

Team ST²

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Abstract

To help diagnose neurological disorders, a portable thermal probe is needed to determine if a patient has a loss of temperature sensation in a specific area of the body. The probe itself is an aluminum surface that is heated with a resistive heating element to desired target temperatures. A microprocessor-based system controls heating of the probe surface. The physician will place the probe on the patient's skin, depress a button to begin testing, and an LED will signal when five seconds has elapsed. Safety is a primary concern; the device indicates circuit failure or abnormal operation by a flashing red LED. The device is powered by an 8 V AC/DC converter that plugs into a wall outlet.

Problem Definition

Doctors are now finding it necessary to test for neurological damage in patients who experience pain or numbness with warm/heat sensitivity. Currently, there is no portable device that a physician can use to apply hot sensation to a patient's skin. Physicians investigating sensory loss could use a device that heats up to warm and hot target temperatures of 38°C and 45°C respectively as a prescreening process before a more rigorous quantitative sensory test is performed. This device should be convenient to use and safe to apply to patients.

Motivation Why Design such a Device?

- The need for a quick and easy-to-use method to preliminarily test for neuropathic disorders.
- Pre-screening to possibly avoid more complete and rigorous Quantitative Sensory Testing; saves the patient and clinician valuable time.
- A portable device can be moved between exam rooms or carried by a physician very easily.
- A safe, easy-to-use testing device that requires little training and will not cause any harm to the patient or the user.

Background

The peripheral nerves innervate the skin of the body allowing the skin to transmit stimuli along these nerves to the brain. The conscious perception of these stimuli is called sensation.

"Neurologists need to judge severity of neuropathy in order to:

- Ascertain the degree of neurological impairment.
- Decide on how comprehensive an evaluation for underlying cause is justified.
- Come to a conclusion about whether therapy should be begun, altered, or stopped.
- Make inferences about outlook
- Decide whether a given therapy is efficacious."

Peter J. Dyck, MD, Mayo Clinic, Rochester, Minn.

Quantitative Sensory Testing

Method used to assess degree of neurological disorder

- Uses hot, cold, and vibration stimuli to determine sensitivity thresholds
- Performed on different areas of the skin—six times at each location for each stimulus
 - Temperature never exceeds 50°C
 - Tests take 1-3 hours

Current devices are bulky and inconvenient to use!

Product Design Specifications

Client Requirements

The product should:

- Be safe and not burn patients; i.e. the temperature must never rise above 50°C
- Heat up to target temperatures of 38°C and 45°C (within 1°C) relatively quickly
- Maintain the target temperature through several successive tests on the same patient
- Have a probe surface with an area of 4.0 cm²
- Indicate when the probe surface has reached the target temperature
- Indicate when the probe has been applied to a patient's skin for five seconds

- Be convenient to use and easy to clean with alcohol and/or soap and water
- Be powered by a readily available power source

Design Requirements

Performance: The device should be able to be used to test a maximum 20 patients per day, each including up to 3-4 minutes of testing at 38°C and 3-4 minutes of testing at 45°C.

Safety: The probe temperature must not exceed 50°C in any event (including user abuse and circuit element failure).

A five-second timer should be used to alert physician to remove device from patient's skin.

Operating Environment: The device will be used under normal indoor hospital/clinical conditions (20-25°C, 1 atm pressure, less than 60% relative humidity, and very little dust) by trained physicians.

The probe will primarily be used on a patient's hands and feet. The skin may possibly be moist.

Ergonomics: Size of probe should allow for full contact to the skin of the various areas of the body tested.
Placement of operator controls should not cause undue strain in the hand, wrist, or fingers.

For more information see the ST² web site at:

