LION PRECISION

TechNote

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Capacitive Sensors – Ungrounded Targets

Contents

Applicable Equipment:

Capacitive displacement measurement systems.

Applications:

Capacitive measurements of floating targets such as spindles or linear air-bearings.

Summary:

In some cases, ungrounded targets may affect measurement results. This TechNote examines when ungrounded targets may cause errors and the parameters that determine their magnitude.

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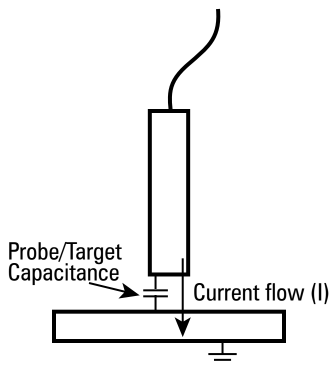
Synopsis

Most ungrounded targets have a large capacitance to ground. In these instances, there are no measurement errors. This is the case in the great majority of ungrounded target applications. The greatest potential for errors from ungrounded targets is when the target is very small or a significant distance from any other grounded object. Higher resolution calibrations are more susceptible to these errors than standard or extended range calibrations.

Symptoms of an ungrounded target

Low sensitivity, decreased standoff, output varies when operator's hand is brought near the measurement area; any of these may indicated a poorly grounded target.



Sensing-current flows to ground through the probe/target capacitance. The amount of capacitance (proximity of the target) determines how much current will flow.

The role of ground in capacitive sensing

Capacitive sensors work by measuring the amount of electric current that flows between the probe's sensing surface and ground—usually the target. The greater the capacitance between the probe and the target (the closer they are), the greater the current flow. The driver electronics are responsible for creating, controlling, and measuring the sensing current.

The mathematical details

$I=V/X_C$, and $X_C = 1/(2\pi FC)$

where:

I = Current

V = Voltage of drive from driver electronics

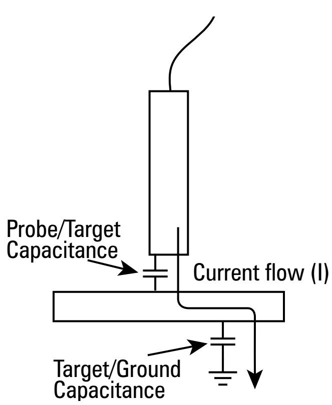
F = Frequency of drive from driver electronics

C = Capacitance

X_C = Capacitive reactance (resistance to current flow)

Capacitive sensors assume that all changes in the sensing current are a result of a change in the probe/target capacitance because of a change in the probe/target distance.

Ungrounded targets



With ungrounded targets, sensing-current flows through the probe/target capacitance and then through the target/ground capacitance. If the target/ground capacitance is 100 times (or more) greater than the probe/target capacitance, the measurement is virtually unaffected.

For sensing current to flow, it must find a path to ground. Anything that changes the resistance to the current flow will affect the measurement. The effect of using an ungrounded target depends on the alternate path the sensing-current takes to ground and how much resistance (X_C) it encounters along the way.

Capacitive grounding

Many targets, while not directly grounded, have a capacitance to ground. In this case, the sensing current will flow through the probe/target capacitance and then through the target/ground capacitance. If the target/ground capacitance is considerably larger than the probe/target capacitance (>100 times), the total change in resistance to the current flow is negligible and the measurement remains unaffected. If the target/ground capacitance is smaller than this, the measurement will be affected.

Estimating capacitance

Roughly speaking, the capacitance between a probe and the target is about 1pF (picofarad). The approximate capacitance between two parallel plates is:

Metric: $C = [8.86 \times 10^{-15}][\text{Area}(\text{mm}^2)/\text{Gap}(\text{mm})]$

Inch: $C = [0.225 \times 10^{-12}][\text{Area}(\text{inch}^2)/\text{Gap}(\text{inch})]$

Example: Two 1" square plates, 0.001" apart have a capacitance of 225pF.

A typical air-bearing spindle rotor has about 1000pF to ground, making the measurement error essentially zero.

Offset and sensitivity errors

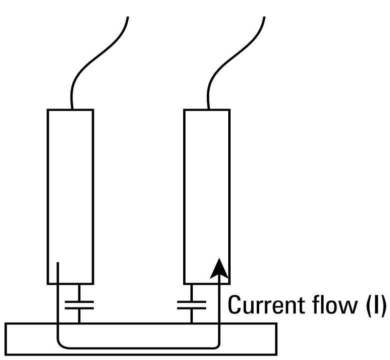
When an error is introduced by an ungrounded target, it comes in two forms: offset error—a shift in absolute probe/target distance at zero volts output, and sensitivity error—a change in the amount of output voltage change relative to a given change in probe/target distance. Because capacitive measurements are usually relative to some set point as opposed to absolute gap measurements, the offset error is usually of no consequence. The greatest concern is with changes in sensitivity, as this will change the relative measurements made with the system.

Varying target/ground capacitance

If the target/ground capacitance is small enough to generate errors *and* it varies with time, the variance of the capacitance will appear as time-variant noise on the output. When the capacitance changes, a small DC shift will occur in the output voltage. Continuous changes in the capacitance will create a corresponding continuous change in the output voltage which will appear as noise.

Solutions for ungrounded targets

Two-channel, out-of-phase measurement



Two-channel measurements can eliminate the need for a grounded target by providing a return path for the sensing current, but only when the two channels are synchronized 180° apart.

Make measurements with a two-channel system in which two drive channels are synchronized 180° out of phase. In this configuration, the current path is “out” of one probe, and “in” to the other. Grounding is no longer an issue. A simple gap measurement only requires the output from one channel. The second channel only provides a return path for the sensing current. Some measurements, such as two-channel thickness, can make use of both channels.

Note:
The two channels must be synchronized and 180° out of phase. Just using two channels not configured accordingly will not be beneficial.

Grounding with brushes

A grounded piece of flexible conductor can often be used as a "brush" to maintain a ground connection to an otherwise ungrounded target. Strips of copper or a metal brush will work well for this.

Specific data

The tables below show specific results of ungrounded targets with two different calibrations. Both calibrations are higher resolution calibrations. Higher resolution calibrations hold the probe closer to the target. This increases the probe/target capacitance, which in-turn increases the required target/ground capacitance.

Probe Model	Calibration	Range	Standoff	Sensitivity
C7-C	Fine	±25μm	100μm	0.400V/μm
Probe/Target Capacitance pF	**Target/Ground Capacitance pF**	**Capacitance Ratio**	**Standoff μm (% chg)**	**Sensitivity V/μm (%chg)**
0.43	10	23:1	95.8 (4.2%)	0.389 (2.8%)
0.43	100	230:1	99.7 (0.3%)	0.399 (0.3%)
0.43	Grounded	—	100	0.400

Probe Model	Calibration	Range	Standoff	Sensitivity
C7-C	UltraFine	±5μm	25μm	2.000V/μm
Probe/Target Capacitance pF	**Target/Ground Capacitance pF**	**Capacitance Ratio**	**Standoff μm (% chg)**	**Sensitivity V/μm (%chg)**
1.74	10	6:1	20.0 (20%)	1.750 (12.4%)
1.74	100	60:1	24.53 (1.8%)	1.970 (1.4%)
1.74	Grounded	—	25	2.000