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Literature Review, Analysis of the Performance of Operational Amplifier Applied in Controlling Systems: Summary, Analysis, and Overview

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Abstract:

As part of modern electronic technology, the operational amplifier is widely used in signal conditioning, sensor interface circuits, controller design, and actuator drives of automatic control systems. Improvement: In accurate controlling systems, factors such as linearity, noise performance, and stability directly influence the accuracy and speed of response of the whole system. Thus, it is vitally important for Improving the overall performance of automated control systems to learn and improve the performance of the operational amplifier. With the development of Industry 4.0 and intelligent manufacturing, modern controlling strategies such as adaptive control and intelligent controlling demand much more from the operational amplifier.

Keywords: Controlling Systems; Operational Amplifier; automatic

1. Introduction:

The operational amplifier is a kind of high gain, DC-coupled voltage amplifier integrated circuit containing several cascaded amplifier circuits. It is one of the most important basic components in analog electronic circuit design and is widely used in signal processing, filtering, signal modulation, signal comparison, and linear and nonlinear transformation. We study operational amplifiers to optimize controlling loop designs, lowering the power and cost consumption, enhancing the system's robustness, and so on. To sum up, the study of performance analysis and optimization of operational amplifiers in automatic control systems is one of the core contents to continuously promote the technical progress of control systems. It has a far-reaching impact on improving automation in various fields, ensuring production efficiency and product quality.

2. The basic structure of the operational amplifier

1. input stage(differential amplifier)

This is the first amplifying stage of the operational amplifier, whose core effect is to receive and amplify the difference value of the two input signals(Vp-Vn). At the same time, it has high input impedance and Common Mode Rejection Ratio(CMRR). The stage normally takes the design of a differential amplifier, which consists of a pair of highly matched transistors to reduce the impact of zero draft.

2. medium stage(voltage amplifier stage/gain stage)

The main task of the intermediate stage is to provide additional voltage amplification capabilities, which may contain multiple amplification stages to achieve very high open-loop gain. This stage is often used to compensate for the lack of gain in the input stage while improving the frequency response and stability through proper circuit design.

3. output stage(power amplifier)

The output stage effectively transmits the amplified signal to the load, so it requires low output impedance, high current drive capability, and certain bandwidth limitations. In practical applications, the output stage mostly uses complementary symmetrical push-pull circuits or transistors with open collector configurations to ensure that the load can be driven bidirectionally while maintaining good linearity at saturation

4. bias circuit(static working point settings)

An important part of the operational amplifier is the bias circuit, which provides stable static operating points for all levels of the circuit to ensure that the transistors always work in the linear region and that the whole amplifier is normal and stable.

5. voltage resource

Although not directly part of the three stages described above, operational amplifiers also require a power supply, usually positive and negative, to provide suitable DC operating conditions for the internal components.

*It should be noted that different types of operational amplifiers have differences in internal structure details according to their different applications. Still, the basic composition described above is the core architecture of the universal integrated operational amplifier.

3. Input and output characteristics of operational amplifiers

The input and output characteristics of operational amplifiers mainly include the following key aspects:

1. High gain

The operational amplifiers exhibit negligible current flow through the positive and negative terminals, grounding them as short-circuited switches. Consequently, all input circuits experience an increase in current that ultimately flows into the output. However, the output voltage equals the input voltage minus the impedance over time.[2]

2. input characteristics

• High input impedance: The input of an ideal op amp has an infinite input impedance, which means that it draws almost no current from the signal source, so there is no loading effect on the input signal.

• Virtual Short: Under negative feedback conditions, the voltage difference between the two inputs of the ideal op amp is zero, that is, V+ = V-, which is called the “virtual short” condition.

• Virtual Open: Also, in negative feedback, there is no incoming or outgoing current at the input end of the ideal op-amp; that is, the input current is zero, I+ = I- = 0, which is a “virtual break” condition.

3. Output characteristics:

• Low output impedance: The ideal operational amplifier has zero output impedance, can provide any required output current while keeping the output voltage constant, and can effectively drive various loads.

