DESIGN AND DEVELOPMENT OF SPRING FATIGUE TEST RIG

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ABSTRACT

Fatigue tester is a special equipment used to test the fatigue of various materials and equipment. These machines apply cyclic loads to the data, simulating conditions where the data would fail due to higher stress. These machines are widely used in industries such as aerospace, automotive, civil engineering and information science. The main purpose of the fatigue tester is to determine how many cycles a material or component can withstand before failing. The information obtained from these tests is used to evaluate the design, performance and durability of the product, identify possible weaknesses and create design improvements suitable for production or production.

Fatigue testers can take many forms, from simple benchtop machines to large hydraulic machines that can generate millions of pounds of force. These systems are often equipped with advanced sensors and software systems that collect and analyse data and display results in real time.

Overall, fatigue testers play an important role in the quality, reliability and safety of materials and equipment in a variety of industries. It is therefore important that scientists, engineers and manufacturers participate in the development and evaluation of new products.

In this paper, fatigue machines are first classified according to certain characteristics, including purpose, type of load, type of load applied, transmission and control system.

I. INTRODUCTION

Most mechanical devices rely on the flow of water, an elastic material. When the spring is loaded, it uses its flexibility to cause significant deformation; When the spring load is removed, the deformation disappears and returns to its original shape. In the process of deformation or recovery, the spring can convert any work or kinetic energy into deformation energy, and also convert deformation energy into any work or kinetic energy.

In real engineering, most springs operate under different loads and their operating stress is usually lower than the yield strength of the product. The result of failure after long-term operation and the effect of the spring on this change are collectively called spring fatigue.

The weakness of the material due to repeated loading is called fatigue. When a product is subjected to cyclic stress, it causes gradual and localized structural deterioration. The rated maximum stress that causes such damage may be less than the strength of the material and is often reported as the ultimate tensile stress limit or yield stress. Fatigue occurs when the material is recycled and removed. If the load exceeds a certain point, small cracks begin to form and grow until they reach a size that will spread rapidly, eventually breaking the structure.

The form of the structure is beneficial for the poor life; square holes or sharp corners cause local stress, where fatigue cracking will occur.

In the 19th century, the absence of visible plastic deformation in fatigue cracks was considered peculiar, leading to the mistaken belief that fatigue was merely an engineering problem. Not only are they anachronistic, but only one of the important scientists of this century, especially August Wohler, who later published the concept of the stress-life curve (S-N curve), performed the fatigue test. we understand fatigue failure mechanisms.

Thanks to more powerful tools like computers, powerful microscopy tools, advanced numerical analysis techniques, and more research.

Fatigue began to be seen not as an engineering problem, but as a material and design phenomenon. Although fatigue failure has been widely studied, its true nature is still largely unknown, and cyclic loading can cause damage, cracking, or even complete failure. After a century of research, questions remain.
II. LITERATURE REVIEW

Pastoric et al. (2019), this paper presents the results of a failure and fatigue analysis of a coil spring removed from a passenger car after a traffic failure. Using experimental procedures such as visual observation, optical and scanning electron microscopy, inspect the defective coils to determine the cause of the fracture. The chemical composition of the material hardness test was determined and carried out. It was concluded that the continuous contact between the coils formed corrosion pits which acted as crack initiation points leading to eventual failure.

Based on these results, a coil spring model with finite elements has been established, allowing stress analysis under stochastic variable dynamic loads. Rainfall counting and cumulative damage assessment of a miner are performed using MATLAB numerical routines according to Goodman's failure criterion. The results obtained make it possible to predict the fatigue life of the spring. The results can help further optimize the design of automotive coil springs. [1]

Berger & Kaiser (2006), This report presents the first results of very high cycle fatigue tests of compression coil springs in response to an external compression force with torsional stress.

The results of this study could greatly contribute to the experiment of fatigue behaviour in very high cycling schemes. Most research in this area involves specimens subjected to rotational tensile or bending loads. The springs tested were made of Si-Cr alloy valve spring wire with a wire diameter between 2 and 5 mm, turned and pre-adjusted. Fatigue strength has been significantly reduced from the fatigue limit of these springs assessed in fatigue tests up to 107 cycles. Follow up if fatigue testing continues to 108 or more cycles.

