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## Modern Instruments

# DIGITAL TEMPERATURE PROGRAMMER* WITH TWO TEMPERATURE SENSORS

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A new temperature programmer has been developed to provide accurate and sharp temperature programs for different ovens and furnaces, including those of thermoanalytical instruments. Control is based on two temperature sensors (thermocouples or resistance thermometers); sensor "A" is situated in the working space of the furnace (in the vicinity of the sample), while sensor "B" is near the heating wire.

The principle of operation and the effects of controls are discussed, and several examples are presented to demonstrate the use of the programmer with different heater assemblies.

Investigations with thermoanalytical and other methods using electrical heating often require reliable maintenance of the temperature, or temperature changes with accurate heating and cooling rates, or some other type of temperature program. Several modern digital and analog temperature programmers of high accuracy are used for this purpose. A common feature of these devices is that the temperature is measured near the heating element by one sensor only (thermocouple, thermistor or resistance thermometer). The control signal from the temperature sensor and the reference signal from the program generator are led into a comparator unit, whose output is fed into the heater control unit.

These programmers satisfy most of the requirements of the users, but their disadavantage becomes significant in the controlling of heaters of higher mass (thermal inertia). In this case, the temperature of the working space (sample temperature) and the rate of temperature change during the initial period do not entirely correspond to the selected value or program, because of the thermal inertia of the heater. The inertia will also result in slow and inaccurate switching from constant-rate heating or cooling to isothermal. Another disadvantage of these programmers is that the temperature displayed in digital or analog form corresponds to the program value, but is not the temperature of the working space (sample), this being important for the user. (It is well known that a signif-

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* Digital Temperature Programmer LP 839 has been developed at Budapest Technical University. It is manufactured by CHINOIN, and exported by METRIMPEX and AKADIMPORT, Budapest, Hungary.

icant difference, depending on the construction of the oven, can exist between the sample and the program temperatures.)

These problems are overcome by the digital temperature programmer developed at our Institute. Control of the temperature is based on two temperature sensors (thermocouples or resistance thermometers). One of them senses the temperature of the working space (sample) and its digitalized signal is displayed on the front of the apparatus. Another sensor is situated (as usual) near the heating wire, and both temperature signals are used by the programmer-controller.

## Operating principle

The block diagram of the programmer is shown in Fig. 1. Two temperature sensors (thermocouples or resistance thermometers) are mounted into the oven. Sensor "*A*" measures the temperature of the working space (sample), while sensor "*B*" measures that in the surroundings of the heater wire.

The signal of sensor "*A*" (after cold-junction compensation) is measured by a digital thermometer. The thermometer, which is a double integrating type voltmeter, has a linearizer corresponding to the characteristics of the thermocouple. The measured value (shown on the display) is led to the comparator circuit.

The signal from sensor "*B*" (after cold-junction compensation) is led into an amplifier separating sensor "*B*" galvanically from the inner circuits of the instru-

