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A Method for Temperature Variation and Control of an Isolated Heart Muscle Bath, using Peltier Effect Semiconductors

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ABSTRACT

An isolated tissue bath with a temperature control system is described. By using semiconductors of the Peltier type for continous heating or cooling of the inflowing solution, the bath temperature can easily be varied and kept constant within $\pm 0.1°C$, with very good long-term stability.

INTRODUCTION

In experimental work with tissues *in vitro,* it is often important that the temperature of the perfusion fluid and the bath is kept constant during the course of an experiment. Temperature fluctuation may exert strong influence on the response of the tissue to other, controlled, stimuli, making the reproducibility poor and the interpretation of the results uncertain. On the other hand, if the purpose of the experiment is to investigate the effect of temperature variations on physiological properties, it is necessary that different temperature levels be achieved without long delays and with good accuracy. One common method for temperature control is to keep the tissue chamber in a water bath with a considerable heat capacity. With this method it takes a great part of the experimental period to heat or cool the large volume of the water bath. Furthermore, the method has the disadvantage that it is difficult to obtain constant temperature levels below the ambient temperature.

A system with much less inertia can be constructed if the tissue bath and the inflowing solution alone are heated or cooled. Semiconductors of the Peltier type can be used for this purpose. Temperature control systems following this principle have been described by Kaufmann & Krause (1), Hayashi & Austin (2), Raikhbaum (3), Noyes (4) and Leopold (5). In all these systems a regulation principle of on–off type is used, i.e. the Peltier element is supplied with maximal effect either for heating or for cooling of the tissue bath. This kind of regulation has the disadvantage that it will give unwanted temperature fluctuations. Continuous regulation is therefore preferable. This paper describes a muscle bath, designed for electrophysiological experiments on isolated heart tissue (ventricular strips), with temperature regulation according to a continuous principle.

The mechanical construction of the bath

The muscle bath is made of perspex. The mechanical construction is shown in Fig. 1. The Ringer solution flows through an antechamber with the dimensions $40 \times 15 \times 1$ mm, in which it is heated or cooled before entering the tissue bath. The dimensions of the bath are $40 \times 10 \times 10$ mm. Its bottom is made from 1 mm perspex. The bottoms of the antechamber and the muscle bath are in close contact with the Peltier element. The contact surface between the Peltier element and the heat sink is coated with a thin layer of silicone heat sink compound to give optimum heat exchange. The flow rate of the Ringer solution is set at 4 ml/min. Tap water, thermostatically controlled at 20°C flows through the heat sink.

The electronic control circuit

The bath temperature is measured by a thermistor GA 43 P28 (Fenwal Electronics Inc., Framingham, Mass., USA). The thermistor is part of a conventional bridge circuit (Fig. 2). This circuit has been designed with calibration facilities at the temperatures 5° and 40°C. The voltage source consists of two mercury cells of the type Mallory RM-4. High quality components have been chosen in this circuit to prevent errors due to temperature drift. The principles of the rest of the control loop are illustrated in Fig. 3.

