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Teaching Research on Wien-Bridge Oscillation Simulation Experiment

Xiufen Wang*, Shengyi Yang, Pu jiang

School of Physics and Mechatronic Engineering, Guizhou Minzu University, Guiyang, China

Email address:
xiufen_wang@yeah.net (Xiufen Wang), yangyshy@163.com (Shengyi Yang), 472210046@qq.com (Pu jiang)
*Corresponding author

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Abstract: Wien-bridge oscillation circuit is an important part of analog circuit experiment. Its theoretical knowledge covers a wide range of contents, which are abstract and difficult to understand. However, in the experiment, due to the solidification of hardware equipment and the poor observability, the experimental effect is not ideal, which is not conducive to the understanding and mastery of theoretical knowledge. This paper simulates the experiment with the help of Multisim simulation software, which can visually and vividly demonstrate the changes of circuit characteristics, and realize the observation and verification of circuit mechanisms such as starting, balancing, frequency selection, distortion, and stopping vibration. That enhances students' perceptual understanding of abstract and complex theoretical knowledge and is of great significance to their understanding of the structure, principle and operation mechanism of Wien-bridge oscillation circuit. It can be seen that Multisim simulation teaching is an effective supplement to traditional teaching methods and means. Students not only observe the "results" of waveform generation, but also experience its "micro-process". At the same time, it contributes to the expansion, deepening and integration of knowledge learned, which has important value for the improvement of students' exploration and innovation ability, so as to better exert the experimental efficiency, further realizing the combination of theory and practice. Moreover, the Multisim simulation software has rich components, which increases the flexibility of the experiment, and is also of great significance for the implementation of online teaching mode.

Keywords: Analog Circuit Technology, Multisim Simulation, Experimental Teaching, Wien-Bridge Oscillation

1. Introduction

The oscillation circuit can convert DC energy into AC energy with a certain frequency, amplitude and waveform [1, 2]. According to the oscillation waveform, it can be divided into sine wave oscillation circuit and non-sinusoidal wave oscillation circuit. Sine wave is a basic waveform signal, which is widely used in many fields such as test and measurement, automatic control, wireless communication, etc. [3]. Wien-bridge oscillation circuit is a typical sine wave RC oscillator, which has the advantages of stable output waveform and convenient frequency adjustment. It does not need external excitation, and uses the RC series-parallel system to realize oscillation to produce a sine wave circuit with a frequency of 1Hz-1MHz [4-6]. As an important knowledge content of "analog electronic technology" course [7], it is not complicated, but involves many concepts such as circuit positive and negative feedback, amplification and amplitude stabilization, which is relatively abstract [8, 9].

Experimental course is an important course in the higher education system. It is based on observation and improves students' ability of practice, thinking and innovation through operation [10, 11]. In the analog circuit experiment course, the general experimental box is equipped with the corresponding Wien-bridge oscillator module, but most of them have the problems of hardware solidification and inflexibility of adjustment, resulting in poor experimental observability and unsatisfactory experimental teaching effect [12]. In this paper, the simulation analysis ability of Multisim is used to assist the experimental teaching, and the simulation design of Wien-bridge oscillator experiment is carried out to help students deepen their understanding and mastery of abstract theory.

2. Wien-Bridge Oscillation Circuit

Wien-bridge Oscillation Circuit is shown in Figure 1, where $R_1 = R_2 = R, C_1 = C_2 = C$.

RC sine wave oscillator is formed by using resistor R and capacitor C as feedback frequency selection network. RC series-parallel oscillators are widely used in RC sine wave oscillators [13]. In Figure 1, Rp, R3, and R, C series-parallel branches form a four-arm bridge, which is called a Wien-bridge oscillator. Its composition can be summarized into the following three parts.

(1) Amplification circuit. The amplifier is an in-phase amplifier with a gain of $\dot{A} = 1 + R_F / R_3$. The gain can be changed by adjusting the potentiometer Rp to meet the oscillation conditions and improve the waveform quality.