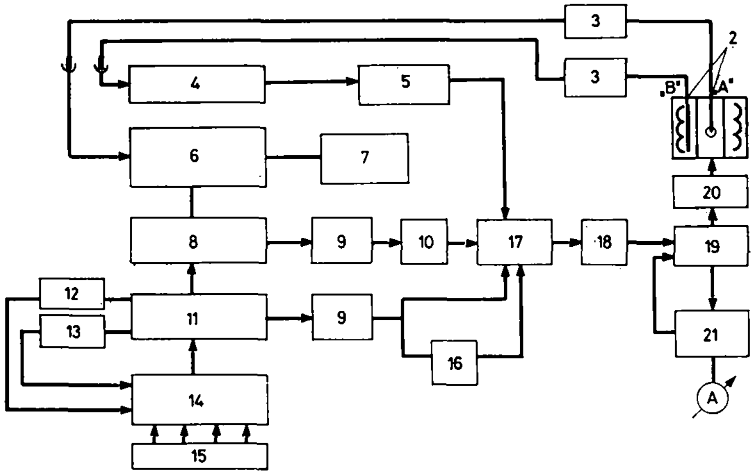

Fig. 1. Block diagram of the temperature programmer

1 — furnace; 2 — temperature sensor; 3 — cold junction compensator; 4 — "*B*" amplifier; 5 — linearizer; 6 — digital thermometer and linearizer; 7 — display; 8 — comparator; 9 — D-A converter; 10 — $P_2$ control; 11 — program counter; 12 — upper limit selector; 13 — lower limit selector; 14 — operating unit; 15 — operating switches; 16 — $\Delta T$ control; 17 — summing amplifier and $P_1$ control; 18 — $I$ control; 19 — thyristor driver; 20 — power control; 21 — current limiter

ment. (This is needed because sensor "*B*" may be touching the heating wire for accurate measurement.) The amplified signal passes to a summing amplifier through a linearizer. The other three inputs of the summing amplifier are the program signal, the output of the $\Delta T$ circuit and the $P_2$ control signal.

The program signal is an analog signal converted from the digital signal of the program counter. The program counter is controlled by the operating unit. The number of steps corresponding to the heating or cooling rate is given by the time base divider in the operating unit, dividing the line frequency (50 Hz) according to the selected rate. The signals of the operating unit depend on the positions of the operating selectors, including the temperature limits. The required lower and upper temperature limits are set by means of direct-reading dial switches, whose binary coded signals are compared to the actual value of the program counter.

The signal of sensor "*A*" is led to the comparator circuit, as mentioned below. The difference between the digital signals of the program counter and the digital thermometer is formed by the comparator circuit, and this difference signal passes to the summing amplifier through a $D-A$ converter.

In the summing amplifier, the effect of the amplified signal of sensor "*B*" has a sense opposite to that of the program signal and the $\Delta T$ and $P_2$ control signals. The resultant signal of the summing amplifier passes through an *I* control unit to the power-controlling thyristors.

In order to protect the heating wire, a maximum heater current can be chosen by means of a current-limiter circuit.

Four control circuits ($P_1$, $P_2$ , *I* and $\Delta T$ control) provide a precise fit of the programmer to the heater in question. These control circuits can be adjusted with potentiometers mounted into the front panel of the instrument.

In the following, the effect of controls on the heating curve will be demonstrated. It is important to mention that if the $P_2$ control is set to zero (it has no effect) the apparatus will operate as a conventional one-sensor programmer-controller.

(a) Proportional control $P_1$ controls the level of the summing amplifier output. Its effect is demonstrated in Fig. 2, provided $P_2 = 0$. The curves were measured in the furnace shown in Fig. 6, having a power of about 900 W.

The curves of Fig. 2 show the temperature of the sample situated inside the furnace. It may be seen that the temperature curve has a prolonged starting and levelling-off period, even at the optimum $P_1$ value. At higher $P_1$ values the starting period is better, but the temperature runs over the upper limit and returns to the selected value very slowly. Even at the optimum $P_1$ position, the temperature of the inner space increases with the selected 10°/min rate after 100–120° only. Before that, the real heating rate is slower than 10°/min.

(b) The initial and levelling-off part of the curve can be improved by means of the $P_2$ control. $P_2$ controls the level of the signal, proportional to the difference of the temperature value from sensor "*A*" and the program count. The effect of $P_2$ (at the optimum of $P_1$) is demonstrated in Fig. 3.

