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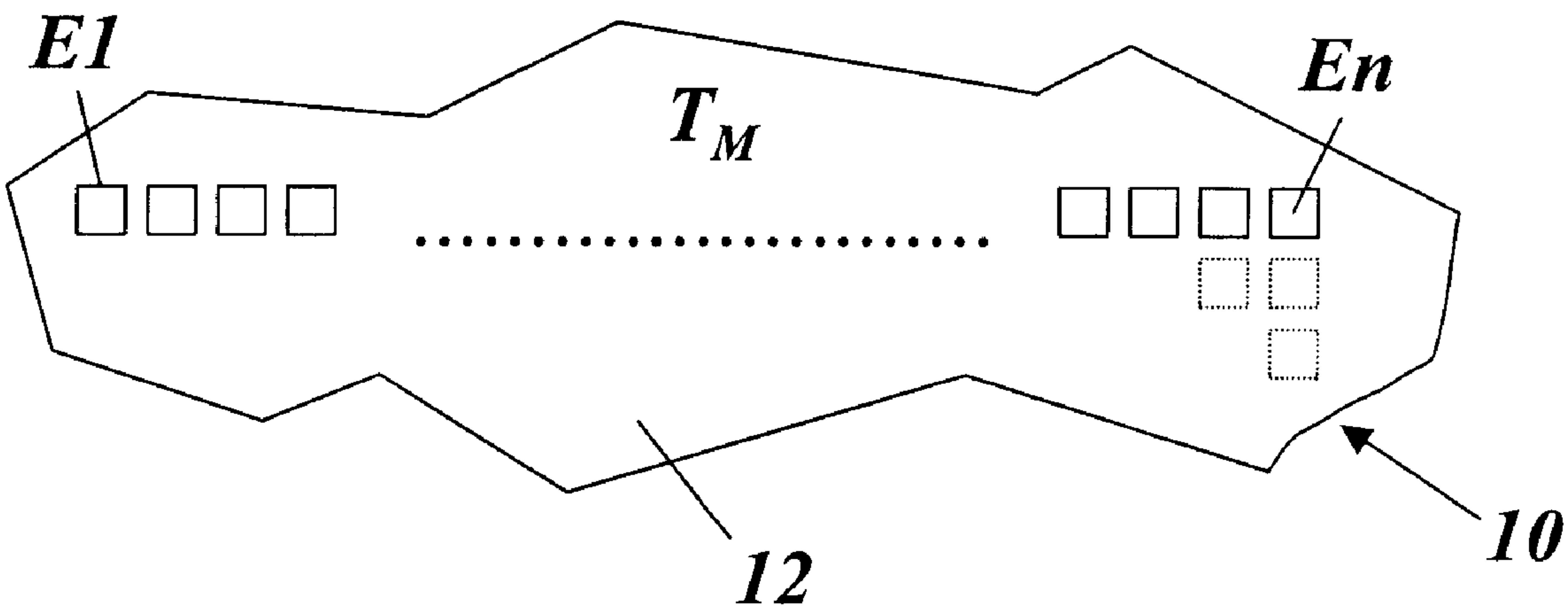
(54) **Titre :** PROCEDE DE DETERMINATION PASSIVE DE LA TEMPERATURE DE FONCTIONNEMENT DANS UN DISPOSITIF THERMIQUEMENT TRES SOLLICITE ET APPAREIL POUR METTRE EN OEUVRE LE PROCEDE

(54) **Title:** METHOD FOR PASSIVE DETERMINATION OF THE OPERATING TEMPERATURE IN A THERMALLY HIGHLY LOADED DEVICE, AND APPARATUS FOR CARRYING OUT THE METHOD




(57) **Abrégé/Abstract:**
Arrangements (10) of individual measurement elements (E1,...,En) in which a physical parameter is unambiguously dependent on the temperature at which a heat treatment is being carried out and used for passive measurement of the operating temperature in thermal machines (12) or boilers. Each measurement element (E1,...,En) has been preset by a different heat treatment temperature. In order to determine the operating temperature, the physical parameter of each measurement element (E1,...,En) is measured before and after use in the machine, and the measured values are compared in pairs.

# ABSTRACT

Arrangements (10) of individual measurement elements (E1,...,En) in which a physical parameter is unambiguously dependent on the temperature at which a heat treatment is being carried out and used for passive measurement of the operating temperature in thermal machines (12) or boilers. Each measurement element (E1,...,En) has been preset by a different heat treatment temperature. In order to determine the operating temperature, the physical parameter of each measurement element (E1,...,En) is measured before and after use in the machine, and the measured values are compared in pairs.

(Figure 5)

DESCRIPTION

# METHOD FOR PASSIVE DETERMINATION OF THE OPERATING TEMPERATURE IN A THERMALLY HIGHLY LOADED DEVICE, AND APPARATUS FOR CARRYING OUT THE METHOD

## TECHNICAL FIELD

The present invention relates to the field of temperature metrology. It relates in particular to a method for passive determination of the operating temperature in a thermally highly loaded device, and to an apparatus for carrying out the method.

