RENCO Encoders, Inc.
26 Coromar Drive, Goleta, CA 93117
PH: 805-968-1525 FX: 805-685-7965
www.renco.com

Encoders, Bearings and Reliability

Some rotary encoders are designed with bearings and some are not. Over the years, bearing manufacturing has improved, and consequently the reliability of bearings has generally improved. Still, there are applications where a rotary encoder should be selected with a bearing and applications where it should not.

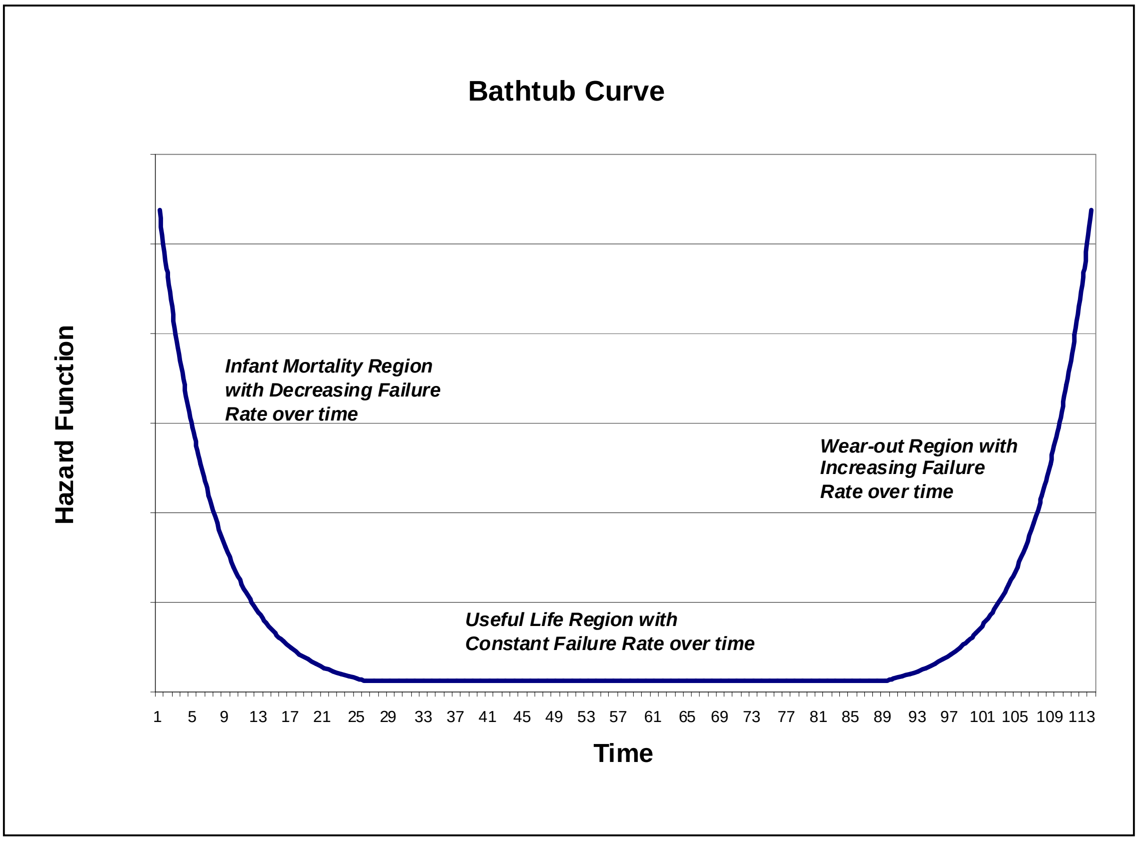
Massachusetts Institute of Technology (MIT) has a website that describes bearing life and associated reliability calculations[i].

Some notes describing the scope of the applicability of those calculations are quite interesting, and help us understand why it is still possible to choose a bearing with excellent reliability ratings and still have it fail early in its expected lifetime.

But first, let's review the reliability "bathtub curve," which maps the typical failure rates of electromechanical products over time.

The "hazard function" or "instantaneous failure rate" is "the limit of the failure rate as the time interval approaches zero." [ii]

The Hazard Function (instantaneous failure rate) is calculated as the number of failed units during a time period divided by the product of the number of operating units at the beginning of the time period times the length of that time period. It is the failure rate at some defined point in time. As that defined point in time changes, so does the Hazard Function. The typical form those changes in failure rates over time takes is the bathtub curve:



In the earliest stage of the product's life, those weaknesses or defects in the product that are time-sensitive and short-lived fail. As these fail, they are weeded out of the population, until all the weak ones with time dependent failures are eliminated. This is the Infant Mortality zone of the bathtub curve, and this is the zone that is addressed by "burn-in" of many electromechanical products. This zone is often as long as a year in length, but because it decays exponentially, even a short burn-in is effective in greatly reducing failures in the field.

