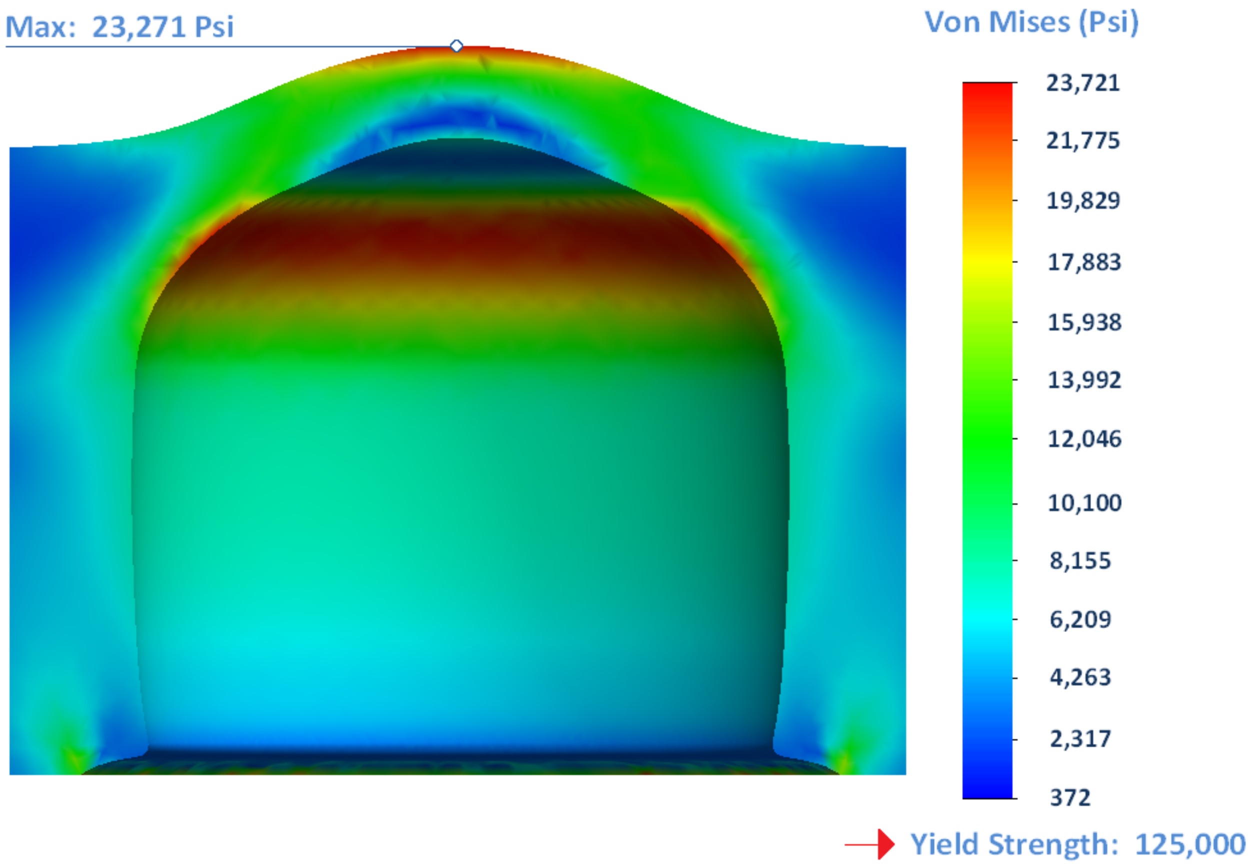
white paper



Sense Element Pump Ripple Fatigue

Providing and analyzing solutions to protect sensitive components in aircraft hydraulic systems from prolonged exposure to pump ripple.

HydraElectric

Sense Element Pump Ripple Fatigue

CONTENTS

Abstract

The hydraulic systems on an aircraft perform various critical functions such as fuel transport and mechanical work through the transmission of fluid. The forces necessary to regulate these functions require a pump, which introduces noise in the form of "pump ripple." These pump ripples can damage sensitive components along the hydraulic line particularly due to fatigue from prolonged exposure. Many of the pressure transducer series designed and manufactured by Hydra-Electric make use of a special sense element of stainless steel construction capable of withstanding these effects without the use of a snubber.

Background

During normal pump operation, an acoustic noise is introduced into the hydraulic line. This noise takes the form of a pressure pulse that travels through the fluid at the speed of sound. Typical pressure transducers will often use delicate sensors such as a piezoresistive silicon (PRT) wafer mounted onto a PCB. These materials have limited mechanical strength and often require a snubber to protect components from in-flight hydraulic pressure spikes. These effects are even more damaging if the fluid is already being maintained at a high constant pressure.

