SUGISAKA MASANORI

Journal of Advances in Artificial Life Robotics
Vol. 3(1); June (2022), pp. 56–60
ON LINE ISSN 2435-8061; ISSN-L 2435-8061
https://alife-robotics.org/jallr.html

Research Article

# Compression Spring Fatigue Tester Design and Development

Peng Lu, Peng Jia
*Tianjin University of Science and Technology, China*

ARTICLE INFO

*Article History*

Received 24 November 2021
Accepted 04 May 2022

*Keywords*

spring
fatigue test
tester
structural design

ABSTRACT

Fatigue damage is the main form of spring failure, the spring fatigue test is a mandatory test item before the spring is put into use. Especially for springs in key parts such as automobile suspension springs, train damping springs and engine valves, they can only be put into use after passing strict tests. Since there are many different types of spring structures with different stresses, the fatigue detection and evaluation methods are also different. This paper designs the compression spring fatigue tester from several aspects, including composition structure, working principle, and technical points. This spring tester can test the maximum number of cycles of a spring for a given failure condition by applying a cyclic variable load to the spring.



## 1. Introduction

Spring is an elastic element, most mechanical equipment are inseparable from the spring. The spring uses its own elasticity to produce a large deformation after being loaded, and after unloading the deformation disappears and the spring will return to its original state. In deformation and restoration, the spring is able to transform mechanical work or kinetic energy into deformation energy, or transform deformation energy into mechanical work or kinetic energy.

In actual engineering, most springs work under variable loads, and their working stress is often lower than the yield strength of the material. Spring in the role of this variable load, after a longer period of operation and the phenomenon of operational failure is called the spring fatigue damage [1, 2]. Fatigue damage is the main form of spring failure, according to statistics, about 80% or more of the spring failure is caused by fatigue damage [3]. With the development of modern machinery in the direction of large-scale, many springs in high temperature, high pressure, heavy load and corrosion and other harsh operating conditions, fatigue damage accidents are numerous [4]. Therefore, the evaluation of the spring quality should meet the design requirements in addition to the elasticity, shape, surface quality and the corresponding surface coating, fatigue design performance becomes an important indicator to evaluate the quality of the spring.

Experimental verification of the fatigue strength design of springs is of great importance to improve the reliability and service life of mechanical products [5]. The spring fatigue tester is a special instrument to verify the fatigue characteristics of the spring. Its main role is to test and analyze the tension, pressure, stiffness and displacement of the spring during operation to verify the true effect of the fatigue design. The compression spring fatigue tester designed in this paper can effectively determine the mechanical properties, process properties and fatigue strength of coil springs. It can help spring manufacturers

*Corresponding author's E-mail: lupeng970504@163.com www.tust.edu.cn*

to improve the quality of their products and ensure the safety and reliability of their products.

## 2. Main Technical Indexes

The main technical specifications of the spring fatigue tester designed in this paper are.
Maximum load: ±50KN.
Maximum loading displacement: ±15mm.
Test frequency: 0.1~10Hz.
Load displacement deviation amount: ≦3%.
Test length space: 60-300mm.
Counting range: 1~100000 times.

## 3. System Composition and Working Principle

The spring fatigue tester designed in this paper is realized by plane mechanical type, and the tester is composed of motor, transmission mechanism, frame, fixture and other parts. The structure of the spring fatigue tester is shown in Fig.1.

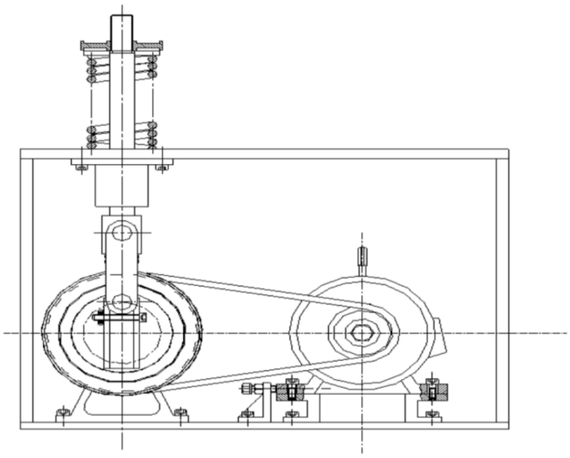


Fig.1 Test machine structure

This spring fatigue tester uses an eccentric wheel and a crank linkage mechanism to perform fatigue testing on springs. When testing the fatigue characteristics of a compression spring, the spring is positioned between the spring platen and the upper surface of the frame. After the test starts, the motor drives the turntable to rotate and the eccentric shaft on the turntable drives the driving rod to move in the guide rail, which applies a periodically varying working load to the spring to realize the fatigue test of the spring.

