



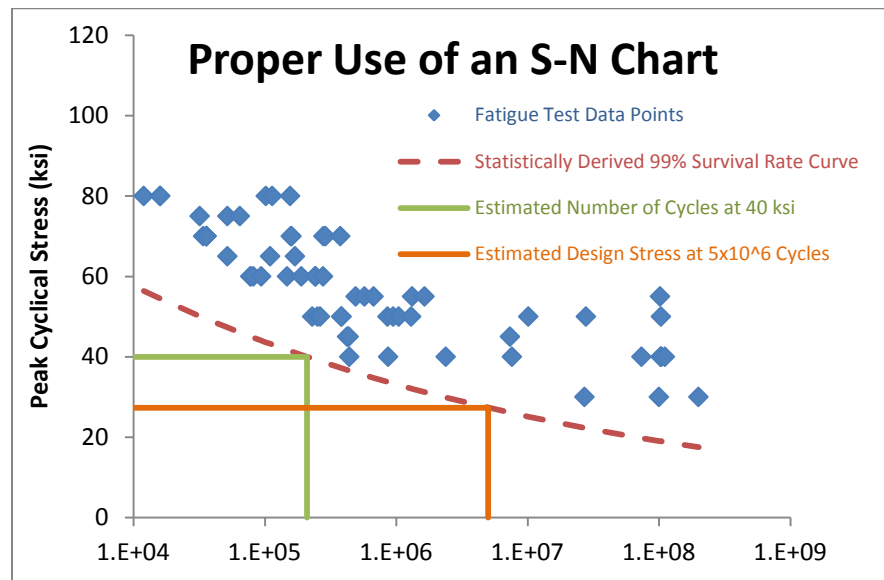
So, how long will it last, anyway? – A discussion on how properly obtained and analyzed fatigue data can be used to estimate the design life of a component.

- S-N Diagram (Wöhler Diagram)
- Modifying Factors
- Preload
- Mean Stress
- Alternating Stress

## Fatigue Life Prediction using S-N (Wöhler) Diagrams

(This issue of Technical Tidbits continues the materials science refresher series on basic concepts of material properties.) The last few month's edition of Technical Tidbits discussed how to make a material's S-N (Wöhler) curve statistically relevant, and how to use the appropriate modification factors to account for specific variables that may affect fatigue life. This month, we will put it all together to discuss prediction of fatigue life.

The S-N (Wöhler) diagram below combines the features of those from several prior issues of Technical Tidbits. Issue 56 described how to perform a proper statistical analysis of fatigue test data (blue diamonds), in order to generate curves corresponding to a given failure rate, for fully reversed bending. The 1% failure rate, or 99% survival rate, curve is shown as the red dashed line. Using the techniques outlined in Issue 55, we can say that at a peak alternating stress of 40 ksi, we could expect 99% of the parts to survive at least 200,000 cycles (intersection of the green line with the X axis). Similarly, if we want 99% of the parts to survive at least 5,000,000 cycles, we should limit the peak alternating stress to no more than 27 ksi.



**Figure 1.** Statistically Analyzed R=-1 S-N (Wöhler) Diagram Used for Fatigue Life Prediction. The statistical analysis discussed in Issue 56 allows you to determine what the fatigue life would be, for a given failure rate, under ideal conditions. Numerous fatigue life reduction factors exist to account for the less than ideal situations often encountered in reality.

Note, however, that the above discussion would be valid if the part is geometrically identical to the fatigue test specimen used, and if the loading is identical. In prior additions, we learned that these predicted stress levels need to be modified to account for real life differences. For example, assume you have a design requiring survival of at least 100,000 cycles. You select a material to use in this component. You can use the relevant (i.e. appropriate stress ratio and loading condition) S-N data for this material to calculate the strain corresponding to the six sigma failure rate (3.4 ppm failures, or 99.99966% survival rate) at each stress level. You can then mathematically determine the stress level corresponding to a six sigma failure rate at 100,000 cycles, which we will call  $\sigma'_{max}$ . Next, we will determine the appropriate fatigue strength **modifying factors**:  $k_a, k_b, k_c, \dots, k_n$ , however many are required based on the physics of the problem.

The next issue of Technical Tidbits will continue the discussion on fatigue, and begin the discussion of strain life methods.

## Fatigue Life Predictions Using S-N (Wöhler) Diagrams (continued)

Now, it is simply a matter of plugging in the modification factors to get the new maximum permissible stress level as shown below.

$$\sigma_{max} = k_a \cdot k_b \cdot k_c \cdot \dots \cdot k_n \cdot \sigma'_{max}$$

If your stress level is higher than this value, it would be time to select a new material, modify the design to reduce the peak stress or stress concentration, or take additional measures to improve the fatigue life by using a more ductile plating, adding compressive stress to the surface, deburring, etc. Of course, this all comes with a few caveats.

There are a few applications out there in which the cyclic loading experienced in service would directly correspond with a particular test method. Axles on a car or train would, for the most part, directly correspond to rotating beam fatigue specimens. (There will always be random, stray loads in different orientations due to shock and impact in a travelling vehicle, but most of the damage would come from the cyclic loading.) Therefore, fatigue data derived from a rotating beam fatigue chart would be appropriate.

Some electrical contacts and switches would be subjected to loading that corresponds to R=0 bend tests. This would be the case if, for example, the contact were completely free and unstressed in the off position, and then subjected to a perfectly repeatable stress level in the on position. In both of the above cases, the loading experienced in service directly corresponds to a common fatigue test type.

However, real life loading of components is often much more complicated than that of rotating beam, unidirectional bending, fully reversed bending, or unidirectional tension fatigue tests. Often, snap switches and relay contacts are preloaded to have some stress level in the off position, and a different stress level in the on position. This means that R will be either some small positive value (**preload** and load are in the same direction), or some small negative value (preload and load are in opposite directions.) If this is the case, it would appear that you would need to calculate the actual R ratio, and then conduct fatigue testing at a similar R ratio.

It sounds simple, but in reality, it is simply not practical for material suppliers cannot to test every material at every possible R ratio. Usually, you will only be able to obtain R=0 or R= -1 data. Luckily, there are numerous techniques available to estimate performance at other R ratios from these two data sets. This is accomplished by breaking down the cyclic stress into two components, the **mean stress** and the **alternating stress**. The mean stress and alternating stress can be plotted against each other, and a number of methods can then be used to interpolate/extrapolate the fatigue performance using the R=-1 fatigue strength at the appropriate number of cycles. The next few editions of Technical Tidbits will discuss these methods.

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