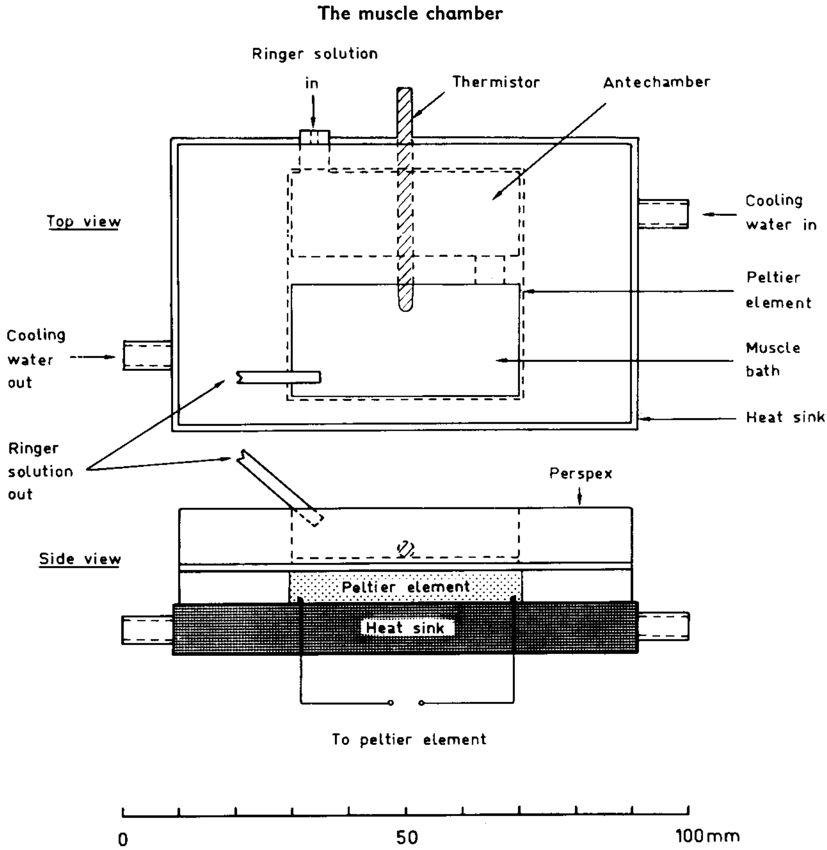

Fig. 1. The mechanical construction of the bath.

The thermistor bridge output voltage is a non-linear function of the bath temperature in the given temperature range. To allow convenient measurement of the temperature with this part of the control system a linearization circuit has been designed. This circuit, using a non-inverting operational amplifier, is shown in Fig. 4. The gain in this circuit is given by the equation

$$\frac{Uo}{U_i} = 1 + \frac{R_F}{R}$$

where R is the compound resistance of the network with two diodes and four resistances. In this circuit R is input voltage dependent and can be calculated by using the conventional circuit theory, given in the Appendix. This theory can be used to calculate the values of the different components for arbitrary temperature ranges and thermistor types.

The linearization circuit is followed by a summation- and voltage amplifying circuit (Fig. 3) in which the temperature reference of the control loop is also included. A two-channel current amplifier using the Darlington configuration feeds the two final complementary transistors Motorola MJ 3771 and MJ 450. A negative feedback between the Peltier element and the voltage/summing amplifier is used to control the dynamic properties of the system.

During the development of the control circuits different kinds of regulatory principles have been studied. A so-called PID system, for instance, has been used. The specified properties of the system could be attained, however, by a simple proportional control circuit.

Achievements

In comparison with similar systems described previously the present system has two definite advantages: 1) Changes between different temperature levels can be produced very quickly. An increase in bath temperature from 5° to 40°C takes $3\,^1/_2$ min and cooling from 40°C to 5°C

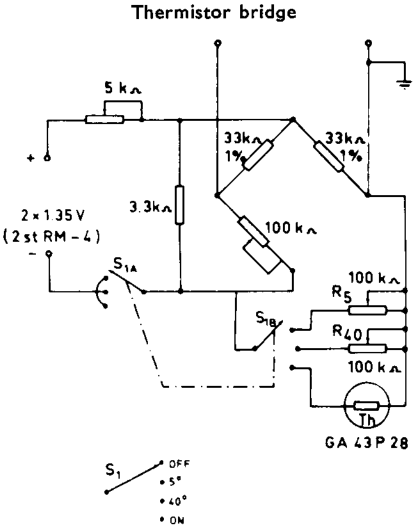

Fig. 2. The thermistor bridge.

takes 4 1/2 min. These measurements were made with a flow rate of the solution of 2 ml/min and with the system critically damped. 2) The deviation in temperature from the preset value is very small; within the interval 5–35°C this amounts to ±0.1°C and the long-term stability is very good. The temperature of the cooling water influences the calibration of the system to some extent. The cooling water must have approximately the same temperature and have a constant flow rate to attain reliable calibration of the system.

APPENDIX

The linearizing circuit

Bridge circuits using thermistors usually show a non-linear relation between measured temperature and output voltage. Linearization methods have been described previously by Beakly (6), Lövborg (7) and Bowman (8). To be able to linearize thermistor bridges in a more flexible way for different thermistor types in different temperature ranges, a new circuit has been developed (Fig. 4).

