2GP5

Measuring linear thermal expansion coefficients

Introduction

Most materials expand when heated through a temperature range that does not produce a change in phase. The added heat increases the average amplitude of vibration of the atoms in the material, which increases the average separation between the atoms.

Suppose an object of length L undergoes a temperature change of magnitude ΔT. If ΔT is reasonably small, the change in length ΔL is generally proportional to L and ΔT. Stated mathematically,

$$\Delta L = \alpha L \Delta T,$$

where α is called the coefficient of linear expansion for the material.

For materials that are not isotropic, such as an asymmetric crystal for example, α can have a different value depending on the axis along which the expansion is measured. The coefficient α can also vary somewhat with temperature. Therefore, the degree of expansion depends not only on the magnitude of the temperature change, but also on the absolute temperature.

In this experiment, you will measure α for three types of metal i.e. copper, aluminium and brass. These materials are isotropic, so it is sufficient to measure α along one dimension. Also, within the limits of this experiment, α does not vary with temperature.

Setup

1. **Attach the Rotary Motion Sensor (RMS) to the large end block on the apparatus (Figure 1).** Use the black thumb screws to attach the RMS to the larger of the black end blocks. Place the pinion onto the shaft of the RMS and rotate clockwise to tighten.

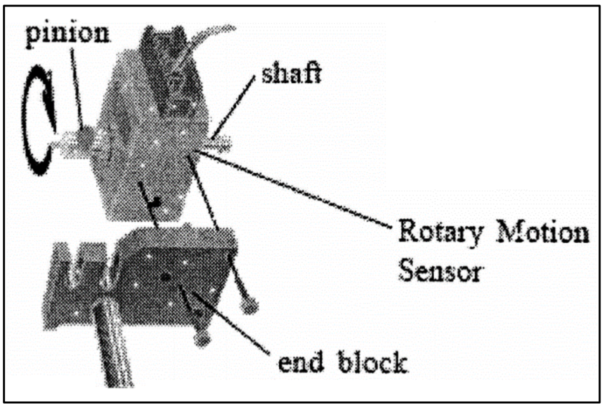

Figure 1 Mounting the Rotary Motion Sensor to the end block of the apparatus

2. **Align and anchor the metal rod in the expansion base (Figure 2 and Figure 3).** Place the rod so that the retaining ring on the rod fits into the groove on the labelled mounting block, and the metal rod lies

over and presses against the pin on the RMS. To anchor the rod and establish the zero position, hook the spring clip (on the support rod) over the metal rod, to the left side of the grip ring. If the spring clip is not available, use some wires (Figure 3) or a hook-and-loop fastener instead to anchor the metal rod sufficiently tightly to the expansion base.

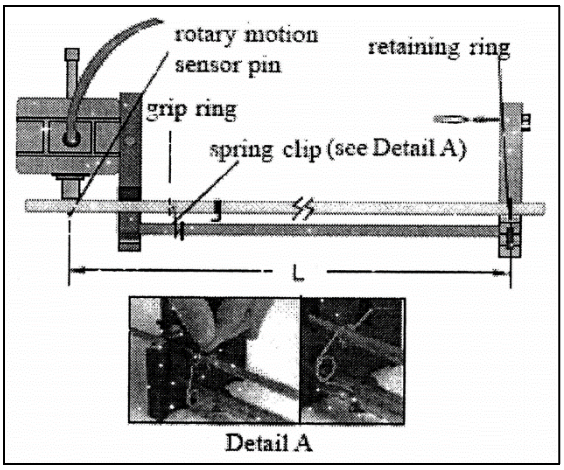

Figure 2 Aligning and anchoring the metal rod in the expansion base.

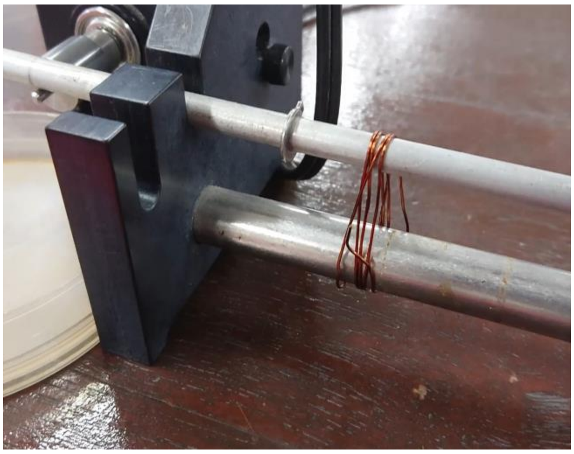

Figure 3 Aligning and anchoring the metal rod using some wires.

