Study on static and dynamic characteristics of metal helical spring

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Abstract. In order to study the static and dynamic characteristics of metal helical spring ,a finite element model of the spring was set up by using Ansys, An experiment was designed to validate the result, the results of the experiment and the Ansys proved that the static stiffness of metal helical spring is changed and remarkable dynamic characteristics existed in metal helical spring, The dynamic stiffness of the spring increases with the increase of driving frequency in general tendency, it is minimal and smaller than the static stiffness of the spring corresponding to resonant frequency, however, it is maximal and greater than the static stiffness corresponding to ant-i resonant frequency

1. Introduction of spring

All In recent years, with the vigorous development of railway undertakings, the speed of the train increases, followed by the growing of vibration of the train, the vibration seriously affects the train's safety and comfort seriously, metal helical spring is the main suspension components of vehicle, and therefore it must have higher requirements.

The stiffness of metal helical spring is a very important parameter in the previous calculation and analysis, The stiffness of metal helical spring has been involved in the calculation as a constant analysis, helical spring's own mass distribution of steel springs and vibration characteristics cannot be ignored, the dynamic stiffness characteristics become significantly under the high-frequency vibration.The dynamic stiffness of the spring is the magnitude of the force which can only generate a unit elastic displacement , dynamic stiffness =the amplitude of force / the amplitude of displacement ,

Studies have shown that the dynamic properties of the rubber component is significant, but the dynamic properties of the steel springs often be ignored, but in fact steel springs have similar characteristics, steel springs are widely used as the main suspension components of vehicle, therefore, studying the static and dynamic characteristics of metal helical spring is very important.So this paper study the static and dynamic characteristics of the helical spring by using finite element method,

And an experiment was desigened to validate the result.

2. Theoretical Study of dynamic stiffness characteristics

In this paper, a model with a kind of metal helical springs is for the study, studying the static and dynamic characteristics of the helical spring by using finite element method, The parameters of the helical spring listed in theTable 1 .

Tab1. parameters of the helical spring

Parameters	value	Parameters	value
Total number of coils（N=n+n1）	5.5	Mean diameter of coil（D/mm）	250
Number of active coils（n）	4	Pitch（t/mm）	72
Number of end coils(n_1)	1.5	Free hight（H_0/mm）	326
Diameter of coil（d/mm）	42	Modulus of elasticity(E/Mpa)	2.10E+05
Outer diameter of coil（D_2/mm）	292	Poisson ratio（v）	0.3
Inside diameter of coil（D_1/mm）	208		

One end of the spring is forced by a kinematic harmonic exciation,This force is corresponding to different angular frequency of the exciation, $F=F_0\sin(\omega t)$, F_0 is the amplitude of force, ω is the angular frequency of the exciation of the force, t is the time.so the steady-state response of the free end of the spring can be calculated $x=B\sin(\omega t-\varphi)$, B is the amplitude of displacement, φ is the phase difference, In a cycle, a cycle of work done in harmonic excitation is W,W was decided by the force and amplitude and phase.

$$W=\int_0^{\frac{2\pi}{\omega}} Fxdt=\pi F_0 B\sin(\varphi) \tag{1}$$

When the displacement and force have the same phase,that is φ=0 or φ=180^0, When damping exists φ≠0 orφ≠180^0, The imposed force F_0 is decomposed into two components of π/2 advanced one named F_2 and co-phase or anti-phase one named $F_1$and calculate the works done separately, F_1 do not work because of F_1 has the same phase with the displacement . damping force is harmonic force, damping force has a phase difference of π/2 advanced of the displacement, The negative work done by the within a period of a circle is W_c,which ξ is damping ratios andis the mass of spring.

$$W_c=\int_0^{\frac{2\pi}{\omega}} Fcxdt=2\pi\xi\sqrt{mK_s}B^2\omega \tag{2}$$

At the beginning of vibration, the amplitude of displacement is small,during a period of a circle, The negative work is W_1,the work done by the exciation isW_2,when W_1=W_2 ,it is called a harmonic vibration with equal amplitude.

$$W_1=2\pi\xi\sqrt{mK_s}B^2\omega \; (3) \qquad W_2=\pi F_0 B\sin(\varphi) \; (4)$$

In this situation, the amplitude of displacement is B,so the dynamic stiffness K_d can be getted, when phase difference reaches the maximum,and we can get the The minimum dynamic stiffness K_{min} and the maximum amplitude of displacement B_{max}, when phase difference reaches the minimum, we can get the The maximum dynamic stiffness K_{max} and the minimum amplitude of displacement B_{min}.