(2) Feedback and frequency selection network. The series-parallel circuit composed of R_1, R_2, C_1 and C_2 forms a positive feedback branch and serves as a frequency selection network to obtain a sine wave oscillation signal of a single frequency. Its feedback magnification is

$$\dot{F} = \frac{U_O}{U_+} = \frac{R // \frac{1}{j\omega C}}{(R + \frac{1}{j\omega C}) + (R // \frac{1}{j\omega C})} = \frac{1}{3 + j(\omega RC - \frac{1}{\omega RC})} = \frac{1}{3 + j(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega})}.$$

When the oscillation frequency $f_0 = 1/(2\pi\omega_0)$, the phase shift $\varphi_F = 0$, $\dot{F} = 1/3$.

(3) Stable amplitude part. In order to output a stable sine wave, two diodes are used to form a stable amplitude circuit. When the oscillator is stable, the loop gain is $\dot{A}\dot{F} = 1$, and the amplifier gain is 3.

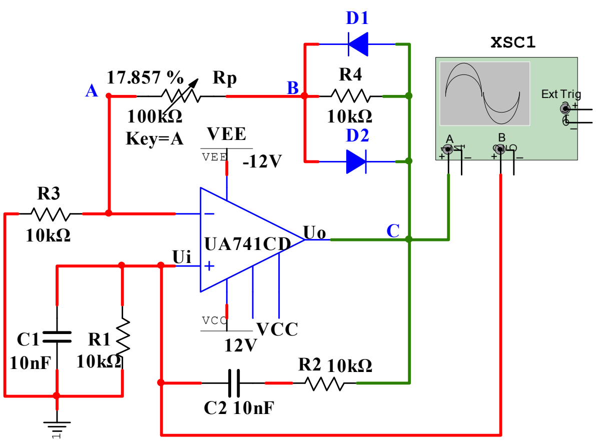

Figure 1. Wien- bridge oscillation circuit.

3. Existing Problems

Limited by the hardware environment of the laboratory, the experiment is usually divided into the following three steps in routine teaching:

(1) Adjust the variable resistor Rp to make the output waveform from nothing to generation and to distortion. Record the value of Rp, the amplitude of input voltage Ui and output voltage Uo under the condition of initial vibration, maximum sine wave output amplitude and distortion.

(2) Measure the amplitude and frequency of the output waveform when C_1=C_2=10nF and 20nF (maximum undistorted output waveform), and compare with the theoretical value.

(3) Disconnect diodes D1 and D2, repeat step (1) and compare with the result of step (1).

It can be seen that the design of such teaching content is only to position it as a confirmatory experiment project. Students only mechanically complete the wiring, operation and use of instruments and equipment, read the experimental data, and record the experimental waveform according to the experimental instructions. This experimental teaching mode, which is mainly based on teacher teaching, causes students to ignore the importance of the phenomenon that occurs in the experiment and have no way to solve the problems they meet. In addition, due to the over-emphasis on the unity of the experimental process and the verification of the experimental content, the experimental content is completely dependent on the theoretical teaching, which is not conducive to the further development of students' ability to integrate theory with practice and the development of innovative thinking. For example, by completing the above experimental content, students rarely think about the following problems. The Wien-bridge oscillator is a circuit that can generate sine wave output without external excitation. As long as the amplification gain meets the conditions, the circuit can self-excited to generate signals [14]. So, the question is, where does the amplified come from? Secondly, is the output of the Wien-bridge oscillator necessarily a sine wave when it meets the oscillation conditions? As a key part to cultivate students' practical and innovative abilities, experimental teaching is an important part of the teaching system of colleges and universities [15]. By visualizing complex and abstract theories, it not only enhances students' perceptual knowledge, but also improves students' interest in learning. It plays an irreplaceable role in theory teaching in electronic information specialty. For this reason, this paper starts from the teaching design of the overall experimental simulation design, and combines the Multisim simulation software to make students have a deeper understanding of the knowledge of the Wien-bridge oscillator.

4. Simulation Design

In the theoretical teaching, the analysis method of the Wien-bridge oscillator is mainly to obtain the oscillation conditions from the positive feedback block diagram, and then to obtain the composition principle of the Wien-bridge oscillation circuit by analyzing the frequency characteristics of the RC network, or to obtain the output expression of the Wien-bridge oscillator by solving the differential equation. With the above theoretical basis, students can be guided to understand the working principle of oscillator step by step by observing the experimental phenomenon in experimental teaching [16].

The experiment contents include: the oscillation conditions, amplitude balance conditions and phase balance conditions that sine wave oscillation circuit must meet to generate oscillation.