The curves show that setting $P_2$ to the optimum value improves the initial and the levelling-off part of the temperature curve in comparison to conventional

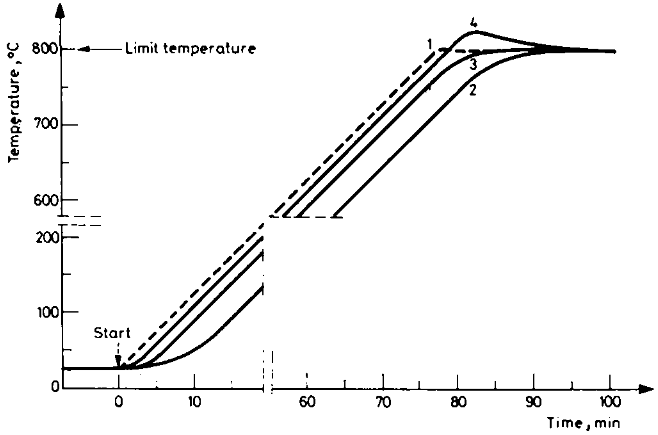

Fig. 2. The effect of $P_1$ control on heating (temperature vs. time) curves. Heating rate: 10°/min; $P_2 = 0$. 1 — theoretical; 2 — $P_1$ is low; 3 — $P_1$ is optimum; 4 — $P_1$ is too high

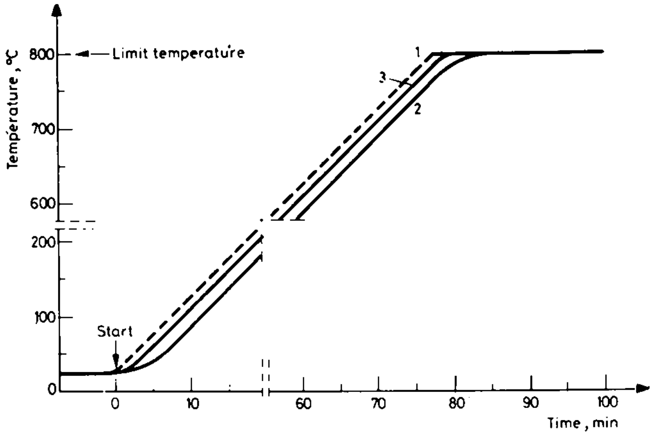

Fig. 3. The effect of $P_2$ control on heating (temperature vs. time) curves. Heating rate: 10°/min $P_1$ is optimum. 1 — theoretical; 2 — $P_2 = 0$; 3 — $P_2$ is optimum

programmers ($P_2 = 0$). In the case of the furnace shown in Fig. 6, this means that the heating rate in the working space was 10°/min from even 35—40° on (the starting temperature being 25°). At the same time, switching to isothermal is very sharp too: the sample temperature increased with the selected 10°/min rate up to 795°, and did not start to decrease earlier. The temperature of the working space then levelled off at the selected 800° value.

(c) In order to increase the temperature of the working space (sample) up to the selected value, a higher furnace temperature is necessary. This difference is adjusted by the $\Delta T$ control, whose effect is shown in Fig. 4.

(d) The $I$ integrating control diminishes the effect of noises.

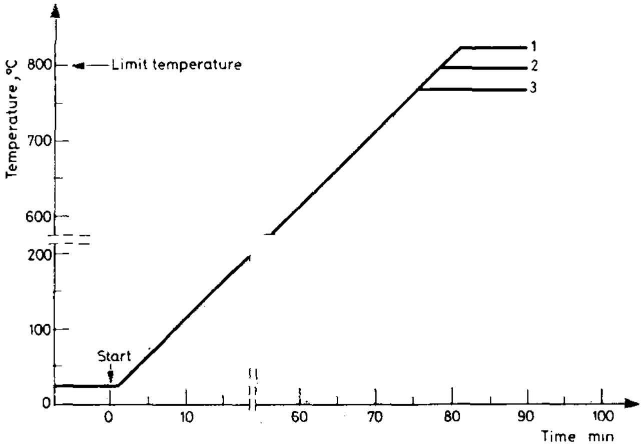

Fig. 4. The effect of $\Delta T$ control on the final temperature. Heating rate: 10°/min; both $P_1$ and $P_2$ are optimum. 1 — $\Delta T$ is high; 2 — $\Delta T$ is optimum; 3 — $\Delta T$ is low

Fig. 5. Temperature programmer model LP 839

The temperature programmer can be connected to programmable calculators or computers. Logical outputs needed for this purpose are led to the rear panel of the apparatus. In this case, the calculator controls the operation, giving commands according to the computer program. Thus, non-linear temperature changes can be programmed too.