## PRIOR ART

In the field of thermal machines (for example gas turbines) and boilers, it is of very major importance to know the actual operating temperatures (typically 700-1000°C) at various points in the apparatus. However, it is frequently impossible to retrospectively additionally fit active (wired) sensors in an apparatus which is already in use, as a result of which passive sensors, which indicate the temperature by a (permanent) change in their physical characteristics, are the means of choice in situations such as these.

Thermal paint is known, a paint which changes its color permanently as a function of the temperature. Among the various disadvantages of this solution, the necessity should be stressed, in particular, for the apparatus to be disassembled before the parts to be investigated can be painted, the relative inaccuracy of the temperature determination, and the need for a closely monitored "extra run" of the apparatus, as a result of which the measurement does not reflect the normal operating conditions. However, one major disadvantage is that the chemical reaction which leads to the color change is not reversible. It is therefore possible to measure only the maximum temperature reached on each occasion throughout the entire operation.

Furthermore, metallographic temperature determination is known, but this is not non-destructive and is therefore not feasible for the stated applications.

In addition to the thermal paint technique, there are numerous other experiments involving the part of the apparatus to be investigated being provided with a thick-film coating which has thermal memory characteristics, that is to say which uses a stable change in the molecular structure with a number of the high-temperature operations to which it was most recently subject.

An ideally reversible process (reversible in the sense that the process follows the operating temperature and does not just register the highest temperature measured in each case) leads to a measurable change in the physical characteristics (variables, parameters), which may be electrical (resistivity), magnetic (permeability, magnetization, magnetic saturation), mechanical (hardness, modulus of elasticity, Poissin ratio, yield point, strain, density), acoustic (compression wave velocity, shear-wave velocity, bar velocity), thermal (thermal conductivity and strain) or optical (color change).

Once the coating has cooled down, the aim is to determine the last high-temperature operation by subjecting the parts investigated to various heat treatments, and by finding the sought temperature through the use of empirical interpolation rules.

DESCRIPTION OF THE INVENTION

According to an aspect of the present invention, there is provided a method for passive determination of the operating temperature in a thermally highly loaded device comprising the following steps: a plurality of individual passive measurement elements are provided, which have at least one measurable physical parameter which depends unambiguously on a constant temperature which is set during heat treatment of the measurement element or of a material which is used in the measurement element, and which parameter is set differently for the different measurement elements, the individual measurement elements are combined to form a one-dimensional or multi-dimensional arrangement such that the entire arrangement is subject to essentially only one temperature during the measurement of the operating temperature; in a first measurement, the values of the physical parameter are determined for all the measurement elements in the arrangement, before the arrangement is subjected to the operating temperature to be measured; the arrangement is subjected over a relatively long time period to the operating temperature to be measured in the device; in a second measurement, the values of the physical parameter are then determined for all the measurement elements in the arrangement; and the values of the physical parameter measured in the first and the second measurement for each of the measurement elements are compared with one another and the temperature of the heat treatment of that measurement element whose value of the physical parameter has changed the least in the two measurements is taken as the measured temperature.

According to another aspect of the present invention, there is provided an apparatus for carrying out the method described above comprising a plurality of individual passive measurement elements which have at least one measurable physical parameter which depends unambiguously on the constant temperature which is set during heat treatment of the measurement element or of a material which is used in the measurement element, and which parameter is set differently for the different measurement elements, wherein the individual measurement elements are combined to form a one-dimensional or multi-dimensional arrangement such that the entire arrangement is subject to essentially only one temperature during the measurement of the operating temperature.

Some embodiments may specify a method for determination of the operating temperature in a thermally highly loaded apparatus, which method avoids the disadvantages of known methods and is distinguished by the capability to be carried out in a simpler manner, good accuracy and flexible use.

The solution according to some embodiments proposes that a set of thermal memory elements be subjected to the high temperatures to be determined, with each element in the set previously having been subjected to a heat treatment at a well-defined temperature, which differs from one element to another. That element whose heat treatment temperature is closest to the operating temperature will indicate the least changes in its physical characteristics. The resolution is in this case a function of the accuracy with which the heat treatment was previously applied to the elements.

One refinement of the method according to some embodiments is distinguished in that in the course of the comparison of the values from the first and the second measurement, the measured values of the physical parameter are subtracted from one another in pairs. However, it is also possible to use other mathematical approaches for comparison of the two measurements. Another refinement of some embodiments is characterized in that in order to set the different physical parameter in the measurement elements, the measurement elements are each subjected to a heat treatment at a different temperature, wherein the different temperatures of the heat treatment are in a predetermined temperature range and are distributed uniformly over the predetermined temperature range.

One refinement of the apparatus according to some embodiments is distinguished in that the measurement elements are solid bodies with a volume of a few $mm^3$.