3. **Attach the Thermistor lug beneath the spring clamp on the metal rod (Figure 4).** With one hand, place the Thermistor lug over the top of the metal rod, such that the concave side fits snugly over the rod. Align the lug with the axis of the rod, so that there is maximum contact between the lug and the rod. With your other hand, press the ends of the spring clamp together. Slide the lug underneath the capture spring to attach the thermistor lug beneath the clamp.

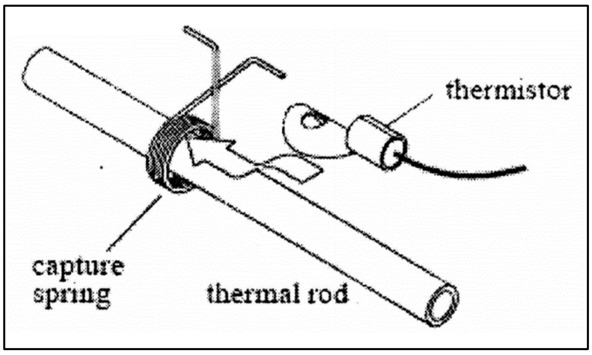

Figure 4 Placing the Thermistor lug (with thermistor) on the metal rod.

4. **Plug the Sensors into the Interface (Figure 5).** Insert the DIN connector of the Thermistor Sensor into an analog channel in the *ScienceWorkshop* interface. Attach the stereo plug of the Thermistor Sensor cable into the 10 kΩ jack on the Thermistor Sensor. Insert the banana plugs for the RMS into digital channels 1 and 2 (yellow = channel 1, black = channel 2) on the *ScienceWorkshop* interface.

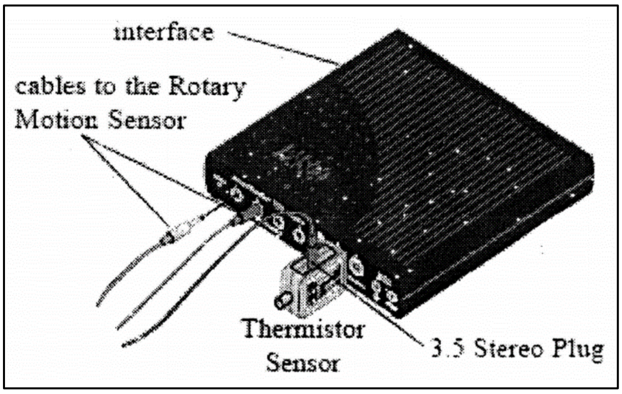

Figure 5 Plugging the Thermistor and Rotary Motion Sensors into the ScienceWorkshop *Interface.*

5. **Attach the Thermistor Sensor leads to the apparatus (Figure 6).** Insert the red and black banana plugs from the Thermistor Sensor into the jacks on the end block (the one with the Thermistor label).

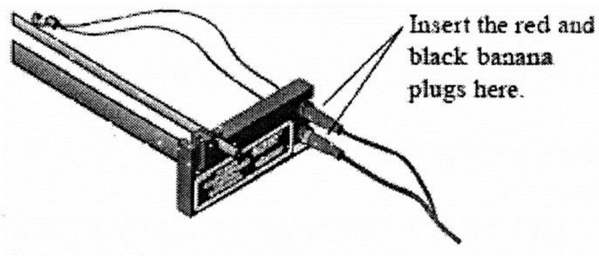

Figure 6 Attaching the banana plugs from the Thermistor Sensor to the end block of apparatus.

The following paragraphs describe how to setup the DataStudio:

1. Launch DataStudio via the Start menu.
2. On the Welcome to DataStudio window, click “Create Experiment”.
3. On the Experiment Setup window, click the digital channels 1 or 2 (see Figure 7) on the virtual *ScienceWorkshop* interface. Since the RMS cables are the ones plugged into the physical digital channels 1 and 2, choose the “Rotary Motion Sensor” from the pop-up list (see Figure 8).

