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Thermovision quality testing of home electric heaters

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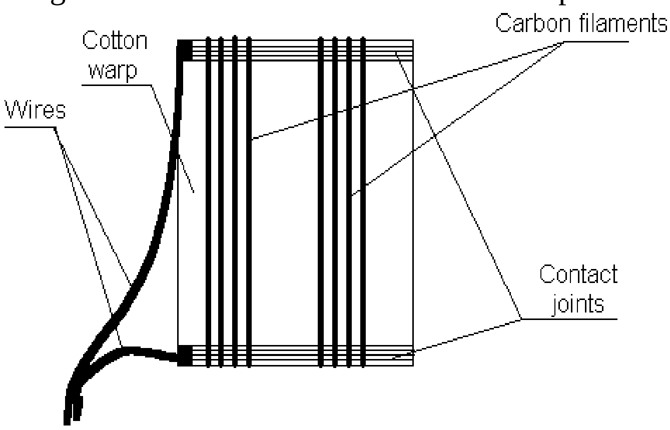
1. Woven electrical heating elements and thermal fabrics

For the latest years woven electrical heating elements (heaters) and thermal fabrics were broadly utilised. Such fabrics and manufactures out of them are successfully used in automobile industry, medicine, sports and other spheres of human activity. In most cases the fabric electroconductive properties are obtained by means of including in the warp carbon or metallized filaments. Broad expansion to woven electric heating fabrics is ensured by it's features, that is high flexibility, softness and suppleness, possibility of heating process control, technological simplicity of production and consequently moderate price.

In different woven electrical heating fabrics the size of the passing in the warp heaters with conducting filaments and the intervals between them may be quite different, also as between filaments in heaters. As well the patterns of warp and weft thread interlacing and directions of weaving may be changed. All these dimensions and technology variety are usually determined on assumption of the demands which are required to electrical heating fabrics and manufactures by the exploitation conditions.

Frequently, and also in the present case of woven electrical heaters testing, the thermal effect emerges out of some parallel eletroconductive filaments situated with interval from one to another (drawing picture 1). But the calculations just in this quite simple task are not trivial. In general the temperature distribution on the heater's surface is described by the system of Fourier equations.

Fragment of electrical heater woven in warp fabric.



Picture 1.

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In the table there is the system of Fourier equations for thermal field distribution of the heater from picture 1. The initial system of Fourier equations is in location 1.

1	3
$\begin{cases} c\gamma \frac{dt}{d\tau} = q_{v1} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \\ c\gamma \frac{dt}{d\tau} = q_{v2} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ c\gamma \frac{dt}{d\tau} = q_{vn} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \end{cases}$	$\begin{cases} 0 = q_{v1} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} \right) \\ 0 = q_{v2} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} \right) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ 0 = q_{vn} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} \right) \end{cases}$
2	
$\begin{cases} 0 = q_{v1} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \\ 0 = q_{v2} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ 0 = q_{vn} + \lambda \left(\frac{d^2t}{dx^2} + \frac{d^2t}{dy^2} + \frac{d^2t}{dz^2} \right) \end{cases}$	

Here:
c – specific heat capacity;
γ - specific weight of material;
dt - temperature difference;
$d\tau$ - heating process time;
q_v - quantity of heat emerging into unitary volume per unit of time;
λ - heat conductivity;
dx, dy, dz - dimensions of elemental parallelepiped along x, y, z axes.

In the case of stationary conductivity this system of Fourier equations simplifies to the form in location 2 of the table.

Taking into consideration the length of filaments which is much longer then their cross sections the system of equations may be overwritten to the form like in location 3 of the table.

In the “Ecometr” company the mathematic thermal modelling for different types of woven electrical heaters, thermal fabrics and manufactures out of them are developed. Usually they are used for men warming. Comfortable and nonhazardous temperature of the inner surface of heating clothes for a man’s body is considered no above 45^{o}C. That is the reason to stipulate for comfort temperature range while designing the fabric and manufacture, as the overheating can cause discomfort or stimulate disease increasing. (Other manufactures are developed for drain some heat from men being under overheating.)