BRIEF EXPLANATION OF THE FIGURES

The invention will be explained in more detail in the following text with reference to exemplary embodiments and in conjunction with the drawing, in which:

Figure 1 shows an example of the dependency of a physical parameter P on the heat treatment temperature $T_{HT}$ of the elements with temperature memory, according to an embodiment of the invention;

Figure 2 shows an example of a 1-,2- or 3-dimensional arrangement of individual elements with temperature memory for measurement of the temperature;

Figure 3 shows the first measurement of the physical parameter P of the individual elements in the arrangement shown in Figure 2 before use for temperature determination;

Figure 4 shows the values of the physical parameter determined in the measurement shown in Figure 3 for the individual elements in the arrangement;

Figure 5 shows the use of the element arrangement in a thermal machine, for example a gas turbine;

Figure 6 shows the second measurement of the physical parameter P of the individual elements in the arrangement shown in Figure 2, after use for temperature determination;

Figure 7 shows the values of the physical parameter determined during the measurement shown in Figure 6 for the individual elements of the arrangement; and

Figure 8 shows the comparison of the results of the two measurements in the form of a subtraction of the value matrices.

APPROACHES TO IMPLEMENTATION OF THE INVENTION

As shown in Figure 1, the exemplary embodiment of the invention as described in the following text is based on a measurement element Ex, which by way of example is cuboid, with the edge lengths 2×2×1 mm, which is composed of a material with a physical parameter P, for example electrical conductivity, which depends, on the basis of the curve illustrated in Figure 1, on the temperature $T_{HT}$ at which the measurement element Ex was subjected to a relatively long-lasting heat treatment (HT). Other physical parameters of a mechanical, magnetic, visual or thermal nature may, of course, also be used.

The value of the physical parameter P reached during this heat treatment is maintained when the measurement element Ex is cooled down sufficiently quickly to normal temperature after the heat treatment. This makes it possible to produce correspondingly different values $P_1, \ldots, P_n$ of the physical parameter P for different measurement elements E1,...,En in an unambiguous and reversible manner by a choice of different temperatures $T_1, \ldots, T_n$ for the heat treatment. If, for example, the measurement element E3 whose physical parameter P has been set to a value $P_3$ by a heat treatment at the heat treatment temperature $T_{HT} = T_3$ is then subjected to a heat treatment at the lower temperature $T_2$, the value of the physical parameter P changes from $P_3$ to $P_2$.

When the aim is now to measure the current operating temperature on a part of the apparatus in a thermal machine (gas turbine or the like) or a boiler (steam generator etc.) which is operated at high temperatures, a multiplicity of individual measurement elements E1,...,En are produced which have been heat treated at different, graduated temperatures $T_1,...,T_n$ and have correspondingly different values $P_1,...,P_n$ of the selected physical parameter P. In order to allow accurate measurement of the temperature, the temperature values $T_1,...,T_n$ should be distributed as uniformly as possible around the operating temperature to be expected.

The measurement elements E1,...,En prepared in this way are now combined as shown in Figure 2 to form a linear, two-dimensional or else three-dimensional element arrangement 10 (Figure 2 shows a linear arrangement of the measurement elements E1,...,En; a 2-dimensional arrangement is indicated by the additional elements shown by dots). When choosing the element arrangement 10, care should be taken to ensure that the individual measurement elements E1,...,En contained therein are as far as possible all subjected to the same operating temperature during the measurement at the subsequent measurement location, in order to allow unambiguous temperature determination.

Now, as shown in Figure 3, the value of the physical parameter P is determined at each of the measurement elements E1,...,En for the element arrangement 10 as shown in Figure 2, in a first measurement by means of the suitable measurement apparatus 11. As shown in Figure 4, a linear arrangement of measurement elements E1,...,En then results in a linear series of associated P values, $P_1$, $P_2$, $P_3$, ..., $P_{n-2}$, $P_{n-1}$, $P_n$; a 2-dimensional arrangement and measurement elements Ex will correspondingly result in a 2-dimensional matrix of P values.

After the first determination of the P-values, the element arrangement 10, as shown in Figure 5, is fitted to the point selected for temperature measurement on a machine part 12 or the like and is subjected to an operating temperature $T_M$ there throughout the duration of the measurement.

Then, in a second measurement (Figure 6), the P values of the individual measurement elements E1,...,En of the element arrangement 10 are then measured. This measurement now results in a series of P-values $P'_1$, $P'_2$, $P'_3$, ..., $P'_{n-2}$, $P'_{n-1}$, $P'_n$, which in general differ from the P values $P_1$, $P_2$, $P_3$, ..., $P_{n-2}$, $P_{n-1}$, $P_n$ from the first measurement. This applies to the measurement elements Ex whose heat treatment temperature $T_{HT}$ differs from the operating temperature $T_M$. The operation of the operating temperature $T_M$ results in these measurement elements in practice being subjected to a heat treatment at a different heat treatment temperature, as a result of which their value of the physical parameter P changes. Only for that measurement element Ex whose heat treatment temperature $T_{HT}$ is equal to the operating temperature $T_M$, or differs only slightly from it, does the value of the physical parameter P not change, or changes only slightly.

