Considerations for using Capacitive Position Sensors for Feedback in a Servo System

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Introduction

In many ways, capacitive position sensors from ADE Technologies are ideally suited to be used as the feedback element in a servo system. Some of their specifications that are important for servo use are:

- Wide bandwidth
- Low noise
- No hysteresis
- No added mass, force, or damping to the servo system's moving elements
- Excellent linearity
- Small sensor size

For most servo systems, ADE Technologies' MicroSense passive-probe line of capacitive position sensors (4800 or 8800 series) will be optimal due to their exceptional stability, linearity, and small sensor size. For applications in which long-term stability is less important, but the lowest possible noise and widest bandwidth are keys to success, active probe MicroSense 5800 or 6800 series will be the sensors of choice.

Bandwidth and Phase Shift

Excessive phase shift is always one of the banes of any servo system, and usually the various masses and mechanical resonances of the mechanical components of the system are already headache enough—if the electrical parts of the system can respond in close to an ideal way, the servo-loop design task is more manageable.

The phase and bandwidth response of ADE's capacitive position sensors is determined by various minimum-phase filters that are part of our electronics. The 4800 and 8800 gage signal chain includes a 5-pole Butterworth filter set at 14 KHz, and a 2-pole Butterworth filter that is jumper selectable at bandwidths of 10 Hz, 100 Hz, 1 KHz, and 10 KHz. The phase and frequency response of the Butterworth filter are well known, and ADE Technologies can supply both Bode plots and the s-plane analytical expressions for them.

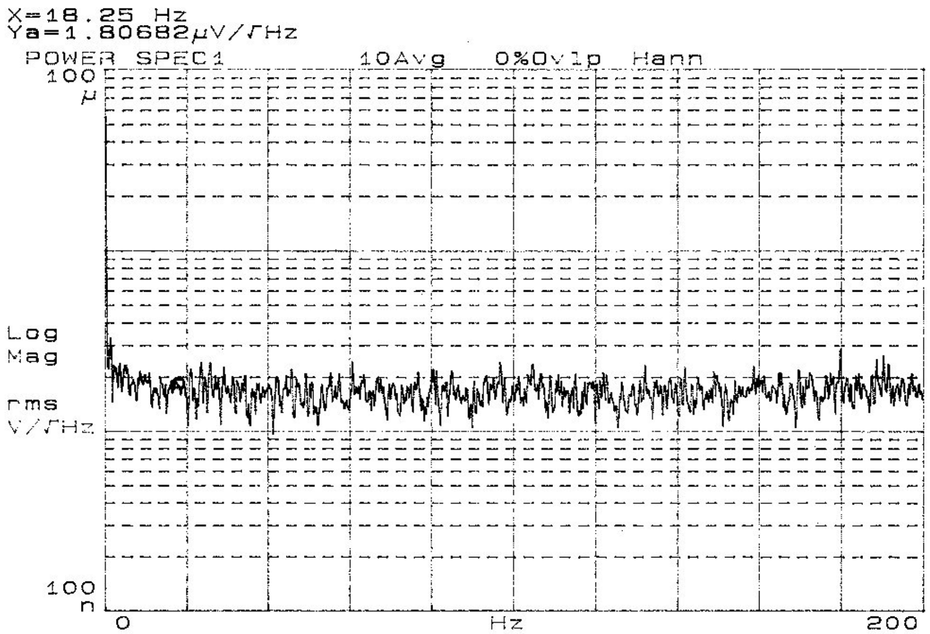
The 5800 and 6800 gages have a single 2-pole Butterworth filter that can be set at 1 KHz, 5 KHz, 20 KHz, or 100 KHz. Again, ADE Technologies can supply plots and the analytical expression for this filter.

Noise

Of course, noise in a servo system is one determinant of its ultimate precision and settability. The servo designer would like, in order to minimize phase shift, to use our sensors set to a bandwidth well beyond that of his system's. It will come as no surprise that the total output noise of our gages goes up with bandwidth. However, this increase in total gage noise as a result of using a wide bandwidth should not cause the servo designer any problem. It is specifically the spectral noise energy density of the gage ($V/\sqrt{Hz}$) within the servo-system bandwidth that is of primary interest.

