Celera MOTION
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Accurate Position Measurement at Varying Temperatures

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INTRODUCTION

Measuring position in a laboratory is usually carried out at a constant temperature to ensure accuracy, but some specifications require accurate position measurement over a wide range of operating temperatures. This is a much tougher challenge. This paper discusses the key issues and suggests 10 helpful hints for design engineers.

UNDERSTANDING THE PROBLEM

The first step in designing for accurate position measurement over wide temperature ranges is to be clear about what is required. The main data requirements are:

- Max. & min. operating temperatures
- Max. & min. storage temperatures
- Max. permissible measurement error at the various operating temperatures.

Tip #1 – be clear about what the real requirements are.

In considering the technical solution to any requirement, there should be two realistic budgets: a cost budget and an error budget.

THE ERROR BUDGET

The difference between true and measured position will comprise several different sources of error:

- Errors from the position sensor measurement performance.
- Thermal drift in the sensor output.
- Mechanical effects from clearances in couplings or bearings, backlash in gears, etc.
- Thermal effects in the host mechanical structure, notably from differential thermal expansion.

Tip #2 – prepare an error budget & ensure all contributing factors are considered.

UNDERSTANDING MEASUREMENT PERFORMANCE

Position sensor measurement performance can be summarized as follows:

- ***Accuracy*** refers to maximum deviation from true position.
- ***Resolution*** refers to the smallest measurable change in position.
- ***Repeatability*** refers to the degree of reproducibility.
- ***Linearity*** refers to how well, over a range, the output matches a straight line. In many instances, *Linearity* and *Accuracy* are the same if there is no offset.

Tip #3 - understand what aspects of measurement performance are important in your application and ensure the sensing system aligns with these requirements.

TEMPERATURE COEFFICIENT

Whenever measurement performance parameters are stated they should be specified at a temperature along with a temperature coefficient. This coefficient refers to the change in the sensor output as temperature varies. A small temperature coefficient means a thermally stable device. Typically, temperature coefficients are stated in parts per million per Kelvin. This is an unfortunate unit as it is usually a very small number and often overlooked. The number has to be multiplied by the temperature differential.

Tip #4 – make sure your error budget includes the sensor temperature coefficient.

DIFFERENTIAL THERMAL & MECHANICAL EFFECTS

Typically, it is not the sensor elements that are of interest but rather the position of the host elements, such as the angle of a shaft. Of course, these will have their own contributions to the error budget caused by factors such as mechanical tolerances, backlash, clearances and thermal expansion. Thermal expansion is a natural phenomenon which should not be ignored. More problematic is ***differential*** thermal expansion and this can lead to significant measurement errors if its effects are not minimized by appropriate mechanical design and material selection.

If the sensor mounting structure expands or contracts by the same amount as the components being measured, the effect of thermal expansion can be negated. Ideally, the sensor thermal coefficient either matches the effects of thermal expansion. In many cases, the sensor mechanical arrangement relative to the host equipment means that differential thermal expansion has to be included in the error budget. In instances where this effect dominates the error budget, there is always the option for temperature compensation. This requires the local temperature to be measured and the output from the sensor to be compensated accordingly. This is undesirable as temperature is unlikely to be uniform; there will be temperature/time lags; there is an increase in cost and complexity and so a reduction in reliability.

Tip #5 – Mechanical effects & differential thermal expansion must be included in any error budget. Wherever possible, these should be minimized through careful mechanical design and material selection.

CHOOSING THE RIGHT SENSOR

A position sensor's fundamental physics generally determines how big its temperature coefficient is. A basic understanding helps in choosing the right sensor for the job. Some of the common principles used to measure position are:

- **Potentiometers:** measure resistance of an electrically conductive material. Since conductivity varies with temperature, coefficients are likely to be large.
- **Optical:** transmission of light is independent of temperature but alignment can be affected by thermal drift, compromising precision.
- **Magnetic:** magnetic sensors measure field strength which varies with temperature, so thermal coefficients may be significant. Precision magnetic sensors also need tight installation tolerances so additional thermal effects may be large.
- **Capacitive:** since capacitance changes with temperature, many capacitive devices have large temperature coefficients, which are further exacerbated by changes in humidity. Capacitive sensors are also susceptible to condensation and foreign matter.

- **Inductive:** inductance varies with temperature but most precision inductive sensors use a ratiometric technique based on the ratio of at least two inductances. Since the values of both will vary by similar amounts, thermal coefficients are typically low.

Tip #6 – design the host system to minimize differential thermal expansion.
Tip#7 - select a sensor with a small thermal coefficient or one whose temperature coefficient matches the host system.

Inductive sensors (resolvers) use transformer techniques with precision wound spools. They have become the automatic choice in the oil & gas, aerospace and military sectors, where there is often a wide temperature range. The basic physics means that they are ideally suited to difficult operating environments but they are not widely used due to their high cost, weight and bulk.

Tip #8 – Resolvers are often an automatic choice for high temperature applications.

NEW GENERATION INDUCTIVE SENSORS

A new generation of inductive sensor, the inductive encoder uses the same basic physics as the resolver, but rather than the bulky transformer constructions and complex analog electronics, the inductive encoder uses printed circuit boards and digital electronics. This approach opens up the range of applications for inductive sensors to include 2D & 3D sensors, short throw (<1mm) linear devices, curvilinear geometries and high precision angle encoders.

Tip #9 – if a traditional inductive sensor is too big, bulky, expensive or not sufficiently accurate, consider one of the new generation of inductive sensors.

As well as being compact and lightweight, the inductive encoder delivers extremely stable measurements over wide temperature ranges. Incoders have very small temperature coefficients of <0,25ppm/K, which equates to less than one fifth of an arc-second per Celsius change.

Tip #10 – Inductive encoders offer especially low thermal coefficients.