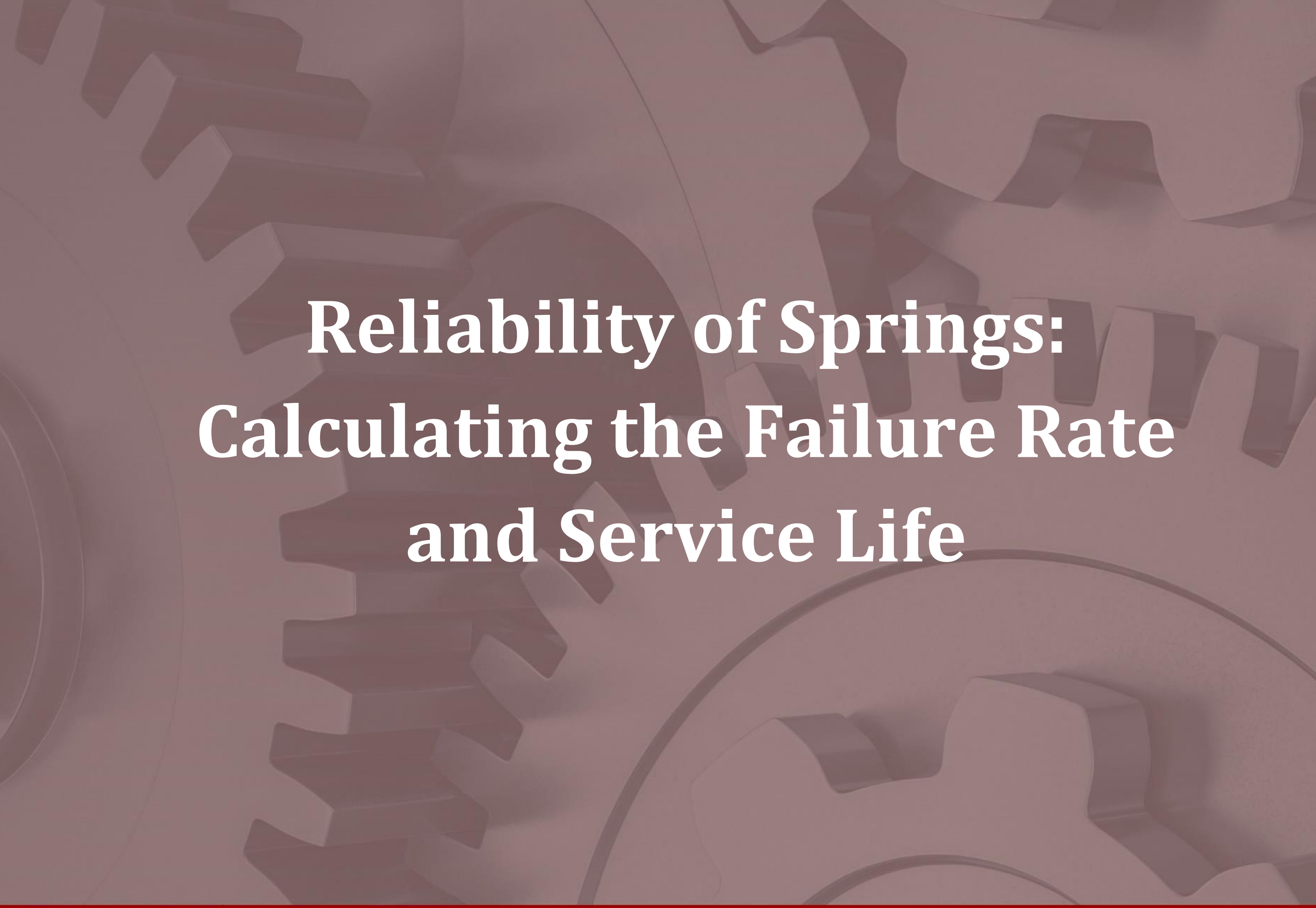

Reliability of Springs: Calculating the Failure Rate and Service Life

An Online Continuing Education Course for Engineers

Course Number: C-2050

Credit: 2 Hours / 2 PDH / 2 CPD

Reliability of Springs: Calculating the Failure Rate and Service Life

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Introduction

This course will present the calculation of a mechanical spring's failure rate and service life. Background information on spring failure will be presented in terms of fatigue. Fatigue is commonly referred to as wear out, or wear and tear. The equations applied in this course to determine the failure rate due to fatigue are based on reliability research funded by the United States Navy. Also, data from the Spring Designer's Handbook by Harold Carlson is referenced.