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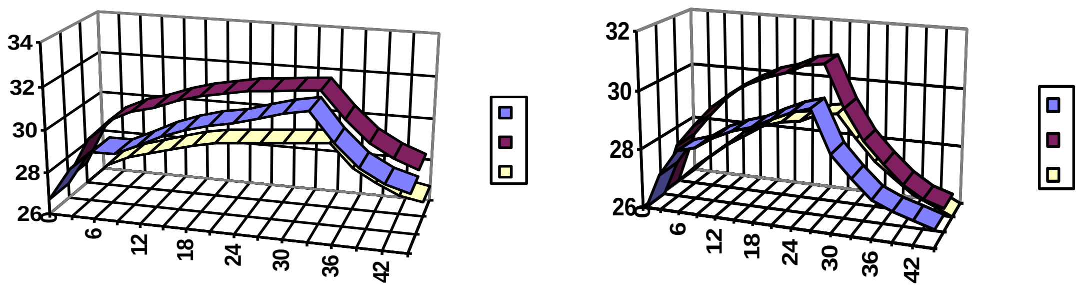
Solving the system of equations for woven heater under different limitations caused by boundary conditions we involve some discrepancies in thermal model simulating. Thus at times real thermal distribution of the woven specimen and it’s thermal model distinguishes essentially. More difficult situation exists while designing manufacture things as clothes with woven electrical heating fabrics. We can get the result reflecting object situation with significant disturbances.

Therefore such calculations are frequently utilized for approximate evaluations of thermal properties of woven electrical heaters and manufactures but the operational development is implemented according to the experimental data. Accounting-experimental technology gives an opportunity to diminish considerably the time for woven electrical heaters and manufactures designing.

Originally in experimental investigations of woven heaters thermal processes we employed thermometers and thermocouples of different types. However the nature of surface temperature distribution in woven electrical heaters is generally not uniform since conducting filaments and insulating yarns are interlaced. Spot temperature measurements with the help of radiometers is possible only in individual points. It is difficult to determine precisely the specific spots on a woven electrical heater surface and this cause considerable divergence while reiterated temperature testing. This method gives significant inaccuracy.

Clothes with electrical heating fabric. Heating and cooling process.

a) Specimen 1 b} Specimen 2



Picture 2.

In picture 2(a) and 2(b) there are testing results carried out by thermocouples situating in different layers of thermoclothes with woven electrical heater inside. They illustrate possibilities in changing thermal behaviour inside the specimen with the woven electrical heater. The temperature was measured on the surface areas of cloth above and beneath down to the heater and directly on the heating fabric.

Strip of blue corresponds to heater’s temperatures, yellow strip below is for the side of surface that ought to be outside of man and black above is for the surface of clothes towards man.

The diagrams 2(a) and (b) differ in temperature ranges: from inside temperature to both outer temperatures. The upper diagram was carried out by specimen with approximately equal thermal flows in both directions from inside heater to outsides, and lower diagram corresponds with specimen in which thermal flow was directed a great deal towards client’s side.

This example shows that temperature gradients in outer sides of thermacloth in the region with woven electrical heater follow after temperature changing in the heater inside. This gives the opportunity to use any technology for analysis thermal

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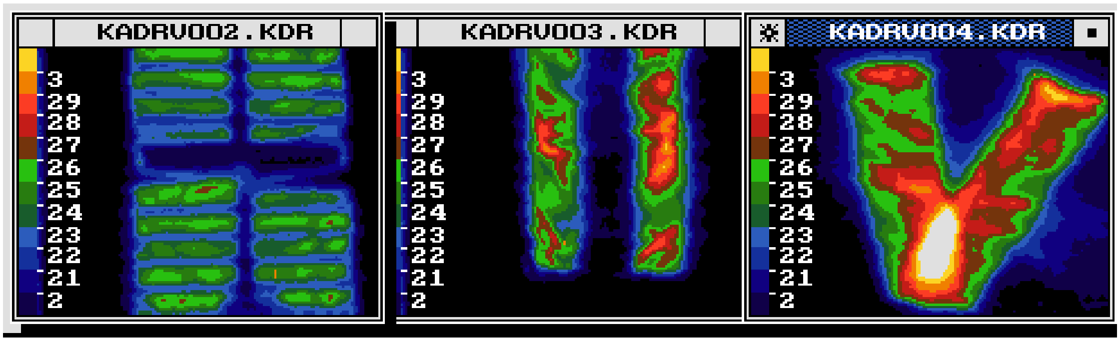
state of the woven electrical heater and the whole workpiece by the outer surface's temperatures.

