MTBF and Product Reliability

Product Reliability is defined as the probability that a device will perform its required function, subjected to stated conditions, for a specific period of time. Product Reliability is quantified as MTBF (Mean Time Between Failures) for repairable product and MTTF (Mean Time To Failure) for non-repairable product.

Now that we've defined it, how can we measure it, or better yet, how can we predict it?

The Famous Bathtub Curve
Figure 1 shows the reliability "bathtub curve" which models the cradle to grave instantaneous failure rate vs. time, which we would see if we were to wait long enough and keep good records for a given lot of devices. This curve is modeled mathematically by exponential functions. More on this later.
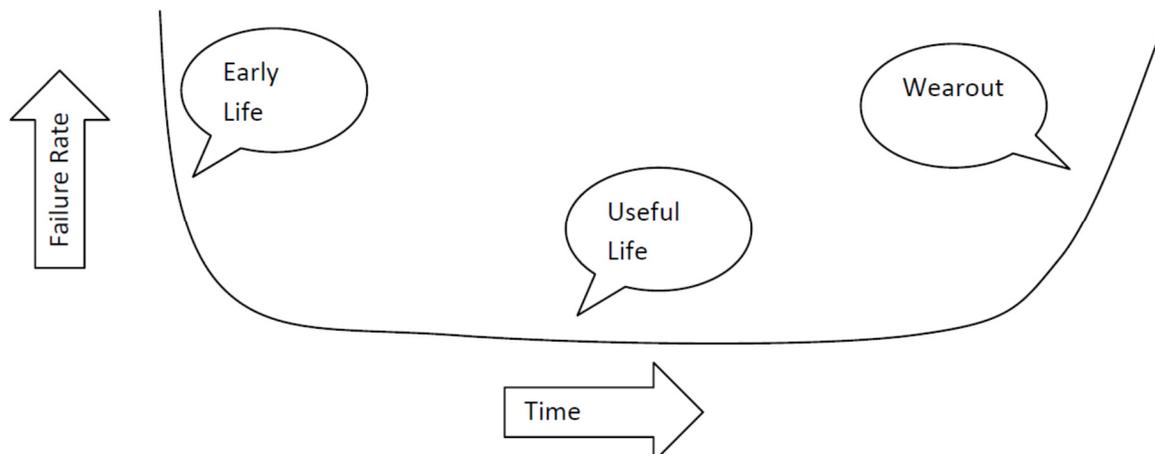

Figure 1. Reliability Bathtub Curve

The life of a population of devices (a group of devices of the same type) can be divided into three distinct periods:

Early Life
If we follow the slope from the leftmost start to where it begins to flatten out this can be considered the first period. The first period is characterized by a decreasing failure rate. It is what occurs during the "early life" of a population of units. The weaker units fail leaving a population that is more rigorous.

Useful Life
The next period is the flat bottom portion of the graph. It is called the "useful life" period. Failures occur more in a random sequence during this time. It is difficult to predict which failure mode will occur, but the rate of failures is predictable. Notice the constant slope.

Wearout
The third period begins at the point where the slope begins to increase and extends to the rightmost end of the graph. This is what happens when units become old and begin to fail at an increasing rate. It is called the "wearout" period.

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Early Life Engineering Considerations

We use many methods to ensure the integrity of design. Some of the design techniques include: burn-in (to stress devices under constant operating conditions); power cycling (to stress devices under the surges of turn-on and turn-off); temperature cycling (to mechanically and electrically stress devices over the temperature extremes); vibration; testing at the thermal destruct limits; highly accelerated stress and life testing; etc. All of these methods are designed to bring us to the useful life period before the customer sees the product.

Useful Life Engineering Considerations

As the product matures, the weaker units fail, the failure rate becomes nearly constant, and devices have entered what is considered the normal life period. This period is characterized by a relatively constant failure rate. The length of this period is also referred to as the "system life" of a product or component. It is during this period of time that the lowest failure rate occurs. Notice how the amplitude on the bathtub curve is at its lowest during this time. The useful life period is the most common time frame for making reliability predictions. Two important practical aspects of these failure rates are:
The failure rates calculated from MIL-HDBK-217 apply to this period and to this period only. More on this later.

MTBF is the inverse of the failure rate in the constant failure rate phase.

Wearout Engineering Considerations

As components begin to fatigue or wear out, failures occur at increasing rates. Wearout in industrial electronic devices is usually caused by the breakdown of electrical components that are subject to physical wear and electrical and thermal stress. It is this area of the graph that the MTBFs calculated in the useful life period no longer apply. A product with an MTBF of 10 years can still exhibit wearout in two years. No parts count method can predict the time to wearout of components. Industrial electronic devices are designed so that the useful life extends past the design life (when the device is obsolete). This way wearout should never occur during the useful life of a device.

Prediction Considerations

Predicting with some degree of confidence is very dependent on correctly defining a number of parameters. For instance, choosing a "probability distribution" or probability model that matches the data is of primary importance. If a correct distribution is not chosen, the results will not be reliable. The "confidence", which depends on the sample size, must be adequate to make correct decisions. Individual component failure rates must be based on a large enough population and relevant to truly reflect present day normal usages. There are empirical considerations, such as determining the slope of the failure rate, as well as environmental factors, such as temperature, humidity, and vibration. Lastly, there are electrical stressors such as voltage and current.