It is clear that the fracture nucleation tends to occur below the surface if the fracture occurs after more than 107 cycles. Scanning electron microscopy of the fractured spring shows an atypical appearance of the fracture initiation site, with no nonmetallic inclusions in the fracture nucleation. [2]

Pyttel et al., long-term fatigue testing was performed on coil compression springs with projectiles using a dedicated spring fatigue testing machine operating at 40 Hz. Three materials Different spring types were used to manufacture the test springs: stainless steel, SiCr and SiCrV alloy valve spring steels, and oil quenched and tempered SiCr and SiCrV steels. Up to 500 springs with wire diameter d = 3.0mm or 900 springs with d=1.6mm can be tested simultaneously at different stress levels when tested using a single test strategy. Based on fatigue studies of springs with d = 3.0 mm up to the number of cycles N = 109, the tests were extended to N = 1.5 109 and the results were compared.

The effect conditions of various striker technologies on a spring with d = 1.6 mm were studied. To analyze the fracture behavior and fracture mechanism of the fracture test springs, metallographic microsections, optical microscopy and scanning electron microscopy (SEM) were used. The report compares results for different spring sizes, materials, injection cycles and conditions, and also discusses future research in the field of VHCF. As the picture shows, Figure 1 summarizes the results for springs with Ps = 98% and d = 1.6 mm and 3.0 mm. Springs with d = 3.0 mm have higher fatigue strength than springs with d = 1, with the exception of stainless-steel wire springs. 6 millimetres. The size effect means that the smaller the wire diameter, the higher the fatigue strength. [3]

Peng Lu & Peng Jia (2022), Fatigue damage is the primary form of spring failure, and spring fatigue testing is a test that should be performed before the spring is put into service. In particular, the springs of key parts such as automobile suspension springs, train shock absorber springs and engine valves can only be put into service after passing strict tests. Due to the variety of spring structures and different forces, the methods of detecting and evaluating fatigue are also different. This article introduces the compression spring fatigue testing machine from the aspects of assembly structure, working principle and technical points. This spring tester can test the maximum number of spring cycles for a given fault condition by applying a cyclic variable load to the spring.[4]

Pyttel et al. (2014). Long-term fatigue testing was performed on 40Hz rotating screw compression springs using a dedicated spring fatigue testing machine. The test springs were made from three different spring materials - oil quenched and tempered valve spring steel and SiCr and SiCrV alloy stainless steel. Using a special test strategy during the test, up to 500 springs with a wire diameter of d = 3.0 mm or 900 springs with a wire diameter of d = 1.6 mm were tested simultaneously at different voltage levels. Based on the fatigue test spring...
with $d = 3.0$ mm, the number of cycles $N = 109$ after the continuation of the test, the analysis is carried out up to $N = 1.5 \times 10^9$ and their results are compared. For a spring with $d = 1.6$ mm, the effect of different firing conditions was studied.

The broken test springs were examined by light microscope, scanning electron microscope (SEM) and metallographic microsections to analyze fracture behavior and fracture mechanisms. The post contains comparison results for different spring sizes, materials, cycle counts, and firing conditions, and describes further investigations in the VHCF field. [5]

Akiniwa et al. (2008), The fatigue strength of Si-Cr refined steel (JIS G3561, SWOSC-V) for valve springs in oil was investigated. Smooth specimens without residual surface tension were fatigued by two types of ultrasonic fatigue testing machines to elucidate the fatigue behaviour under a large number of cycles (gigacycle mode) under axial and torsional loading. The maximum size of inclusions in the critical sample volume predicted by the extreme statistics is 7.9. Although the scatter is somewhat large, the S-N data can be approximated by a linear line in the log-log plot for both load conditions up to gigacycle mode.

At the same number of load cycles, the fatigue strength ratio under torsional and axial loads is about 0.68, which remains almost constant even in gigacycle mode. Under a loading in tension-compression and in torsion, the cracks leave from the surface of the test-tube. None of the samples had cracks starting from the inside. Inclusions and grain phase domains cannot be observed.

