MEASUREMENT OF TEMPERATURE FIELDS IN 3D AIRFLOWS USING AN INFRARED CAMERA

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This article deals with the measurement of temperature fields in 3D airflows using an infrared camera and the measuring net with measuring targets. This method is based on the visualization of temperature fields on an auxiliary material (paper targets) which is inserted into the non-isothermal airflows. In the article is the description of the new developed measuring equipment for visualization 3D airstreams by an infrared camera. Temperature fields are made visible by an air-heating ventilator, and consequently the temperature field is evaluated. The ventilator generates approximately a rotate-circle airstream in the axis of ventilator mouth outlet. The results are compared to the similar measurement the using the equipment for visualization a temperature field in 2D airflows by an infrared camera and the compact sheet of textile. This measuring method can be used in many various applications such as air-heating and air-conditioning.

Keywords: *airflow, temperature fields, infrared camera*

1. Introduction

The infrared camera is a very effective device for a noncontact measurement of temperature fields in many scientific disciplines and industry [7]. Thermography (Infrared thermal imaging) is applied in research and development such as medical science [2], heat transfer and thermomechanics (Fig. 1), non-destructive testing (Fig. 2), reducing energy costs of monitoring in civil engineering (Fig. 3), and many more. This measuring method provides a visual image records allowing obtain information for a deeper knowledge of thermal states and processes in the research object. Visualization is a technique for creating images and animations to formulate a particular argument to put the possible problem right [6].

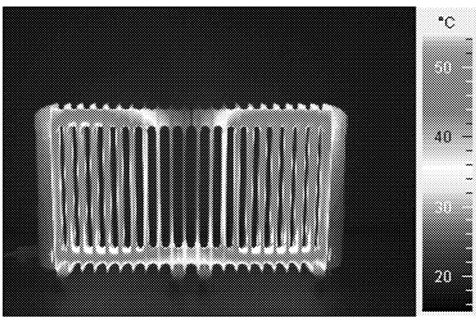

Fig.1: Thermogram of two working radiators

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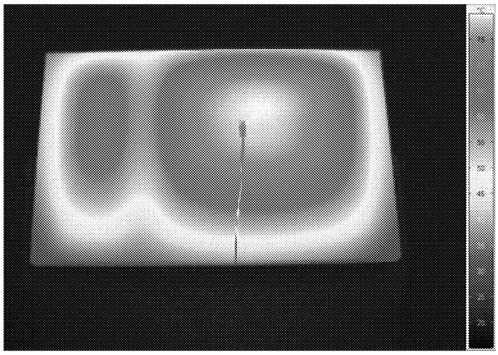

Fig.2: Thermogram of the infrared heating panel – the defective electrical spiral

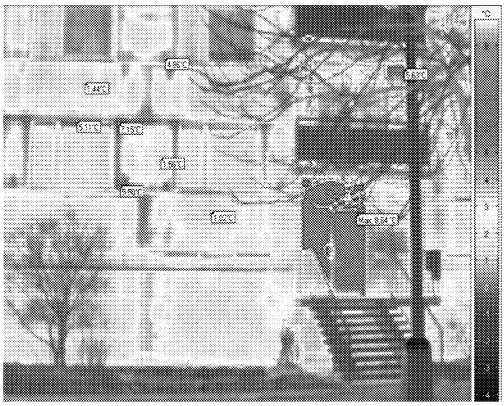

Fig.3: The infrared monitoring in civil engineering

The thermography is being used mainly for determining surface temperatures but the described measuring method tries to explain the possibilities of monitoring and measurement temperature fields in the air. Immediate knowledge of the distribution of temperature field in the non-isothermal airflow can allow to quickly identify a possible problem in the design or equipment in an ordinary usage of air conditioning or hot-air heating. The visualization of temperature fields in the air can also detect the spatial and time context of monitored processes.