Hydra-Electric utilizes a special technology that allows pressure to be monitored through a stainless steel flexure. This robust construction eliminates the need for additional pressure spike attenuation. There are also no moving parts that can "lock up" due to rapid pressure fluctuations.

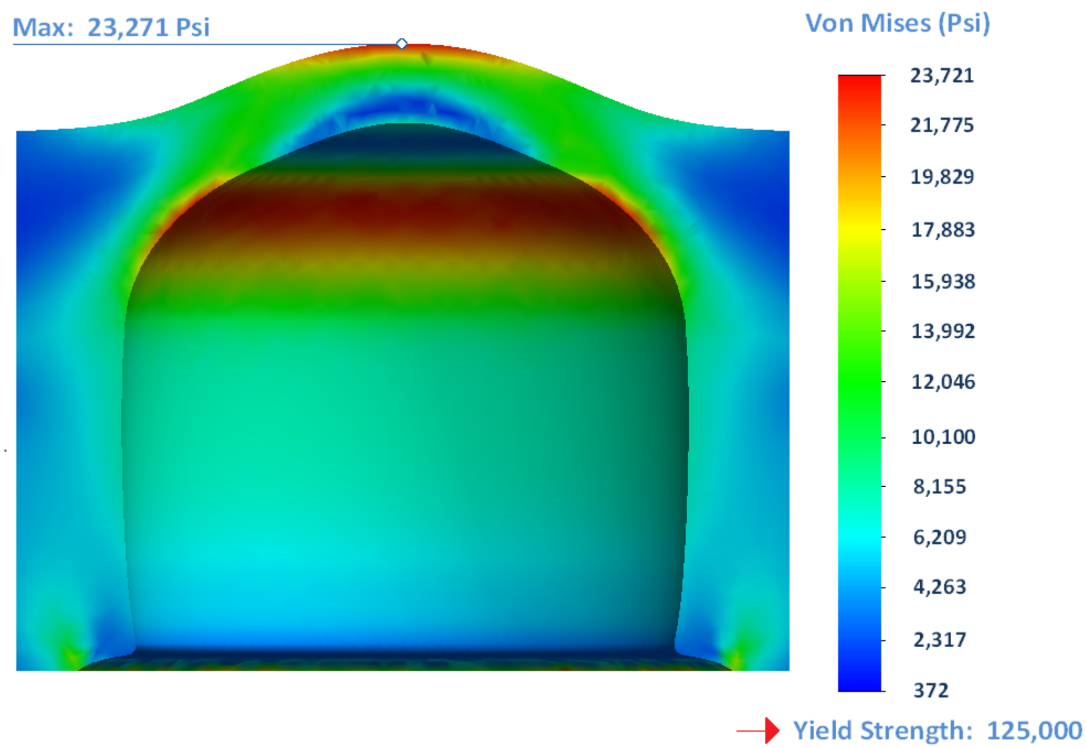
What is Pump Ripple?

Hydraulic systems will often include an impeller pump to supply pressure. The pump utilizes centrifugal force to accelerate fluid outward through small veins, generating a pressure spike. Sensors located near the impeller pump outlet will be exposed to the full force of the pressure spike and could fatigue over time.

Fatigue Analysis

The following will demonstrate that the stainless steel sense element is capable of withstanding the pressure cycling associated with pump ripple without the use of a snubber. The analysis will cover an application with a 4,000 Psi full scale pressure and a 600 Psid pump ripple pulse that is continuously applied over the life of the transducer.

Figure 1 **Sense Element Stress Analysis**



Von Mises Stresses on the sense element with 4,600 Psi applied. A max stress of 23,721 Psi is located on the top surface of the flexure. Deformation is exaggerated for clarity. Features that are non-critical to the analysis are not shown for proprietary reasons.

The stainless steel element provides the ability to withstand direct exposure to a harsh pump ripple environment within aerospace systems, outperforming conventional technology like silicon PRT.

Figure 1 shows a finite element stress analysis of the sense element. The max pulse pressure of 4,600 Psi was applied with the sense element fixed at the location of a typical weld. Figure 1 shows the Von Mises stress plot. The max stress is estimated to be 23,721 Psi while the deformation is on the order of 0.0001". This value falls well below the annealed yield stress of 125,000 Psi. A similar analysis was performed for the low pressure condition of 4,000 Psi. The results are summarized in Table 1. These values will be used to determine the stress ratios for fatigue life analysis.

