# Understanding Fatigue Rated Sensors

## Abstract

Often a manufacturer will advertise a force sensor as being fatigue rated while, in fact, the force sensor is nothing more than a de-rated general-purpose type. Users with an application requiring the full life capability of a fatigue rated force sensor should be cautious of using a sensor that is advertised as being fatigue rated but, in fact, is a de-rated general-purpose type.

## Introduction

In the measurement community, the term fatigue rated is understood to mean a force sensor:

- That is designed for operation at a stress level obtained from a Stress/Strain or S/N diagram for the particular sensor material (see Fig 1 and Fig 2).
- That has a rated life of 100 million fully reversed cycles as a minimum. A fully reversed cycle is defined as a load excursion from a certain positive value to the negative of the same value and back to the first value.
- Where design considerations and manufacturing procedures used are compatible for fatigue service.
- That is more resistant to off axis loading than a similar general-purpose type.

Three major parameters influence the design of a force sensor. They are **S**ervice, **C**ost and **P**erformance. In weigh scale applications "cost" dominates the design criteria. In aircraft structural testing, "performance" becomes the major criterion. In material testing applications, "service" takes the center stage. Because "life" is a "service" condition, fatigue rated force sensors fall within this last category.

## Design considerations for fatigue rated sensors

Select a material for the sensing element that can operate at stress levels sufficient to survive 100 million fully reversed cycles of stress and still provide a full scale output of 2 mV/V. See Fig 1 and Fig 2 on the following page. The sensing

## Design considerations for fatigue rated sensors (continued)

element of a fatigue rated sensor should be machined from a single billet. Make sure the point of load is removed from the strain gage measurement area. A uniform strain field, where the bridge is located will maximize the fatigue life of the gages and minimize the deflection of the sensing element. Sharp corners and stress risers in the vicinity of the sensing element should be avoided. Reduce or eliminate stress concentration at dimensional transitions so that both stress and strain are more evenly spread throughout the sensing element. Unless addressed in the design phase, stress concentrations can be the cause of early fatigue failure when the sensing element is subject to numerous cycles of stress. The design of a Fatigue-Rated Sensor will vary among manufacturers and is usually the result of the designer's experience, uniqueness of design, modulus of elasticity, gage factor of the strain gages, values of the bridge compensating elements, method of compensation, and the need for reasonable sensitivity coupled with a conservative overload capability. Much of the know-how needed to refine a Fatigue-Rated sensor design is considered proprietary or is in the form of "art," i.e. unpublished knowledge and insight gained through years of experience in sensor design

## Fatigue Limit

The asymptote of the S/N curve in Fig 2 for a particular material defines the fatigue limit or endurance limit for that material. Therefore, the fatigue limit of a material is defined as the stress level below which a material can endure an infinite number of completely reversed cycles of stress without failure.

## Combined stress

In most applications, a force applied to a force sensor consists of a principal force as well as extraneous forces, $F_i$, and moments, $M_i$, that give rise to the existence of combined stresses being applied to the force sensor. The combined stress, $\sigma_{max}$, can be determined by first identifying and quantifying the levels of stress caused by each component of force acting separately on the sensor. The resultant level of stress is then determined by algebraically adding the contributions of each of the components. The following empirically derived equation, usually called the governing, or the characteristic equation of the sensor, can be employed to determine combined stress and has the relationship:

$$\sigma_{max} = a_i \,.\, F_i + b_i \,.\, M_i$$

**where;** **i = x, y, z**
**a and b are special load factors**

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## Other Considerations

Design stress will help to distinguish a general-purpose force sensor from a fatigue rated force sensor. However, design stress is not the only difference between the two types of force sensors. Other differences can be grain orientation of the sensing element material, geometry of the sensor design and the presence or avoidance of stress risers in the design. From a manufacturing point of view, EDM machining and most forms of welding, usually induce microscopic cracks, and should be avoided in the manufacture of the sensing element used in a fatigue rated force sensor. If a fatigue rated sensor is poorly designed poorly fabricated, or exposed to significant extraneous forces or torsional vibrations that when combined with the normal force exceeds its fatigue limit, the fatigue rated sensor may fail prematurely.

## Misconceptions about Fatigue Life

Fatigue life numbers used by manufacturers and suppliers of fatigue rated force sensors range from 50 million to 1 billion cycles. There should really be no difference in the performance between a sensor rated for 50 million cycles or 1 billion cycles. If a fatigue rated sensor lasts for more than 10 million fully reversed cycles of stress, the fatigue rated sensor should last beyond 100 million cycles and even beyond 1 billion cycles - theoretically "forever."

## Misconceptions about short term creep

*Continuous increase in deformation under constant or decreasing stress…Creep at atmospheric temperature due to sustained elastic stress is sometimes called drift. Another manifestation of creep, the diminuation in stress when deformation is maintained constant, is called relaxation.** Some manufacturers and suppliers would lead you to believe that a fatigue rated sensor with a longer specified fatigue life will experience less short term creep under load than a fatigue rated sensor with a shorter specified fatigue life. There is no demonstrable evidence that confirms that the rate of creep is a function of a fatigue rated sensor's specified fatigue life. All force sensors experience short term creep and the amount is primarily related to the methods employed by the manufacturer to gage and wire the sensor, the cleanliness of the gaging and wiring operation and the quality of the gaging and wiring materials used.

*Young, W. C. (1989) *Roark's Formulas for Stress and Strain* - 6th Edition, McGraw-Hill (New York, NY

## Long term creep

From a metallurgical point of view, long term creep is the failure mode of a member under a constant or decreasing load, when exposed to elevated temperatures for extended periods of time. Notice here that the stipulation of a constant or decreasing load (static loading) excludes fatigue (dynamic loading) from the scope of metallurgical creep. Also the temperatures involved here, are beyond the scope of applications for strain gage transducers. At any rate, one would still fail to see any connection between a higher fatigue life and a more creep resistant load cell material.

## Stress & Strain Diagrams

Fig. 1- A Stress/Strain Diagram for a Steel Alloy

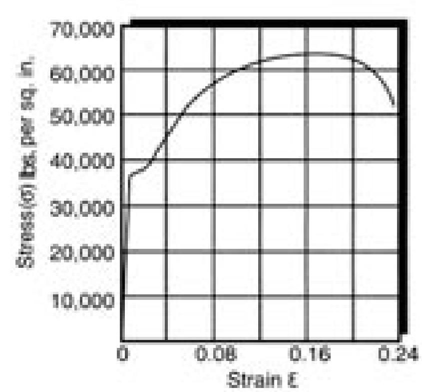
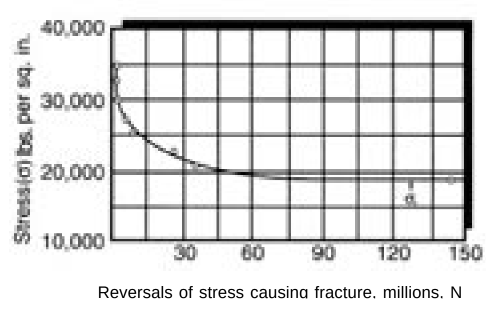



Fig. 2- A S/N Diagram for a Steel Alloy

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