Comparative Experimental Study on Mechanical Properties of Rubber Band and Metal Spring

Yan Huang¹ and Songlin He²*

¹ School of Physical Science and Technology, Kunming University, Kunming 650214, China
² School of Mechanical and Electrical Engineering, Kunming University, Kunming 650214, China
Email: hslkm8888@126.com

Abstract. The tensile tests of a metal spring and a rubber band are studied comparatively. It is found that the elastic force of rubber band is proportional to its elongation in a certain range of deformation, which satisfies Hooke’s theorem. This is same as the result of the metal spring. By comparing the vibration property of the systems composed of metal spring and rubber band respectively, it is found that the property of “intrinsic” damped vibration of the rubber band oscillator is completely different from that of the viscous damped vibration of the harmonic oscillator. It is concluded that the static mechanical property of rubber band is similar to that of metal spring, but its dynamic mechanical property is completely different from that of metal spring.

Keywords. Metal spring, rubber band, tensile test, damped vibration.

1. Introduction
Rubber band is a common object in our daily life. It has both high elasticity and viscosity. We often use its high elasticity to meet all kinds of needs in our life and work, such as ejecting objects, binding objects, and sometimes using its viscosity to increase the friction of the contacting surface. The mechanical properties of various rubber materials are very important for their use, so there are always research reports [1-4]. In this paper, the mechanical properties of rubber bands are studied by means of comparative experiments. Firstly, the elastic coefficients (stiffness) of the metal spring and the rubber band are measured by tensile test [5]. Then, the vertical vibrations of two systems, one of which is composed of metal spring and mass block (hook code), another is composed of rubber band and mass block, will be studied.

2. Measurement of Elastic Coefficient by Tensile Method
The elastic coefficients of metal spring and rubber band were measured by tensile method and analysed by comparison. The experiments were carried out with the standard spring of FD-GLB-II new type Joule scale produced by Fudan Tianxin company and the commercial rubber band made in Vietnam. The instrument is shown in figure 1. In the experiment, the appropriate weight has been added to straighten the spring or rubber band firstly. Then the cursor has been moved. When the pointer, the image of the pointer and the scribe on the cursor coinciding, the initial value of pointer has been recorded. The experiments of increasing and decreasing codes are carried out in turn. After increasing or decreasing code, when the pointer being stationary, the position indicated by the pointer has been recorded. Due to the large deformation of the metal spring used in experiment, 1 g chip code is changed each time. The
deformation of the rubber band is small, 5 g chip code is changed each time. Thus, the relationship between strain and stress of the spring or rubber band can be obtained. The experimental data are shown in table 1.

Table 1. Tensile test data of metal spring and rubber band.

| Mass increment of hook code dm1 (g) | Length increment of spring dl1 (m) | Increment of spring elastic force df1 (N) | Mass increment of hook code dm2 (g) | Length increment of rubber band dl2 (m) | Increment of rubber band elastic force df2 (N) |
|------------------------------------|-----------------------------------|-----------------------------------------|------------------------------------|----------------------------------------|----------------------------------------|
| 1.01                               | 0.00615                           | 0.00988                                 | 5.01                               | 0.00392                                | 0.0490                                 |
| 2.00                               | 0.01224                           | 0.0196                                  | 9.99                               | 0.00846                                | 0.0977                                 |
| 2.99                               | 0.01835                           | 0.0292                                  | 15.01                              | 0.0130                                 | 0.1470                                 |
| 4.01                               | 0.02425                           | 0.0392                                  | 20.02                              | 0.01791                                | 0.1960                                 |
| 5.00                               | 0.03035                           | 0.0489                                  | 24.99                              | 0.02297                                | 0.2440                                 |
| 6.02                               | 0.03638                           | 0.0589                                  | 30.01                              | 0.02827                                | 0.2930                                 |
| 7.01                               | 0.04250                           | 0.0686                                  | 35.00                              | 0.03408                                | 0.3420                                 |
| 7.99                               | 0.04840                           | 0.0781                                  | 39.99                              | 0.03996                                | 0.3910                                 |
| 9.01                               | 0.05500                           | 0.0881                                  | 45.01                              | 0.04582                                | 0.4400                                 |
| 10.00                              | 0.06040                           | 0.0978                                  | 50.00                              | 0.05215                                | 0.4890                                 |

According to the data in table 1, the scatter diagram of the relationship between stress and strain have been drawn by Excel, and the diagram has been shown in figure 2.

