AUTOMATIC LOW-TEMPERATURE CONTROL FOR FRACTURE MECHANICS TESTS

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Many materials used in critical applications must be tested at low temperature to simulate their operating environment or, as with ferritic steels, it is important to know their behavior at the ductile-to-brittle transition. In the latter case the temperature control of the test must be very accurate because of the abrupt variation that steel properties suffer in a narrow temperature range.

In order to do reliable quasi-static fracture mechanics tests, (K_{IC}, CTOD, J_{IC}, R-Curves) at temperatures between 0°C and −100°C, a control system was built. A schematic representation of the system is shown in Fig. 1.

The specimen to be tested is submerged in a vat containing methyl-alcohol. The fluid is circulated by two pumps, one draws liquid from the cold source, the other returns liquid to the cold source. The vat level is maintained by the position of the intake of the returning fluid.

The temperature is measured by means of a Fe-CuNi thermocouple placed in the notch root. The amplified signal is compared with the set point giving an error signal which passes through a proportional plus-integral control. The output determines the time relationship of the signal that will, or will not, be connected to the electrovalve, allowing the circulation of the cold fluid towards the vat. Figure 2 shows a schematic block diagram.

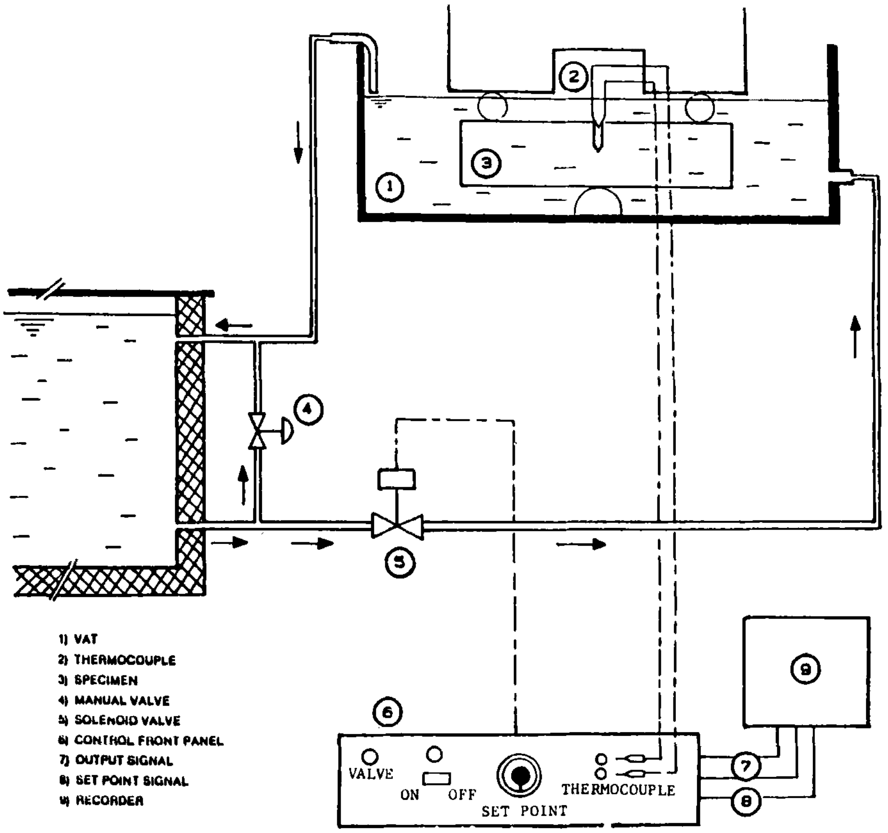