• Single-ended output: The operation amplifier is a double-ended input, single-ended output device; the output voltage is proportional to the voltage difference of the input and can output positive and negative signals of both polarity.

• Linear and nonlinear region: within a certain input range (linear region), the output of the op-amp is linear with the input. Beyond this range (saturation or cut-off region), the op-amp output reaches the maximum or minimum limit of the power supply voltage and no longer follows the linear law.

4. Power impact:

An op-amp with a dual power supply can swing its output voltage within the positive or negative range of its supply voltage. The single-supply op-amp operates at a single supply voltage, and the output is usually limited between the supply rails. Rail-to-rail op-amps are designed to output signals within a range close to the supply voltage rail.

In practice, these characteristics will vary depending on the op-amp model and circuit configuration, but the above are the basic characteristics in an idealized case.

4. Nonideal property and source of operational amplifier

The nonideal characteristics of operational amplifiers are mainly due to the limitations in the actual design and manufacturing process, which are significantly different from the assumptions of infinite gain, zero input bias current, infinite input impedance, and zero output impedance of ideal operational amplifiers. Here are some common nonideal characteristics and sources of error:

1. Gain-Bandwidth Product

Actual operational amplifiers have a limited open-loop voltage gain, which decreases gradually at a certain frequency. This means that the magnification decreases as the frequency increases, a property determined by the gain bandwidth product。

2. Offset Voltage, Vos

When the two inputs of an operational amplifier have no external signal input, the output is not zero but has a static offset voltage. This results in a DC voltage output at the output even when the input differential voltage is zero.

3. Input Bias Current, Ib

Both inputs of the actual op amp have small but non-zero input currents, which can cause a voltage drop at both ends of the resistance in the access circuit, thus affecting the output result.

4. Common-Mode Rejection Ratio, CMRR

The ideal op-amp can completely suppress the common-mode signal. Still, the op-amp has a certain amplification ability for the common-mode signal, and CMRR measures the difference between the gain of the op-amp and the common-mode signal.

5. Power Supply Rejection Ratio, PSRR

To measure the influence of the operation amplifier in suppressing the power fluctuation on the output, the actual operation amplifier can not eliminate the power supply noise.

6. The input and output impedances are not perfect.

The input impedance is not infinite, and the output impedance is not zero, which can cause load effects on the front and rear circuits connected to the op-amp.

7. Nonlinear distortion

In large signal working areas or near saturation, the op-amp may exhibit nonlinear behavior, resulting in distortion of the output signal.

8. Temperature drift

The internal parameters of the op-amp vary with temperature. For example, the offset voltage and input bias current are greatly affected by temperature, which may cause the system performance to be unstable with temperature.

9. Noise

The actual operational amplifier will produce thermal, flicker, and other noises, affecting the signal-to-noise ratio and the system's detection accuracy.
10. Frequency response limitation
The op-amp gain decays at high frequencies, and there may be phase lag, limiting its performance in high-speed applications.
By understanding and analyzing these nonideal characteristics, designers can take compensatory measures or select the appropriate operational amplifier for the specific application requirements to optimize system performance and accuracy.

5. An overview of automatic controlling systems

Aiming to indicate the performance of operational amplifiers in automatic control systems, I have to demonstrate the importance of automatic generation control. Automatic generation control (AGC) ensures stable power system operation by maintaining the system frequency within an acceptable range and optimizing the grid's economic efficiency[1]. Next, I will show the basic principles of automatic generation control:

1. Feedback control:

The core of the automatic control system is the feedback mechanism, which compares the system's output signal with the set target value (given quantity). When the actual output deviates from the expected output, the system takes corrective action to reduce the deviation.

2. Error detection:

The sensor detects and quantifies the state information of the controlled object and converts it into a signal form that can be processed (such as voltage, current, or digital signal).

3. Controller:

The controller calculates the appropriate control signal based on the received error signal, and various control algorithms may be used inside the controller, such as proportional-integral-differential (PID) control or other advanced control strategies.

4. Actuator:

The control signal output by the controller drives the actuator to work, and the actuator changes the working parameters or state of the controlled object to approximate the system output to the set value.

