Fatigue Analysis in LabVIEW

Fatigue is localized damage to a material or component as a result of cyclic loading. As a material experiences an increasing number of loading cycles, minute cracks appear and cause the material to separate. Structural failures from material fatigue can result in accidents. Thus, in structural and mechanical engineering, reliable designs are required to protect against structural fatigue. Fatigue life prediction, based on prototype testing, is an important part of the product development processes. National Instruments provides fatigue analysis and life prediction solutions for fatigue testing. The following paper discusses the hardware platform and fatigue analysis methods industry uses for fatigue analysis and life prediction.

Click here to download the Fatigue Analysis LabVIEW VIs

*Note that to apply these functions, you need to install LabVIEW 8.5 or later.

Fatigue Analysis

Several methods are available for performing fatigue analysis and predicting the lifetime for a material or component including stress-life, strain-life, crack propagation, and spot weld methods. The stress-life method is a well-established technique, which is extensively used in design. The following figure shows the stress-life fatigue analysis process.

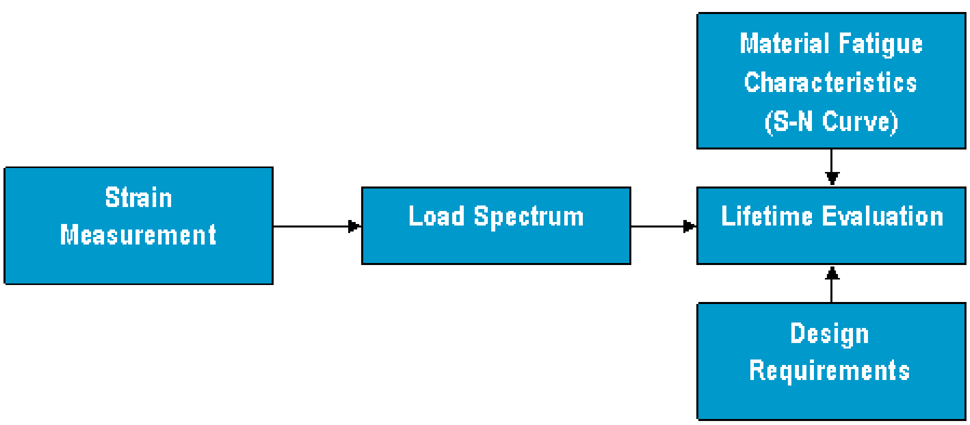


Figure 1: Stress-life fatigue analysis process

Fatigue analysis involves performing experimental measurements to obtain localized loads on a component or structure. Strain gauges fixed to the component or structure show the load endured during operation by measuring the local stress over time.

A load spectrum describes the statistical distribution of the service load experienced during the operating life of a component, represented by a stress range histogram. Load spectra represent the complex load history of a component or structure by a series of cyclic events with simple constant amplitude loads associated with fatigue damage.

The damage contribution is calculated by comparing the experimental measurements with material fatigue data from laboratory tests on material specimens. Fatigue analysis typically uses a material S-N curve, also known as a Wohler curve, to describe the fatigue characteristics of a material, where S is the cyclical stress and N is the number of cycles to structural failure.

Using the fatigue characteristics, the total damage to a material or component can be estimated for a particular load history. You can use this to evaluate the lifetime of a material or component and verify if the design requirements are satisfied.

Stress Measurement

Use a strain gauge to record the stress on a material or component when performing fatigue analysis. Refer to the Measuring Strain with Strain Gages tutorial on the NI Developer Zone Website for more information about using strain gauges.

Load Spectrum

There are two methods to compute the load spectrum for a material or component: time-domain and frequency-domain.

Rainflow cycle counting is a time-domain method to convert an irregular load history into a stress range histogram (load spectrum). Refer to the ASTM E–1049 Standard Practices for Cycle Counting in Fatigue Analysis for more information about rainflow cycle counting. The following figure shows a rainflow cycle counting matrix plot,which represents the load spectrum from rainflow cycle counting for a material or component.