Fig. 1—*Low-temperature control scheme*

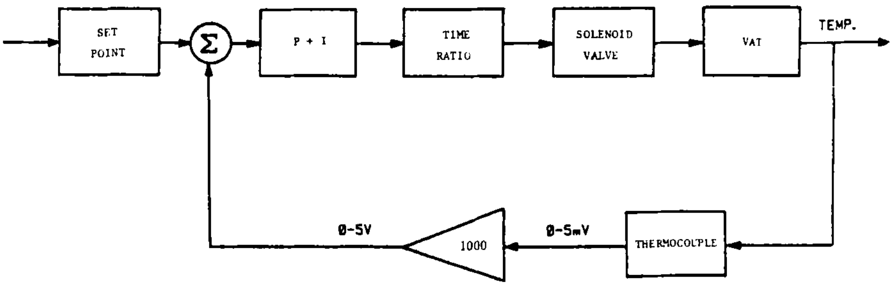

Fig. 2—*System block diagram*

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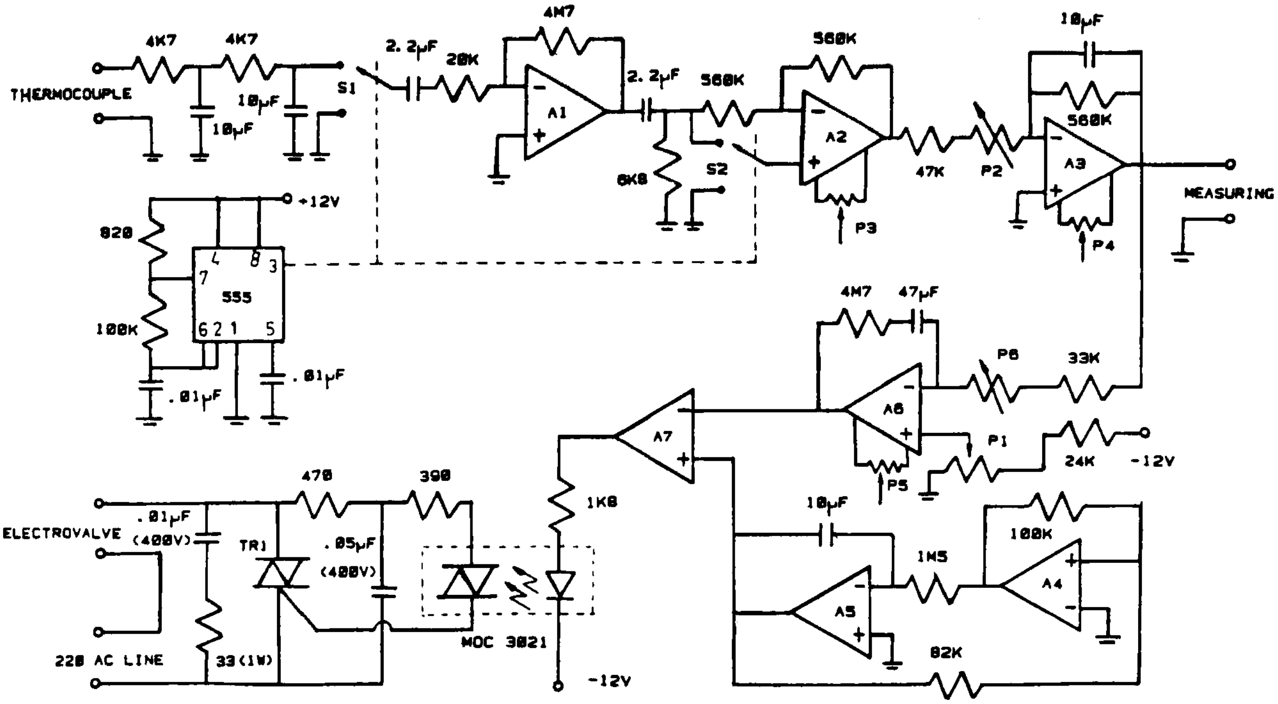

A1-A2-A3-A4-A5-A7 : LM741

A6 : CA3140

TR1 : TIC 226 D

P1 : 10 Kohm Potentiometer

P2 : 10 Kohm Preset

P3 : 10 Kohm 15 turn Preset

P4 : 10 Kohm 15 turn Preset

P5 : 10 Kohm 15 turn Preset

P6 : 470 Kohm Preset

S1-S2 : CD4053

Fig. 3—*Temperature control circuit*

CONTROL CIRCUIT

Figure 3 shows the complete control circuit and a photograph of it is shown in Fig. 4. Three stages can be recognized.

Thermocouple Signal Amplification

In this stage the thermocouple signal voltage (0 to −4.63 mV, corresponding to 0° to −100°C) is amplified 1000 times. With this level of amplification, an offset in the first stage would produce drift. In order to avoid this problem, the analog input is chopped by a switch S1, the resulting A.C. is amplifiied by A1 and then, through S2 and A2, a synchronic detection is achieved. A3 amplifies the signal from 100 to 1000 times. It is also a low-pass filter which eliminates noise from chopping and detection.

The IC 555 gives a 500-Hz signal governing the analog switches S1 and S2.

The adjustments that must be done in this stage are the A2 and A3 offsets (by P3 and P4) and the overall gain which must be adjusted by P2.

The output of A3 is on the front of the control panel where it is easily accessible to drive an external temperature recorder.