2. Description of using method

It is well known that the air is a transparent material in infrared radiation, and therefore it is impossible to make the air temperature visible directly by the infrared camera [4]. For visualization the air temperatures the measuring targets are necessary to be used which are situated in the measuring frame that is inserted into the research area [3]. The measuring target is created as a point where the surface temperature as the air temperature is measured. For successful application of this method, the suitable material, which the measuring target was made of, was needed to choose. This material must especially have a large emissivity value and the quick response to the temperature difference (small time constant) [5]. The visualization of temperature fields in the air by the infrared camera on measuring targets is especially suitable for measuring temperature fields in 3D airflows.

3. Description of air temperature measuring equipment

The equipment for measuring temperature field in the air streams using an infrared camera is composed of the measuring frame and the IR camera. On wires inside the measuring frame the measuring targets are situated and this entire component is hanged on the height-adjustable tripod-stand (Fig. 4).

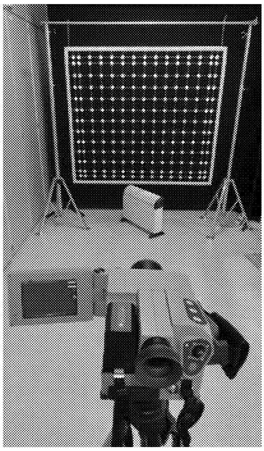

Fig.4: The photo of air temperature measuring equipment

Spectral range	8 – 13 μm
Resolution	320 × 240 pixels
Detector	Uncooled
Temperature measurement range	-40 … 1200 °C
IR image frequency	50 Hz
Measurement accuracy	±2 K, ±2 %
Analogue interfaces	PAL/NTSC-FBAS and S-Video, headset
Image storage	CF card, optional FireWire

Fig.5: Technical data of IR camera Jenoptik – VarioCam

3.1. IR camera

The experiment was done by an infrared camera Jenoptic – VarioCam with the resolution 320×240 pixels (Fig. 5) with using a standard lens (32° H × 25° V). The inside sizes of developed measuring net are 1400×1200 mm. These sizes were calculated for fully visualization of air stream with velocity of $3\,\mathrm{m\,s^{-1}}$. From the frame sizes and from fields of view of the lens the distance for measuring the air temperature on the entire net by this IR camera was determine.

3.2. Measuring frame

The measuring frame is the weldment which was made of bars with sizes $l{\times}t = 60{\times}6$ mm, and its total size is $a{\times}b = 1520{\times}1320$ mm (Fig. 6).

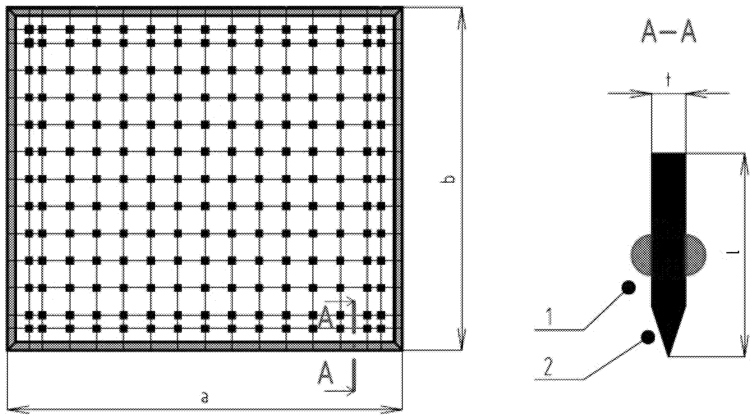

Fig.6: The measuring frame with frame sectional view
1 – both-sizes line weld, 2 – leading edge beveling

The material of this frame is an alloy AlMg3 which is very good for welding, light ($\varrho = 2067\,\mathrm{kg\,m^{-3}}$) and its strength is termed as middle. Because the stiffness of the frame was not acceptable for measuring, the line both-sides weld was welded on the frame. The circumference of the frame was upgraded for aerodynamical profile by the edge beveling. To eliminate the reflectivity the frame with non- reflectivity tape was supplied. The upgraded measuring net is compounded of measuring targets of known properties. The targets are situated on the net with the exactly defined positions. All the measuring targets are situated on cords. The targets are made from the planar office paper (weight $80\,\mathrm{g\,m^{-2}}$) with high emissivity value ($\varepsilon = 0.96$) [5].