Figure 7 The virtual ScienceWorkshop *interface as shown on the Experiment Setup window.*

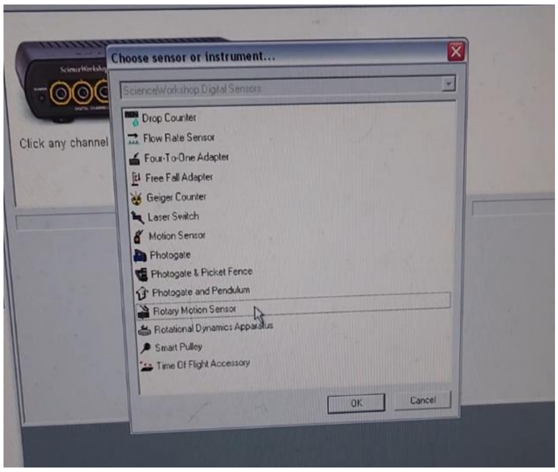

Figure 8 The choice of sensors that could have been connected to the digital channel.

4. Repeat step 3 above for the Thermistor sensor by clicking on the appropriate analog channel on the virtual *ScienceWorkshop* interface and choosing the “Thermistor Sensor” from the pop-up list.
5. The software is now set up and the Experiment Setup window can be closed.

The following paragraphs describe additional setup information:

1. **Sample rate:**
   The default sample rate for both the Rotary Motion and Thermistor Sensors is 10 Hz and 2 Hz respectively. If you want to change the sample rate, click on the sensor icon in the Experiment Setup window. **(Recommended value: 1 Hz.)** In the Sensor Properties dialog, use the plus and minus buttons to increase or decrease the sample rate.

2. **Measurement units:**
   The setup will give you the temperature readings in degrees Celsius. If you also want to view resistance measurements, go to the Experiment Setup window and double-click on the Thermistor Sensor icon. In the Sensor Properties dialog, click on the Measurement tab and click to place a check in the Resistance box.

3. **Equation setup:**
   The following equations are useful for the experiment:

   $\Delta T = \max(T) - \min(T)$ (°C), where ΔT represents the change in temperature, $\max(T)$ represents the maximum temperature achieved and $\min(T)$ represents the temperature at the initial start time.

   $\Delta\theta = \max(\theta) - \min(\theta)$ (rad), where $\Delta\theta$ represents the change in angular position recorded by the RMS, $\max(\theta)$ represents the highest angular position attained and $\min(\theta)$ represents the initial angular position. The initial position is usually zero (by construction).

   $\Delta L = \Delta\theta \times r$ (mm), where $r = 1.327$ mm is the radius of the rotary pin.

   Note: The change in length of the rod is calculated from the rotational change of the RMS pin. As the rod expands, it pushes against the pin and causes the pin to rotate. From the radius of the pin and the amount of angular rotation relative to the pin's zero position, the RMS determines the linear change in length L for the rod.

Procedure

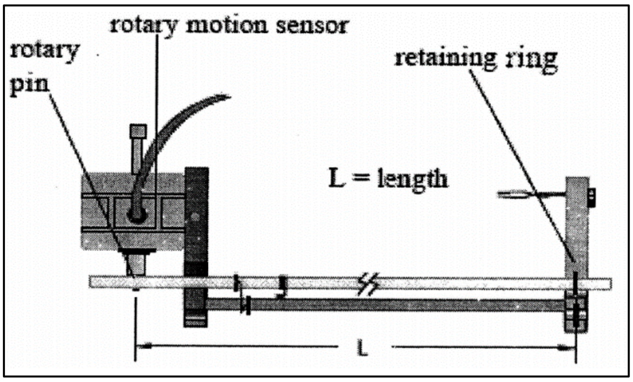

Figure 9 Measuring rod length.

1. With a measuring tape or metric ruler, measure the length L of the aluminium rod at room temperature. Measure from the center of the retaining ring (in the groove of the small end block) to the center of the rotary pin at the other end (see Figure 9). Record your results.

2. Insulate the rod and the thermistor with a slitted, tubular foam wrap. Slide the foam wrap from underneath the rod until the foam covers the circumference of the rod. The spring clamp should jut out from the top of the foam slit (see Figure 10). If the tubular foam wrap is not available, use some generic foam to wrap around the thermistor and the rod and then secure the foam with some wires (see Figure 11).

3. Cut and place the plastic tubing (preferably clear) over both ports on the top of the lid covering the Steam Generator (see Figure 12). [Note: Cut the tubing enough to allow it to reach the rod on the apparatus, but keep the tubing as short as possible, to prevent kinks and maximize rapid heat transfer.] Plug one end off with a plastic tube clamp. Connect the plastic tubing on the other port to one end of the metal rod (at the labelled end block, away from the RMS).