## 4. Drive Train Design

The scheme design of the mechanical drive system is an important part of the overall design of the fatigue testing machine. Its fundamental task is to convert and transmit the power generated by the motor to the actuating part according to the needs of the system. The reasonable transmission scheme is first of all to meet the functional requirements of the machine, such as the size of the transmitted power, speed and form of motion, in addition to meeting the requirements of work reliability, transmission efficiency and so on. The design of the transmission scheme mainly includes the design of transmission ratio, the design of the motion of the transmission device and the design of the power parameters, as well as the selection of the motor.

### 4.1. *Motor selection*

The total efficiency of the system is assumed to be $\eta = 0.8$ in the design because of the power loss in the transmission process. Calculate the work required for the tester to make one stroke.

$$\omega = \frac{1}{2}sf = \frac{1}{2} \times 15 \times 50 = 375j \quad (1)$$

If the transmission ratio is $i = 2.9$ and the motor speed is $n_1 = 1400\text{r/min}$, the spindle speed is $n_1 = 480\text{r/min}$. The time required for one rotation of the spindle is 0.125s. The spindle power can be calculated.

$$\mathrm{P} = \frac{\omega}{t} \approx 3000\mathrm{W} \quad (2)$$

motor power:

$$P_E = \frac{P}{\eta} \approx 3750W \quad (3)$$

Therefore, we can choose the model Y2-112M2-4 servo motor as the power source of the spring testing machine, and its technical parameters are shown in Table 1.

Table 1. Motor parameters

| Model | Y2-112M2-4 |
|---|---|
| Power Rating(kw) | 4 |
| Rotational Speed(r/min) | 1400 |
| Stall torque/rated torque | 2.2 |
| Maximum torque/rated torque | 2.3 |

### 4.2. *Drive train design*

When the machine is overloaded, the motor is easily damaged. In order to protect the motor, the spring fatigue tester designed in this paper adopts the transmission form of belt drive. In the transmission system, the belt drive is connected to the motor, which can play the role of overload protection, thus achieving the effect of protecting the motor.

According to the smooth load of V-belt, 16-hour two-shift working system, take $K_A = 1.3$. The calculated power can be obtained.

$$P_{ca} = K_A P = 5.2KW \quad (4)$$

According to the calculated power $P_{ca} = 5.2KW$ and the small pulley speed $n_1 = 1400\mathrm{r/min}$, by checking the belt type chart, we can know that we should choose the A type V belt. The belt selection diagram is shown in Fig.2.

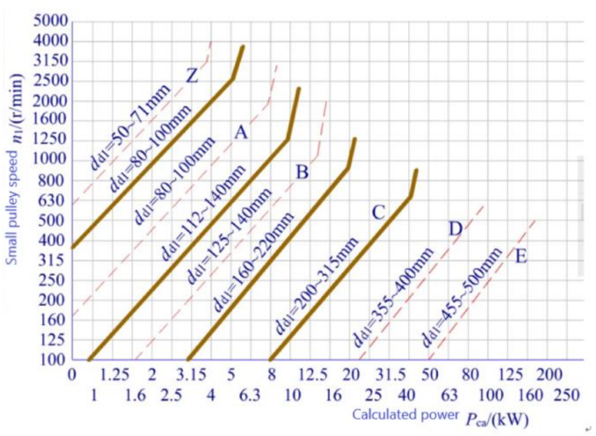



Fig.2 Belt selection diagram

A type V-belt small pulley diameter range is $\mathrm{d_{d1}} = 80{\sim}100\mathrm{mm}$. We take the small pulley diameter as $\mathrm{d_{d1}} = 100\mathrm{mm}$, and since the transmission ratio is $i = 2.9$, the large pulley diameter is derived as $\mathrm{d_{d2}} = 290\mathrm{mm}$, and finally the large pulley diameter is selected as $\mathrm{d_{d2}} = 280\mathrm{mm}$ according to the actual situation.

