

Tuning a Servo System

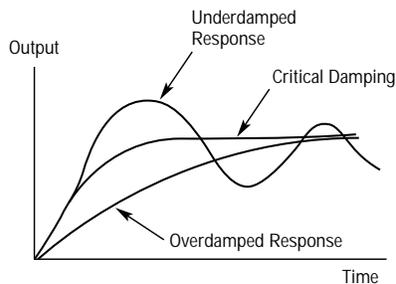
Any closed-loop servo system, whether analog or digital, will require some tuning. This is the process of adjusting the characteristics of the servo so that it follows the input signal as closely as possible.

Why is tuning necessary?

A servo system is error-driven, in other words, there must be a difference between the input and the output before the servo will begin moving to reduce the error. The "gain" of the system determines how hard the servo tries to reduce the error. A high-gain system can produce large correcting torques when the error is very small. A high gain is required if the output is to follow the input faithfully with minimal error.

Now a servo motor and its load both have inertia, which the servo amplifier must accelerate and decelerate while attempting to follow a change at the input. The presence of the inertia will tend to result in over-correction, with the system oscillating or "ringing" beyond either side of its target (Fig. 3.1). This ringing must be damped, but too much damping will cause the response to be sluggish. When we tune a servo, we are trying to achieve the fastest response with little or no overshoot.

Fig. 3.1 System response characteristics



In practice, tuning a servo means adjusting potentiometers in an analog drive or changing gain values numerically in a digital system. To carry out this process effectively, it helps to understand what's going on in the drive. Unfortunately, the theory behind servo system behavior, though well understood, does not reveal itself to most of us without a struggle. So we'll use a simplified approach to explain the tuning process in a typical analog velocity servo. Bear in mind that this simplified approach does not necessarily account for all aspects of servo behavior.

A Brief Look at Servo Theory

A servo is a closed-loop system with negative feedback. If you make the feedback positive, you will have an oscillator. So for the servo to work properly, the feedback must always remain negative, otherwise the servo becomes unstable. In practice, it's not as clear-cut as this. The servo can *almost* become an oscillator, in which case it overshoots and rings following a rapid change at the input.

So why doesn't the feedback stay negative all the time?

To answer this, we need to clarify what we mean by "negative". In this context, it means that the input and feedback signals are in antiphase. If the input is driven with a low frequency sinewave, the feedback signal (which will also be a sinewave) is displaced in phase by 180°. The 180°-phase displacement is achieved by an inversion at the input of the amplifier. (In practice it's achieved simply by connecting the tach the right way round – connect it the wrong way and the motor runs away.)

The very nature of a servo system is such that its characteristics vary with frequency, and this includes phase characteristics. So feedback that starts out negative at low frequencies can turn positive at high frequencies. The result can be overshoot, ringing or ultimately continuous oscillation.

We've said that the purpose of servo tuning is to get the best possible performance from the system without running into instability. We need to compensate for the characteristics of the servo components and maintain an adequate stability margin.

What determines whether the system will be stable or not?

Closed-loop systems can be difficult to analyze because everything is interactive. The output gets fed back to the input in antiphase and virtually cancels it out, so there seems to be nothing left to measure. The best way to determine what's going on is to *open the loop* and then see what happens.

Fig. 3.2 Closed-loop velocity servo

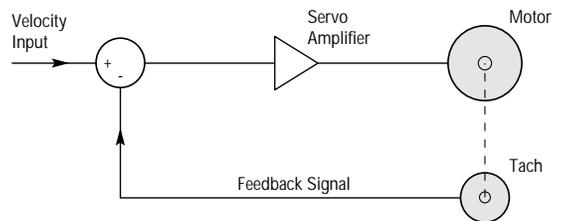
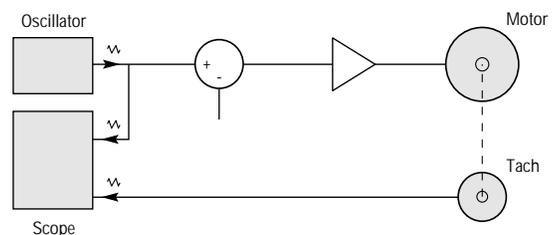
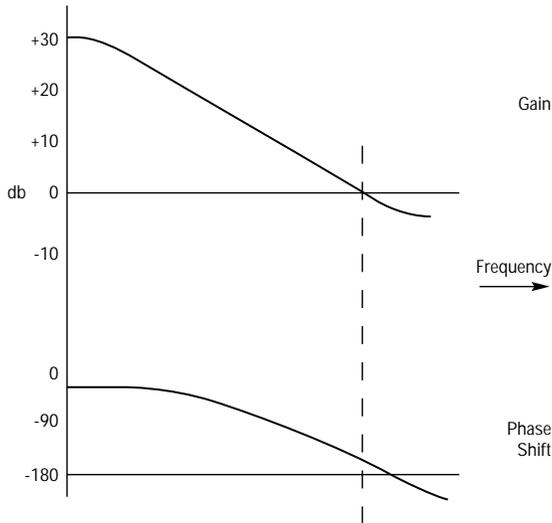


Fig. 3.3A Measuring open-loop characteristics



Measuring the open-loop characteristic allows us to find out what the output (and therefore the feedback) signal will be in response to a particular input. We need to measure the *gain* and *phase shift* at different frequencies, and we can plot the results graphically. For a typical servo system, the results might look like this:

Fig. 3.3B Open-loop gain and phase characteristics



The gain scale is in decibels (dB), which is a logarithmic scale (a 6dB decrease corresponds to a reduction in amplitude of about 50%). The 0dB line represents an open-loop gain of one (unity), so at this frequency the input and output signals will have the same amplitude. The falling response in the gain characteristics is mainly due to the inertia of the motor itself.