The response of servo systems is many and varied, but their system response falls off rapidly beyond their crossover frequency. Given that total noise is the r.s.s. (root sum square) of the various noise components, contribution of out-of-band noise is generally of little consequence.

Our 4800 and 8800 passive-probe capacitive position sensors are demodulated systems, and therefore their noise sprectra are quite flat with a very small 1/f region—this characteristic is good news for the servo designer. The diagram below shows the response of one of our passive-probe gages. This gage was set for a bandwidth of 10 KHz, and its total noise was about 0.19 mV. However, within a 200 Hz bandwidth, which is generous for many servo systems, its total noise is only about 26 μV.



Estimation of servo position uncertainty due to our gage noise is straightforward. Start with the spectral noise density and multiply by the square root of the servo loop's noise bandwidth to calculate rms gage noise. Then multiply the voltage noise by the gage's scale factor to compute distance noise. The example spectral plot was taken from a gage calibrated to a 1v = 10 um scale factor. Using the 200 Hz bandwidth noise of about 26 μV, the rms distance noise would be 0.26 nanometers.

Peak-to-peak noise is about 6 times the rms noise, so the peak position uncertainty will be about ± 3 times the rms noise. For the example above, peak position uncertainty is 0.78 nanometers.

The 5800 gages have a more pronounced 1/f region, but their noise performance is so low that their low-frequency noise components are still exemplary.

Probes and Probe Mounting

Even though our capacitive position sensors have no resonances in their electrical response, mechanical resonances are always lurking, ready to cause unexpected problems. As such, the mounting of our probes always deserves careful consideration. The mechanical resonant frequency of the probe mount should be well above the system's crossover frequency, especially if the mount may be excited by movement in the servo system or by outside influences. Therefore, "sturdy looking" may not be sufficient.

Experiments in our lab have shown that even probes mounted in what may appear to be adequate fixtures can act like microphones, because it really isn't that hard for fixtures to flex a few nanometers. Rest assured, however, that our probes are not microphonic —all such effects are caused by fixture flexing. Keep in mind this maxim, "At sub micrometer levels, the world is made of rubber; at sub nanometer levels, it is made of JELL-O."

Data Acquisition

Our capacitive position sensors put out very little noise, and in order for the system designer to realize that performance, some care must be taken when connecting our gages to your servo system. Ground loops, which can always be problematic, can be avoided with some consideration of your system.

Our probe will monitor some part of your system. That monitored part must be connected, either resistively or capacitively to our gage. This connection usually happens naturally, because the shell of most of our probes is connected to gage common. Thus, when the probe is clamped in a metal fixture that is attached to the mechanical system, the likelihood of a good ground is high. The mechanical system may well be connected to the power-line ground either accidentally, by being mounted to a part that is, or explicitly, for safety considerations.

If our gage is itself grounded, the fixture ground and the gage ground may be different, setting up a potential ground loop. The power supply that we provide with our 4810, 8810, 5810 or 6810 gages has an isolated output, so it makes avoiding this particular ground loop easy.

If, however, your mechanical system is not grounded, it is usually desirable to ground our gage to power-line ground. This task is often most easily made as part of the connection between our gage output and your servo-system input.

Another potential ground loop lies between the gage output and the input to your servo electronics. The servo electronics is most often connected to power-line ground, and if the gage is connected to ground, then another ground loop can be caused. If so, the use of the differential outputs provided on all of our gages is usually sufficient to solve any problem.

No Added Mass

As previously mentioned, our gages add no moving mass to the servo system. Our probes can be mounted to look at any flat spot on the part to be controlled. Unlike some of our competitors, we do not require that you mount a separate driven target. Our probe's target is simply your machine.

Probe Size and Shape

Our passive probes are particularly variable in their form factors. Many sizes and shapes already exist within our probe line. As a custom order, we can produce probes in a surprising array of mechanical configurations to meet size restraints and mounting requirements. One substantial benefit of our small probe size is the ability, in most cases, to mount the probe at the plane of interest and in line with the drive, thus minimizing or eliminating Abbé offset errors.

Vacuum Operation

We regularly supply probes that meet the most stringent outgassing requirements. The 2800 series probes used with the MicroSense 4800 and 8800-series of gages contain no electronics and therefore dissipate no energy. These two characteristics together make them especially useful in a vacuum, as many of our customers have found.