the optimized standardized low stress condition is X_L' =0.682(see table in APP1) when P =0.100, P_d =0.0010, and P_h =0.90.
By equation (2) and (9), this translates into an actual stress of
$T_L = 1/[X_d + (X_h - X_d) \times X_L'] - 273$ = 95 ℃
For the optimum plan with a sample size

N, the variance of the estimate 100p percentile at the design stress is given by

$$V=[S^2\times V(p)]/N \qquad (8)$$

where S is the distribution standard deviation and $V(p)$ depends on the censoring time t and the model parameter b_0 and b_1.

Ⅳ. Recommended Test Plan

An experiment on automotive bond power element was designed so that most of the units would survive at least 10 years at a normal operating temperature (i.e., T_d =50). A life test was needed to estimate the 10th percentile of the time to failure distribution at the temperature(P=0.1). Moreover, the evaluation had to be made within an elapsed test time of 6 months. A sample size available for testing was 300 units. Assume that a reasonable guess for the probability of failure in a 6 month test at 50 is 0.1%(i.e., P_d =0.001). The Arrhenius model and the assumption of a Weibull distribution for time to failure with a constant slope at each stress condition at each stress condition is believed to provide a reasonable representation of life stress relationship up to 120℃. Therefore, 120 is selected as a high test stress(i.e., T_h =120). Also, 90% of the test units would fall within a 6 month period at 120℃(i.e., P_h =0.9) is assumed.

In summary, from the equation(4),

X_h = 1/(T_h + 273) = 1/(120 +273) = 0.002545

X_d = 1/(T_d + 273) = 1/(50 + 273) = 0.003096

P = 0.1000, P_d = 0.0010 and P_h = 0.900

T = 6 months, N = 300 units

Step 1. X_d = 0.003096, T_d =50 and P_h = 0.001

Step 2. X_h = 0.002545, T_h =120 and P_h = 0.900

Step 3. From the table in [4] under optimized 4:2:1 allocation plan and P =0.1000, P_d =0.0010 and P_h =0.900, X_L' is equal to 0.609. Thus, for the assumed Arrhenius model,

X_L = 1/(T_L + 273) = X_d + (X_h- X_d) × X_L'

The tentative actual low test temperature can be obtained

$$T_L = \{1/[X_d + (X_h - X_d) \times X_L']\} - 273 \qquad (9)$$

In this example,

T_L =1/[0.003096+(0.002545-0.003096) × 0.609]-273 = 89℃

A temperature of 89 was thought to involve too much stress extrapolation relative to the design temperature of 50. Hence, a lower temperature is desired for the low temperature. Thus, the adjusted 4:2:1 plans headed "(optimum X_L') ×0.9", etc to find the plan with the minimum stress that still resulted approximately in at least (100 P /3)% failures and at least 5 expected failures at the low stress.

From interpolating between the (optimum X_L') ×0.8 and the (optimum X_L') ×0.70 plans, this resulted in the plan with (optimum X_L') ×0.75. For this plan, P_L=0.035 by interpolating between P_L=0.043 and P_L=0.027.

The expected number of failure is

$$E(R)=(4/7)\times P_L\times N \qquad (10)$$

For this example, $E(R)=(4/7)\times 0.035\times 300=6$. Thus, $P_L > P/3$ and the expected number of failures at the low stress exceeds 5. The resulting standardized low stress is X_L'=0.456(obtained by interpolating between 0.487 and 0.426). This corresponds to an actual low temperature of $T_L=1/[X_d+(X_h-X_d)\times 0.4567]-273=78℃$

Step 4. From interpolating between the (optimum X_L') ×0.8 and (optimum X_L') ×0.7 columns in table. It is obtained that X_m''=0.728. (Average of X_m''=0.744 and X_m''=0,713) and determine the middle stress to be

$$T_m=1/[X_d+(X_h-X_d)\times 0.728]-273=98℃$$

This step is sufficiently far removed from the high stress condition of 120 to permit a reasonable estimate of the slope of the relationship between stress and time to failure based of the results at these two stresses alone.

Step 5. 4/7th, 2/7th and 1/7th of the 300 test units are allocated to the low, middle and high stress conditions.

The developed plan has a variable 13% above that for the optimum 4:2:1 allocation plan [*i.e.*, $R'(p)$=1.13 obtained by averaging $R'(p)$=1.09 and $R'(p)$=1.17]. This is the precision lost by shifting the lowest test stress from 89℃ to 78℃.

It means that approximately 13% more sample units would be needed to achieve the same precision as the 4:2:1 allocation plan with the statistical optimum X_L, assuming that all assumptions are met.

V. Conclusion

The presented accelerated life test could be applied to successfully demonstrating the relationship between failure detection and corrective action, and the achievement of higher reliability designs. We believe that the practical method is common to use for any vehicle development program.

References

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