For designers of woven electrical heating fabrics and for couturiers modelling modern workpieces with them it is desirable to have some sensitive effective instrument for temperature measuring that reveals the whole picture of temperature distribution along the woven electrical heaters and their elements, as well as along surfaces of different manufactures with them. Computerised measuring thermovision КРИТ-Т «ТИСА-Т» utilizing IR-camera «РАДУГА» has become for us such an instrument. In particular it may be used simultaneously with contact thermometry for any chosen point on inside heater or outer surface. Computerised thermovision allow to employ the special programs for space-temporary analysis of thermal images, such as well known "ThermoTom" using series images of heating or cooling process in woven fabrics.

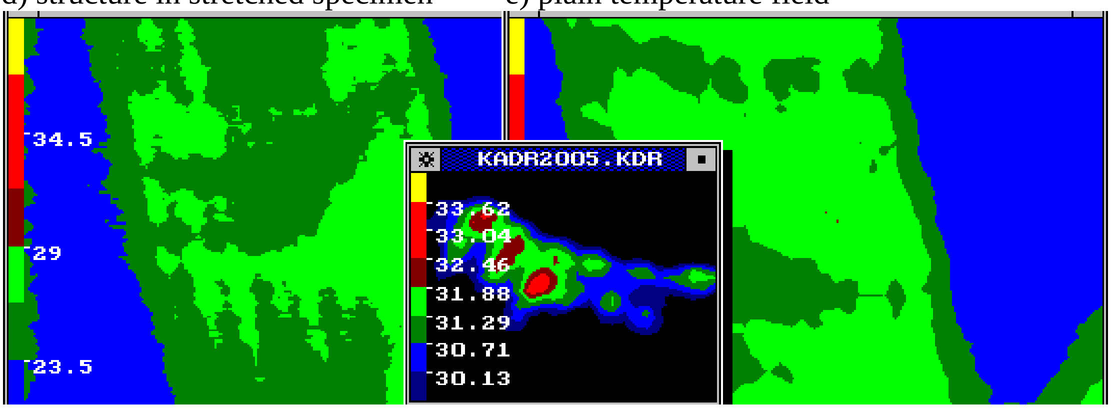
Thermovision КРИТ-Т «ТИСА-Т» being possessed of high sensitivity – as it may be seen out of thermograms in picture 3 the thermography have been fulfilled by temperature gradations in colour scale 0.7 1.5 in range from environmental 18 °C to 40 °C. The higher temperature resolution amounts to 0.07- 0.09 °C. Spatial resolution allows to see "thin" peculiarity in thermal fields of woven heaters and workpieces. Thermovision КРИТ-Т «ТИСА-Т» has computer controlling of IR-camera, it's attractive and convenient user's interface being possessed of multifarious means for thermal image processing.

Thermograms of electrical heating workpieces

a) metal strips b) woven fabric c) woven fabric



d) structure in stretched specimen e) plain temperature field



f) overheating in contact joints

Picture 3.

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In picture 3(a, b, c) thermal images of outer side of workpieces with woven electrical fabrics inside are shown, two of them (b, c) were developed in “Ecometr” company. These workpieces intend for automobiles. These are a heating vest to the driver, heating cushion on the backrest of drive’s seat and heating cushion for the settee. The manufacture for the first two of them is differed. They are differed both in construction of a heating element and in substance of cover. But the cushions for driver’s seat are designed in the same way. The structure of the woven heater in them is shown on picture 1. These have the same composition of materials, the same type of heating element, but they have been placed in two strips for one cushion and in V-configuration with overlapping for another cushion.

The unit of heating element is represented in these cushions as an electro-thermal fabric. This is a strip from the warp cotton with introduction of some carbon filaments and tiny contactors in it. The heating elements in the vest (3(a) thermogram) is realized on thin metal strips.