The phase scale is in degrees and shows the phase lag between input and output. Remember that the feedback loop is arranged to give negative feedback at low frequencies, (i.e., 180° phase difference). If the additional phase lag introduced by the system components reaches 180°, the feedback signal is now shifted by 360° and therefore back in phase with the input. We need to make sure that at no point do we get a feedback signal larger than the original input and in phase with it. This would amount to positive feedback, producing an ever-increasing output leading to oscillation.

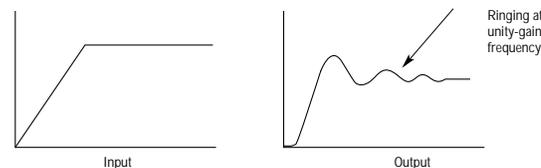
Fortunately, it is possible to predict quite accurately the gain and phase characteristics of most servo systems, provided that you have the necessary mathematical expertise and sufficient data about the system. So in practice, it is seldom necessary to measure these characteristics unless you have a particular stability problem that persists.

We've said that a problem can occur when there is a *phase shift* of 180° round the loop. When this happens, the *open-loop gain* must be less than one (1) so that the signal fed back is smaller than the input. So here is a basic requirement for a stable system:

The open-loop gain must be less than unity when the phase shift is 180°.

When this condition is only just met (i.e., the phase shift is near to 180° at unity gain) the system will ring after a fast change on the input.

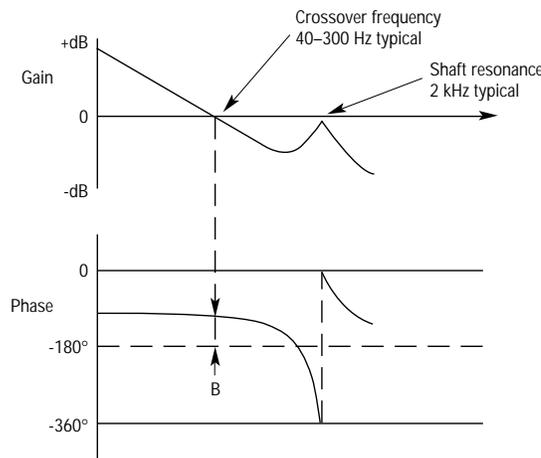
Fig. 3.4 Underdamped response



Characteristics of a Practical Servo System

Typical open-loop gain and phase characteristics of an unloaded drive-motor-tach system will look something like Fig. 3.5.

Fig. 3.5 Characteristics of a practical system



The first thing we notice is the pronounced spike in the gain plot at a frequency of around 2kHz. This is caused by shaft resonance, torsional oscillation in the shaft between the motor and the tach. Observe that the phase plot drive dramatically through the critical 180° line at this point. This means that the loop gain at this frequency must be less than unity (0dB), otherwise the system will oscillate.

The TIME CONSTANT control determines the frequency at which the gain of the amplifier starts to roll off. You can think of it rather like the treble control on an audio amplifier. When we adjust the time constant control, we are changing the high-frequency gain to keep the gain spike at 2kHz just below 0dB. With too high a gain (time constant too low) the motor will whistle at about 2kHz.

The second point of interest is the CROSSOVER FREQUENCY, which is the frequency at which the gain curve passes through 0dB (unity gain). This frequency is typically between 40 and 300Hz. On the phase plot, β (beta) is the *phase margin* at the crossover frequency. If β is very small, the system will overshoot and ring at the crossover frequency. So β represents the degree of damping – the system will be heavily damped if β is large.

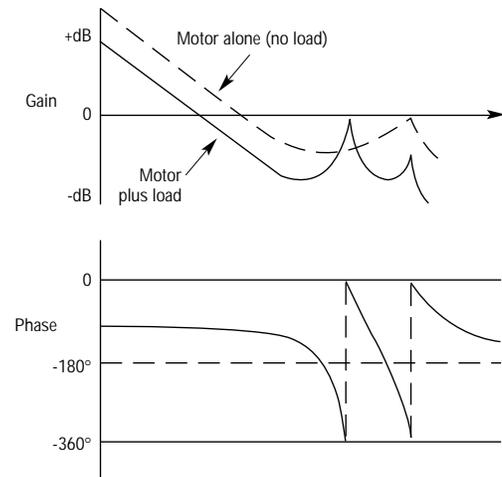
The DAMPING control increases the phase margin at the crossover frequency. It operates by applying lead compensation, sometimes called acceleration feedback. The compensation network creates a *phase lead* in the region of the crossover frequency, which increases the phase margin and therefore improves the stability.

Increasing the damping also tends to reduce the gain at the 2kHz peak, allowing a higher gain to be used before instability occurs. Therefore, the time constant should be re-adjusted after the damping has been set up.

What's the effect of adding load inertia?

An external load will alter both the gain and phase characteristics. Not only will the overall gain be reduced owing to the larger inertia, but an additional gain spike will be introduced due to torsional oscillation between the motor and the load. This gain spike may well be larger than the original 2kHz spike, in which case the motor will start to buzz at a lower frequency when the time constant is adjusted.

Fig. 3.6 Characteristics of a system with inertial load



The amplitude of this second spike will depend on the compliance or stiffness of the coupling between motor and load. A springy coupling will produce a large gain spike; this means having to reduce the gain to prevent oscillation, resulting in poorer system stiffness and slower response. So, if you're after a snappy performance, it's important to use a torsionally-stiff coupling between the motor and the load.