Under torsional loading, cracks form perpendicular or parallel to the longitudinal direction of the specimen. After the shear crack propagates about 1 crack length. 30. Branch and Crack I mode have been improved. [6]

### III. METHODOLOGY

In this mode, the model is not only subjected to axial compression load. The structure is fixed at both ends and loaded cyclically at two high (maximum and minimum) values. Most general-purpose fatigue testing systems have this capability.

This testing apparatus includes, The middle plate is a sliding plate that can freely slide in up and down position using supporting bars and one middle is welded at bottom side of the for measuring accurate reading of the deformation of the spring on scale which is attached at the one middle. The bottom rigid plate has the supports and is bolted to four supporting bars from bottom side. The upper plate is used for only supporting the four bars at the proper positions and is also bolted to these four bars from upper side.

Aluminium rods are also included in the rigid and sliding plates in order to guide the loads and, separately, the location of the springs on the plates at the centre.

1. Conceptual Drawing

![Fig 1: Cad Design](image-url)
2. Design and Assembly

a. CAD Drawing

![Frame Structure CAD Drawing](image1)

**Fig 2:** Frame Structure

b. Part Manufacturing

![Frame Manufacturing Image](image2)

**Fig 3:** Frame
3. FEA Analysis

a. Static Structural Analysis

![Static Structural Analysis](image)

**Fig 4: Boundary Conditions**

b. Modal Analysis: Total Deformation

![Modal Analysis](image)

**Fig 5: Total Deformation**

Modal analysis helps determine the vibrational properties (natural frequencies and modal shapes) of a mechanical structure or component by showing the motion of various parts of the structure under dynamic loading conditions. Modal analysis is the process of determining the inherent dynamic properties of a system in terms of natural frequencies, damping coefficients, and mode shapes, and formulating a mathematical model of this dynamic behaviour. The formalized mathematical model is called the modal model of the system, and the information about its properties is called modal data.

c. Harmonic Response

![Harmonic Response](image)

**Fig 6: Harmonic Analysis**
Harmonic Response Analysis is a linear dynamic analysis used to determine the response of a system to excitation at specific frequencies. It is also referred to as Frequency Response Analysis.

The prerequisite for a Harmonic Response Analysis is a Modal Analysis, as the input frequencies needed for a Harmonic Response Analysis are the results of a Modal Analysis. Due to the analysis using results already calculated, Harmonic Response Analysis is a type of restart analysis which uses modal superposition to calculate its results.

IV. RESULTS AND DISCUSSION

The fatigue testing machine can help us understand the material strength and hence calculate its fatigue limit. The machine can test various different specimens of standard specifications and help us understand the material better.

The digital counter used help us know real time revolutions and also help us identify the number of revolutions required to fracture the specimen with respect to corresponding weights. The device described here can be used in mechanical testing to establish the fatigue limit when tensile and torsional loading are applied simultaneously. In comparison to other methods of determining the same characteristics, the device's main advantage is its simplicity. This feature is based on the original concept of using a fixed, rigid shaft that forces the central shaft to convert translational movements from the testing machine into rotational and translational movements using an inclined channel in the shaft. The elastic specimen experiences both normal stress and shear stress as a result of both movements being transmitted to it.
V. CALCULATIONS

Approximate Spring Life

**Given Data:**
- Outer Diameter: 40mm
- Inner Diameter: 36 mm
- Wire diameter = 2mm
- Material - EN24 steel spring, UTS = 850 N/mm² | Mpa
- % tensile limit allowance = 45%

**Given Data:**
- P1 = force at minimum working length = 9.81 N
- P2 = force at Maximum working length = 49.05 N

- **Wire stress (s)** at working length.
  - K = \[\frac{4\times C - 1}{4\times C - 4} + \frac{4}{C}; \frac{0.615}{19}\]
  - K = 1.074

- **Wire stress (s1) at working length.**
  - S1 = \[\frac{8\times D\times P1}{\pi\times d^3}\]
  - S1 = \[8\times 38\times 9.81\]
  - S1 = 127.50Mpa

- **Wire stress (s2) at working length.**
  - S2 = \[\frac{8\times D\times P2}{\pi\times d^3}\]
  - S2 = \[8\times 38\times 49.05\]
  - S2 = 637.52Mpa