5. Closed and open loop:

• In the closed-loop control system, the output signal is returned to the controller through the feedback loop for comparison, forming negative feedback to achieve accurate adjustment.
• The open-loop control system has no feedback link, and the control function is completely dependent on the input signal without considering the actual output.

6. The effect of the operational amplifier in the feedback control system

1. Gain control

• In a negative feedback system, the operational amplifier can precisely set the system's voltage gain or current gain through the feedback network. By adjusting the resistance value in the feedback loop, the designer can set the linear gain as needed and reduce the gain instability due to device differences.

2. Stability enhancement

• Negative feedback helps improve system stability. When a portion of the output signal is reverse-fed back to the input, it automatically cancels any factors that might cause the output to deviate from the expected value, such as temperature changes, power supply voltage fluctuations, or changes in component parameters.

3. Noise suppression

• Through negative feedback, the system can effectively average internal and external noise, reducing the impact of noise on the output, thereby improving the signal-to-noise ratio.

4. Linearization and nonlinear compensation

Operational amplifiers combined with appropriate feedback networks can be used to implement nonlinear functions, such as logarithms, exponents, and various logic threshold functions, as well as to compensate for the nonlinear characteristics of the controlled object or other circuit elements.

5. Error correction

The feedback mechanism enables the operational amplifier to monitor and correct errors between the output and the set target in real-time, ensuring the system's performance meets the design requirements.

6. Filtering function

In different types of feedback circuits, operational amplifiers can be used to build a variety of filters, such as low-pass, high-pass, band-pass, or band-stop, for signal processing and shaping.

7. Oscillator and waveform generator

• When the positive feedback is used, the operational amplifier can form a self-excited oscillation circuit to generate a stable periodic signal, widely used in clock generation, signal modulation, and other fields.

7. Maladjustment analysis of operational amplifier

1. Theoretical calculation:

Obtain the device's Offset Voltage (VOS) and Input Offset Current (IOS) parameters from the data book, which represent the static offset between the output and the ideal zero in the absence of an input signal.

• Calculate system errors due to misalignment based on circuit structure and external component values. For example, the formula can calculate the effect of offset voltage on the output in a non-inverting or in-phase amplification configurationowing formula:

2. Laboratory measurement:

• A precision source measuring unit (SMU) or digital multimeter is used to measure the offset voltage of the op-amp directly.

• Plug the op amp into a specific test circuit (such as a voltage follower) and read the DC voltage at the output in case of a short circuit at the input, which is the offset voltage.

• For the effect of the offset current, a high-resistance resistor can be used in series with the input, and then the error due to the offset current can be estimated by measuring the voltage drop on that resistor.

3. Noise and drift analysis:

Measurement and analysis of offset voltage changes with temperature and time (offset voltage drift) is essential for applications requiring high stability.

• Similarly, offset currents can vary with temperature and must be assessed for their impact on long-term stability.

4. Compensation technology:

• Design circuits using offset elimination or reduction techniques, such as offset adjustment pins, self-calibration circuits, chopper zero stabilization techniques, etc.

• In some cases, an appropriate network can be incorporated into the feedback loop to dynamically offset the offset voltage, such as using a zeroing potentiometer or automatic zeroing algorithm.

5. Simulation analysis:

• Use SPICE or other circuit simulation tools to simulate the effects of misalignment under different conditions and optimize the system's misalignment performance by modifying design parameters.

Through the above analysis methods, we can fully understand the offset characteristics of operational amplifiers and take corresponding measures to reduce or eliminate the negative effects of the offset so as to improve the overall accuracy and reliability of the circuit.

8. Conclusion

The operational amplifier is widely employed in controlling systems. After decades of iterations, the understanding of employing operational amplifiers on automatic control systems and PID has been profound and mature. Operational amplifiers will make more and more achievements in the future.

In conclusion, learning how an operational amplifier works can help us optimize power efficiency and minimize expenses. It profoundly impacts automation levels across various domains, ensuring optimal production efficiency and product quality.

Reference

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