After selecting the diameter of the pulley, a ratio error check and a belt speed check are required to ensure that the drive belt is selected correctly.

(i) Transmission ratio error check.

$$i_e = \frac{\mathrm{d_{d2}}}{\mathrm{d_{d1}} \times (1-\varepsilon)} = 2.86 \quad (5)$$

$\varepsilon$ is the elastic sliding rate. The percentage error of the transmission ratio is.

$$i = \frac{i - i_e}{i} \times 100\% = 1.3\% \quad (6)$$

The error of 1.3% meets the error range requirement.

(ii) Band speed check.

$$\mathrm{v} = \frac{\pi \times \mathrm{d_{d1}} \times n_1}{60 \times 1000} = 7.33\ m/s \quad (7)$$

The belt speed satisfies $\mathrm{v} > 5\ m/s$, so the belt speed is appropriate.

## 5. Mechanical Component Design

In the design of the mechanical components of the spring fatigue tester, the design of the spindle and eccentric wheel mechanism is the most important.

### 5.1. *Main shaft*

The main function of the spindle is to support rotating parts and transmit torque and motion. The spindle and the general drive shaft are the same in that both transmit motion, torque and bear transmission force, and both have to ensure the normal workpiece conditions of the transmission parts and supports. But the difference is that the spindle directly bears the cutting force and also drives the drive shaft for movement, so there are higher requirements for the spindle.

When designing spindles generally the main focus is on designing the structure, diameter and strength of the spindle.

(i) Structure of the spindle.

The structure of the spindle should be convenient for positioning, fixing and assembling and disassembling of the parts on the shaft, minimize the stress concentration, with reasonable force and good craftsmanship. At the same time, the spindle structure must meet the stiffness requirements, if the stiffness is not enough, the bending deformation of the spindle will deteriorate the meshing condition of the transmission gear and cause the bearing to produce side pressure, which makes the machine wear intensify and shorten the life. Therefore, the spindle is often designed as a stepped shaft, i.e., the shaft diameter decreases from the front shaft diameter to the back. The spindle of this design, also designed as a stepped shape, was also designed as a solid shaft while meeting the stiffness requirements. The structure of the spindle is shown in Fig.3.

Fig.3 Main shaft structure

(ii) Spindle diameter.

When selecting spindle materials, they must be chosen based on factors such as stiffness, load characteristics, wear resistance and size of heat treatment deformation. The spindle is subjected to cyclic stresses during operation, therefore, its material should have the necessary strength. In this design, the spindle is made of 45# steel. Its tensile strength limit is $\sigma_b = 600MPa$, the allowable bending stress is $[\sigma_{-1b}] = 55MPa$, the allowable shear stress is $\tau_T = 30\sim40MPa$, and the coefficient is $C = 106\sim108$. From this, the diameter of the spindle can be calculated.

$$d = C\sqrt[3]{\frac{P}{n_2}} = 19.7\sim21.7\ mm \qquad (8)$$

Considering that there is an eccentric wheel installed on the shaft and a keyway at the end of the shaft, in order to ensure sufficient stiffness. Therefore, the estimated diameter range is increased by 3% to 5% and taken as 20.3~22.8mm. Final take $d = 22$mm.

(iii) Spindle strength check.

We verify the strength of the spindle by torsional strength calculation.

$$\tau = \frac{T}{W_T} = \frac{9.55\times10^6 P}{0.2d^3 n_2} \le \tau_T \qquad (9)$$

In the above equation: $\tau$ is the torsional shear stress of the spindle; $T$ is the torque; $W_T$ is the torsional cross-sectional coefficient, for a circular section shaft $W_T \approx 0.2d^3$.

The final calculation yields $\tau = 37.37$MPa, which satisfies the strength requirement.

### 5.2. *Eccentric wheel mechanism*

The crank slider mechanism is usually designed as eccentric wheel structure, through the rotation of the eccentric wheel, drive the crank to do rotary motion, through the connecting rod drive rod to do linear reciprocating motion. The spring fatigue tester in this design requires amplitude adjustment, i.e., the travel of the slider can be adjusted as needed, so the eccentric wheel is designed is shown in Fig.4.

