Using Constant Voltage Excitation with NTC Sensors.

Negative-Temperature-Coefficient (NTC) resistors are commonly used as low temperature thermometers, especially at ultra-low temperature. Their resistance and sensitivity increase dramatically at low temperature but their sensitivity is relatively poor at warm temperatures. Cryo-con temperature controllers and indicators support these sensors by using a constant-voltage excitation scheme.

The circuitry required for constant voltage excitation is complex when compared to the more common constant current or passive bridge techniques, but it extends the useful temperature range and measurement accuracy of NTC resistor temperature sensors. Therefore, it is a feature that is usually associated with high-end resistance bridges and advanced applications.

The primary advantages of constant voltage excitation used with NTC resistor sensors are summarized as follows:

- Measurement accuracy and temperature range are improved at low temperature because sensor self-heating errors are reduced or eliminated.
- Measurement accuracy is improved at warmer temperatures because the constant voltage circuit increases excitation power in that region.
- The control stability of a temperature controller is improved in the warm region since higher excitation power reduces measurement noise.

Error Sources in NTC Sensor Measurements

At warm temperatures, the major source of error with NTC sensors is the measurement electronics itself. In a well designed instrument, this accuracy is limited to a level established by the measurement's signal-to-noise-ratio where the signal is the power dissipated in the sensor and noise is the collection of all noise sources. So, accuracy can generally be improved by increasing the power dissipated in the sensor.

Conversely, at low temperature, NTC resistors have high resistance and the primary source of error is sensor self-heating caused by excitation power. The resistor will have high sensitivity in this region, so measurement errors are small when viewed in units of temperature.

Constant-voltage sensor excitation increases signal power at warm temperature, thereby improving measurement accuracy in an area where the sensor is less sensitive. At low temperature, constant voltage excitation reduces the power dissipated in the sensor which reduces accuracy in units of Ohms, but more importantly, reduces sensor self-heating. Since low temperature is the sensor's most sensitive area, temperature measurement accuracy will not be degraded. The result is an accuracy improvement that extends the useful temperature range of a given sensor at both the warm and cold ends.

Measurement accuracy may also be improved by averaging over time. This is a common feature in thermometry products and is based on the same signal-to-noise issue described above. However, even the slowest feedback control loop will track low frequency noise, so averaging does not improve control stability like constant voltage sensor excitation does.

To understand the effect of sensor excitation power on measurement accuracy, one might compare a high precision ohmmeter to a resistance bridge designed for cryogenic temperature measurement. The ohmmeter could use 10mA of excitation current to measure a 1KΩ resistor whereas a resistance bridge might measure the same resistance using a 10µA excitation current. The ohmmeter would be dissipating 0.1-Watts in the resistor and the bridge 100-nanowatts. While the ohmmeter may have seven or even nine digits of accuracy, the high power level of it's excitation would render it useless for cryogenic temperature measurement. By contrast, the resistance bridge might only have about 0.5% accuracy because of it's low excitation.

Voltage Bias Level Selection

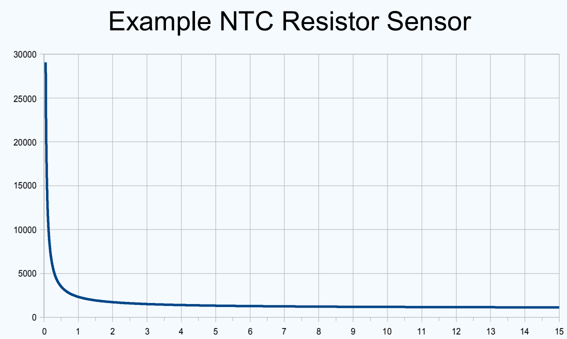
The Cryo-con Model 42/44 temperature controller offers constant-voltage sensor excitation with voltage levels of 100mV, 10mV, 1.0mV and 100µV. Higher voltages improve accuracy at warm temperature and lower levels reduce self-heating at cold temperature. Therefore, the user can select the level for best accuracy over a desired temperature range.

Some NTC resistors have room-temperature resistances in excess of 100KΩ. For these, the choice of excitation voltage is easy because the Model 42/44's 100mV setting is the only one that can accommodate such a high resistance. Example devices include the Cryo-con R500 and SI RO-105. They are commonly used in low-temperature superconducting magnet systems. The Model 44 used with 100mV excitation extends their low temperature operation from about 2.0K to about 1.4K. Other Cryo-con controllers and instruments implement a 1.0-Volt excitation level that is intended for use only with these sensors. It limits the low temperature range to about 2.0K.

In well designed systems where NTC sensors are properly thermally anchored, operation to 1.5K with 10mV excitation will not produce noticeable self-heating errors.

For NTC resistors used below about 1.2K, the proper voltage excitation level is usually determined by experimentation. A simple technique is to stabilize the sensor at the lowest required temperature with the minimum voltage level of 100µA. Then, increase the voltage level until the temperature indication goes up because of self-heating. The proper level is the highest value that gives acceptable self-heating.

As a final note, self-heating errors are usually reproducible. Therefore, you can often use a voltage excitation that produces some self-heating errors, but gives better warm performance. Then, you can correct the low temperature errors by using Cryo-con's CalGen™ feature.



This graph shows a typical temperature vs. resistance plot for a Cryo-con R500 Ruthenium-Oxide NTC resistor temperature sensor.

As can be seen, the sensor exhibits low resistance and low sensitivity in the warmer region. Measurement errors in this area are dominated by the room-temperature electronics and can only be reduced by increasing sensor excitation power.

In the cold temperature region, the sensor has high resistance and high sensitivity, so the excitation current must be cut significantly in order to prevent self-heating.

Constant-voltage excitation improves accuracy in both regions since it provides high excitation power in the warm area and lower power in the cold area.

Minimum temperature vs. Sensor Excitation Method					
	Constant Voltage Excitation			Constant Current Excitation	
Sensor	**10mV**	**1.0mV**	**100uV**	**10uA**	**1.0uA**
Ruthenium-Oxide					
Cryo-con R500	1.2K	200mK	<100mK	NR	600mK
Lakeshore RX-102	1.2K	200mK	60mK	NR	500mK
SI RO600	1.2K	200mK	<100mK	NR	600mK
Lakeshore RX-202	1.2K	100mK	60mK	NR	500mK
Cernox™					
CX-1010	1.2K	300mK	100mK	2.0K	600mK
CX-1030	1.2K	300mK	100mK	3.5K	1.0K

Cryogenic Control Systems, Inc.
PO Box 7012
Rancho Santa Fe, CA 92067-7012

Telephone: 858 756 3900
FAX: 858 759 3515

www.cryocon.com