27 Thermal Expansion

The Bridge Connection

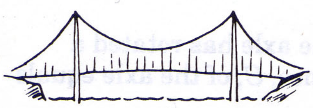
Purpose

To calculate the minimum width of the expansion joints for the Golden Gate Bridge.

Required Equipment and Supplies

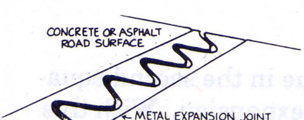
hollow steel rod
thermal expansion apparatus (roller form)
micrometer
steam generator
Bunsen burner
rubber tubing

Discussion



Ideally, all gases expand equal amounts when heated and contract equal amounts when cooled under constant pressure. The molecules of a gas are so far apart that their size and nature does not affect the amount of expansion or contraction. However, liquids and solids are individualists! Molecules and atoms in the liquid state are much closer together, and their particular size and type have a significant effect on expansion or contraction. Molecules and atoms in the solid state are close together in a variety of definite crystalline structures. Different substances expand or contract at different rates when their temperature is changed.

Expansions or contractions of metal can be critical in the construction of bridges and buildings. Temperatures at the Golden Gate Bridge in San Francisco can vary from –5°C in winter to 40°C in the summer. On this very long bridge the change in length from winter to summer is nearly 2 meters! Clearly, engineers must keep thermal expansion in mind when designing bridges and other large structures.



Suppose you owned an engineering firm before the Golden Gate Bridge was built and you were asked for advice on the minimum width to make expansion joints for the proposed bridge. Consider two expansion joints that connect the bridge to land at each end. The steel to be used is the same as that in the steel rods you will use in this experiment. You are to measure how much the steel expands per meter for each degree increase in temperature. This ratio is called the *coefficient of linear expansion*. Then compute the amount that the 2740-meter structure will expand as its temperature increases. Now you can advise a size for the expansion joints needed to assure the success of the bridge.

You will determine the coefficient of linear expansion for steel by measuring the expansion of a steel rod when it is heated with steam at 100°C. The amount of expansion, ΔL, depends on the original length, L, the change in temperature, ΔT, and the coefficient of linear expansion, α (which is characteristic of the type of material).

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

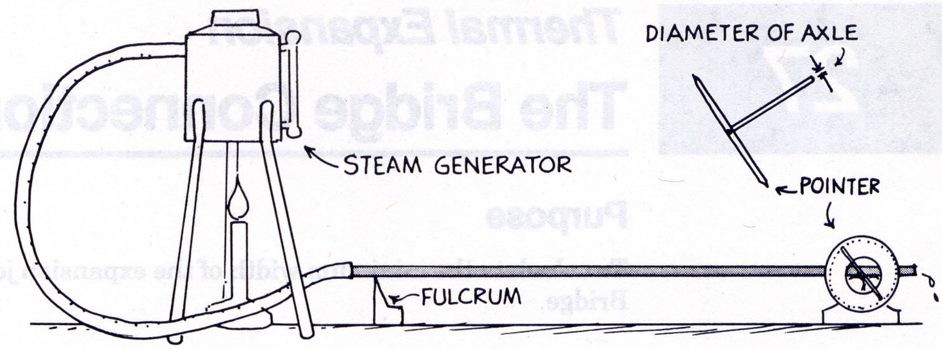


Figure 27.1

The temperature change, ΔT, is simply 100°C minus room temperature. By measuring L, the original length of the rod before heating, and ΔL, the change of the length after heating, you can compute α, the coefficient of linear expansion by rearranging the equation.

$$\alpha = \frac{\Delta L}{L \Delta T}$$

It is difficult to measure how much the rod expands because the expansion is small. One way to measure it is shown in Figure 27.1. The end of the steel rod is placed perpendicularly on the axle of the pointer. When the steel rod resting on the axle expands, it rotates the axle and the pointer through an angle.

The pointer turns 360° (one full rotation) when the axle has rotated a distance equal to its circumference. The circumference, C, of the axle equals its diameter, d, multiplied by π.

$$C = \pi d$$

If the expansion causes a rotatation of the pointer through 180° (a half revolution), then the increase in the length of the rod, ΔL, is equal to half the circumference of the axle. Ratio and proportion give you ΔL for other expansions. The ratio of the actual distance rotated, ΔL, to the distance rotated in one complete rotation, πd, equals the ratio of the angle the pointer rotates through, θ, to 360°.

$$\frac{\Delta L}{\pi d} = \frac{\theta}{360°}$$

Solve this equation for ΔL and substitute this value in the second equation and you can compute α, the coefficient of linear expansion. With this value you can compute the minimum width of the expansion joints of the bridge from the first equation, using the length of the bridge and the estimated temperature difference for summer and winter.

Procedure

Step 1. Using a micrometer, measure the diameter of the axle of the pointer.

d = ________ mm

Step 2. Assemble your apparatus as in Figure 27.1, with the steam generator ready to go. Make sure the tube has a place to drain. Measure the distance in millimeters from the groove in the steel rod to the axle of the pointer (since you are sampling the expansion between these two points). Do not measure the actual length of the rod.

$L =$ ________ mm

Step 3. Connect the steam generator, and observe the change in length of the rod. Is the increase sudden or gradual? Record the change in temperature of your rod, assuming it started at room temperature.

$\Delta T =$ ________ °C

Record the angle, θ, the pointer turned through due to the expansion of the rod.

$\theta =$ ________ °

Step 4. Compute the increase in length of your rod, ΔL, by substituting your measured values of θ and d into the following equation.

$$\Delta L = \frac{\pi \theta d}{360°}$$

$=$ ________ mm

Step 5. Compute the coefficient of linear expansion using your measured values of L, ΔT, and ΔL.

$$\alpha = \frac{\Delta L}{L \Delta T}$$

$=$ ________

Step 6. Express the coefficient of linear expansion in scientific notation (that is, as a number times a power of ten).

$\alpha =$ ________

Step 7. Compute the minimum width of the expansion joint(s). Show your work.

$\Delta L =$ ________

Analysis

1. Why do you measure the diameter of the axle of the pointer in Step 1 instead of the diameter of the steel rod?

2. Why do you measure the distance, L, from the groove in the steel rod to the point of contact with the axle instead of the entire length of the rod?

3. Suppose you placed the roller bearings (the two wheels underneath the rod that rotates) in the *middle* of the rod. Would the coefficent of linear expansion for the steel rod be larger, smaller, or the same? Why?

4. What are the units of α?

5. What are the sources of error in your experiment? List the factors along with an estimate of their percentage contribution.

6. In your consultation, suppose you experimentally determined that the expansion joints had to be a minimum of 2 meters long. How large would you recommend them to be, safely taking your margin of error into account?

7. What do you think would be a good design for an expansion joint?