The next zone is the Useful Life, or Constant Failure Rate zone. Failures still occur here, but they are not time dependent. They occur randomly over time. These failures also occur during the Infant Mortality zone and the Wear Out zones, but the rate is small in comparison, and isn't observed easily. Two apparently identical products can have very different fates in the Constant Failure Rate zone. This is the zone where the term Mean Time To Failure or Mean Time Between Failures is appropriately used, because there is a predictable failure rate which remains the same through the time period. Actually, each component in a product has a stable and predictable failure rate in this zone, and the more components in the product, the higher the overall failure rate becomes.

The last zone is the where product wear takes its toll at an increasing frequency. This is where non-defective parts finally just wear out and fail. As time goes on, more and more failures occur per unit time until all the products have failed, so the zone has an increasing failure rate. This zone is quite important to manufacturers of parts that move and are in contact with other parts. Consequently, bearing manufacturers put a lot of emphasis on this zone, and focus on making design improvements to decrease bearing wear.

As was noted above, the overall failure rate of a product is the sum of its parts. In fact, some attempts have been made to predict the failure rates of products based on the failure rates of the components.[iii] In such models of reliability, the removal of a component removes the risk of failure that that component has. Conversely, adding a component increases the failure rate of the product. If your population is small enough, only the component(s) with the highest failure rate will likely fail, so adding a component with a low failure rate will probably not have much impact. But in large volume production, with a large population, even the best components will get their chance to fail.

Now let's return to the MIT website on bearings. The fundamental equation for basic bearing life is the L_{10} equation. This equation defines the time at which 10% of the bearings population under evaluation will have failed. It is;

$L_{10} = \left(\frac{C}{P}\right)^p$ and has units of 1/minutes. C is the dynamic load capacity of the bearing, and P is the load the bearing will see in service. The exponent is 3 for ball bearings.

Per the MIT website. "Practical tests show that the life of identical bearings differs under the same operational conditions. In order to assess the service life of bearings, the so-called basic life measurement has been introduced. The basic life of rolling bearings is the life that is achieved or exceeded by 90% of identical bearings under the same operational conditions…"

Why not 100% instead of 90%? Because of the expected failures, such as Infant Mortality failures and Useful Life failures. The focus is on the life expectancy of *most* of the bearings, which is to say the time they will last before they wear out.

Once L_{10} has been calculated, the "Adjusted Bearing Life" is determined. The adjusted bearing life is used to "take into account any other effects such as operational conditions, production quality or properties of the materials used." Key components of the adjustment are the desired reliability of the bearing, the way the bearing is loaded, the quality of lubrication of the bearing, the level of contamination of the lubricant, and the effects of temperature. The choice of lubricant viscosity is noted to depend on the speed the bearing will operate at. Later in the article MIT provides some guidance on selection of bearing size depending on the expected application and the nature of the bearing material.

Looking at this from the perspective of reliability and the model of the bathtub curve, we can see a lot of emphasis placed on best selection of the bearing and lubricant depending on the application, with the primary focus on the 90% (or, hopefully more) of the bearings that make it to the Wear Out zone.

This leads to the somewhat ironic question: "Why use a bearing at all?" A modular encoder has no bearings, and so all these concerns about bearing reliability are eliminated. The modular encoder is *intrinsically more reliable*. But life is not always so simple. For example, in some encoder/motor designs there is a large amount of shaft movement ("end play") during operation. For these situations a bearing is a necessity and the choice of bearing becomes a critical decision in the reliability of the encoder. However, choosing a bearing encoder over a modular encoder strictly for perceived benefits during installation should be avoided. Although a bearing encoder comes pre-assembled, and removes the potential of failure during the assembly process, consider the cost. Not just the cost of the bearing, which could be considerable if you want the encoder to last, but the cost to your product's reliability. Consider that the MIT analysis weeds out 10% of the bearings right off the bat to ensure that the early failures do not muddy the predictions made by the calculations. What is the impact of those early (non wear-out zone) failures on your customers? Consider this seriously even when you spend additional money on the best bearings to ensure a much lower failure rate, because there are still unexpected failures, and the impact of environmental conditions (dust, grit, temperature).

By adding a bearing to an encoder when you do not really need a bearing, you are increasing cost while decreasing reliability for your customer. You avoid the cost of mis-mounting an encoder to a motor, but this is a failure mode that you will catch immediately, and never pass on to your customer.

At RENCO Encoders, we offer bearing encoders and we also offer modular and kit encoders without bearings. We offer clear instructions on mounting encoders, and are willing to work with our customers to provide training and guidance on the use of our products. We are constantly listening to our customers and use their feedback to improve encoder designs and mounting methods. We recommend that you use bearings where bearings are needed, and we recommend that you not use bearing encoders just to avoid the risk of mounting a modular encoder incorrectly.

Please visit www.renco.com to see our line of bearing, modular, and kit encoders.

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[i] MIT Website: www.mitcalc.com/doc/bearings/help/en/bearingskftxt.htm

[ii] Certified Quality Engineer Handbook, ASQ Press ©2002 by ASQ. Chapter 8, "Reliability and Maintainability Engineering" by Elsayed A. Elsayed, PhD Rutgers University.

[iii] An early example of this was MIL HDBK 217 which provides "typical" failure rates for electronic components, and a method to add them together, and even a method to adjust for their loading and their operating temperature.