As it is seen, thermograms of workpieces with woven electrical heating fabric and metal heating strips reflect essential differences in their construction and quality. The thermal electrical heating fabric is woven by an usual way. The weaving manufacture technology adds to this electro-thermal fabric lightness and softness, appropriate to usual cotton materials, and also settles homogeneity of thermal field, safety and reliability for contacts under current load.

On the heat patterns in thermograms 3(b) and 3(c) the soft crimps of a substance are observed and there are no visible structure of carbon treads. The heat patterns in thermogram 3(a) hold fixed regular inhomogeneous structure of thermal field. Such workpieces are rather rough and less comfortable.

Some of soft crimps of a covered blankets which are observed on the heat patterns at thermograms 3(b) and 3(c) have higher temperature. These “local” spots with increasing temperature in visible thermal field have been forming over isolating air bubbles under blankets. This is the main peculiarity of thermal workpieces with woven electrical heaters, especially for those which are suspended freely. It is necessary to straighten the workpiece to observe homogeneity of heater’s thermal field more attentively. But this action ought to be executed carefully for exclude pressing and tumbling of downy insulating material inside such as synthepon, synsurlait and others.

In thermograms 3(d, e) the thermal field of some part of heater after straightening workpiece is observed. It was thermographied with larger scale. The structure of heating filaments (according to the drawing on picture 1) is slightly seen there as well as the lower temperature in the centre of the cloth between two row of heating filaments, but the homogeneity is just high.

Observing the heat patters 3(c) in compare with 3(b) we note the specific hot spot for strip at the place of V-figurative return layout. This is caused by double overlapping of the strip here. Hence it is possible to improve the laying-out of workpieces for optimization their thermal state.

Thermovision КРИТ-Т «ТИСА-Т» is quite useful while optimizing the working mode – investigating the current trough the heater when choosing autonomic power element for workpieces designed for extreme conditions. Due to thermovision it is possible to examine reliability of contactors by their heating patterns i.e. the quality of terminal contact joints - these are the most complex units in woven electrical heater. By the heating patterns in thermograms one can verify the thermal state of contact joins. The absence of temperature differences over the heating fabric in the zone of contact joints is the evidence to report about the high quality of the heater. But

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thermography by КРИТ-Т «ТИСА-Т» permits to qualify the contact joins' state by thermal patterns of the whole workpiece with the heater inside.

Thermograms 3(b, c) and (d, e) to be compared point out that there are no overheating in the place of contact joints for workpiece with parallel heaters. But it is clear that contactor's temperature is risen above for workpiece with V-formed heater (see right high up on V-pattern and especially 3(f)). So the quality of this settee cushion would be lowering faster. For this modification it is necessary to realize correction on power mode or to change the technology of assembling contact joints.

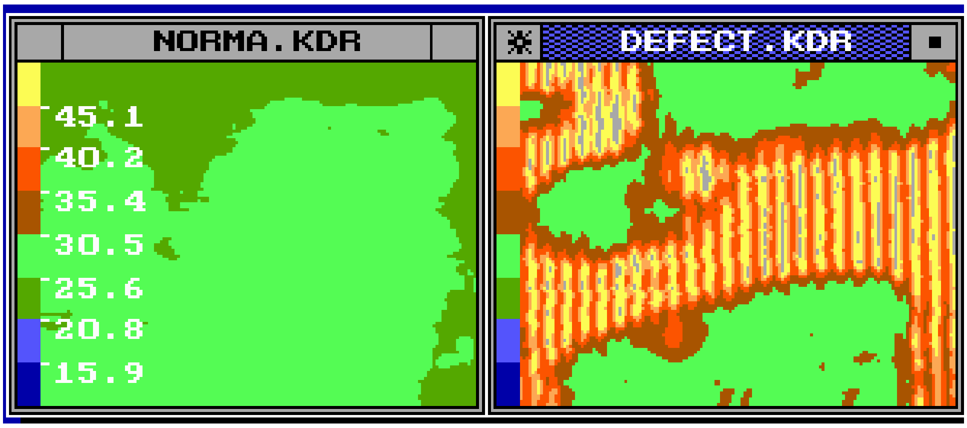
Thus the computerized measured thermovision (or modern compact IR-camera as well) represents as convenient auxiliary means .for designers of clothes and other manufactures with woven electrical heaters and for certification the complete product.