## Technical data of the programmer

Temperature accuracy: ±1% and ±1 digit.

Program modes:

1. programmed heating and switching-off at the upper limit;
2. programmed cooling and switching-off at the lower limit;

3. programmed heating and switching to isothermal at the upper limit;
4. programmed cooling and switching to isothermal at the lower limit;
5. cyclic program between the selected lower and upper limits;
6. isothermal.

Temperature limits: the upper and lower limits can be set to any degree C.
Program rates: 1, 2, 5 and 10°/hour,

0.5, 1, 2, 5, 10, 20 50°/min.

Program rate accuracy: depends on line frequency.

External clock signal: TTL level impulse. One impulse results in a 1° step of the program.

Control mode: $P - I$ type based on two temperature sensors.

The apparatus is manufactured with a Pt-100 resistance thermometer, and PtRh – Pt, NiCr – Ni, chromel-alumel and Fe-constantan thermocouples.

$$\text{Characteristics of the heater circuit: } \begin{aligned} V_{\max} &= 250 \text{ V;} \\ I_{\max} &= 10 \text{ A;} \\ f &= 50 \text{ Hz.} \end{aligned}$$

An adapter is available for programming heaters of higher power, up to 25 kVA.

Mains: 220 V, 50 Hz.

Voltage deviation permitted: $-15\% - +10\%$.

Sizes: width: 325 mm;
depth: 300 mm;
height: 90 mm.

Figure 5 presents a photograph of the programmer.

## Fields of application

The temperature programmer can be used with several types of apparatus: laboratory furnaces, drying ovens, apparatus for thermal treatment (up to pilot-plant size), thermoanalytical instruments (DTA and heat-flux DSC cells, thermobalances, derivatograph, dilatometers, thermomagnetic balances), liquid thermostats, microscope hot-stages, heated X-ray diffraction chambers, gas chromatographs, zone-melting ovens, furnaces for single-crystal growing and other special devices.

Some examples of thermocouple accommodation will now be presented.

(a) Figure 6 shows the cross-section of the furnace of a derivatograph (manufactured by MOM, Hungarian Optical Works). The maximum power of the furnace is about 900 W. Thermocouple "*B*" is situated near the heater coil, or may even touch it. Two locations of thermocouple "*A*" have been tried. In the arrangement shown in the Figure, it is between the two crucibles, its distances from the sample and reference being the same. However, the sample thermocouple originally built in the derivatograph can also be used as sensor "*A*". In our experience, this does not influence the DTA signal.