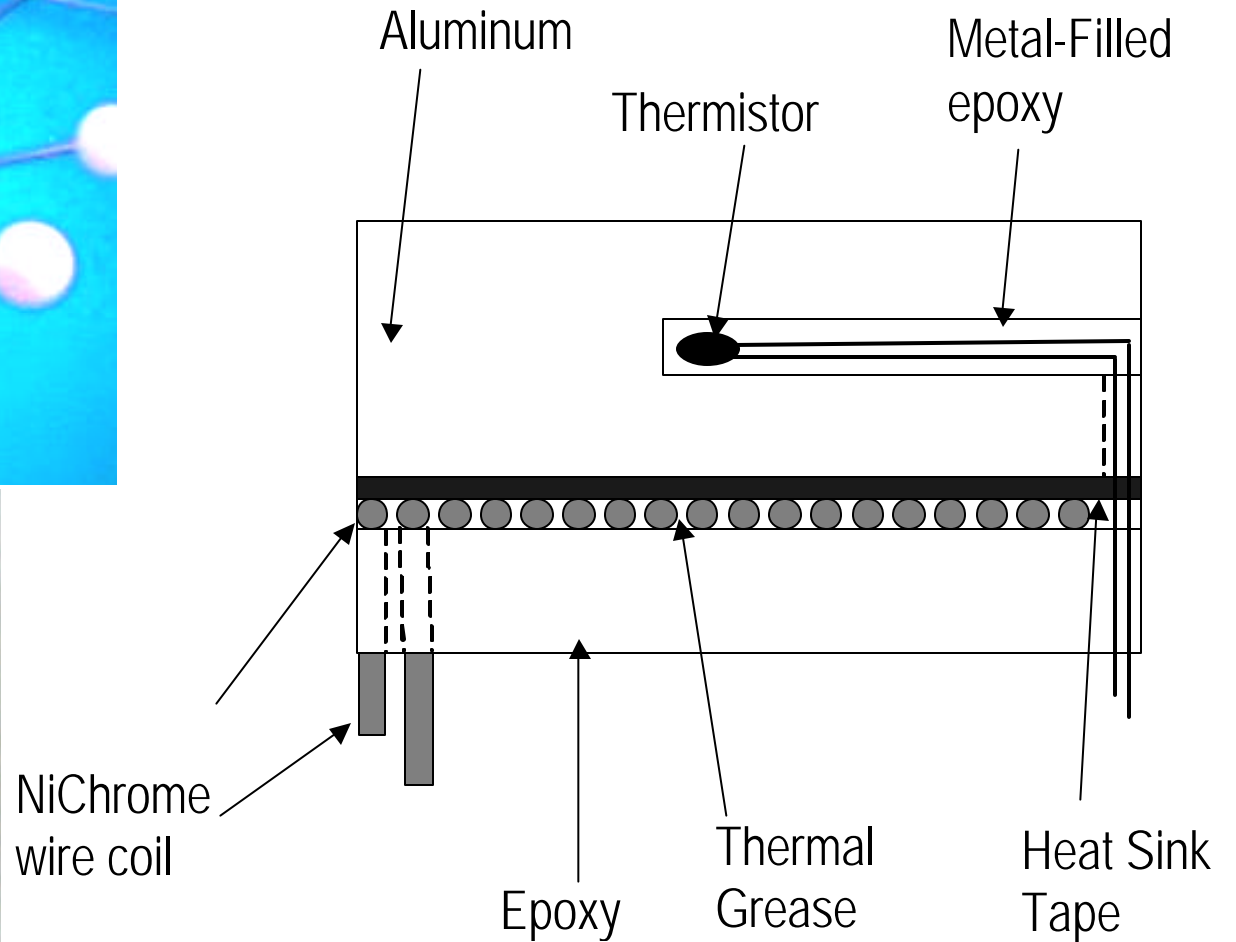
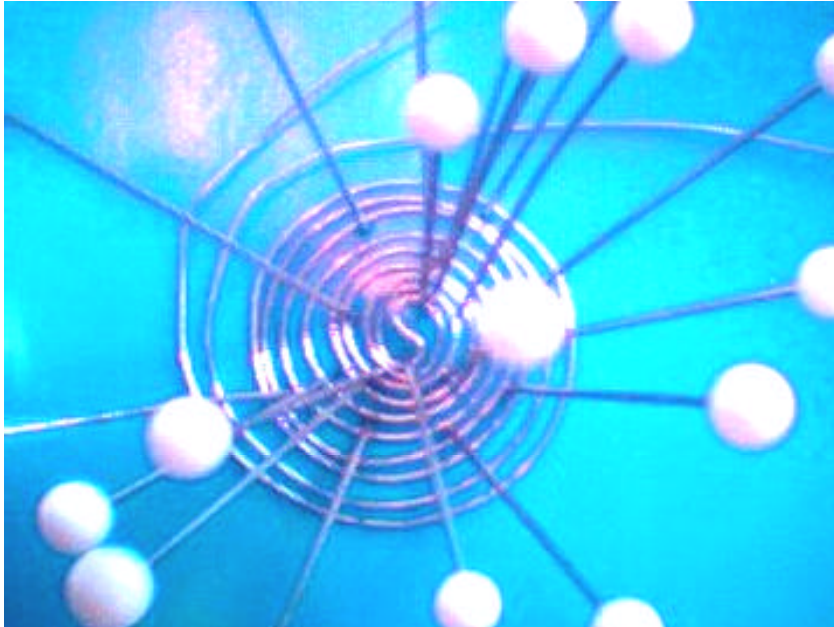
<http://www.cae.wisc.edu/~thermpro/>

