TEMPERATURE MEASUREMENTS OF INTERNAL-COMBUSTION ENGINE PISTONS

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The temperature of components with a reciprocating movement, especially of internal-combustion engine pistons, is measured with thermometers connected to the measuring circuit by means of special contacts which close periodically at one of the extreme positions of the component.

Such a contact device is in fact a pulsating element, whose operation precludes the possibility of using measuring circuits normally applied for measuring temperature by means of thermocouples.

Pulsating thermoelectric measuring circuits are distinguished by several specific features. The most substantial difficulty arising in a pulsating element consists in the lowering of the measuring circuit's sensitivity as compared with that of a constant coupling.

The temperature of internal-combustion engine pistons is measured in the Soviet Union, as distinct from foreign countries, only by means of compensated circuits, which provide higher precision.

A simplified compensated circuit is shown in Fig. 1, where E is the thermocouple's emf, U_k is the compensating voltage, r is the total resistance of the thermocouple circuit, r_n is the resistance of the null-detector, r_k is the internal resistance of the compensating voltage source, K are the coupling contacts.

The current which flows through the null-detector with closed contacts and E = U_k + ΔE amounts to

\[ I = \frac{\Delta E}{r + r_n + r_k} \]

The voltage across the null-detector is

\[ u_n = r_n \frac{\Delta E}{r + r_n + r_k} \]

The voltage sensitivity of the circuit for a constant coupling (static sensitivity) is

\[ S = \frac{u_n}{\Delta E} = \frac{r_n}{r + r_n + r_k} \]

(1)

The contact resistance of engine contacts does not remain constant with generous lubrication at high piston speeds. Therefore, the shape of current pulses in the null-detector circuit is not constant. However, a study of certain contact designs has shown that it is possible to provide a pulse shape approaching a rectangle.

The mean voltage at the input of the null-detector for a pulse repetition period T is

\[ U_{n,av} = \frac{1}{T} \int_0^T u_n dt. \]
The amplitude of the voltage pulse at the null-detector with closed contacts is represented by (1). During the spacing between pulses, there is no voltage or current at the null-detector. For a pulse duration $T_p$ (the time the contacts remain closed) by the factor $\gamma = T_p/T$ (the pulse duty factor of the contact device). Thus, the sensitivity of the compensated circuit in a pulsed condition is equal to its static sensitivity multiplied by the duty factor. Since the duty factor of the above-mentioned contact systems sometimes amounts to 0.02–0.03, the pulsed sensitivity is so low that ordinary compensators become unusable.

The reduction in sensitivity can be compensated by raising the sensitivity of the null-detector. Normally the null-detector's sensitivity is raised by using an ac amplifier with a differentiating transformer at its input. This method of raising the sensitivity is used in manually-operated compensators. Its application to automatic compensators entails substantial difficulties in determining the polarity of the pulses and providing stable operation of the instrument's tracking system in a pulsed condition.

Automatic operation can be provided by raising sharply the duty factor. The author of this article has developed a method for raising the pulse duty factor in the compensated measuring circuit by storing the pulses without changing the duty factor in the contact device. The attachment of a pulse-storing unit to the measuring circuit, whose effective power is relatively small, simplifies the design of that unit. A capacitor can be used for storing voltage pulses in the measuring circuit. The capacitor is charged through the closed contacts, and its charge helps to maintain the voltage across the null-indicator in the intervals between the closing of the contacts.

Figure 2 shows a compensated pulsed circuit with a storage capacitor $C$ in the thermocouple circuit. The thermocouple circuit resistance consists of resistance $r_1$ of the circuit components in front of the storage capacitor, and resistance $r_2$ of the circuit between the capacitor and the compensating voltage source and null-detector. The currents flowing through the circuit components are denoted respectively by $i_1$, $i_2$, and $i_3$. $U_C$ is the voltage across the capacitor. The remaining notations are similar to those of Fig. 1.

Assuming that the circuit is balanced ($E_0 = U_C = U_k$) and during the spacing between pulses the thermocouple emf becomes $E = E_0 + \Delta E$, whereas voltage $U_k$ remains constant, we find that for closed contacts

$$E - r_1 i_1 + u_c; \quad u_c - U_C = (r_2 + r_0 + r_n) i_2;$$

$$i_1 = i_c = i_2 + i_d; \quad C \frac{du_c}{dt}.$$

By adopting the notation $\Delta u_c = u_c - U_C$ we find by means of consecutive substitutions that

$$\frac{d\Delta u_c}{dt} = \frac{r_1 + r_2 + r_n + r_k}{r_1 C (r_2 + r_n + r_k)} \Delta u_c - \frac{\Delta E}{r_1 C}.$$

The general solution of this equation is

$$\Delta u_c = \Delta E k_1 \left(1 - e^{-\frac{t}{k_2}}\right),$$

where $k_1 = \frac{r_1}{r_1 + r_2 + r_n + r_k}$ is the ratio of the capacitor-charging circuit resistance to the total circuit resistance,

$k_2 = \frac{r_2 + r_n + r_k}{r_1 + r_2 + r_n + r_k}$ is the ratio of the capacitor discharging circuit resistance to the total circuit resistance,

$r = C(r_2 + r_n + r_k)$ is the capacitor discharging time constant.

From the above formulas it is possible to derive expressions for currents and voltages at any parts of the circuit. In particular, the voltage at the input of the null-detector is

$$u_{in} = E S \left(1 - e^{-\frac{t}{k_2}}\right).$$

611