2. Heating composite panels

Thin electro-heating panels out of composite materials with an internal layer of carbon or metal conductive strips (heater) and insulating covered blankets are broadly applied into prestigious indoors apartments in offices and in private cottages or dwelling houses. Dimensions and power of electro-heating panels vary into wide ranges - from 30 x 30 to 1.5 x 2. m and from 100 to 700 Watt. Thickness changes from 0.7 mm to 5 mm (2 mm panels are much in demand). There may be multifarious forms of plane panels, uniform plane or plane with different holes, for client's desire. The temperature of panels is regulated usually not above 70 °C by power load alteration.

Designing and thermal mode testing of panels became easier while computerized thermovision is used. The all functions of thermovision are the same as in case of designing woven electrical heaters and workpieces with them. But manufacturing technology differs. Thermograms of heating panels below have been got by КРИТ-Т «ТИСА_Т» as well.

Fragments of heating composite panels (a, b)



Picture 4.

On following thermograms the heat patters (thermal images) of two thin heating composite panels (qualitative and defect) with an internal conductors are represented. Sharp violation in a thermal distribution on the right pattern is observed (due to inhomogeneous layers and internal gas bubbles).

Thermal field for upper layer of qualified as "norma" panel is more homogeneous. The temperature becomes quite lower to plate's edges out of electrical

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heater's zone. The heater's structure in "norma" is not observed. Simulating and designing of panels are stipulated for optimal homogeneous thermal field.

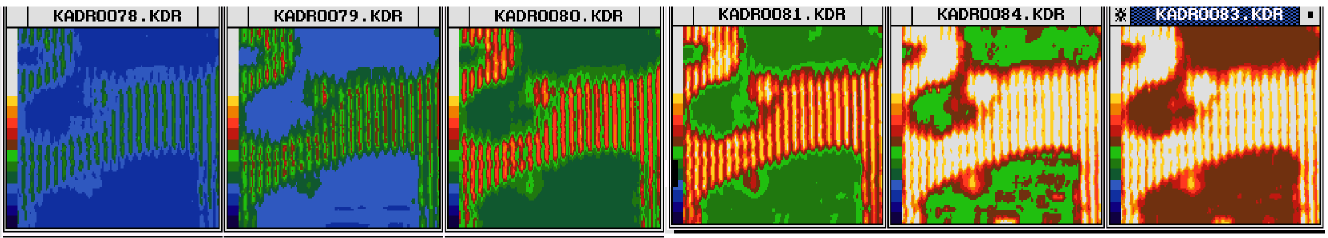
The "defect" thermogram have been got during resource testing of the panel under considerable power load. In hot spots there is the structure of electrical heater observed rather brightly. Round them there are cooler zones. The cause of such kind of thermal field is in great overheating with burning-trough some part of entire covered layer. Some gases emerging in such conditions fill in any cracks while layers exfoliating, the layer bubbles, so the outer surface may become more dark and with some damages in it's appearance.

On next thermograms there temporary heating process is fixed for "defect" panel (upper row) and the new made "non-norma" panel with slightly changing narrow strip on one of surfaces (lower row). It is formed by roll of drawing mechanism while short-term instability.

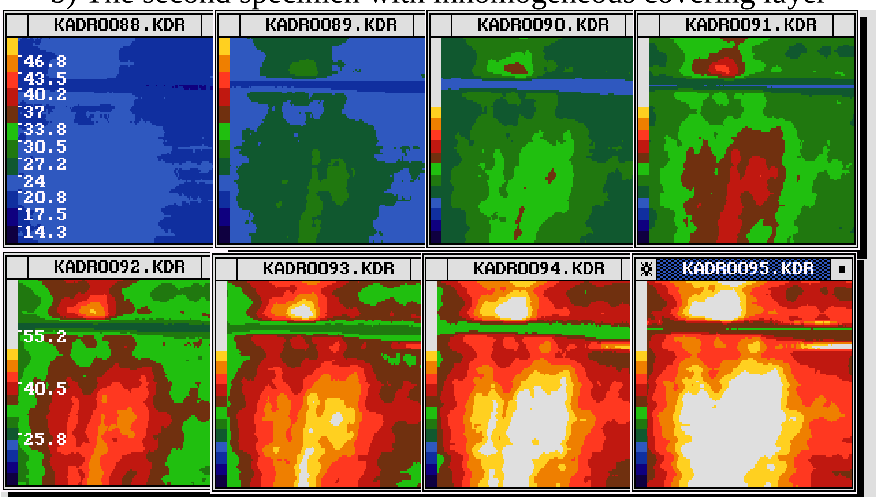
Thermograms have been got in every 10 sec for upper specimen and in 15 sec for lower one. Time delay for the first image is the same for each specimen and the whole time is 70 sec and 150 accordingly.

