

# Analyzing the thermal regime of power supply units in portable betatrons by using infrared thermography

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**Abstract.** Potentials of infrared thermography in analyzing a thermal regime of the 7.5 MeV betatron power supply are discussed. Both the heating rate and thermal inertia of particular electronic components have been evaluated by processing pixel-based temperature histories. The data treatment has been performed by using the original ThermoFit Pro software to illustrate that some advanced processing algorithms, such as the Fourier transform and principle component analysis, are valuable in identifying thermal dynamics of particular power supply parts.

## 1 Introduction

Portable betatrons are widely used in various industrial sectors as sources of electrons and X rays, in particular, for nondestructive testing of materials, components and installations, examining luggage and cargo at airports, sea ports and heavy truck check points, performing X ray computer tomography and treating malicious tumors in medical practice [1-4]. The known advantages of betatrons are their relative simplicity and low mass compared to other types of high-energy X ray sources, as well as in-use comfort and low cost.

National Research Tomsk Polytechnic University is a unique world developer of portable betatrons which implements a whole production cycle starting from designing and finishing with commercial units for turn-key supply.

Reliable operation of betatrons depends on characteristics of a thermal regime in principle accelerator parts. Betatrons operate within a heating/cooling mode with the whole cycle time period being about 45 and 15 minutes for an emitter and a power supply respectively.

Figure 1 shows the construction of a typical betatron [1]. Each betatron is supplied with an air cooling system which helps to cool down overheated components. However, it is still a challenge to sink thermal energy from those components which are not in contact with the cooling air. Such components include a magnet guide which consists of the central poles (2) with the inserts (3) separated by dielectric gaskets, as well as the backward magnet guide

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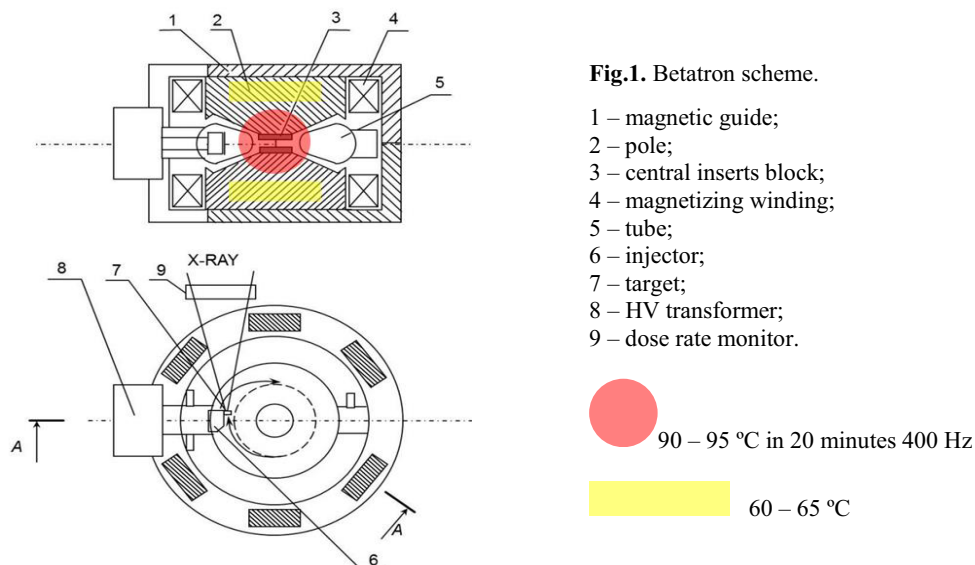
consisting of six supports which also represent a section of the power supply case (1). The magnet guides are made of transformer steel plates bonded altogether with epoxy adhesive.

Most of materials used in betatrons are of a low thermal conductivity; therefore, the heat energy sink by heat conduction is negligible. Until recently, the designing of betatrons has been fulfilled by using standard analytical approaches which can be scarcely applicable to the complicated 3D geometry of betatrons. Therefore, there is still a practical need to ensure lower heating level of betatron key components.

## 2 Research Questions

In this study we investigate applicability of infrared (IR) thermography for analyzing thermal regimes of the power supply unit used in a 7.5 MeV betatron (Fig. 2a).