Figure 2 shows that the trend curve of data fitting are straight lines, and the slopes of straight lines obtained are the elastic coefficients of the metal spring and rubber band.

The results show that the elastic coefficient of metal spring $k_1=1.6158 \text{ Nm}^{-1}$, and that of rubber band $k_2=9.0958 \text{ Nm}^{-1}$. The measured data points of rubber band in figure 2 are not strictly in a straight line, and the intercept cannot be regarded as zero, which shows that the elastic force and elongation of rubber band do not strictly comply with Hooke’s theorem, but they are approximately true within the deformation range possibly involved in our experiment. In the experiment, each increase or decrease of the weight is very slow, and each reading of the data can only be done when the system reaches the equilibrium state, so the obtained elastic coefficient is the static elastic coefficient.

3. The Observation of Vibration and Experimental Research
The two different vibration systems have been formed by using metal spring and rubber band to combine hook code respectively. The movement of hook code in the vertical direction is observed and analysed.
Pulling the hook code downward from the balance position along the vertical direction to make it vibrate, then the vibration of system has been observed.

![The relationship curve between elastic force and elongation.](image)

**Figure 2.** The relation curve between elastic force and elongation.

In the vibration system composed of metal spring and hook code, the hook code moves up and down in the balance position, and the amplitude does not decrease obviously in the process of vibration. During the experiment process, the hook code can trigger the position of Hall sensor hundreds of times. In the case of neglecting the air resistance and the friction at the contact surface, the vibration of the system composed of metal spring and hook code can be regarded as simple harmonic vibration.

For the system which is composed of rubber band and hook code, when the hook code is pulled away from the balance position, it moves up and down in the balance position also, but the amplitude decays quickly. Generally, after more than ten times of vibration (related to the initial displacement of the hook code), it will stop at the balance position. Because the air resistance and the friction at the contact surface can be neglected, the damping force comes from the rubber band itself certainly. So this movement can be called “intrinsic” damped vibration.

In order to study the different characteristics of the two vibration systems, the above-mentioned instrument is still used, and the Hall sensor is added beside the cursor as the switch of the vibration meter. The sensor is connected with a timer which can record time and vibration times. One small magnetic steel is adsorbed at the bottom of the hook code under the vibration system, which is used to trigger the Hall sensor to measure the period during the vibration process. Although the amplitude of the rubber band vibration system decays rapidly, the period can also be measured by this device as long as the hook code is adjusted to the appropriate weight. The experimental data are recorded in table 2.

For the system composed of metal spring and hook code, the elasticity coefficient of the spring used in the experiment is $k_1 = 1.6158 \text{ Nm}^{-1}$, the mass of the hook code is $m_1 = 24.41 \text{ g}$, and the mass of the spring is $m_{01} = 13.74 \text{ g}$. Assuming that the system is regarded as a harmonic oscillator, considering the correction of the mass of the spring itself, the mass of the harmonic oscillator is $M_1 = m_1 + 1/3m_{01} = 0.02599 \text{ kg}$. The theoretical period of this harmonic oscillator can be obtained, written as $T_{1th} =$
2π√\(\frac{M_2}{k_2}\) = 0.7969S. The difference between the theoretical value and the experimental value is only 0.5%, which can be regarded as the same within the allowable error range. This shows that the hypothesis is correct, that is, the system composed of metal spring and hook code can be regarded as a harmonic oscillator.