The focus will be on mechanical springs that undergo fatigue. A formal definition referenced in ASTM E1823 (Standard Terminology Relating to Fatigue and Fracture Testing) states fatigue is a process where localized and accumulating permanent damage to a structure occurs based on dynamic, alternating, or cyclical stress; after enough stress cycles, cracks may form or worse there may be a complete fracture of the structure. Dynamic or alternating loading particularly applies to springs used for civil engineering and mechanical engineering applications.

Most springs that experience fatigue are mechanical engineering applications such as engine valves, automotive transmission clutches, and suspension systems. Civil engineering examples of springs undergoing fatigue (albeit at a lower number of cycles) include a floating slab train track system supported by steel springs to reduce vibration transmission and a tuned mass damper (TMD) for a structure like a high-rise building. A tuned mass damper composed of springs and viscous dampers is commonly used for tall buildings such as the John Hancock Tower in Boston to reduce the response to wind gust loading. Another application for TMDs is with London's Millennium Bridge.

Reliability engineering will be discussed such as failure rate, fatigue curves, and endurance stress. Also, an overview of spring material and nomenclature is provided. A basic background in mechanics is needed to be able to successfully understand this course. This course is particularly applicable to engineers who work with structures and equipment that utilize coil springs, such as mechanical engineers, civil engineers, and chemical engineers.

This course will present reliability calculations for a compression coil spring of a footbridge's TMD, and a torsion spring of a renewable energy device (i.e., wave energy converter). The course material can be applied for preliminary planning such as estimating the expected service life of a spring within an assembly. The estimated service life will be calculated for the compression coil (or helical) spring of the TMD, and for the torsion coil spring of a wave energy converter. These two coil spring examples will reinforce the concepts of spring fatigue and how spring characteristics like wire diameter and number of active coils affect the spring's service life.

Acronym list

AMS	Aerospace Material Specifications
CR	cycle rate
DC or DM	mean diameter of the coil
DI	inner diameter of coil
DO	outer diameter of coil
DW	wire diameter of the coil
e	a natural number (also called Euler’s number) approximately equal to 2.718
1 ksi or KSI	1,000 pounds per square inch
KW	spring stress concentration factor
MTTF	Mean Time To Failure
r	spring index, which is outer diameter of coil divided by wire diameter of coil
R(t)	Reliability at time t
RAC	Reliability Analysis Center
TMD	tuned mass damper
psi	pounds per square inch
λ	failure rate
λb	base failure rate
σ or S	stress
Θ	torsion spring deflection angle

Static and Dynamic Loading

Springs play a significant role in absorbing energy and mitigating the effects of dynamic forces in various structures and devices. Springs are manufactured for various applications such as compression, tension, torsion, power, and constant force. A spring is usually considered to be static if a change in deflection or load occurs only a few times, such as less than 10,000 cycles during the expected life of the spring. A static spring may remain loaded for very long periods of time.

Figure 1 shows a notional graph of static stress applied over time for a spring. The stress is constant and always below the yield stress. If the average static stress is below the yield stress, the spring undergoes elastic (or reversible) deformation. It undergoes plastic (or irreversible) deformation if it exceeds yield stress.

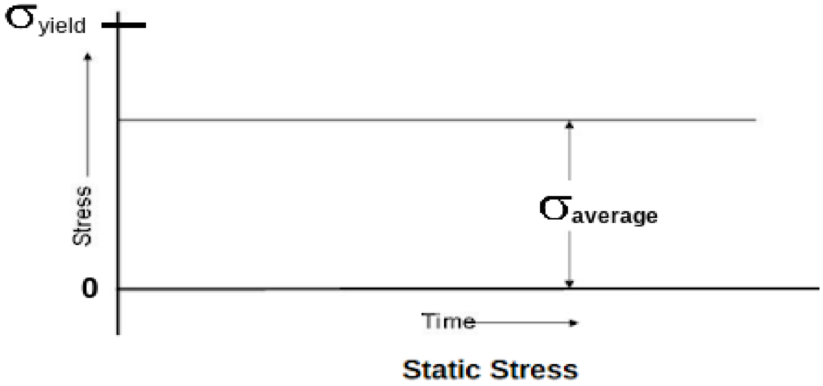


Figure 1. Static stress versus time for a spring

Dynamic loaded or cyclic springs may be operated in one direction, such as only compression, or both directions, which are compression and tension (or extension). Both directions may be referred to as reversed stress mode, whereas one direction is considered unidirectional. Figure 2 shows unidirectional stress over time. Since the stress is positive, then the spring is compressed. The spring is always compressed, evidenced by the minimum stress greater than zero. Hence, the minimum stress may result from a constant load; consider a spring part of a tuned mass damper as part of a footbridge. The footbridge structure supported by the spring is the constant load, and the additional cyclic load would be a force of the foot traffic or people walking on the bridge.