The following equations are valid for the circuit.

$$I_1 = I_{01} \exp\left(\frac{V_1 q}{kT}\right) \tag{1}$$

$$I_2 = I_{02} \exp\left(\frac{V_2 q}{kT}\right) \tag{2}$$

where

V_1 = the voltage over diode D_1
V_2 = the voltage over diode D_2
q = charge of the electron = $1.602 \cdot 10^{-19}$ As
k = Bolzmann's constant = $1.381 \cdot 10^{-23}$ $J/°K$
T = temperature in Kelvin degrees

Also

$$V_2 = U_i - R_4 \cdot I_4 - R_2 \cdot I_2 \tag{3}$$

$$V_1 = U_i - R_1 \cdot I_1 \tag{4}$$

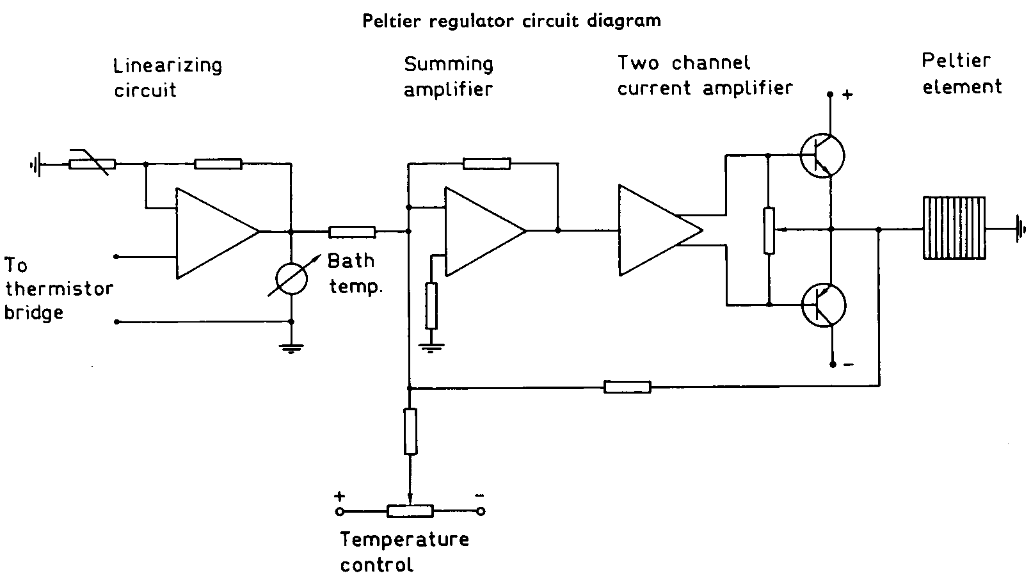

Fig. 3. The control loop.

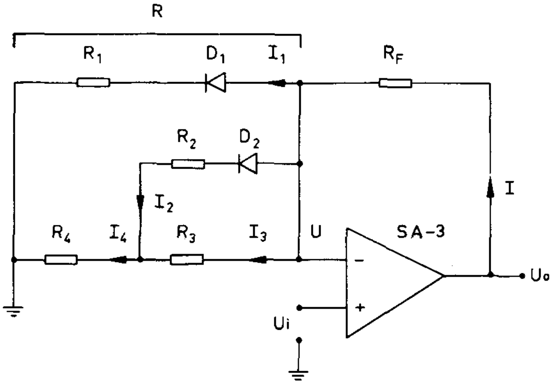

Fig. 4. The linearization circuit.

but $U \approx U_i$

$$I = I_1 + I_2 + I_3 \tag{5}$$

$$I = I_2 + I_3 \tag{6}$$

$$U_i = R_3 \cdot I_3 + R_4 \cdot I_4 \tag{7}$$

From these equations an expression for the gain A can be derived

$$A = 1 + \frac{R_f}{R_3 + R_4} (\delta + 1) \tag{8}$$

where

$$\delta = \frac{R_3 + R_4}{U_i} \cdot I_1 + \frac{R_3}{U_i} \cdot I_2$$

Equations (1)–(8) can be used for approximate calculations and choice of components in this type of linearization circuit.

The following components were chosen for the circuit used (thermistor GA 43 P28, gain 10-fold).

D_1, D_2 = BAX 17	$R_3 = 38.4\ k\Omega$
$R_1 = 33.7\ k\Omega$	$R_4 = 12.0\ k\Omega$
$R_2 = 237.6\ k\Omega$	$R_F = 470\ k\Omega$

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