Vibration conditions: loop gain $AF > 1$;

Amplitude balance condition: loop gain $AF = 1$;

Phase balance condition: the phase shift of the amplification circuit plus the phase shift of the feedback network is equal to 2nπ (n=0, 1,...).

If the circuit meets the loop gain $AF > 1$, then the circuit generates amplification oscillation, that is, the output signal changes from small to large after vibration, and then the gain of the amplification circuit is adjusted to balance through the nonlinear amplitude stabilization part in the feedback network. Wien-bridge oscillation circuit is extremely short from the vibration to the stable amplitude. In the teaching process, because the content of this part is very abstract, it is often difficult for students to understand, and it is difficult to catch this phenomenon even when observing with oscilloscope in the laboratory. Therefore, combined with virtual simulation technology, the waveform generation principle of the oscillator is visually demonstrated in the following steps.

4.1. Initial

Wien-bridge oscillator should make the circuit self-excited to produce continuous oscillation, which is converted from DC to AC. When the circuit is connected to the DC power supply, due to the existence of electric shock, noise or interference, they will generate weak clutter signals with wide spectrum distribution, as shown in Figure 2. There are always harmonics with the same frequency as the oscillation frequency $f_0 = 1/(2\pi RC)$. Due to the small amplification multiple, the circuit has not yet met the conditions for self-excited oscillation.

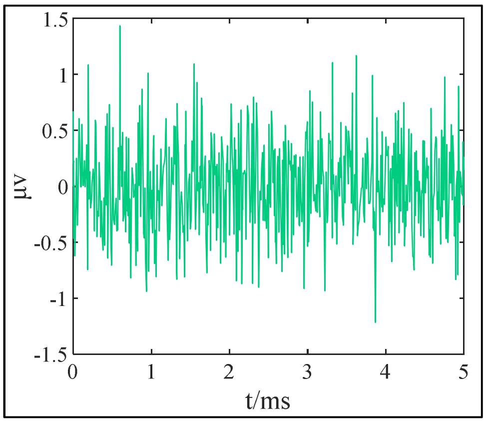

Figure 2. *Initial clutter in the circuit.*

4.2. Oscillation

4.2.1. Oscillation Process

The Rp resistance is gradually increased from small to large. When the gain of the amplifier is slightly greater than 3, that is, the weak signal in Figure 2 is amplified by the amplification circuit and the frequency selection function of the positive feedback frequency selection network, and the output sine wave oscillation is established from small to large, as shown in Figure 3. This process is called the formation of vibration. Then gradually increase the Rp value, and it can be observed that the output sine wave amplitude increases. When the Rp value increases to 17.857%*100 kΩ, the output sine wave reaches the maximum undistorted state, as shown in Figure 4. It can be seen that the output waveform does not exist from the beginning, but has experienced a gradual process from nothing to something, from small to large.