One cycle is shown on the graph in Figure 2. The failure rate is measured by the number of failures during a specified time, such as 4 failures every 30,000 hours. This relates to the number of cycles corresponding to a specific period, such as a spring completing 2,000 cycles in one hour. If this spring can operate for 2,000,000,000 cycles before failing due to fatigue, then the spring's service life is 1,000,000 hours based on the below calculation.

2,000,000,000 cycles / 2,000 cycles per hour = 1,000,000 hours

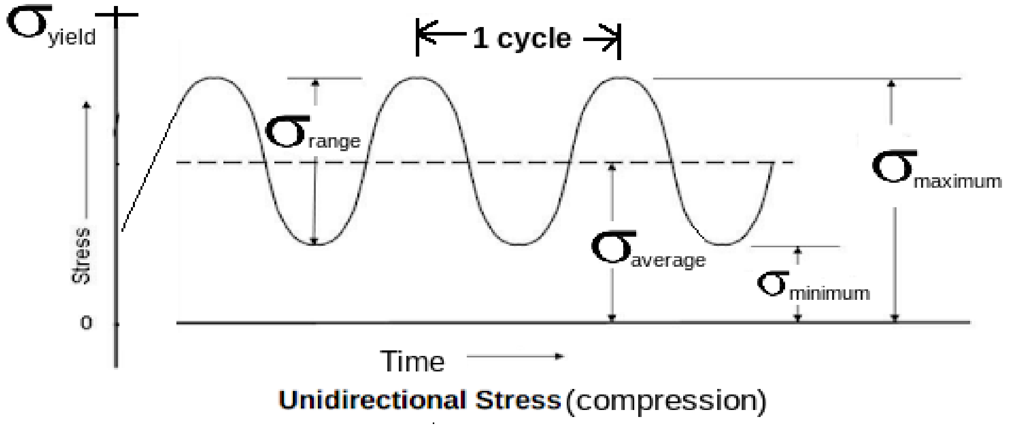


Figure 2. Dynamic loading of a spring

Shock and Resonance

The failure rate calculations are preliminary in nature and based on the spring being properly operated throughout its expected life such that its yield stress limit is not repeatedly exceeded. Shock loading is the exception, as the spring load is applied very fast so that the first few spring coils initially support more of the load than would be calculated in a static or dynamic loading condition.

Resonance occurs when the spring speed equals its natural frequency or to a multiple (i.e., harmonic) of the natural frequency. Springs are primarily attached to a mass they support, such as a slab for a train station or a foundation of an engine. The attached mass results in a lower natural frequency; resonance will occur at a lower cycle rate or frequency than the spring operating alone.

Both resonance and shock loading cause spring clash when two or more coil springs contact each other. This contact may cause binding and interference, whereas the coils cannot freely move. Coils rubbing or contacting each other creates additional stress points and localized stress concentrations, increasing fatigue risk and reducing the spring's service life.