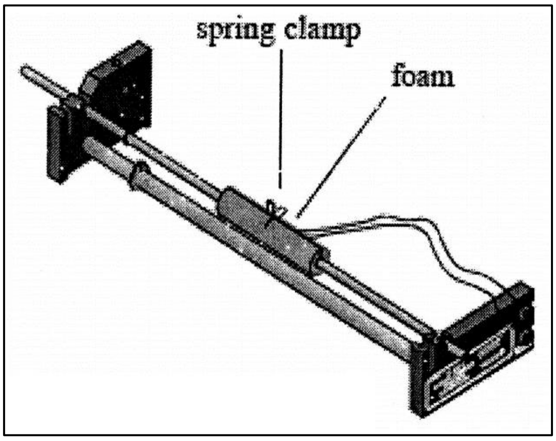

Figure 10 Insulating the rod with tubular foam wrap.

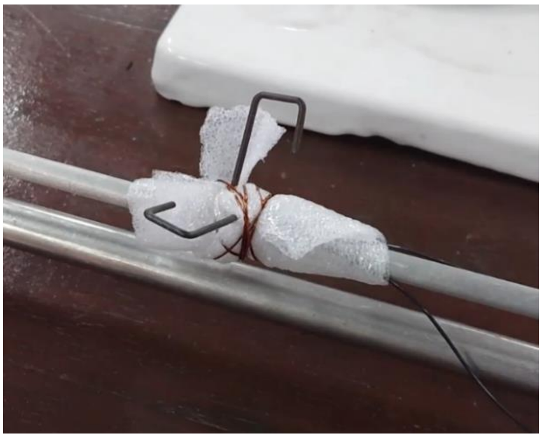

Figure 11 Insulating the rod with some generic foam and secured with some wires.

4. Fill the Steam Generator half to three quarters full with water. Plug the Steam Generator into a three-receptacle outlet.

5. Turn on the Steam Generator and wait for it to warm up. When you first hear a gurgle sound (but before the steam travels through the tubing), click the START button on DataStudio to begin recording the temperature (see Figure 12). Steam will begin flowing through the rod shortly thereafter. As steam begins to flow, watch the temperature rise in the DataStudio Graph display as the rod heats. When the temperature reading stabilizes, record the temperature change ΔT. Also, record the expansion of the rod's length ΔL as indicated by the position displacement ΔX (in mm).

   [Note: To display the graphs, double-click "Graph" in the Displays list (bottom left of DataStudio) and choose the appropriate data source.]

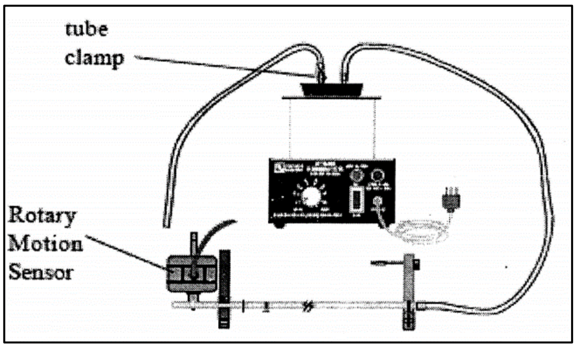

Figure 12 Connecting the tubing from the Steam Generator to the Thermal Expansion Apparatus.

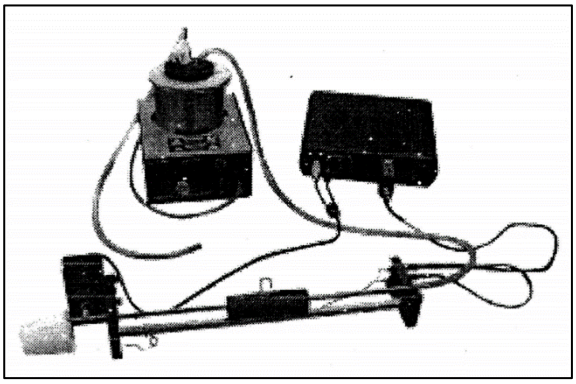

Figure 13 Experiment Setup

6. In DataStudio, save your activity file for the aluminium rod and repeat the measurement for at least three times. Then, repeat the experiment for the copper and brass rods.