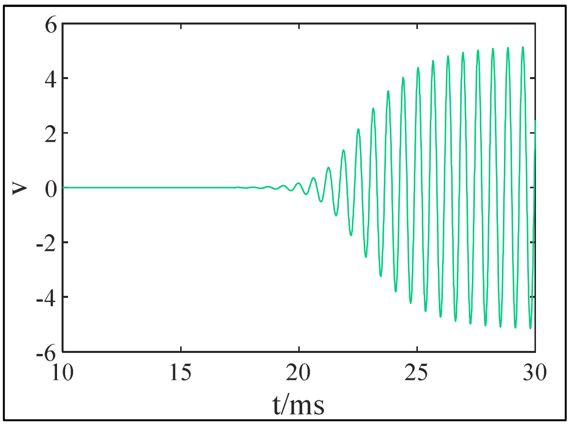

Figure 3. *Oscillating process.*

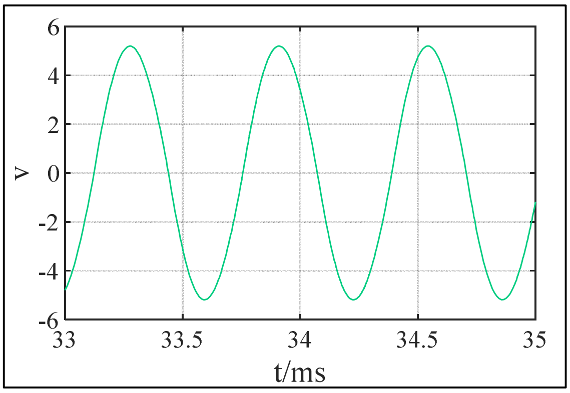

Figure 4. *Maximum undistorted waveform.*

4.2.2. Phase Balance

Through the oscilloscope in Figure 1, the input signal Ui and output signal Uo of the amplifier can be observed at the same time. Obviously, the amplitude ratio of Uo to Ui is the amplification multiple of the amplification circuit, and the phase difference between Uo and Ui is the phase difference of the amplification circuit. After the output waveform is stable, the waveforms of Ui and Uo are as shown in Figure 5.

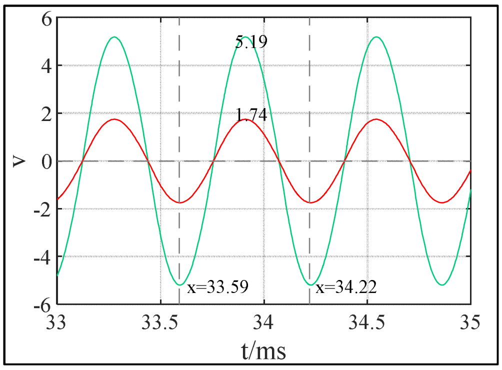

Figure 5. *Maximum input and output waveform in undistorted state.*

At this time, the circuit oscillation frequency meets the frequency condition, and the input and output signals are completely in phase, that is, the phase balance condition is met. The amplitude ratio of Uo to Ui is 3, and the amplitude balance condition is met.

$$f = 1.59KHz = f_0$$

4.3. Stability of Amplitude

The forward volt-ampere characteristic of the diode is nonlinear, as shown in Figure 6. This experiment uses this characteristic of the diode to automatically adjust the strength of the feedback with the change of the output voltage to maintain the constant output voltage. When the output signal is small, the diode is in the cut-off state, and its electrical resistance is very large. After vibration, with the increase of the output voltage, the diode conducts at the peak of the output waveform, and its conduction resistance decreases nonlinearly. Its adjustment mechanism is as follows:

$$U_o \uparrow \rightarrow r_D \downarrow \rightarrow R_4 // r + R_p = R_f \downarrow \rightarrow A \downarrow$$

When $A \approx 1 + R_p / R_1 = 3$, the output waveform is stable. To ensure the symmetry of the positive and negative half cycle of the output waveform, two reverse parallel diodes D1 and D2 with matching characteristics and good temperature stability are used in Figure 1.

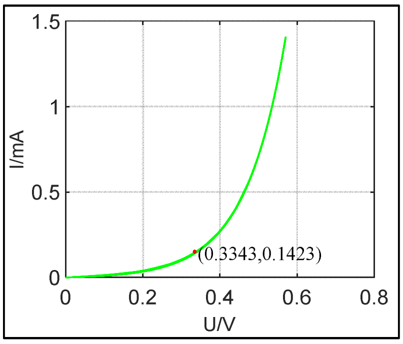

Figure 6. *Volt-ampere characteristic curve of diode.*

Connect the voltage of nodes A, B and C to the multi-channel oscilloscope according to the circuit in Figure 7, and the diode resistance can be calculated as

$$r_D = \frac{U_D}{I_D} = \left| \frac{U_B - U_C}{(U_C - U_A)/R_P - (U_B - U_C)/R_4} \right|.$$

The overall change of the waveform measured by the oscilloscope is shown in Figure 8. Figure 9 selects a section of waveform during the oscillation process, and Figure 10 selects a section of waveform after the oscillation is stable, and calculates the corresponding diode resistance value to verify the resistance change of the diode.

According to Figure 9, when the voltage difference between the two ends of the diode UD=43.6mV, its resistance $r_D = 8.51K\Omega$; according to Figure 10, when the voltage difference between the two ends of the diode UD=330mV, its resistance $r_D = 2.34K\Omega$. It can be seen that with the increase of the output voltage, the diode changes the amplifier gain by automatically adjusting the nonlinear change of the resistance. The corresponding gain can be calculated as

$$A = \frac{U_D}{I_D} = 1 + \left| \frac{U_B - U_A}{(U_C - U_A)/R_P} \right| / R_3 = 3.$$

It is thus verified that when the oscillator is stable, the loop gain is $\dot{A}\dot{F} = 1$ and the amplifier gain is 3.