By pair-by-pair comparison of the P values $P_1$, $P_2$, $P_3$, ..., $P_{n-2}$, $P_{n-1}$, $P_n$ measured before use with the P values $P'_1$, $P'_2$, $P'_3$, ..., $P'_{n-2}$, $P'_{n-1}$, $P'_n$ measured after use, it is possible to determine in a simple manner the measurement element Ex whose P value has not changed, or is virtually unchanged. The heat treatment temperature associated with these measurement elements is then equal to or approximately equal to the operating temperature $T_M$ during use at the location of the element arrangement 10.

If the mathematical comparison method is subtraction, the comparison can be formalized by subtracting the rows or matrices of the measured P values from one another before and after use, as is illustrated schematically in Figure 8. For the measurement element E1, the subtraction $P_1-P'_1$ results in a difference value $x_1$, the subtraction $P_2-P'_2$ for the measurement element E2 results in a difference value $x_2$, etc. If, for example, it is found that the measured value $P'_{n-2}$ is approximately equal to the measured value $P_{n-2}$, the subtraction results approximately in the difference value 0 (Figure 8). This can be used to deduce that the operating temperature $T_M$ to be measured was approximately equal to the heat treatment temperature $T_{n-2}$ of the measurement element $E_{n-2}$.

The measurement method according to the invention can be summarized, once again, as follows:

(1) Thermal memory elements are produced.

(2) The elements are preset by a heat treatment, with each element being subjected to a different heating temperature.

(3) The preset elements are combined in a suitable arrangement (1-, 2-, or 3-dimensional).

(4) Specific physical characteristics (parameters) of the elements are measured and stored.

(5) The element arrangement is installed at the measurement location and is subjected to the operating temperature there.

(6) After completion of operation, the arrangement is removed and the selected physical characteristics of the elements are measured again.

(7) The measured values are compared in pairs, for example by subtraction from one another. In the case of subtraction, that element whose values have changed the least and which is therefore most severely affected by the subtraction has a heat treatment temperature

which comes closest to the operating temperature.

The proposed new measurement method is a relative measurement, and not an absolute measurement. It allows precise, low-cost measurement of the thermal operating conditions in gas turbines and boilers. Different temperature ranges can be covered depending on the material of the elements used, thus allowing the method to be used for thermal apparatuses with different operating temperatures.

LIST OF REFERENCE SYMBOLS

| | |
|---|---|
| 10 | Element arrangement |
| 11 | Measurement apparatus |
| 12 | Machine part |
| E1,...,En | Measurement element (passive) |
| $P, P_1, ..., P_n$ | Parameter (temperature-dependent) |
| $T_{HT}, T_1, ..., T_n$ | Temperature of the heat treatment |
| $T_M$ | Operating temperature (of the machine) |

CLAIMS:

1. A method for passive determination of the operating temperature in a thermally highly loaded device comprising the following steps:

- a plurality of individual passive measurement elements are provided, which have at least one measurable physical parameter which depends unambiguously on a constant temperature which is set during heat treatment of the measurement element or of a material which is used in the measurement element, and which parameter is set differently for the different measurement elements,

- the individual measurement elements are combined to form a one-dimensional or multi-dimensional arrangement such that the entire arrangement is subject to essentially only one temperature during the measurement of the operating temperature;

- in a first measurement, the values of the physical parameter are determined for all the measurement elements in the arrangement, before the arrangement is subjected to the operating temperature to be measured;

- the arrangement is subjected over a relatively long time period to the operating temperature to be measured in the device;

- in a second measurement, the values of the physical parameter are then determined for all the measurement elements in the arrangement; and

- the values of the physical parameter measured in the first and the second measurement for each of the measurement elements are compared with one another and the temperature of the heat treatment of that measurement element whose value of the physical parameter has changed the least in the two measurements is taken as the measured temperature.

2. The method as claimed in claim 1, wherein, in the course of the comparison of the values from the first and the second measurement, the measured values of the physical parameter are subtracted from one another in pairs.

3. The method as claimed in claim 1 or 2, wherein, in order to set the different physical parameter in the measurement elements, the measurement elements are each subjected to a heat treatment at a different temperature.

4. The method as claimed in claim 3, wherein the different temperatures of the heat treatment are in a predetermined temperature range and are distributed uniformly over the predetermined temperature range.

5. The method as claimed in any one of claims 1 and 4, wherein the thermally highly loaded device comprises a gas turbine or a boiler.

6. An apparatus for carrying out the method as claimed in claim 1, comprising a plurality of individual passive measurement elements which have at least one measurable physical parameter which depends unambiguously on the constant temperature which is set during heat treatment of the measurement element or of a material which is used in the

measurement element, and which parameter is set differently for the different measurement elements, wherein the individual measurement elements are combined to form a one-dimensional or multi-dimensional arrangement such that the entire arrangement is subject to essentially only one temperature during the measurement of the operating temperature.