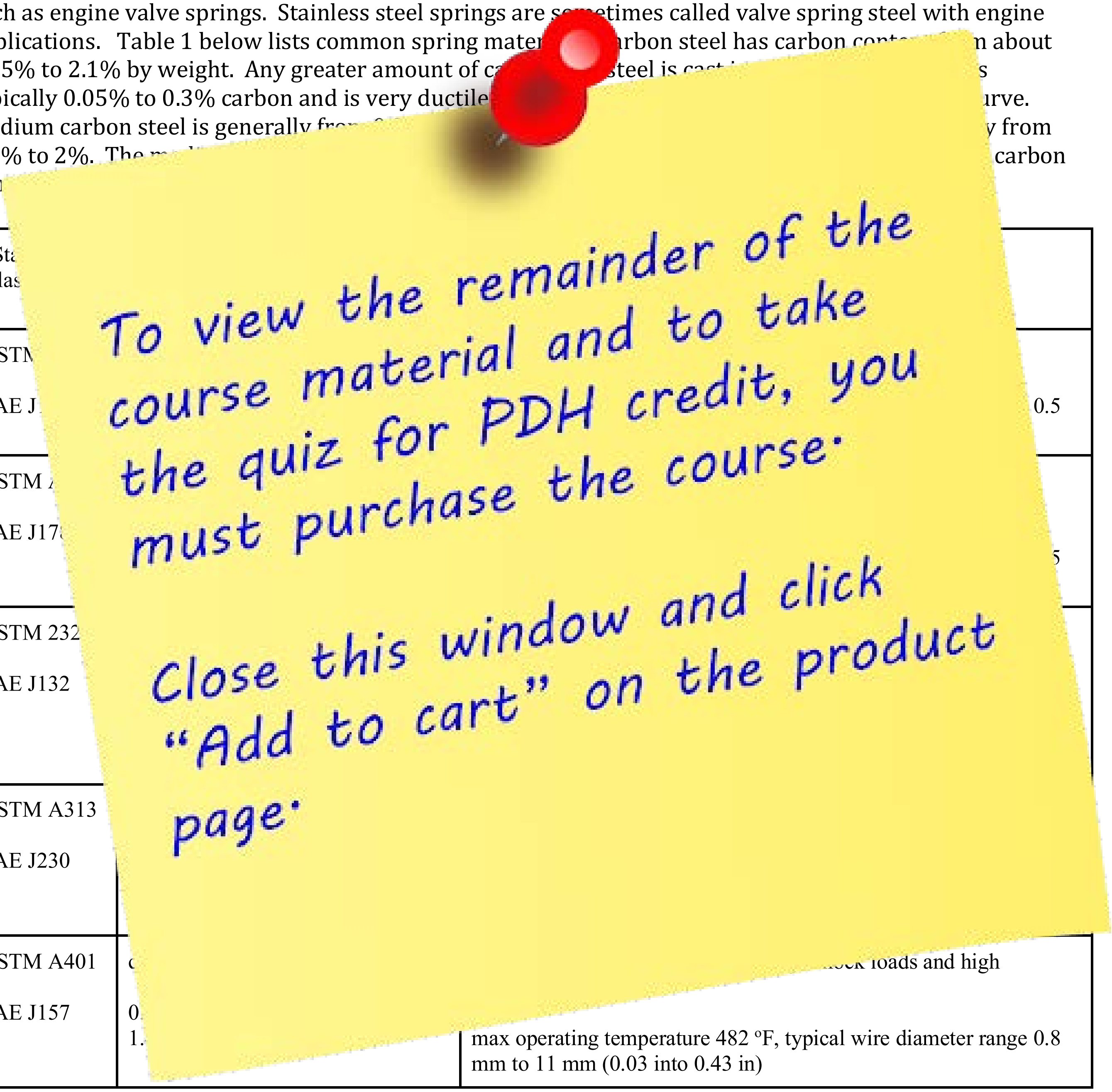
A spring design course will present various actions to reduce resonance and shock loading risks. One is to install dampers to significantly slow the rate of the load being applied to the spring. Another is to use higher-strength materials with greater fatigue resistance and design the spring system to distribute the load more evenly to avoid overstressing the first few coils.

Additionally, protective measures can be installed within the spring. Spacers or isolation components between the springs will facilitate proper spacing and prevent spring clash. Another action is to design the spring's no-load or free length with a clash allowance. Typically, the length is increased by about 20% to 30% with this allowance to reduce the risk of spring clashes.

Spring Material

Most springs are steel; therefore, their strength is typically modeled as a ductile material. Common materials are spring steel, stainless steel, nickel alloy, copper alloy, and bronze alloy. American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE) define standards for spring material.

Unlike high carbon steel, stainless steel is ideal for high corrosion and/or high-temperature environments, such as engine valve springs. Stainless steel springs are sometimes called valve spring steel with engine applications. Table 1 below lists common spring mater rbon steel has carbon conte n about 0.05% to 2.1% by weight. Any greater amount of ca steel is cast i s typically 0.05% to 0.3% carbon and is very ductile urve. Medium carbon steel is generally fr y from 0.6% to 2%. The m carbon con



Sta Clas		
ASTM SAE J		0.5
ASTM A SAE J17		5
ASTM 232 SAE J132		
ASTM A313 SAE J230		
ASTM A401 SAE J157	c 0. 1.	ock loads and high max operating temperature 482 °F, typical wire diameter range 0.8 mm to 11 mm (0.03 into 0.43 in)

Table 1. Common spring wire (reference: SAE coil spring design manual)