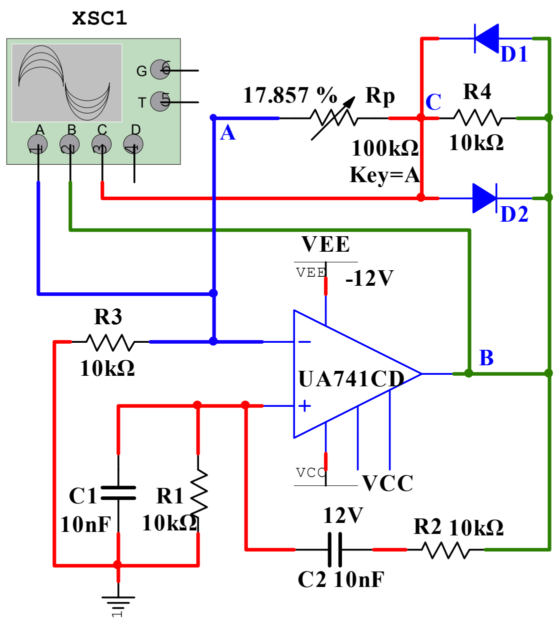

Figure 7. *Measurement of amplitude stability characteristics.*

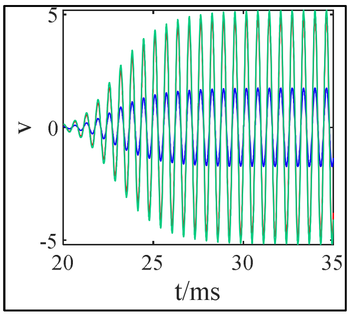

Figure 8. *Output waveform.*

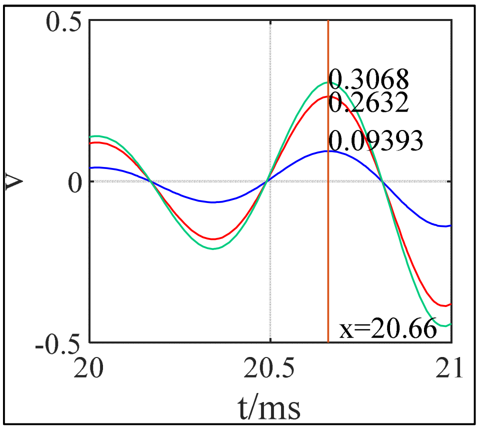

Figure 9. *Fragment of waveform before stabilization.*

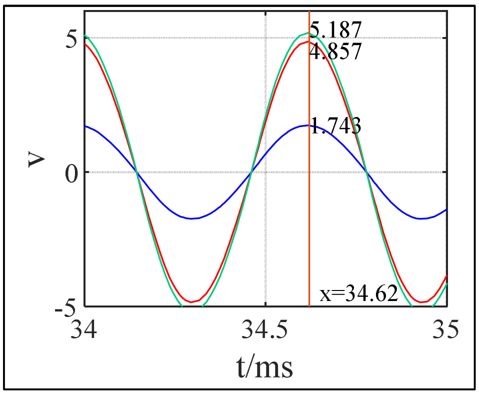

Figure 10. *Fragment of waveform after stabilization.*

4.4. Filtering

The RC frequency selection network in Figure 1 plays a filtering role. Many students in this part feel abstract about the role of filtering. With the help of Multisim simulation, as shown in Figure 11, the weak clutter signal is filtered through the RC frequency selection network twice, and the output waveform is observed respectively, as shown in Figure 12. After the initial waveform passes through the frequency selection network, the frequency band of the waveform is gradually reduced, which verifies the frequency selection characteristics of the RC series-parallel network.