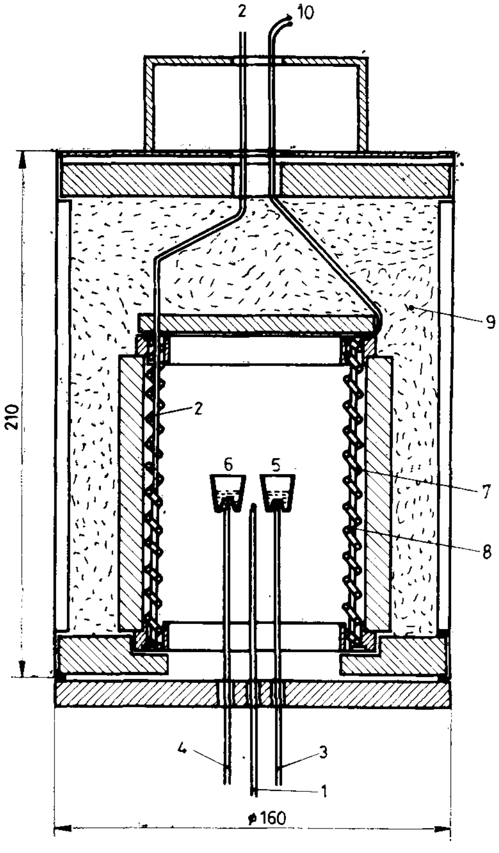

Fig. 6. Arrangement of the sensors in a derivatograph furnace. 1 — thermocouple "A"; 2 — thermocouple "*B*"; 3 — sample thermocouple; 4 — reference thermocouple; 5 — sample crucible; 6 — reference crucible; 7 — heating wire; 8 — ceramic beam; 9 — thermal insulator; 10 — heater terminals

Temperature vs. time curves are presented in Figs 2 and 3. Both thermocouples are PtRh(10%)-Pt.

(b) In Fig. 7 part of the cross section of a DuPont 910 DSC Cell can be seen. In this case, thermocouples built in the cell by the manufacturer were used. A platinel II thermocouple measuring the temperature of the silver heating block was used as sensor "*B*", and the chromel-alumel sample thermocouple as "*A*". The heater power is about 600 W.

(c) Figure 8 shows the cross-section of the furnace of a DuPont 951 thermobalance. Both thermocouples are chromel-alumel; "B" is situated between the heating wire and the ceramic tube, while "*A*" is 1–2 mm above the sample. The power of the furnace is near 2 kW. This arrangement can be regarded as typical of any horizontal type furnace.

(d) Figure 9 gives a drawing of a microscope hot-stage connected to the programmer. Different parameters of the program make investigations very easy and

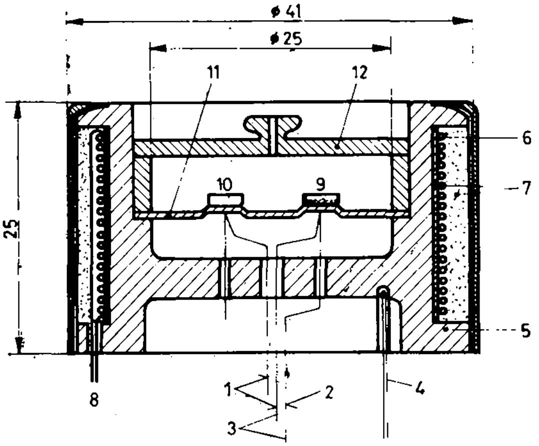

Fig. 7. Cross-section of the DuPont 910 DSC cell. 1 — chromel wire; 2 — alumel wire; 3 — thermocouple "*A*" (chromel-alumel); 4 — thermocouple "*B*" (platinel II); 5 — silver block; 6 — heating wire; 7 — thermal insulation; 8 — heater terminals; 9 — sample; 10 — reference; 11 — constantan disc; 12 — lid

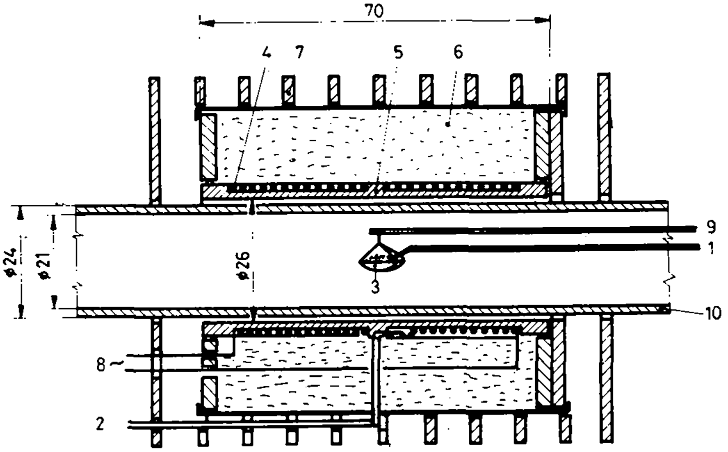

Fig. 8. Arrangement of thermocouples in the furnace of the DuPont 951 thermobalance. 1 — thermocouple "*A*"; 2 — thermocouple "*B*"; 3 — sample; 4 — heating wire; 5 — ceramic tube; 6 — thermal insulator; 7 — gill; 8 — heater terminal; 9 — balance beam; 10 — quartz tube