Heating Element

The complete probe assembly consists of:

- The wire coil, a resistive heating element
- Heat sink compound to maximize heat transfer to probe surface
- Thermally conductive tape to couple the heating element the surface that requires heating, and electrically isolate the coil
- The aluminum “probe head”, which is warmed to a desired temperature and is the point of application of the probe
- A thermistor that measures the temperature of the aluminum
- Clear epoxy layer to seal and insulate the heating element

Heating Element



Circuitry

The circuit consists of analog and digital circuitry to perform temperature control of the probe surface. The analog section performs temperature measurement and prepares a voltage equivalent to temperature for being digitally processed. The digital section makes an analog-to-digital conversion and determines the probe heating and user outputs based on the temperature level and the user inputs.

Analog Circuitry

- Thermistor whose resistance decreases exponentially with temperature
- Wheatstone Bridge containing thermistor provides differential input to...

- Op amp with feedback resistor has a linear output with temperature
- Low-Pass filter to cancel high-frequency noise and to prevent aliasing of that noise when sampled at 20 Hz by the analog-to-digital converter (ADC)

Digital Circuitry

- Serial 8-Bit ADC reads voltage equivalent to temperature is read by...
- Basic STAMP II microcontroller which has:
 - EEPROM to store program, programmable thru PC serial port
 - 16 programmable I/O pins
 - Internal 5.0 V regulator supplying up to 50 mA to STAMP II and the other control circuitry
- LEDs to alert user to state of the device
 - Green to tell normal operation

- Red to tell too hot or that an error has occurred
- Yellow to tell that 5 s timer has expired
- Switches allowing user input
 - Temperature selection: 38 or 45°C
 - Timer start, held down while performing a test
 - Sound on timer-end enable switch
 - Reset switch, to allow operation after an error has been reported (located through small hole in case)
- N-channel MOSFET as switch to allow power to reach heating element

Program

- Checks for abnormal modes of operation
 - Temperature changing too quickly
 - Temperature not rising upon startup
 - Reset button being depressed upon startup
- Maintains probe temperature
- Notifies user of thermal probe status
- Alerts the user after 5 seconds of skin contact time
- Shuts the device down after 5 minutes of inactivity

Threshold Control

- Heat with full power until a threshold, set a few degrees below target
- Then heat with a 16.7% duty cycle if heating to warm or 33.3% if heating to hot
- While applying to patient's skin, increase duty cycle by one step (16.7% – 20%, 33.3% – 50%)
- Apply no heat when above target temps

Error Checking

The program will give an error code if unexpected results are obtained (tTemp is the converted temperature value).

0. If reset button is depressed upon startup, or shorted
1. If tTemp does not rise enough upon startup
2. If tTemp rises too fast during operation
3. If tTemp falls too fast during operation
4. If tTemp approaches high saturation
5. If tTemp approaches low saturation

Display

- Blinking Green:** Below temperature and heating
- Solid Green:** Within 1°C of target; ready to test
- Solid Red:** Over 1°C above target temperature
- Blinking Red:** Error; stores failure code
- Solid Yellow:** 5 seconds of skin contact has elapsed
- Blinking Yellow:** Blinks according to error code
- All Solid:** One second duration at startup of normal operation

Possible Enhancements

Possible enhancements include both short-term and long-term items. This team will not be continuing this as a design project, but will remain involved as necessary to provide support for the device.

Short-term

- Allow client use of prototype and fix any operation issues.
- Assess sensitivity and selectivity to detecting circuit errors.
- Map the temperature distribution at the probe surface.

Long-Term

- Design new more ergonomic prototype – circuitry in the handle.
- New more compact printed circuit board (PCB) implementation.
- Find better switches.

- Update probe assembly as needed to make it easier to attach to the case.
- Verification of exam results, compared to the standard neurological exam

Testing Results

Graph A shows initially rapid heating, from room temperature, as the probe temperature approaches the warm target (38°C) for both the duty cycle and on/off heating controls. Graph B shows the same response for the hot target (45°C).

In both graphs target temperature is reached within 20 seconds. For the on/off control there is an initial overshoot of the $+1^{\circ}\text{C}$ allowed over target temperature. The duty cycle control provides smaller deviation from the target temperature than the on/off control. These graphs represent temperature control with no skin contact.

References

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