7. The apparatus as claimed in claim 6, wherein the measurement elements are solid bodies.

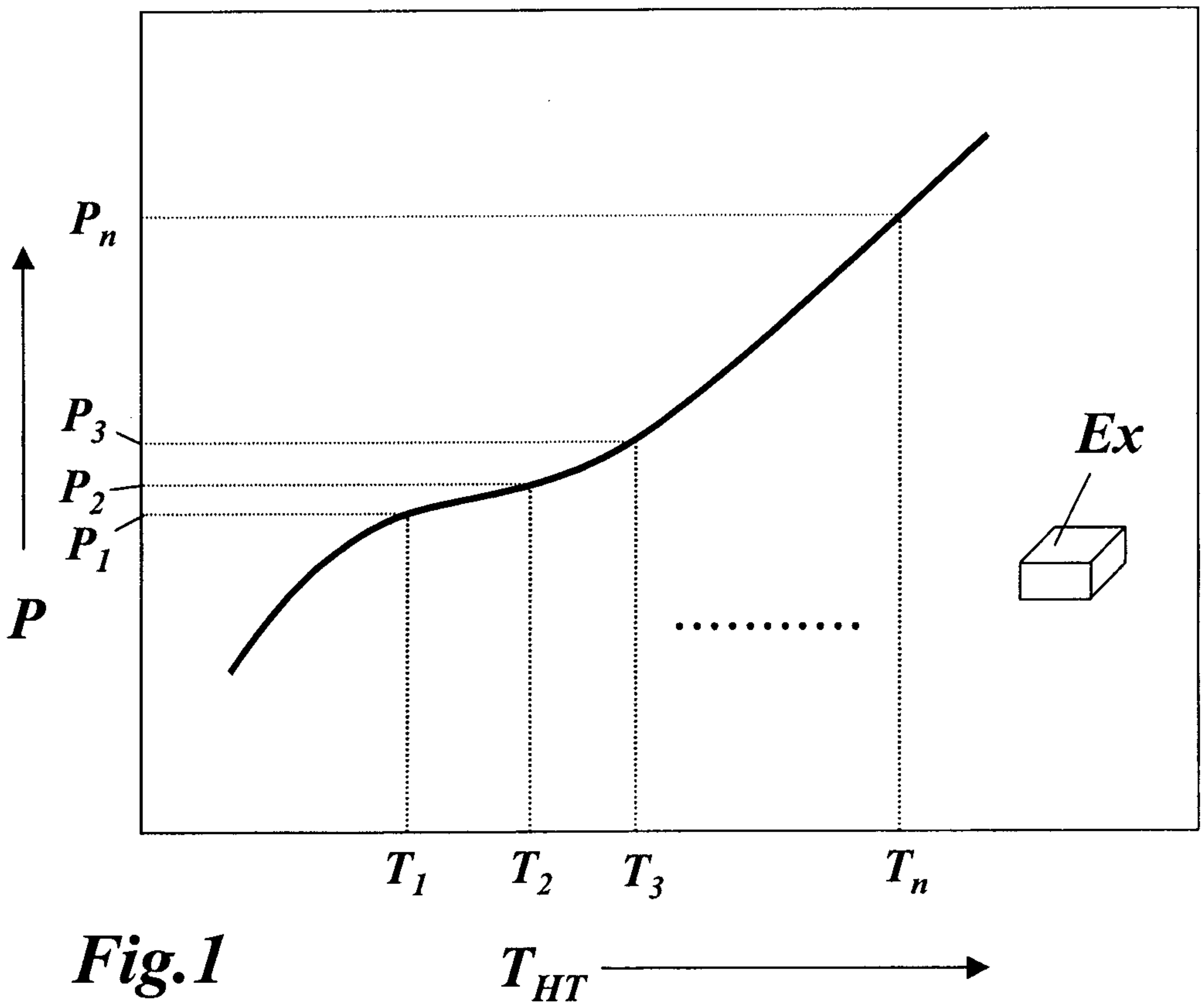



Fig.1

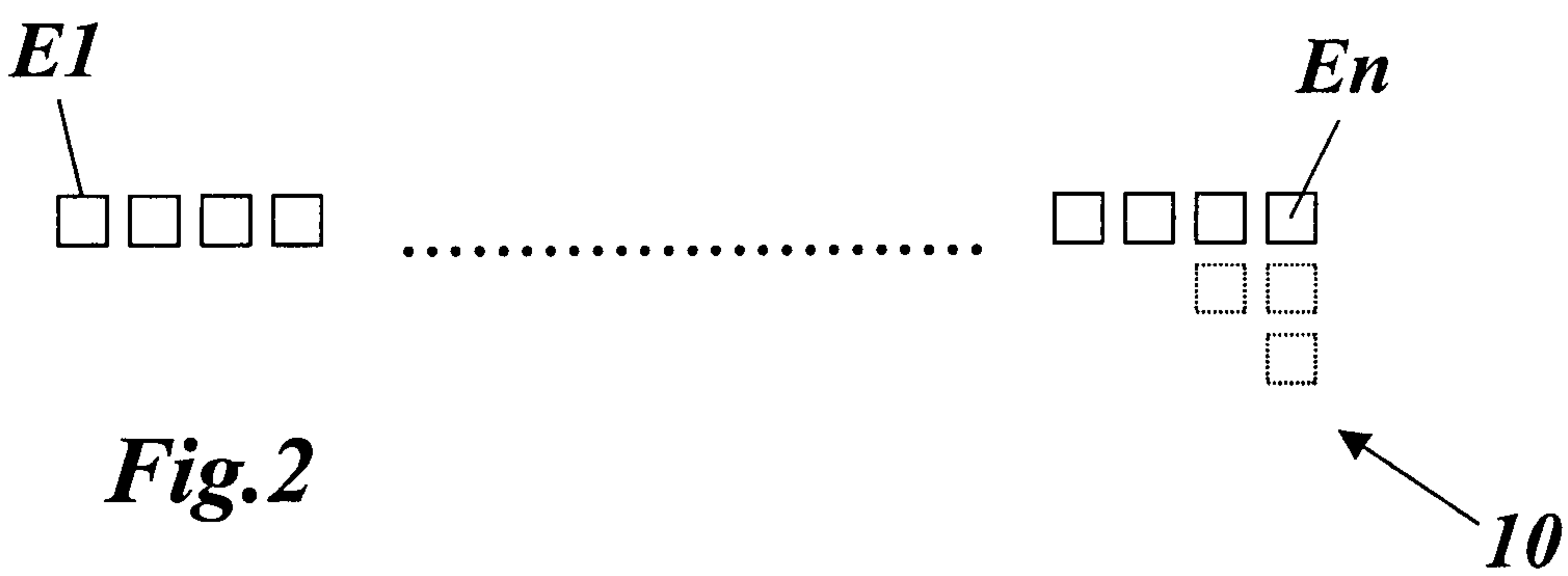



Fig.2

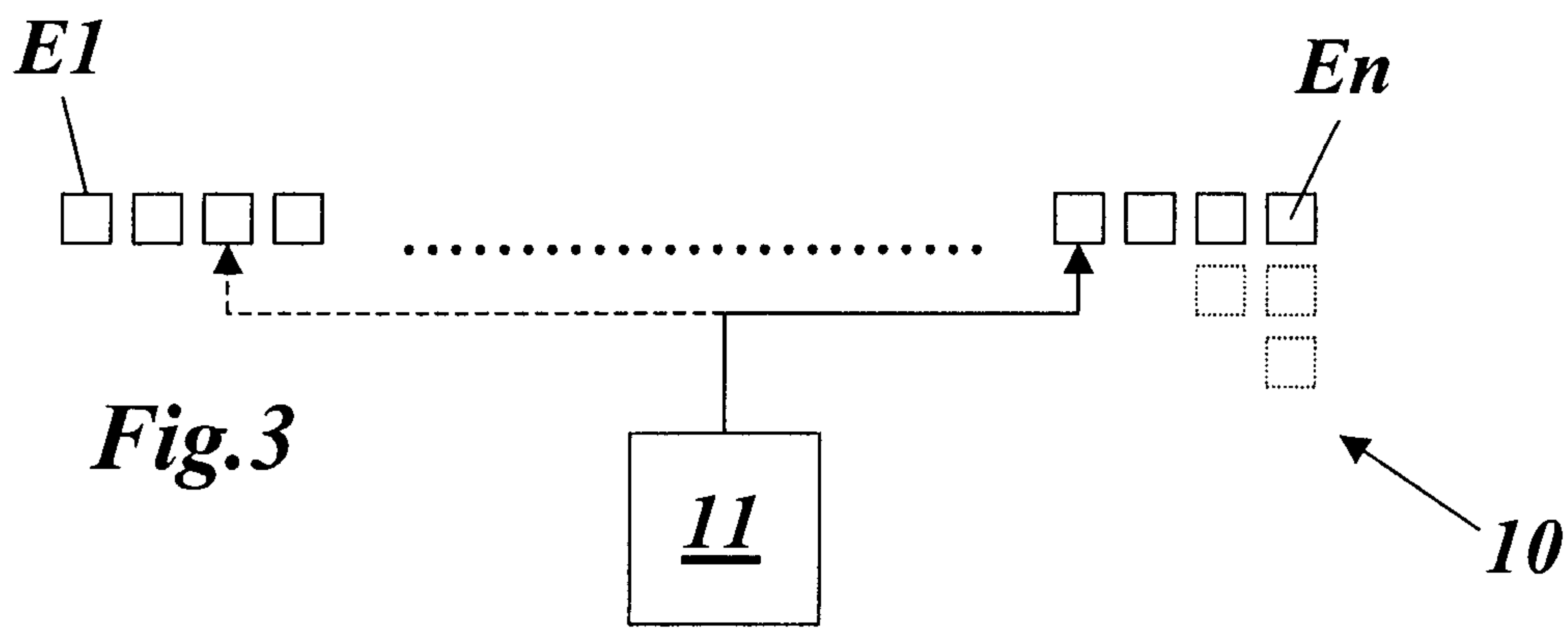