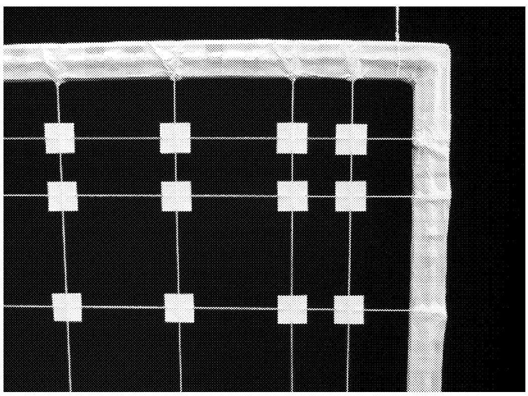

Fig.7: The detail of measuring targets configuration

The cords are made of non-colour polypropylene (non-colours polypropylene cords have better properties compared to the coloured polypropylene cords). The cord diameter is $\not{o}D = 1.1\,\mathrm{mm}$ and the thermal expansivity of these cords is no more than 19 % of their length in the temperature range from 20 °C to 90 °C. At a higher temperature difference the cords extension would be too long and the measuring net would collapse. The cords are firmly attached to the frame by a tape for every cords line separately. The measuring targets are situated equidistantly with the distance of 10 cm; only two lines at the edge are situated with the equidistant distance of 5 cm (Fig. 7). The size of measuring targets should be chosen such that their sizes are 3×3 whole pixels on the thermogram. To guarantee this condition the measuring targets were suggested to be 5×5 pixels minimally. The measuring target was calculated as 26×26 mm in order to visible the entire frame on the thermogram from horizontal (HVOF) and vertical field of view (VFOV) of using lens and the resolution of the VarioCam infrared camera from Jenoptic Corporation (Fig. 8). The paper targets are situated on both the sizes of cords on measuring net by an adhesive. To eliminate the reflection the frame was upgraded by non-reflection tape after assemblage.

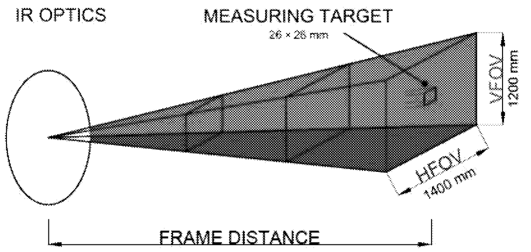

Fig.8: The determination of paper target size

The inner size area of measuring frame is 1.68 m^2. The 195 pieces of targets and cords have together only 9.6 % of total area the measuring frame. The percentage part of this area of targets and cords has a minimal influence on the restriction of the measuring air stream. The frame is equipped for safety transport by a compact case. The whole measuring equipment is mobile and air temperature measuring is practically immediate.

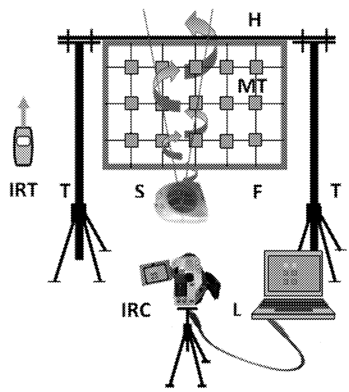

Fig.9: The stand for measuring temperature fields in 3D airflows by the fan with a rotate circle airstream by an infrared camera; IRC – Infrared Camera, L – Laptop, MT – Measuring Targets, T – Tripod, H - Holder, IRT – Infrared Thermometer, S – Source of 3D Non-Isothermal Airstream, F – Frame

4. Measuring temperature field in the air by IR camera – experiment

For the following experiment the hot-air rotation fan was chosen. The fan produces the hot airflow as convective heat transfer to the surface of measuring targets that changes their surface temperatures which are measured as an air temperature by the infrared camera. The device shows the temperature field on measuring targets *MT* from heat sources *S* using the infrared camera VarioCam *IRC* linked to laptop *L*. At the same time the radiating temperature is measured in the measuring area by the infrared thermometer Testo *IRT*. The frame of the square net with measuring targets is attached to the holder *H* to the height-adjustable tripod stand *T*. The schema of this experiment is shown in Fig. 9.