- **wire stress (S) as a percentage of ultimate tensile strength.**

<table>
<thead>
<tr>
<th>Maximum working length</th>
<th>Minimum working length</th>
</tr>
</thead>
<tbody>
<tr>
<td>% tensile = (100 \times \frac{S2}{UTS})</td>
<td>% tensile = (100 \times \frac{S1}{UTS})</td>
</tr>
<tr>
<td>% tensile = (100 \times \frac{637.52}{850})</td>
<td>% tensile = (100 \times \frac{127.50}{850})</td>
</tr>
<tr>
<td>% tensile = 75.002%</td>
<td>% tensile = 15.00%</td>
</tr>
</tbody>
</table>

- **Reference max. wire stress**
  - 1000 cycles.
  - \(S_{10^3} = UTS \times 0.9\)
  - \(= 850 \times 0.9\)
  - \(S_{10^3} = 765.00\)Mpa
100,000,000 cycles.

\[ S_{10^9} = UTS \times 0.45 \]

\[ = 850 \times 0.45 \]

\[ S_{10^9} = 382.50 \text{Mpa.} \]

- **Wire mean stress** \((M_s)\).

\[ M_s = \frac{S_1 + S_2}{2} \]

\[ M_s = \frac{127.50 + 637.52}{2} \]

\[ M_s = 382.51 \text{Mpa.} \]

- **Wire stress amplitude**

\[ S_a = \frac{S_2 - S_1}{2} \]

\[ S_a = \frac{637.52 - 127.50}{2} \]

\[ S_a = 255.01 \text{Mpa.} \]

- **Shift Stress** \((S_s)\)

\[ S_s = S_1 \]

\[ S_s = 127.50 \]

- **Reference Maximum Stress At 1000 Cycles**

\[ S_{max}^{10^3} = S_{10^9} \times 1 - \frac{S_a + S_s}{UTS} \]

\[ S_{max}^{10^3} = 765 \times 1 - \frac{255.01 + 127.50}{850} \]

\[ S_{max}^{10^3} = 420.74 \text{Mpa.} \]

- **Reference Maximum Stress At 1000000000 Cycles**

\[ S_{max}^{10^9} = S_{10^9} \times 1 - \frac{S_a + S_s}{UTS} \]

\[ S_{max}^{10^9} = 382.50 \times 1 - \frac{255.01 + 127.50}{850} \]

\[ S_{max}^{10^9} = 210.37 \text{Mpa.} \]

\[ S_{ref} = a \times N^b \]

\[ a = \left[ \left( \frac{S_{max}^{10^3}}{S_{max}^{10^9}} \right)^{1/3} \left[ \frac{420.74}{210.37} \right] \right]^{1/3} \]

\[ a = 595.0183356 \]

\[ b = -\left( \frac{1}{0.3} \right) \log \left[ \frac{S_{max}^{10^3}}{S_{max}^{10^9}} \right] \]

\[ b = -0.05017183798 \]

\[ S_{ref} = a \times N^b \]

Rearranging the formula......

\[ N = \frac{b}{a} \left( \frac{S_{ref}}{S_2} \right) \]

\[ N = \frac{-0.05017183798}{595.0183356} \times \left( \frac{595.0183356}{637.52} \right) \]
N = 25280356

∴ Therefore N = 25280356 is the number of cycles.

VI. CONCLUSION

The so-called fatigue failure occurs when fatigue stress is induced on the material due to the reversal and transfer of energy. Current studies and tests have shown that fatigue cannot be accurately predicted because failure of the material at fatigue is affected not only by its inverse, but also by minute variations and stress variations, as well as by other factors such as temperature, weather, internal and external effects. External defects of the product under fatigue stress. These disorders include spelling, inclusion, stress, and inequality. Fatigue failure in this context is sudden and common and therefore dangerous and causes serious accidents resulting in loss of life, property and equipment. Therefore, all measures should be taken to deal with this problem as it cannot be cured completely.

VII. REFERENCES


https://www.jstage.jst.go.jp/article/jaalr/3/1/3_10/_pdf/-char/ja.

