Component *vs* System Burn-in Techniques for Electronic Equipment

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Key Words — **Simulation, Mean residual life function, Optimization.**

Reader Aids —
Purpose: Widen the state of the art
Special math needed for explanations: Elementary probability
Special math needed for results: Same
Results useful to: Reliability analysts.

Abstract — **Our method shows that optimal burn-in at each stage of component assembly is not always optimal for the final system. Simulation is used to evaluate a non-repairable system and provides individual component burn-in times that optimize the mean residual life of the assembled system.**

1. INTRODUCTION

Researchers have shown that by accelerating the ageing process through component burn-in under extreme environmental conditions, early component failure can be observed and corrected before assembly into systems. Potential damage that occurs to components during the assembly process and that affects system reliability is generally not considered. Some researchers have attempted to screen out these assembly defects by using system burn-in (burn-in of a finished subassembly or product). Further study is required in the area of in-process burn-in (at different subassembly levels, from components to systems) to determine its advantages and disadantages. This paper investigates the effectiveness of in-process burn-in on non-repairable systems as illustrated by a 2-component example.

In today's electronics industry, determining whether to burn-in components, subassemblies or completed systems becomes very difficult. According to Kuo & Kuo [1], "Very little work exists applying burn-in at various assembly levels." Most of the current research on burn-in considers techniques applied to components or to systems as a whole. Kuo & Kuo also state that, "... at the system level, determining various burn-in periods for the system's subassemblies and components has never been done." These statements indicate that subassembly burn-in periods have not been calculated at system burn-in, and little research is available to evaluate burn-in at each subassembly level. Therefore, methods are needed to determine whether to perform a burn-in test and how long burn-in should be performed at each subassembly level to optimize prescribed system objectives.

Given a component subassembly model, we show the consequences of using or not using burn-in at various subassembly levels, from components to systems. The component model contains components in *parallel* and *series*; the terms *parallel* and *series* refer to the reliability logic (block) diagram, not necessarily to a schematic diagram. The impact of component burn-in on system reliability is analyzed along with the damage acquired during the assembly, material handling, and burn-in processes.

In order to determine the effectiveness of burn-in, an objective must be established. The objective used here is to burn-in the components and the system until the system mean residual life (MRL), $L(t)$, is maximized. Other objectives may be optimized in a similar manner. Let the continuous, nonnegative random variable T denote the system lifetime. The mean residual life is the mean remaining life at time t, given the system survives to time t, and is defined by

$$L(t) \equiv \mathrm{E}\{T - t \mid T \geq t\}$$

$$= \int_t^\infty S(\tau)d\tau / S(t)$$

where $S(t)$ is the survivor (reliability) function.

A generic subassembly model is used in the example to simplify calculations for the optimal burn-in procedure. Other models can include burn-in constraints, such as: availability of test facilities, increases in investment, inventory, order to ship-time limits, and overall costs.

Recently there has been more interest in system burn-in due to factors that affect the system after component burn-in; some examples for electronic products are:

- Creation of new components such as solder joints, component sockets, cables, backplanes, or printed wiring boards.
- Damage from assembly processes or burn-in tests such as electro static discharge (ESD), component inser tion machines, manual operations, temperature (eg, excessive from wave solder or soldering irons), environmental conditions (eg, moisture), or general handling.
- Electrical functions at the system level that cannot be tested at the component level, eg, interaction of components and subassemblies under various voltages.

• Ability to simulate system reliability as seen by the customer, which may not be possible with only component burn-in.

2. EXAMPLE

Consider the 2-component subassembly in figure 1. Prior to assembly, components 1 and 2 have unique individual lifetime distributions. In order to calculate the burn-in period for component *i*, we use the criteria of maximizing each one's mean residual life $L_i(t)$. Component *i* has known survivor function $S_i(t)$.

$$L_i(t) = \int_t^\infty S_i(\tau)d\tau / S_i(t), \quad \text{for } i = 1, 2.$$

Setting $L_i'(t)$ equal to zero yields burn-in times that maximize the mean residual life for component *i*, $i = 1, 2$ individually.

This method of optimizing burn-in periods is correct for individual components, but not desirable in this

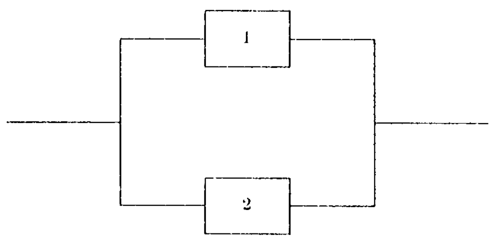

Fig. 1. 2-Component *Parallel* System

example if system and component burn-in are used together. When system burn-in occurs, components undergo additional aging that may decrease the system lifetime. Thus, we want to determine what component burn-in times prior to assembly and what system burn-in times after assembly will maximize the system MRL.