Fig.3


Fig.4

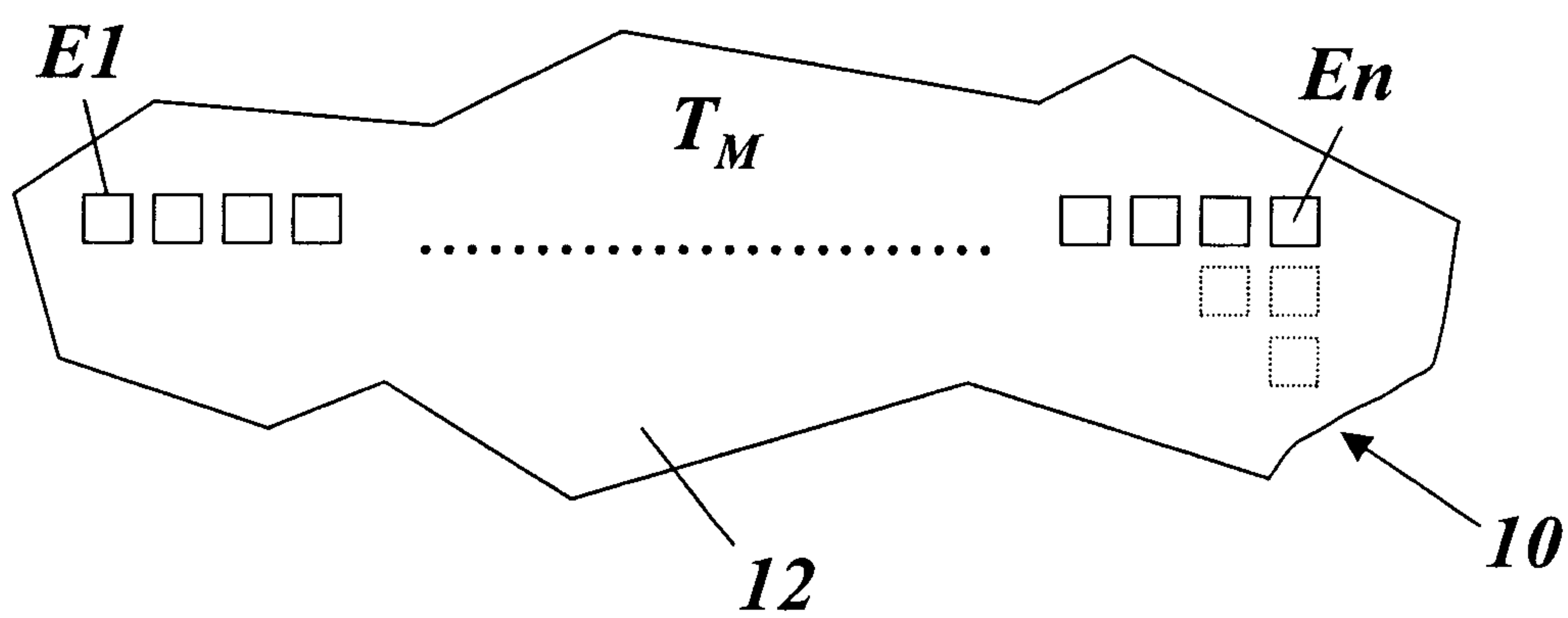



Fig.5

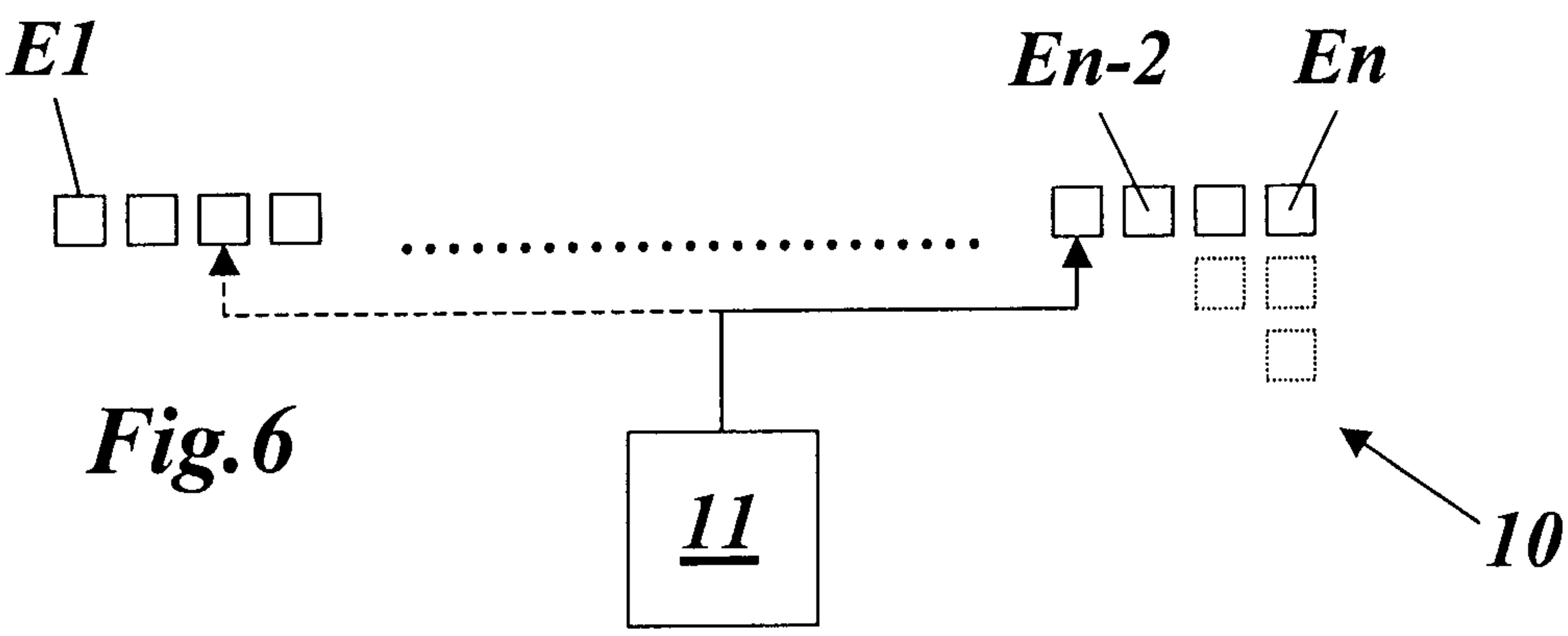



Fig.6

E1 ↓                            En ↓

$P'_1 \; P'_2 \; P'_3 \; P'_4 \; \ldots\ldots\ldots\ldots\ldots \; P'_{n-2} \; P'_{n-1} \; P'_n$

Fig.7

$P_1 \quad P_2 \quad P_3 \quad P_4 \; \ldots\ldots\ldots\ldots\ldots \; P_{n-2} \; P_{n-1} \quad P_n$

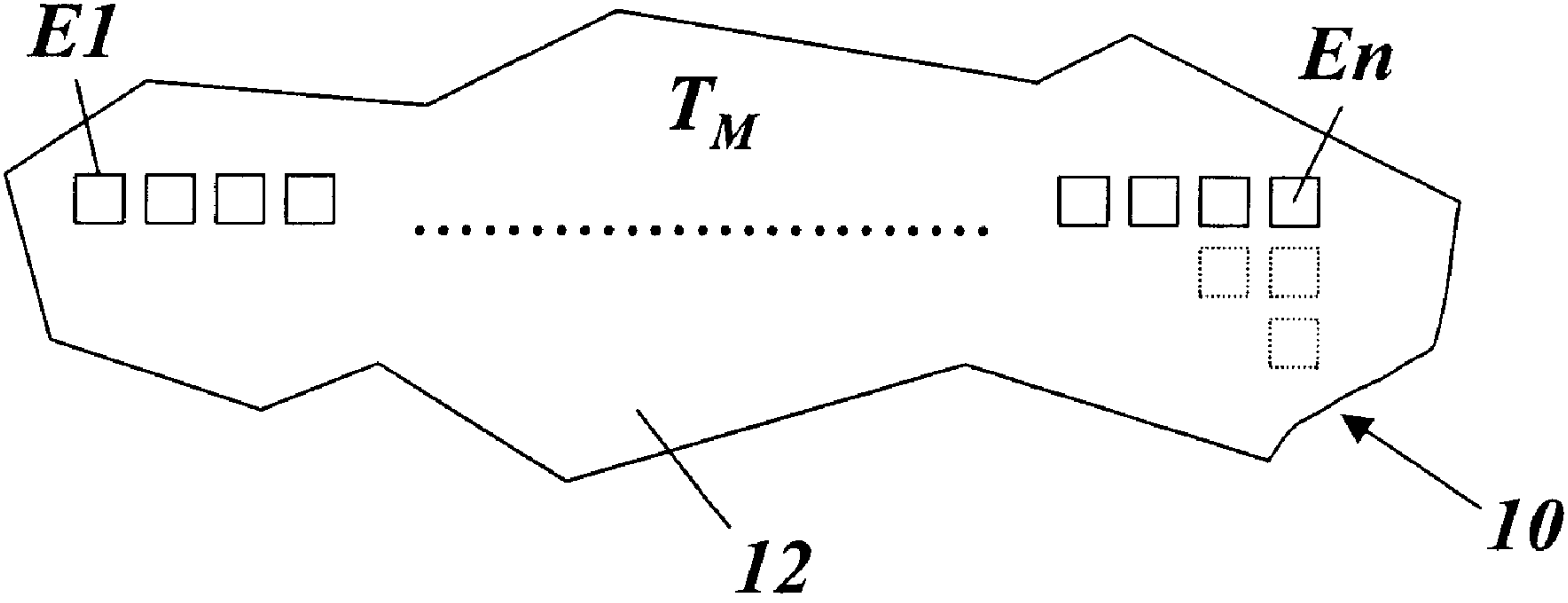
$\boxed{-}$

$P'_1 \; P'_2 \; P'_3 \; P'_4 \; \ldots\ldots\ldots\ldots\ldots \; \sim P_{n-2} \; P'_{n-1} \; P'_n$

↓

$x_1 \quad x_2 \quad x_3 \quad x_4 \; \ldots\ldots\ldots\ldots\ldots \; \sim 0 \quad x_{n-1} \quad x_n$

Fig.8



E1
$T_M$
En
12
10