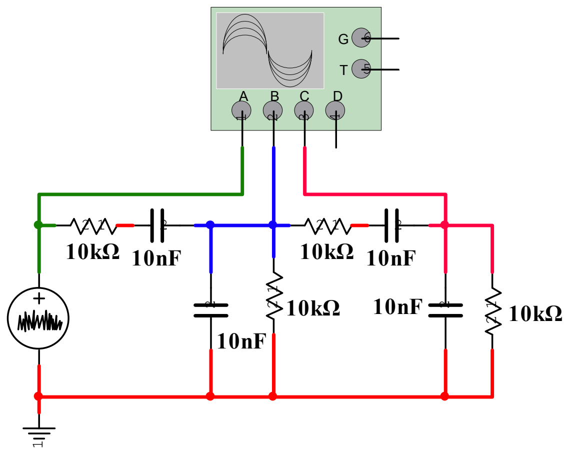

Figure 11. *Filter circuit.*

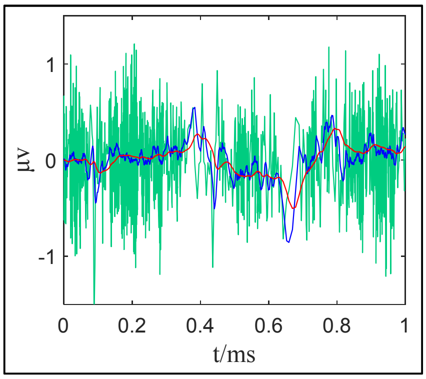

Figure 12. *Filtering process.*

4.5. Distortion and Vibration Stop

Adjust the Rp until the output waveform reaches the maximum undistorted state, at this time, the amplification circuit gain A=3. Continue to adjust and increase the Rp value. When A>3, the output waveform will start to distort due to too large amplification multiple, as shown in Figure 13. At this time, if the Rp value is reduced to make AF<1, the amplitude of output waveform gradually decreases until it disappears, this phenomenon can be called vibration loss, as shown in Figure 14.

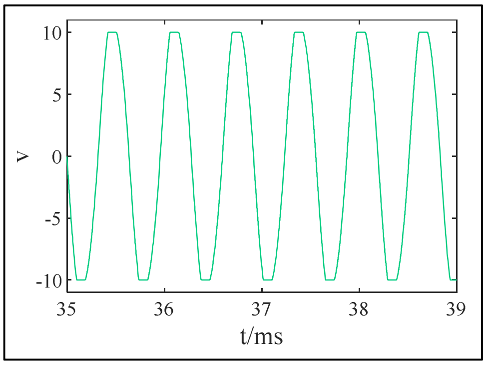

Figure 13. *Distorted output waveform.*

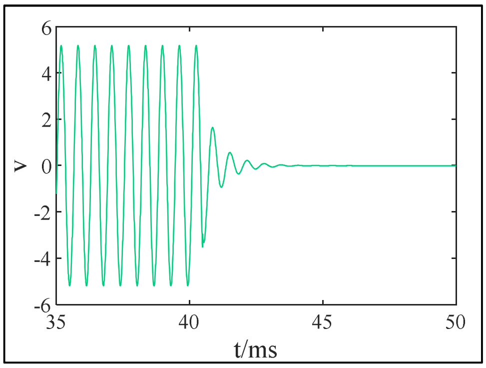

Figure 14. *Vibration stopping process of output waveform.*

It can be seen that the introduction of Multisim simulation software into electronic circuit experiment teaching has prominent advantages. First, the circuit construction is convenient, and the circuit structure and parameter adjustment are flexible. Second, the simulation process has strong observability. The software itself provides many instruments and components to facilitate the simulation and observation of more waveform changes. This is of great benefit to students’ understanding of abstract theoretical knowledge. Through experiments, the textbook knowledge is internalized into their own understanding, which is the key means to cultivate students’ innovative awareness.

5. Conclusion

The Multisim virtual simulation software is introduced into the experimental teaching of Wien-bridge oscillator, which can intuitively and vividly demonstrate the changes of circuit characteristics, such as changing the structure and parameters of the circuit to observe the vibration process, distortion, amplitude stability characteristics, filtering and vibration stopping, etc. It enables students to have a comprehensive and in-depth understanding of the local and overall characteristics of the circuit, enhances their perceptual understanding of the abstract analog circuit theory, and deepens their understanding of the knowledge learned, and improves the experimental efficiency and teaching effect [17]. The teaching design combined with virtual simulation technology is an effective supplement to the traditional analog electronic technology experiment teaching method, and has more diversity in the design of experiment content [18], which can fully mobilize students' subjective initiative, further cultivate students' engineering awareness and practical ability, and thus improve the experimental teaching quality.

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