Obviously, system burn-in is not required if burned-in components could be assembled without introducing damage to the system. Since damage does occur in this example, a third pseudo-component is added in *series* with the original model in figure 2. This third, pseudo-component represents assembly defects which affects the system MRL. Assembly defects are typically caused by machines or operators. An operator, for example, might introduce ESD damage by handling components. This weakening of the system is most easily modeled by placing this pseudo-component in *series* with the prior assembly. The pseudo-component's survivor function is $S_3(t)$.

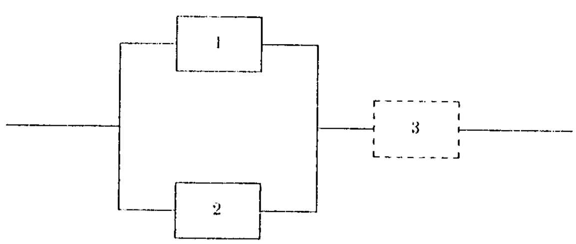

Fig. 2. 2-Component *Parallel* System and Assembly Pseudo-Component

When components 1 and 2 are burned in for times b_1 and b_2 prior to assembly, the survivor function of the system is (assuming the component failure times are *s*-independent):

$$S(t) = \left[1 - \left(1 - \frac{S_1(t+b_1)}{S_1(b_1)}\right)\left(1 - \frac{S_2(t+b_2)}{S_2(b_2)}\right)\right] \cdot S_3(t)$$

$$= \frac{S_1(t+b_1)}{S_1(b_1)} \cdot S_3(t) + \frac{S_2(t+b_2)}{S_2(b_2)} \cdot S_3(t)$$

$$- \frac{S_1(t+b_1)}{S_1(b_1)} \cdot \frac{S_2(t+b_2)}{S_2(b_2)} \cdot S_3(t)$$

The system is then placed on burn-in test for time b_3. Our objective is to find the burn-in times b_1, b_2, b_3 that maximize the system MRL.

As mentioned earlier, optimizing burn-in times for individual components prior to assembly may not maximize MRL after system burn-in. What is required is a method of predicting the optimal component and system burn-in times prior to assembly. Due to tractability difficulties in obtaining a closed form equation for the system MRL, a simulation program (written in C) is used to determine the $\boldsymbol{b} = (b_1, b_2, b_3)$ vector yielding the largest MRL, $\boldsymbol{b}^*$. The simulation determines the system lifetime T by taking $T = \min(\max(T_1, T_2), T_3)$, where T_i is the conditional lifetime of component *i*, given its survival through the burn-in period, $i = 1, 2, 3$. Therefore, T is the system survivor time after burn-in.

Data for components 1 and 2 were collected from two different subassemblies in a manufacturing test burn-in facility, with each subassembly undergoing identical stress. Failure times were fitted to the 2-parameter exponential power distribution [3]:

$$S_i(t) = e^{1 - e^{\alpha_i t^{\beta_i}}} \qquad t > 0$$

for $i = 1, 2$. This is one of the few simple 2-parameter distributions with a U shaped hazard rate. Parameters for components 1 and 2 were calculated by linear regression: $\hat{\alpha}_1 = 0.013$, $\hat{\alpha}_2 = 0.015$, $\hat{\beta}_1 = 0.603$, and $\hat{\beta}_2 = 0.621$. Many dangers are present when extrapolating beyond the range of observed failure times. The pseudo-component was used to model the effect of ESD damage. ESD was determined to have a 30% chance of occurring and when it did occur, its effect was modeled using the Weibull distribution. The result had a decreasing hazard rate, and —

$$S_3(t) = (1-p) + p \cdot e^{-\alpha_2 t^{\beta_3}} \qquad t>0$$

with $\hat{p} = 0.30$, $\hat{\alpha}_3 = 0.008$ and $\hat{\beta}_3 = 0.98$. Hazard rate functions for these distributions are given in figures 3 - 5 (note: scales are different).

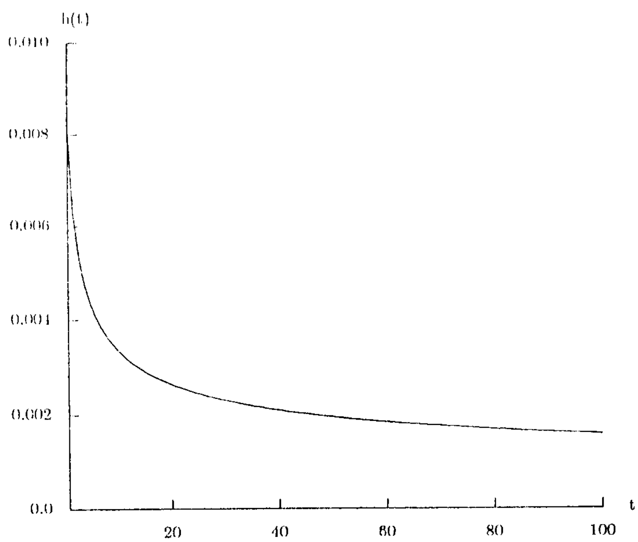

Fig. 3. Hazard Rate for Component 1.