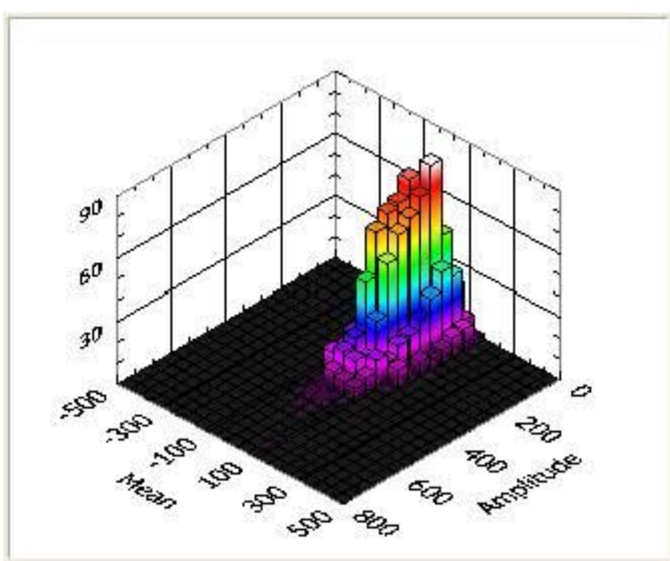


Figure 2: Rainflow cycle counting matrix plot

The parallel approach in the frequency domain can also be used to obtain a load spectrum. The power spectral density (PSD) is the most common approach to represent the service load. Based on the PSD, you can obtain the stress range probability density function (PDF) using a number of fatigue models. The stress range PDF can be converted into a stress range histogram. There are two common empirical methods to estimate load spectra: the narrow band (Bendat) method and broad band (Dirlik) method.

Stress-Life Based Damage Estimation

For high-cycle fatigue, you can estimate the damage to a material or component, based on the nominal stress-life method, using stress cycle counting and Palmgren-Miner linear damage summation. This method assumes that all stresses in the component are less than the elastic limit at all times and the number of cycles to failure is large.

Stress-life based damage estimation involves the following steps:

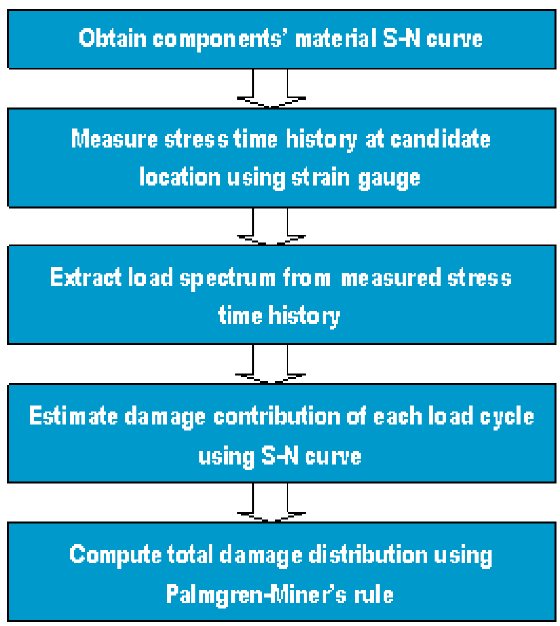


Figure 3: Stress-life based damage estimation process

Material S-N Curve

An S-N curve characterizes the fatigue behavior of materials. An S-N curve indicates the number of cycles a material can sustain under repeated loading at a given stress level before fatigue occurs. The following figure shows a typical material S-N curve.