Temporary films of defect panels

a) The first specimen after resource testing



b) The second specimen with inhomogeneous covering layer



Picture 5.

The various rate of heating process for different zones of panels becomes evident, even for the new panel's patterns. For this panel it clears up that in place under higher pressing homogeneity is damaged at least for upper layer. Heating spots round this strip are extending fast so in some time of operating the same damage phenomena there may be involved.

The space-temporary filtering of the thermogram's serial being written the heating process in panels gives for designers complementary knowledge about thermal disturbance of inside layers homogeneity on different depth. For this purpose

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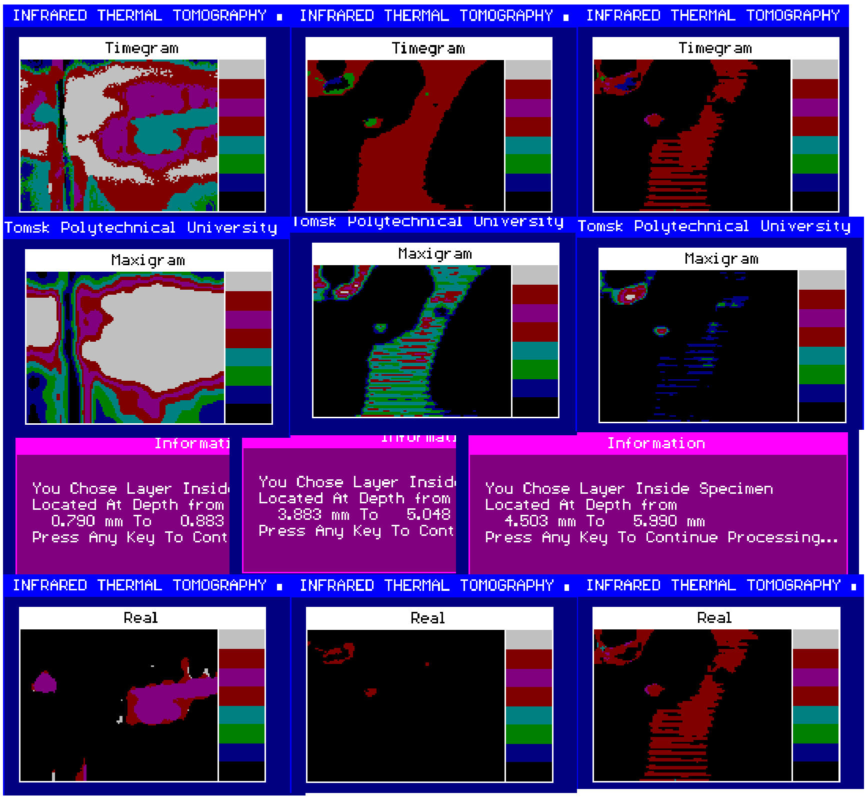
the well known calculating technology “ThermoTom” developed in Tomsk polytechnic university (Russia) by professor V.P. Vavilov has been utilising.

Heating panel’s timegram and maxigram, depth and tomogram of layers.



Picture 6.

Thermal images on picture 6 illustrate examination the thermal fields inside heating panels. (The scale for depth here is 6mm to 2mm of panel.)

Hence computerized measuring thermovision and technologies of image processing may find application in designing and certification the broad spectrum of new manufactures with thermal electrical heating fabrics and heating composite panels.