Prediction Methods

A lot of time has been spent on developing procedures for estimating reliability of electronic equipment. There are generally two categories: (1) predictions based on individual failure rates, and (2) demonstrated reliability based on operation of equipment over time. Prediction methods are based on component data from a variety of sources: failure analysis, life test data, and device physics. For our calculations

MILHDBK-217 is used, which is considered to be the standard reliability prediction method. MIL-HDBK-217 contains failure-rate models for various parts used in electronic systems, such as integrated circuits, transistors, diodes, resistors, capacitors, relays, switches and connectors. These failure-rate models are based on a large amount of field data that was analyzed and simplified by the Reliability Analysis Center and Rome Laboratory at Griffiss Air Force Base at Rome, N.Y.

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Understanding MTBF and MTTF Numbers

Remember, Reliability is quantified as MTBF (Mean Time Between Failures) for repairable product and MTTF (Mean Time To Failure) for non-repairable product. Let's look at some examples:

Example: A power supply with an MTBF of 40,000 hours does not mean that the power supply should last for an average of 40,000 hours. According to the theory behind the statistics, the statistical average becomes the true average as the number of samples increase. An MTBF of 40,000 hours, or 1 year for 1 device, becomes 40,000/2 for two devices and 40,000/4 for four devices.

The formula for calculating the MTBF is

MTBF= T/R where T = total time and R = number of failures

MTTF stands for Mean Time To Failure. To distinguish between the two, the concept of suspensions must first be understood. In reliability calculations, a suspension occurs when a destructive test or observation has been completed without observing a failure. MTBF calculations do not consider suspensions whereas MTTF does. MTTF is the number of total hours of service of all devices divided by the number of devices. It is only when all the parts fail with the same failure mode that MTBF converges to MTTF.

MTTF= T/N where T = total time and N = Number of units under test.

Example: Suppose 10 devices are tested for 500 hours. During the test 2 failures occur.
The estimate of the MTBF is:

MTBF= (10*500)/2 = 2,500 hours / failure.

Whereas for MTTF

MTTF= (10*500)/10 = 500 hours / failure.

If the MTBF is known, one can calculate the failure rate as the inverse of the MTBF. The formula for failure rate is:

failure rate= 1/MTBF = R/T where R is the number of failures and T is total time.
Once an MTBF is calculated, what is the probability that any one particular device will be operational at time equal to the MTBF?

We have the following equation from our exponential modeling of the bathtub curve:

$$P(t) = e^{-t/MTBF}$$

But when t = MTBF

$$P(t) = e^{-1} = 0.3677$$

This tells us that the probability that any one particular device will survive to its calculated MTBF is only 36.8%.

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What does this calculation really mean? An MTBF of 1.4 million hours, determined in say, six weeks of testing, certainly doesn't mean we can expect an individual device to operate for 159 years before failing. MTBF is a statistical measure, and as such, it can't predict anything for a single unit. We can use that MTBF rating more accurately, however, to calculate that if we have 1,000 such devices operating continuously in a factory, we can expect one to fail every 58 days or so, for a total of perhaps 19 failures in three years.

This example points out one other important characteristic of MTBF --
it is a characteristic which applies to populations (i.e. "lots" or "groups") of things; not a sample characteristic which applies to one specific thing.

So, in summary:
MTBF is an abbreviation for Mean Time Between Failures.

MTBF is a measure of how reliable a product is. MTBF is usually given in units of hours; the higher the MTBF, the more reliable the product is.

For electronic products, it is commonly assumed that during the useful operating life period the parts have constant failure rates, and part failure rates follow an exponential law of distribution. In this case, the MTBF of the product can be calculated as:

MTBF = 1/(sum of all the part failure rates)

and the probability that the product will work for some time t without failure is given by:

$$P(t) = e^{-t/MTBF}$$

Thus, for a product with an MTBF of 250,000 hours, and an operating time of interest of 5 years (43,800 hours):

$$P(t) = e^{-43800/250000} = 0.839289$$

which says that there is an 83.9% probability that the product will operate for the 5 years without a failure, or that 83.9% of the units in the field will still be working at the 5 year point.

MTBF is commonly confused with a component's useful life, even though the two concepts are not directly related. For example a primary battery may have a useful life of four hours, and an MTBF of 100,000 hours.

Another common misconception about MTBF is that it specifies the time (on average) when the probability of failure equals the probability of not having a failure (i.e. an availability of 50%). This is only true for certain special cases. For typical electronic products, MTBF only represents a top-level aggregate statistic, and thus is not suitable for predicting specific time to failure.

Another misconception is to assume that the MTBF value is higher in a system that implements component redundancy. Component redundancy can increase the system MTBF, however it will decrease the hardware MTBF, since generally the greater number of components in a system, the more frequent a hardware component will experience failure, leading to a reduction in the system's hardware MTBF.

MTBF is therefore an excellent characteristic for determining how many spare PLCs are needed to support say, 100 PLCs, but a poor characteristic for guiding you on when you should replace your PLC to