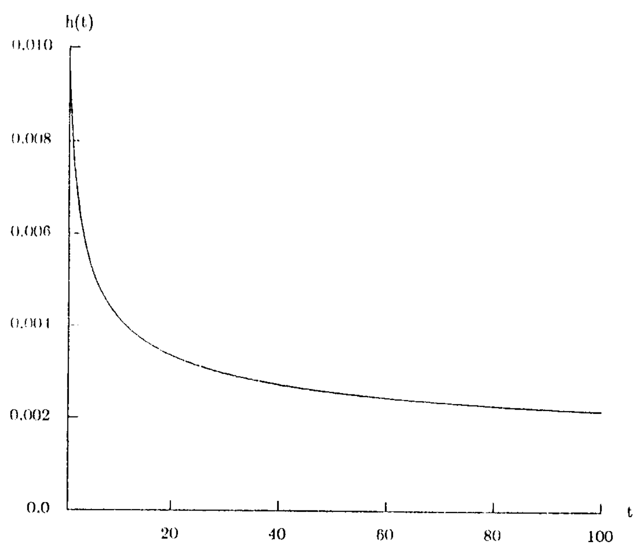

Fig. 4. Hazard Rate for Component 2.

Results from the simulation program using 9000 system lifetimes at each $\boldsymbol{b}$ level showed the MRL to be maximized at burn-in vector $\boldsymbol{b}^* = (20, 21, 26)$, with a system MRL after burn-in of 878. This is in contrast to a system MRL of 799 at $\boldsymbol{b} = (0, 0, 0)$, ie, no component or system burn-in. At $\boldsymbol{b}^* = (20, 21, 26)$, components 1 and 2 have a total burn-in time of 46 and 47 respectively. The mean residual life decreases as burn-in increased as shown by a system MRL of 872 at $\boldsymbol{b} = (30, 30, 30)$. Simulation results for several sample $\boldsymbol{b}$ values are summarized in table 1.

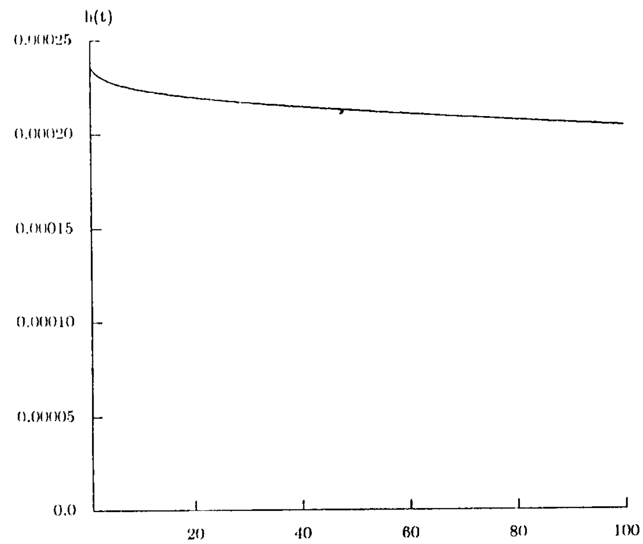

Fig. 5. Hazard Rate to Pseudo-Component 3.

TABLE 1
Results of the System Simulation
*optimal solution

Burn-in Time				Fraction Components Failed thru Time (%)		
b_1	b_2	b_3	System MRL	b_1+b_3 component 1	b_2+b_3 component 2	b_3 component 3
0	0	0	799	0.0	0.0	0.0
30	0	0	846	10.3	0.0	0.0
0	30	0	820	0.0	12.5	0.0
0	0	30	860	10.3	12.5	0.7
30	30	0	862	10.3	12.5	0.0
0	30	30	859	10.3	19.2	0.7
30	0	30	865	15.6	12.5	0.7
30	30	30	872	15.6	19.2	0.7
20	21	26	*878	13.3	16.5	0.6

In the optimal solution, ESD damage modeled by the pseudo-component failed during 26 hours of burn-in only 0.6 percent of the time. Therefore, the assembly operation that creates ESD damage is less critical to infant mortality than components 1 and 2.

3. CONCLUSIONS

Simulation can be used to determine the effect from different combinations of in-process and system burn-in times. Simulation results provide the decision maker with burn-in alternatives that may be optimal for the chosen objective. Burn-in objectives other than maximizing system MRL could also be used. The potential value of simulation for solving in-process burn-in problems and the technique for using simulation is the major emphasis and importance of this paper. The extrapolation of survival times beyond the range of the data used to determine the empirical distributions can negate the results of an analysis such as this. In the case of a right censored data set, some observations from the right hand tail of the lifetime distribution should be obtained and model adequacy assessed prior to using a parametric lifetime model.

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