SELF COMPENSATING FIBER OPTIC DELTA T PROBES

Horace Heffner July 1997

Accurate determination of temperature differences, or delta T, especially without heating the medium being measured, is of special importance to calorimetry, which requires the measurement of temperature differences of liquids at the inlet and outlet of a test chamber, or temperature differences across a thermal conductor to a highly insulated test chamber.

A method is proposed here to determine temperature differences using optical fiber to make two probes P1 and P2 by winding fiber about two cores. The thermal expansion of the glass that comprises the fibers will increase the travel time for a light pulse. A light pulse simultaneously sent through each fiber at the same moment will arrive at the end of the cooler fiber first. One useful feature of the proposed approach is that there is a convenient means of compensating for errors induced by temperature variations in the test probe leads caused by ambient conditions. Another useful feature is the small amount of energy, a series of light pulses in fiber, used to measure the temperature. Additional useful features are that the measurement can be highly accurate due to the measurement being a direct result of the thermal coefficient of expansion of very pure glass, and due to the measurement being time based.

The method of compensation involves passing both the fibers to each probe over the same paths, excluding the actual entry into the test probes. This makes the reading more accurate in two ways: (1) Both loops P1 and P2 experience exactly the same thermal conditions at every point except in the probes and (2) the length of fiber in the test leads can be far less than the length of fiber in the probe coils, thus can play a highly diminished role in the delay time.

Fig. 1 is a representation of the fiber configuration.

SELF COMPENSATING FIBER OPTIC DELTA T PROBES

Horace Heffner   July 1997

```
    ---------------------------------------
  /                                        \
 *              Bundle 1                    P1
  \                                        /
    ----------------------------------    |
                                      |   |
                                      |   |  Bundle 2
                                      |   |
                                       \ /
                                        X
                                       / \
                                      |   |
                                      |   |  Bundle 4
                                      |   |
 R1 ----------------------------------    |
 |                                         \
 dT             Bundle 3                    P2
 |                                         /
 R2 ---------------------------------------

P1 - Probe 1
P2 - Probe 2
 * - Light pulse source
R1 - Reads light pulse 1
R2 - Reads light pulse 2
dT - circuit to convert arrival time difference to temp
```

Fig. 1 - Diagram of Fiber Optic Bundle Configuration

Note that in each path, except at P1 and P2, the fibers for each probe are paired, thus the dime difference due to local ambient temperature is the same in both sensor paths. The above fiber configuration could be folded into a T shape for convenience, with each leg of the T having two bundles of 2 fibers each, as shown in Fig. 2.

```
                                      -----
                                      |    \
                                      |     P1
                                      |    /
                                      |   |
                                      |   |  4 fibers - Bundle 1 +
                                      |   |        Bundle 2
*  -----------------------------------    |
       4 fibers - Bundle 1 +              |
           Bundle 4                       |
R  -----------------------------------    |
                                      |   |   4 fibers - Bundle 3 +
                                      |   |        Bundle 4
                                      |    \
                                      |     P2
                                      |    /
                                      -----
```

Fig 2 - Diagram of Bundle Groping

Instead of measuring the delta T between P1 and P2, the two fibers could each be used as delay lines to make two pulse delay line oscillators O1 and O2. The concept is to use the pulse output of oscillator O1 to drive an interval timer to count the pulses from oscillator O2. The oscillator output would be cleaned up using triggers and the digital pulses used to drive binary counters. The output of O1 (from the reference fiber coil) would drive an interval timer counter being decremented from a preset count Ct2. When the interval timer zeros, the input from O1 and O2 would be suppressed, the contents of a second counter (Ct2) being driven by O2 would then be latched to a buffer for input by a controller for numerical processing, or read directly by the controller. The controller would read the data and then reset the counter for O1 to Ct1, zero Ct2, and open the gates to O1 and O2 to repeat the process. If needed, readings from thermistors or thermocouples in the probes, or at least one probe, could be provided to determine absolute temperature.

The value used to determine the differential temperature DT would then principally be (Ct2 - Ct1), i.e. DT=k1(Ct2 - Ct1)+k2. Calibration would determine if k1 or k2 varied with absolute temperature, i.e. if k1=f1(T), k2=f2(T) for functions f1 and f2. It is also possible (ugly) that k1=g1(T,Ct1,Ct2), and k2=g2(T,Ct1,Ct2), where g1 and g2 are nonlinear functions, but that would have to be determined by calibration. Alternately, given absolute temperatures at the probes T1 and T2, it might be useful to determine functions k1=g1(T1,T2) and k2=g2(T1,T2) during calibration. Of course we can simply say DT=h(Ct1,Ct2,T1,T2) for function h, but that gives no meaning to the linear relationships that are probably sufficient for accurately calibrating to determine DT.

The main advantage to the design should be repeatability. This is due to the the principle value (Ct2 - Ct1) being determined digitally. The absolute temperature only affects determination of k1 and k2, which should be of secondary significance, due to an expected small variation of k1 and k2 over the measurement ranges.