### Table 2. Measurement data of vibrator period.

| No. | Period measurement of metal spring vibrator | No. | Period measurement of rubber band vibrator |
|-----|--------------------------------------------|-----|------------------------------------------|
| 1   | 50 T(s)                                    | 2.222 |
| 2   | 39.642                                     | 2   | 2.201                                    |
| 3   | 39.614                                     | 3   | 2.217                                    |
| 4   | 39.661                                     | 4   | 2.210                                    |
| 5   | 39.650                                     | 5   | 2.236                                    |
| 6   | 39.643                                     | 6   | 2.193                                    |
| Average | 39.646                                    | Average | 2.213                          |
| \(T_1(s)\) | 0.79291                                  | \(T_2(s)\) | 0.5533                                  |

It can be seen from the observation of experiment that the system composed of rubber band and hook code will vibrate with amplitude attenuation, and it will generally stay in the balance position after several times of vibration. In order to measure the attenuation of amplitude, the vibration process of the system composed of rubber band and hook code is recorded into video. Through the playback of video frame by frame, the specific positions of the pointer at the beginning, half cycle and one cycle are determined, and the logarithmic attenuation of vibration is measured. The experimental results show that if the initial vibration amplitude is \(A_0 = 6.50 \text{ cm}\), after half a period, the amplitude becomes \(a = 4.90 \text{ cm}\). Then the logarithmic decrement is calculated as \(\lambda = 0.565\). It can be seen clearly that the vibration system of rubber band has larger damping, which makes the amplitude decay faster.

For the rubber band and hook code system, the elasticity coefficient of the rubber band used in the experiment is \(k_2 = 9.0958 \text{ Nm}^{-1}\), the mass of the hook code is \(m_2 = 79.37 \text{ g}\), and the mass of the rubber band is \(m_{02} = 1.14 \text{ g}\). If the system is regarded as a harmonic oscillator, the mass of the harmonic oscillator is \(M_2 = m_2 + \frac{1}{3}m_{02} = 0.07975 \text{ kg}\). Then the vibration period is \(T_{2th} = 2\pi\sqrt{\frac{M_2}{k_2}} = 0.5883\text{s}\). If the attenuation of amplitude is assumed to come from viscous damping, the damping coefficient can be estimated to be \(\delta \approx 1 \text{ s}^{-1}\) according to the logarithmic decrement and periodic value measured by experiments. It is known from the vibration theory that the viscous damping will make the vibration period larger than the harmonic vibration period. But the period of the rubber band and hook code system measured by the experiment is \(T_2 =0.5533 \text{s}\), which is 6.3% less than that of \(T_{2th}\). This shows that the vibration of rubber band and hook code system can not be described by the viscous damping vibration model of harmonic oscillator.

### 4. Conclusion

Through comparative experimental research and theoretical analysis, we can get the following conclusions.

In the case of static tension, the mechanical properties of rubber band and metal spring are the same, which meet Hooke’s theorem in a certain range of deformation. In other words, involving the application of static deformation, such as spring scale, rubber band can be used instead of metal spring.

For the dynamic case, the mechanical properties of rubber band are completely different from that of metal spring. The dynamic elastic coefficient of metal spring is the same as that in static state, while the dynamic elastic coefficient of rubber band is different from that in static state, which is determined by
the properties of rubber itself. In other words, when it comes to dynamic applications, rubber bands cannot replace metal springs, such as vibration systems. The vibration amplitude of the system composed of rubber band and object attenuates very fast, and this kind of attenuated vibration is totally different from the viscous damped vibration of the simple harmonic oscillator.

If you want to explain the phenomenon that the period of damping vibration of rubber vibrator is less than the period value assumed by the harmonic oscillator model, one view is that the dynamic elastic coefficient of rubber band is directly recognized as greater than its static elastic coefficient, which is a common method used in some engineering practice involving rubber materials, but it lacks the corresponding mechanism support [6, 7]. Another view [8], which is proposed also by writers of this article, is that the elastic coefficient of rubber band derived from high elasticity of rubber is the same in dynamic and static state, but the viscoelasticity of rubber provides additional contribution to its elastic coefficient in dynamic state. The examination of this viewpoint depends on the in-depth study of viscoelastic materials from both experimental and theoretical aspects, which are all the contents to be further explored in the future work.

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