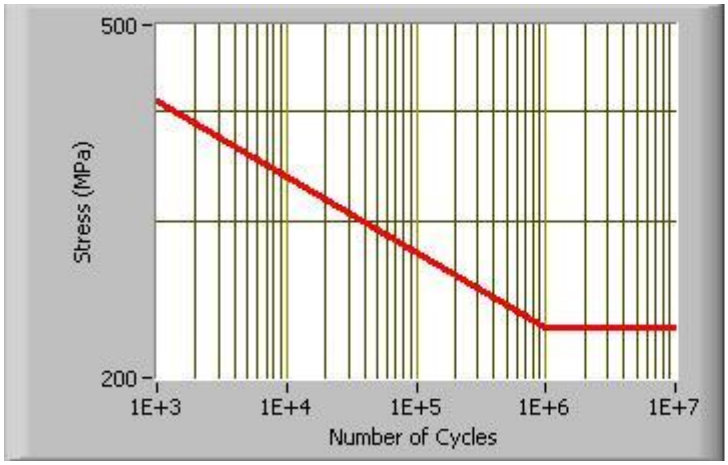


Figure 4: A typical material S-N curve

You can produce an S-N curve by testing specimens under bending loads in a laboratory. If experimental S-N data is unavailable, you can estimate the S-N behavior of a component using the ultimate tensile strength and other manufacturing details. Once you determine the ultimate tensile strength of a given material, you can approximate the fatigue strength at 10e3 cycles and at the fatigue limit life on the S-N curve. You can refine the calculation further by considering other factors such as loading, surface finish, size, and S-N curve reliability.

Palmgren-Miner Rule

An S-N curve defines the lifetime (number of cycles to failure) of a material, at given stress with constant amplitude. In practice, the service lifetime estimation of a component accounts for fatigue failure for loads of varying amplitude, represented in a load spectrum. The Palmgren-Miner rule is a linear cumulative damage estimation method for irregular and repeated loading using a material S-N curve.

According to the Palmgren-Miner rule, the total damage, D, is linear sum of the damage fraction at any stress level, S_i, in the load spectrum. The total damage is given by

$$D = \sum_i \frac{n_i}{N_i}$$

where N_i is the number of cycles to failure at stress level S_i on the material S-N curve and n_i is the number of cycles with stress amplitude S_i in the load spectrum.

You can represent the damage fraction at any stress level, S_i, in the load spectrum using a damage distribution plot, as the following figure shows.

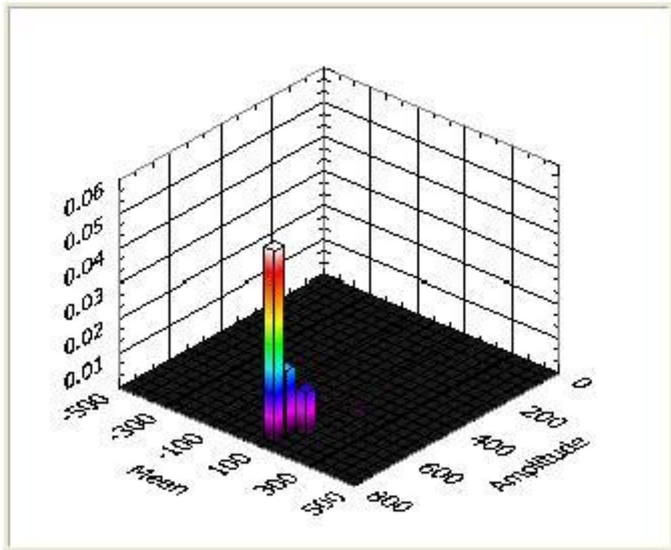
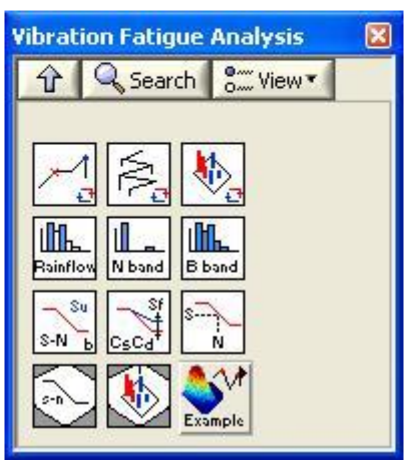


Figure 5: Damage distribution plot

Analysis Vis

LabVIEW Fatigue Analysis consists of a set of VIs for stress-life based fatigue analysis. Analysis functions include peak and trough detection, rainflow cycle counting, rainflow histogram matrix, load spectrum estimation, S-N curve generation, and stress-life based damage estimation.