$$B=\frac{F_0\sin(\varphi)}{2\xi\sqrt{mK_s}\omega} \; (5) \qquad K_d=\frac{F_0}{B}=\frac{2\xi\sqrt{mK_s}\omega}{\sin(\varphi)} \; (6)$$

$$B_{\max}=\frac{F_0}{2\xi\sqrt{mK_s}\omega} \; (7) \qquad K_{\min}=2\xi\sqrt{mK_s}\omega \; (8)$$

$$B_{\min}=\frac{F_0\sin(\varphi_{\min})}{2\xi\sqrt{mK_s}\omega} \; (9) \qquad K_{\max}=\frac{2\xi\sqrt{mK_s}\omega}{\sin(\varphi_{\min})} \; (10)$$

3. Finite element analysis

The modal was builded from bottom to top, Firstly using spiral the centerline equation of spring centerline equation to find out the key points, connecting the key points into a helical line In the coordinates, then draw a circle with a diameter of 42mm, Rotating the circular around the helical spring to get the model which both ends are not polished, part are cutted in both ends, the plane of end is more than 3/4 turn after cutting. Models meets the actual spring, In this paper, the modal which was bulit by the Solid185 of three-dimensional 8-node was meshed as shown in Fig.1

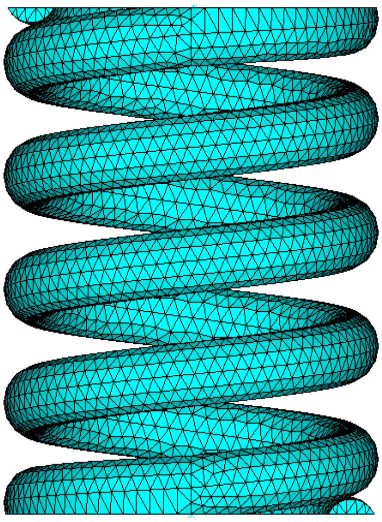

Fig.1 Ansys modal

Fig.2 experiment of the spring

3.1 The calculation of Natural frequency

Then the natural frequency of the spring can be obtained by FEM,As listed in Table 2

Tab. 2 Longitudinal natural modes

modal number	value	modal shape
1	31.079	the first Longitudinal natural frequency
2	89.006	the second Longitudinal natural frequency
3	144.37	the third Longitudinal natural frequency

3.2 The calculation of dynamic characteristics of metal helical spring

The relationship between the amplitude of displacement and the frequency of the exciation can be calculated by the finite element method, the relationship between dynamic stiffness and the frequency of the exciation also can be calculated by the finite element method, the frequency-amplitude relations curve *B*-*f* was shown as below Fig.3. the frequency- dynamic stiffness relations curve K_d-*f* was shown as below Fig.4

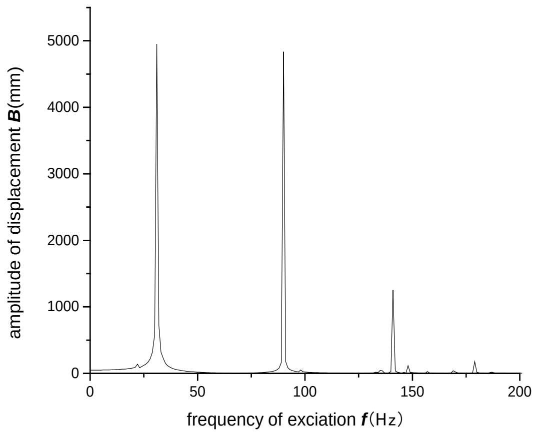

Fig.3 curve of *B*-*f* .