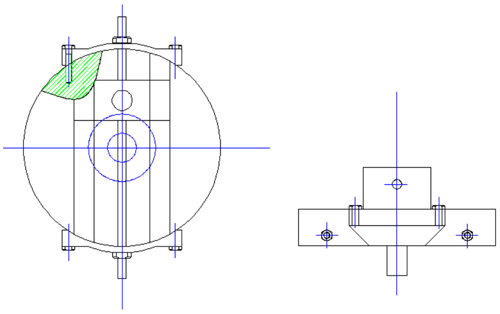


Fig.4 Eccentric wheel mechanism

In order to ensure the stability of the eccentric wheel mechanism, strength calibration of the eccentric wheel is required. The eccentric wheel is made of 45# steel, which is hinged between the round shaft and the connecting rod. The maximum load transmitted to the drive rod by the eccentric wheel is $F_{max} = 250KN$. The articulated part of the slider and the connecting rod is a short circular shaft with a length of $\ell = 200$mm and a diameter of $d = 20$mm. Calculate the maximum bending moment stress on the slider section.

$$\sigma_{max} = \frac{M_{max}}{W} \qquad (10)$$

$$M_{max} = F_{max} \times \frac{\ell}{2} \qquad (11)$$

$$W = \frac{\pi d^3}{32} \qquad (12)$$

The maximum bending moment stress on the slider section is calculated to be $\sigma_{max} = 64MPa$. After the modulation treatment, the flexural fatigue limit of 45# steel is $\sigma_{-1} = 270MPa$. The comparison of the results shows that the strength of the eccentric slider meets the design requirements.

## 6. Conclusion

The spring fatigue tester designed in this paper realizes the fatigue test of compression springs. The machine has a simple structure, accurate and rapid running action, stable and reliable performance, easy to operate, etc. At the same time, the spring fatigue tester designed in this paper can be used not only for fatigue testing of compression springs, but also for fatigue testing of extension springs by simple modification, which has good reliability, stability and versatility.

## 7. Acknowledgement

This paper was supported by the Teaching Reform Project of the Teaching Guidance Committee of Electronic Information in Higher Education Institutions of the Ministry of Education in 2021 (2021-JG-03) and the Graduate Research Innovation Project of Tianjin University of Science and Technology in 2021 (YJSKC2021S09).

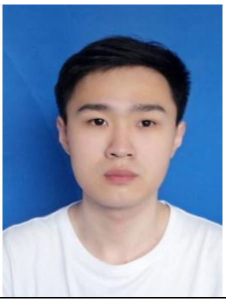
## References

1. Akiniwa Y, Stanzl-Tschegg S, Mayer H, et al. Fatigue strength of spring steel under axial and torsional loading in the very high cycle regime, *International Journal of Fatigue*, 2008, 30(12): pp. 2057-2063.
2. El-Sheikh M M, Godfrey K, Manosudprasit M, et al. Force-deflection characteristics of the fatigue-resistant device spring: an in vitro study, *World Journal of Orthodontics*, 2007, 8(1): pp. 30-36.
3. Maciejewski J, Akyuz B. Spring Fatigue Fractures Due to Microstructural Changes in Service, *Journal of Failure Analysis & Prevention*, 2014, 14(2): pp. 148-151.

4. Mao Q, Jianghua H, Zhao K. Design for Air Spring Fatigue Testing Machine by Simulation of Actual Working Conditions. Machinery & Electronics, 2016, 34(09): pp. 50-54.
5. Wang R Z, Yang W M. An optimized method of loading for the helical spring fast fatigue test, Metal Products, 2013, 39(1): pp. 23-29.

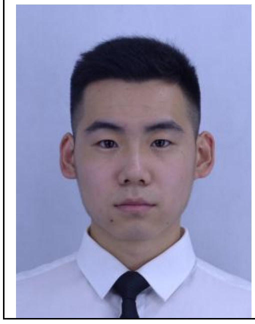
## Authors Introduction

Mr. Peng Lu



He is a second year master student at Tianjin University of Science and Technology. His research is about multi-sensor fusion, artificial intelligence, and robotics.

Mr. Peng Jia



He is a first year master student in Tianjin University of Science and Technology. His research is about embedded hardware design, mechanical and electrical control.