These VIs are designed for use in each step of the stress-life based fatigue analysis process, as the following figure shows.

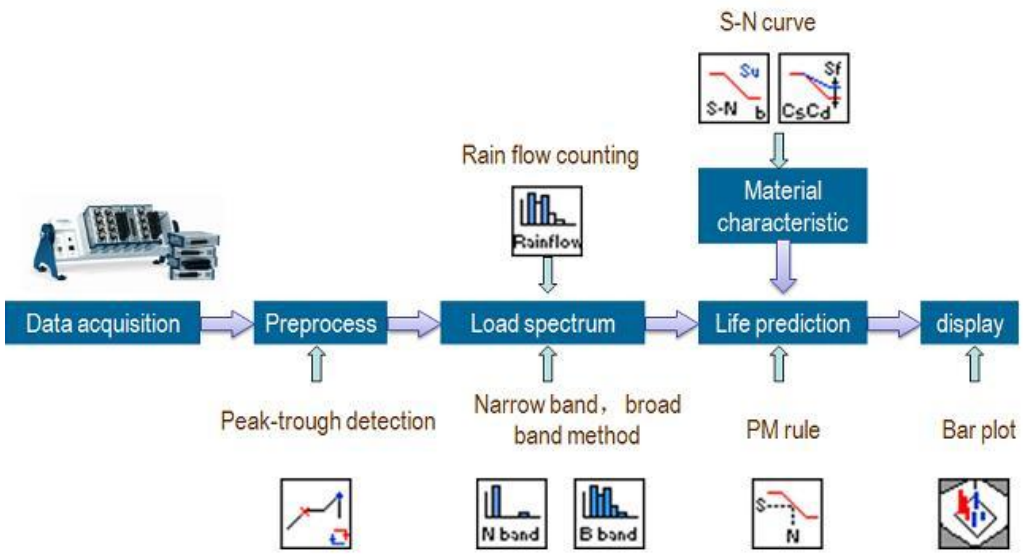


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Figure 6: VIs used in fatigue analysis process

vfa_peak and trough count VI reduces a measured load signal into a sequence of peaks and troughs, which you can further use for cycle counting.

vfa_rainflow cycle counting VI generates a histogram of cyclic stress (load spectrum) from an irregular load history with only peaks and troughs according to the ASTM E–1049 standard.

vfa_rainflow classifying VI converts the histogram of cyclic stress from rainflow cycle counting into a rainflow matrix.

vfa_load spectrum (rainflow) VI generates a load spectrum from a measured load signal using the rainflow cycle counting method.

vfa_load spectrum (narrow band) VI generates a load spectrum from the PSD of a measured load signal using the narrow band (Bendat) frequency-domain method.

vfa_load spectrum (broad band) VI generates a load spectrum from the PSD of a measured load signal using the broad band (Dirlik) frequency-domain method.

vfa_base line S-N curve VI generates an S-N curve based on the ultimate tensile strength of a material.

vfa_S-N curve modifying VI modifies a base line S-N curve with a weighting factor by considering loading, surface finishing, specimen size, notch effect, and reliability.

vfa_damage estimation VI estimates the damage caused under a given load spectrum based on a material S-N curve.

vfa_S-N curve plot VI draws a material S-N curve on an X-Y graph.

vfa_histogram bar plot VI draws a histogram bar plot on a 3D surface graph using load spectrum data.

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