Table 1 **Max Von Mises stresses during pressure cycling**

Pressure Applied (Psi)	Max Von Mises Stress (Psi)
4,600	23,721
4,000	20,637

A close approximation of the SN curve for the stainless steel sense element is shown below in Figure 2. Stress ratios not shown in the figure can be evaluated following the equations:

$$S_{eq} = S_{max}(1\text{-}R)^{0.69}$$

$$N_f = 10^{(14.6 - 5.56(log(S_{eq})))}$$

S_{eq} is the equivalent stress in Ksi, S_{max} is the max stress in Ksi, R is the stress ratio, and N_f is the number of cycles required for failure.

Figure 2 SN Curve for Stainless Steel

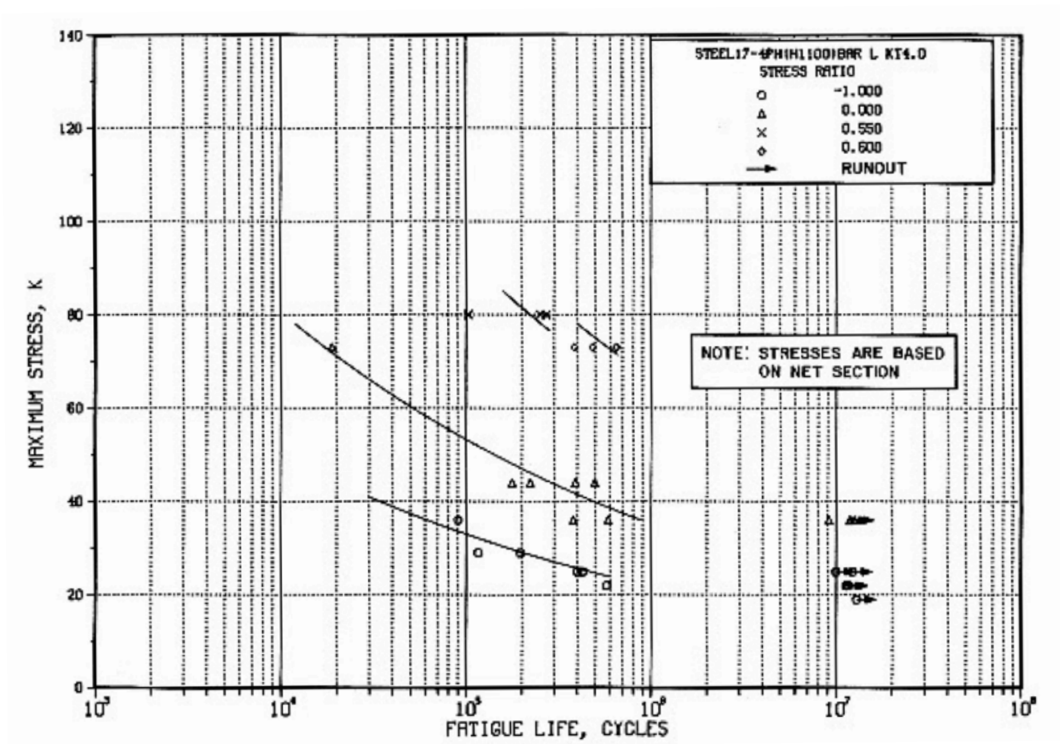


Table 2 Fatigue analysis critical values

R	S_{eq} (Ksi)	N_f
0.870	5.805	$2.26 \cdot 10^{10}$

Using the equations and simulated peak stresses provided, Table 2 provides a summary of all critical values. Total fatigue life is estimated to be $2.26 \cdot 10^{10}$ or over 20 billion cycles for this particular loading condition. To put this in context, a 300 Hz pump ripple would need to be applied for approximately 21,000 hours to reach the fatigue limit. If the average operating pressure was reduced, this number would be even larger.

Conclusion

The stainless steel sense element used in Hydra-Electric pressure transducers is capable of withstanding direct exposure to a harsh pump ripple environment for an extended period of time. Its robust construction allows it to outperform conventional technology such as silicon PRTs in this regard while maintaining equivalent accuracy.

About Hydra-Electric

Hydra-Electric is a provider of breakthrough technology in sensors and switches for the aerospace industry. Its suite of solutions includes pressure, temperature and multi-function sensors; and pressure, temperature and liquid flow switches.

Hydra's high performance sensing technology is able to address problems which were previously thought to be unsolvable, including pressure spike damage, pump ripple, high speed impulses, burst diaphragms, broken wire bonds and more.

The company has been an innovator in the industry since 1948 when it introduced the snap action sensing of pressure by means of the negative rate disk spring, a design that remains the standard today for most aerospace pressure switches. Hydra-Electric's products have been used across hundreds of military and commercial applications, including fixed wing and rotary aircraft, missiles, rockets, ships, submarines, tanks and UCAVs.

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