In notion of measuring temperature fields in 3D airflows it can be imagined that the measurement where the compact auxiliary material (compact sheet) is not parallel with streamlines, or the measurement where a rotate circle airstream is generated by the fan (Fig. 10), or alternatively, more heat sources are used and so one.

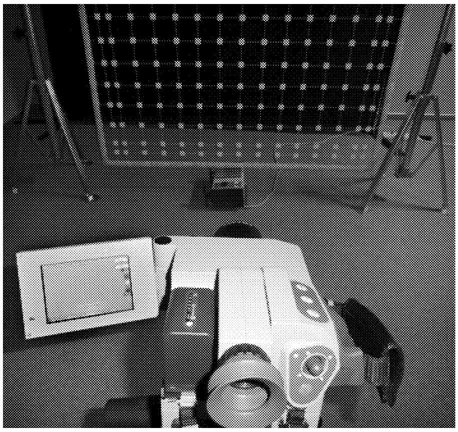

Fig.10: The photo of equipment for measuring temperature fields of the hot-air fan

4.1. Experiment visualization by equipment for measuring 2D temperature air field

If it is not evident that a 3D airstream from this device has to be visualized, the similar device for measuring temperature field in 2D airstream could be wrongly used (Fig. 11). This equipment is based on visualization of temperature field in the air on the compact auxiliary material, such as sheet of paper or textile.

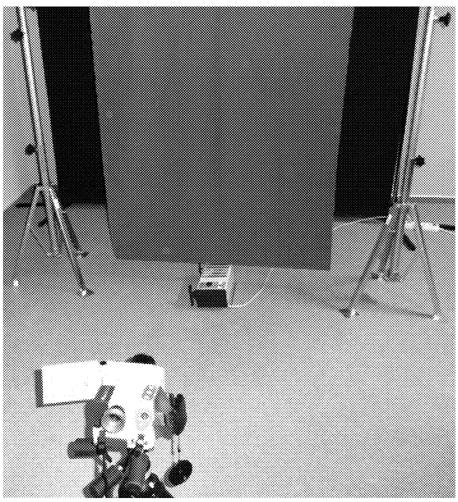

Fig.11: The photo of equipment for measuring 2D temperature fields in the air

The visualization of the temperature field from the hot-air fan by the equipment for measuring 2D temperature fields in the air is shown in Fig. 12. In the thermogram the distribution of the temperature field can be seen and no further modification by the software is needed.

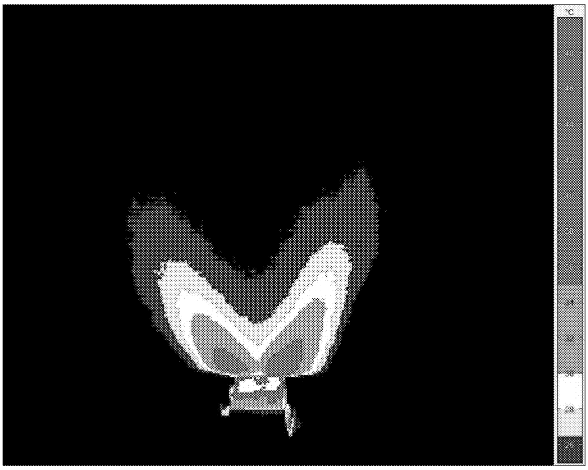

Fig.12: The visualization of temperature field in 3D airstream using a compact sheet of auxiliary material and the infrared camera

4.2. Experiment visualization by equipment for measuring 3D temperature air field

The rotation airstream by the hot-air fan is generated, and therefore it is necessary to use an auxiliary material for the 3D airstream visibility on which is possible to measure temperature field. For this experiment were used the paper measuring targets as an auxiliary material. The air-stream visualization of this fan on the measuring targets of this experiment is shown in Fig. 13.