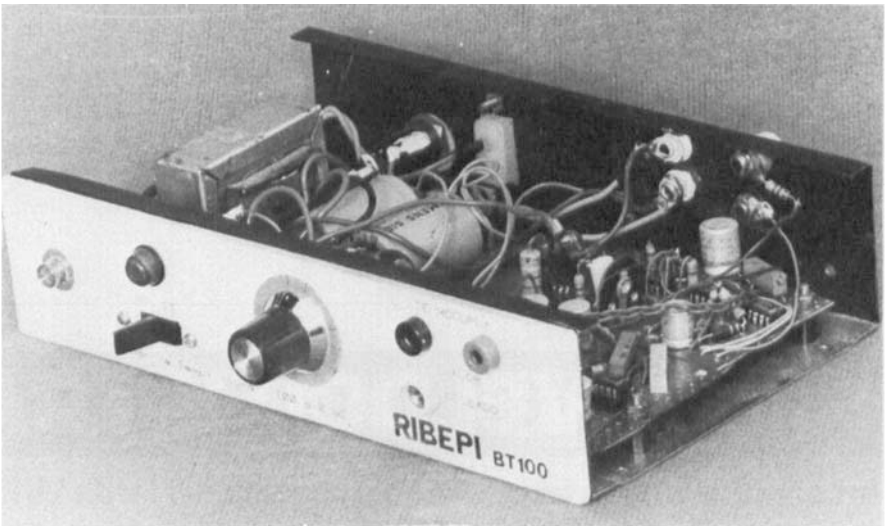

Fig. 4—*Control circuit built*

Proportional Plus Integral Control

The difference between the set point (fixed by P1) and the measurement (output of A3) is amplified and integrated by A6. The gain can be adjusted by P6 between 10 and 150, while the integrating period, given by the resistance R_1 = 4.7 Mohm and the capacitor C_1 = 47 microfarad, is 4 minutes.

The A6 offset must be adjusted by grounding the inputs (measure and set-point signals) and adjusting P5 until constant output is achieved.

The set-point terminal, in the middle of P1, is also at the front panel and its value can be recorded together with the measured temperature signal. The

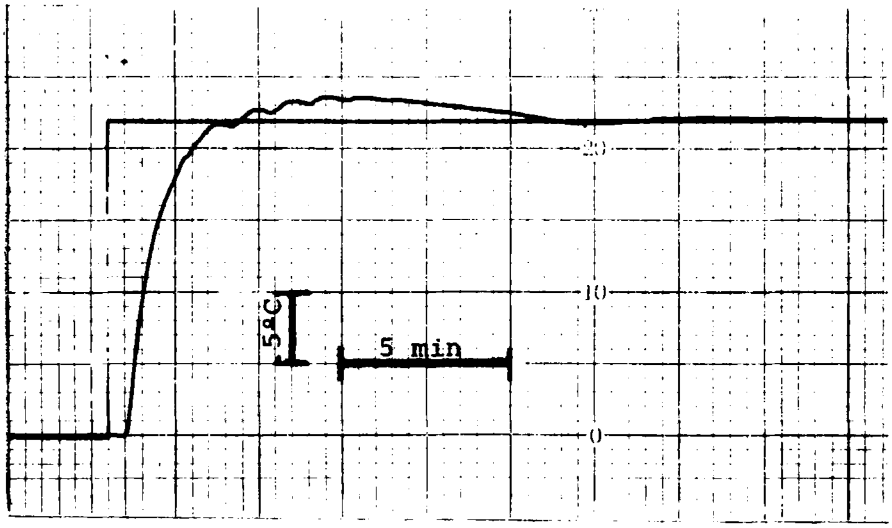

Fig. 5a—*Temperature and set point versus time record*

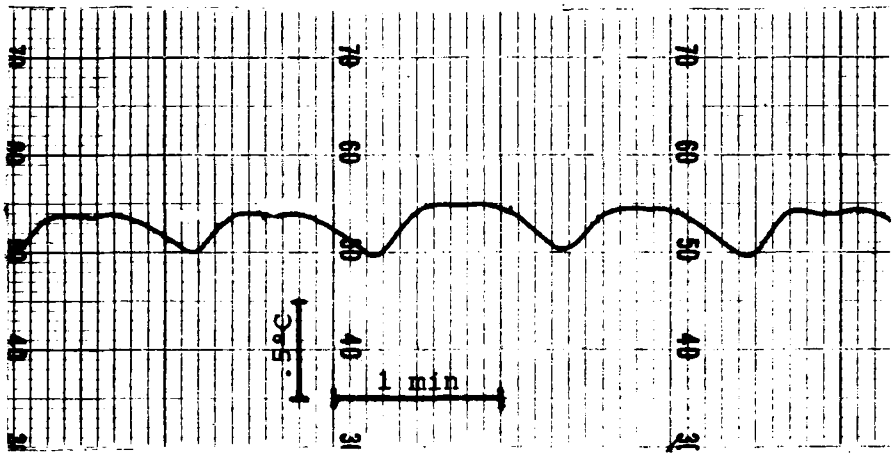

Fig. 5b—*Ripple caused by the on-off valve operation*

set-point value can be adjusted precisely on the recorder's scale.

Time Ratio Determination and Electrovalve Command

P + I control output determines the ON-OFF time ratio of the electrovalve. In A7 the output of A6 is compared with a 1-minute period triangular wave generated by A4 and A5. When A6 output goes up, electrovalve duty time goes down and vice-versa.

A7 output is connected to an optocoupler which fires the TR1 triac. TR1 commands the electrovalve which controls the pass of fluid from the cold source to the vat.

RESULTS

Figure 5a shows a temperature and set point versus time record, in which it can be observed that the integrating action approaches error zero in the steady state. Figure 5b shows the same record but amplified so that the ripple caused by the on-off valve operation is clearly seen. The ripple amplitude changes with the volume of liquid, temperature difference between source and vat, and dissipation conditions between the vat and room conditions. In the figure the conditions were the following: cold-source temperature = −25°C; vat temperature = −18°C; alcohol volume in vat = 3 liters.