fast; in the case of melting-point determination, the sample can be heated with a higher rate at the beginning (e.g. 10°/min), and a slower rate (e.g. 1°/min) can be applied near the melting point.

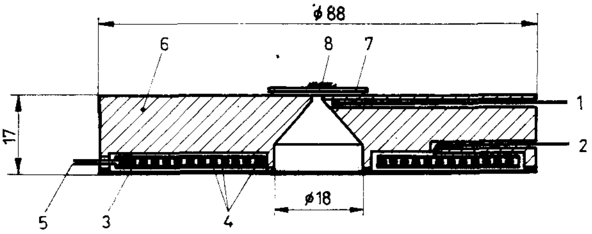

Fig. 9. Arrangement of thermocouples in a microscope hot-stage. 1 — thermocouple "*A*"; 2 — thermocouple "*B*"; 3 — heating wire; 4 — mica; 5 — heater terminals; 6 — aluminium block; 7 — glass plate; 8 — sample

Both thermocouples are of the NiCr—Ni type; thermocouple "*B*" is situated directly above the heating wire, while "*A*" measures the temperature of the surface of the hot-stage. The latter was calibrated by means of melting-point standards. The heater power is about 700 W.

Programming the furnace shown in Fig. 6 was found to be the most difficult of these cases, because of the dimensions and thermal inertia. Using two temperature sensors a heating curve close to the theoretical was achieved even with this furnace. Even better curves were obtained with the other heaters, e.g. with the furnaces shown in Figs 6 and 8 switching to isothermal was sharp and without overshoot, even after 50°/min heating.

RÉSUMÉ — On a mis au point un nouveau programmeur de température afin d'obtenir des programmes de température exacts et nets avec divers fours, y compris ceux des instruments d'analyse thermique. Le contrôle repose sur deux senseurs de température (thermocouples ou thermomètres à résistance); le senseur *A* se trouve dans l'espace de travail du four (à proximité de l'échantillon), le senseur *B* se trouve près du fil de chauffage.

Le principe de l'opération et l'effet du contrôle sont discutés; plusieurs exemples montrent l'application du programmeur avec différents dispositifs de chauffage.

ZUSAMMENFASSUNG — Ein neues Temperaturprogrammiergerät wurde zur Herstellung genauer und scharfer Temperaturprogramme für verschiedene Öfen, thermoanalytische Geräte mit inbegriffen — erarbeitet. Die Steuerung beruht auf zwei Temperatursensoren (Thermoelemente oder Widerstandsthermometer); der Sensor *A* befindet sich im Arbeitsraum des Ofens (in der Nähe der Probe), der Sensor *B* ist in der Nähe der Heizwicklung.

Das Arbeitsprinzip und der Effekt der Steuerungen wird erörtert und mehrere Beispiele angeführt, um die Anwendung des Programmiergeräts mit verschiedenen Heizvorrichtungen zu zeigen.

Резюме — Разработан новый температурный программатор, предназначенный для обеспечения точных и резких температурных программ в различных термостатах и печах, включая таковые в термоаналитических приборах. Контроль осуществляется двумя температурными сенсорами, из которых сенсор „*A*" размещен в рабочем пространстве печи (в непосредственной близости к образцу), а сенсор „*B*"-около нити нагрева. Обсужден принцип работы прибора и влияние регулировки. Представлено несколько примеров, показывающих использование программатора с различными нагревательными устройствами.