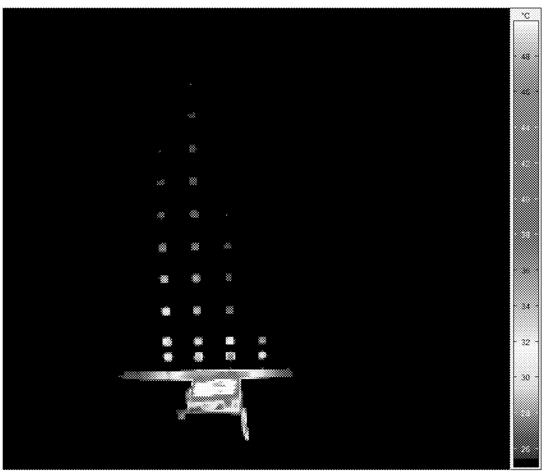

Fig.13: The original thermogram of 3D airstream measuring

In the original thermogram from the equipment for visualization of 3D temperature field in the air is not clearly seen the complete temperature field, and therefore it is necessary to use a software adjustment. The area between the measuring targets must be software adaptable (Fig. 14) to produce a complete thermogram which could be comparable to the thermogram from the device of the temperature field in 2D airflows measuring (Fig. 12).

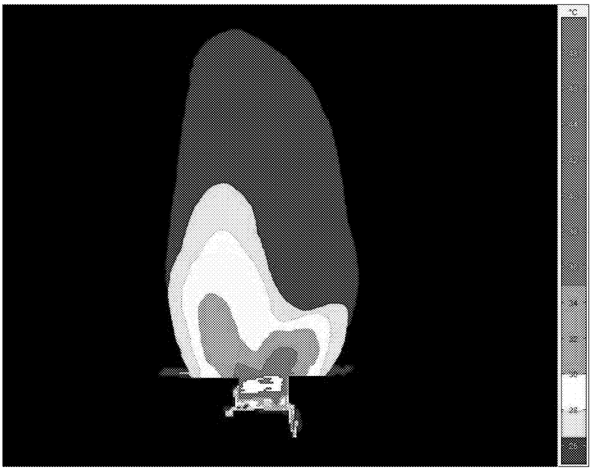

Fig.14: The correct visualization of temperature field in 3D airstream using measuring targets and the infrared camera after software adjustment (by PS6)

5. Discussion

In Fig. 12 and in Fig. 14 there is evidently shown that when the device for measuring of temperature fields in 2D airflows for 3D airstream is used (e.g. it is not obvious at the first sight that it is a 3D airstream), the influence of the airflow distribution on compact sheet of support material has a significant effect on the temperature field (Fig. 12) which is shown on the compact auxiliary material by the infrared camera. The equipment for the measurement of temperature fields in 3D airflows can be also used for measurement of 2D non-isothermal airstreams but the resulting thermogram does not properly show an illustrative figure of the temperature field (Fig. 13) as in the case the temperature field is visualized on a compact sheet of an auxiliary material (Fig. 12). The open question is the number of measuring targets in the measuring net for specific 3D airflows that enables the visualization without the complicated software editing. It is necessary to respond this question in next research of measurement of temperature field in 3D airflows.

6. Conclusion

The measurement of temperature fields in the air by an infrared camera is one of possible methods how to measure the temperature fields in the air. This method was described for visualisation of the temperature field in a heated 3D airflow by using an IR camera. The method was compared with measurements by the equipment for temperature fields measuring in 2D airflows and temperature fields in 3D flows. From the presented experiment is demonstrable that the usage of a spacious sheet of material is suitable only for two dimensional airstreams. For three dimensional airstreams the measuring net is needed to use.

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