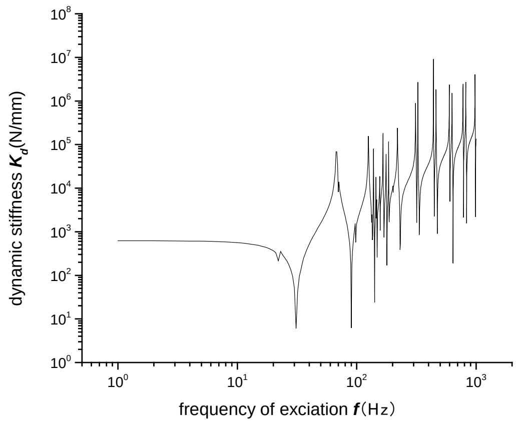

Fig.4   curve of *B*-*f*

As it can be seen from Fig.there are several peaks of the amplitude of displacement when the excitation frequency between 0-200Hz, The corresponding excitation frequencies were 31.079Hz, 89.006 Hz, 144.37 Hz, These are the spring longitudinal vibration frequency of the first 3-order natural frequencies, As it can be seen from the figure that dynamic and static rigidity stiffness are similar when the excitation frequency is close to 0Hz, As it can be seen from the figure that dynamic and static rigidity stiffness are similar when the excitation frequency is close to 0Hz, dynamic stiffness is minimal and smaller than the static stiffness of the spring corresponding to resonant frequency, however, it is maximal and greater than the static stiffness corresponding to ant-i resonant frequency as67Hz,124Hz. It can be concluded, the main reason of the changing of the dynamic stiffness is the resonance and ant-i resonant.

4. Experiment of the spring

the test conditions for the spring is that one end of the spring was fixed and the other end of was forced by a constant force or a harmonic load,the force and the displacement can be measured by the MTS , the dynamic stiffness corresponding to the frequency of the harmonic loads can becalculated. As shown in Fig.2

It can be obtained through experiment and finite element analysis that static stiffness of the spring is not a constant value, Under certain conditions, Static stiffness of the spring increases as the load increases. As shown Fig.5, It can be obtained through experiment and finite element analysis that remarkable dynamic characteristics existed in helical spring. dynamic and static rigidity stiffness are similar when the excitation frequency is close to 0Hz, dynamic stiffness is minimal and smaller than the static stiffness of the spring corresponding to resonant frequency, As shown Fig.6

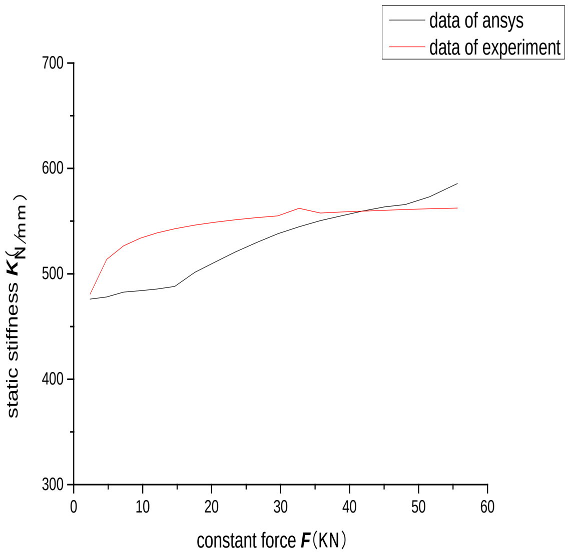

Fig.5 curve of F- x .

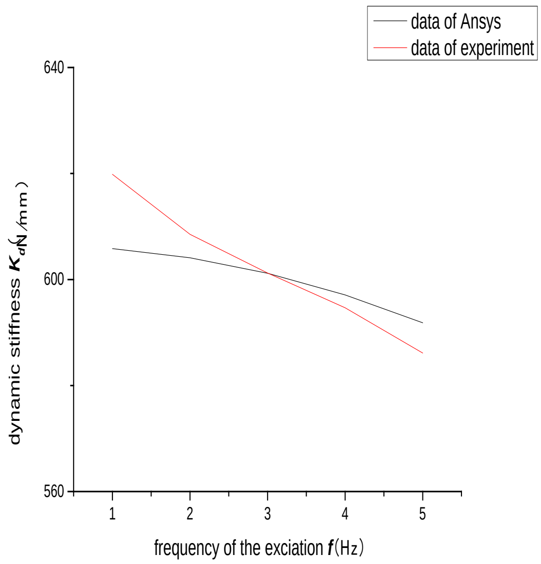

Fig.6 curve of K_d-f

5. Summary

In order to study the static and dynamic characteristics of metal helical spring ,a finite element model of the spring was set up by using Ansys. metal helical spring's own mass distribution of steel springs and vibration characteristics should be considered the results of the experiment and the Ansys proved that the static stiffness of metal helical spring is changed and remarkable dynamic characteristics existed in metal helical spring, The dynamic stiffness of the spring increases with the increase of driving frequency in general tendency, it is minimal and smaller than the static stiffness of the spring corresponding to resonant frequency, however, it is maximal and greater than the static stiffness corresponding to ant-i resonant frequency.

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