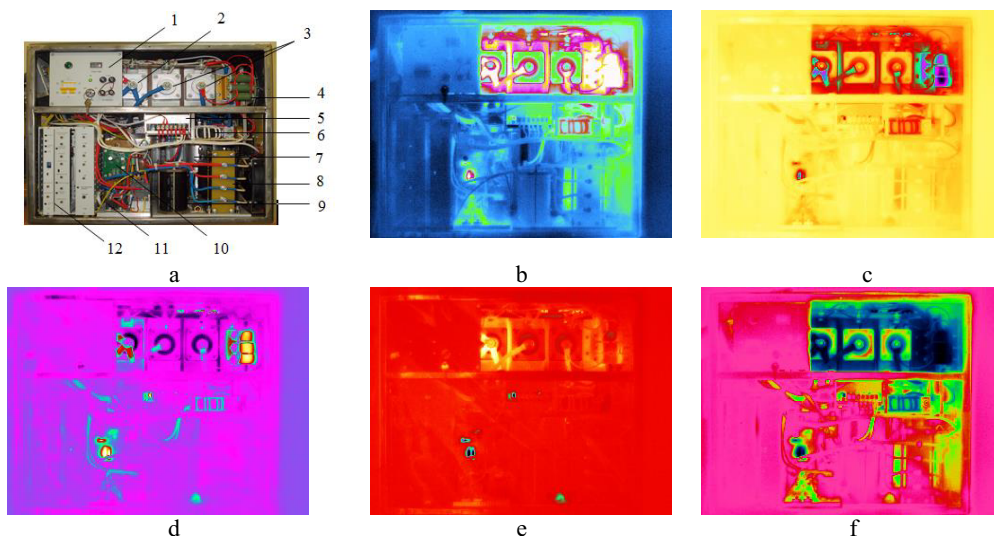
IR thermography as a technique intended for non-contact analysis of physical objects is widely used in electrical engineering and electronics, particularly, for evaluating temperature distributions of boards and electronic components under electrical load. A review of these applications is presented in [5-8]. It is worth noting that the most of practical applications of IR thermography involve steady-state test procedures where object temperature remains constant during inspection.



It is known that a major problem of IR/thermal diagnostics in electronics is the necessity of determining component emissivity which significantly varies depending on a type of a component thus distorting measurements of true temperature [9, 10]. In this study, we consider a relatively unexplored aspect of IR diagnostics of electronic boards and devices, namely, the analysis of temperature dynamics which appears in transition (switch on/switch off) work regimes. The concept of such approach is borrowed from active nondestructive testing of materials where hidden defects reveal themselves in surface temperature distributions due to different behavior of transient temperature in defect and non-defect areas [11]. The analysis of temporal characteristics of temperature distributions allows using modern mathematical approaches in application to IR image sequences evolving in time, such as Fourier and wavelet analysis, the technique of singular value decomposition (method of principal component analysis-PCA), non-linear fitting and many others [11].

### 3 Research Methods

A power supply unit of a small-size portable betatron for 7.5 MeV (Fig. 2a) was examined by using a NEC Avio TH-9100 IR imager which operates in the 7-13  $\mu\text{m}$  wavelength band and ensures the temperature sensitivity of 30 mK (in the averaging mode) with the standard image format being 320 $\times$ 240 pixels. At the inspection side, the unit was covered with a 60  $\mu\text{m}$ -thick polyethylene foil in order to simulate heat convection in a closed box.



**Fig. 2.** Results of infrared/thermal inspection of power supply unit components after switching on a 7.5 MeV betatron:

*a* – 7.5 MeV betatron power supply unit (photo): 1–control panel, 2–preliminary contour diode, 3–power contour thyristor, 4–preliminary contour resistors, 5–auxiliary power supply unit, 6–damping throttle, 7–power contour capacitors, 8–filtering circuit throttle, 9–filtering capacitors, 10–charge switch-off delay board, 11–rectifying diode module, 12–control unit; *b* – IR thermogram in 10 min after betatron switched on; *c* – after applying principle component analysis (PCA), 1<sup>st</sup> component; *d* – PCA, 2<sup>nd</sup> component; *e* – PCA, 3<sup>rd</sup> component; *f* – correlogram.

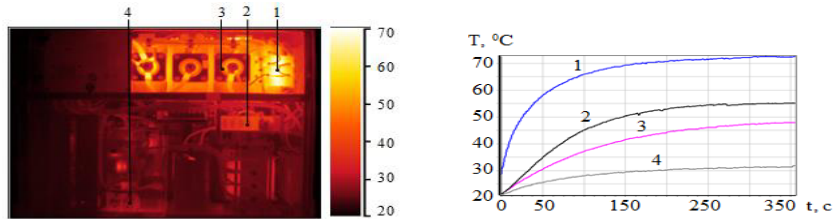
The presence of the foil distorted temperature read-outs not worse than by 1.5 % due to high transparency of polyethylene for IR radiation. The acquisition frequency was 5 Hz thus allowing the recording of 300 images in a sequence for 10 minutes during a single inspection session.

Some examples of the data processed by means of the ThermoFit software (Tomsk Polytechnic University) are shown in Fig. 2b-f. The source IR thermogram obtained in 1 minute after switching the betatron on (no electron acceleration mode) clearly shows the power supply section with the overheated thyristors (Fig. 2b).

The statistical technique of PCA applied to all 300 images in the recorded sequence allows underlining the basic thermal phenomena in the first three components (Fig. 2c-e). The first component (Fig. 2c) is very similar to the source image in Fig. 3b because it shows areas of thermal phenomena with the highest amplitudes. The second component stresses less significant areas while the third component exhibits weak temperature anomalies in the power supply unit. We remind that PCA reduces a source sequence of N images to the corresponding sequence of N components of which only 3-5 first components reflect thermal peculiarities (anomalies) of an object under test. All other component images contain only noise. Figure 2f shows the result of applying a special algorithm of data processing which is based on determining a coefficient of correlation between each

current pixel and a pixel chosen as a reference. The resulting image called correlogram exhibits image sections with a similar behavior of temperature evolution curves. In a particular power supply unit, a special attention should be paid to the section with powerful thyristors (blue green area in Fig. 2f) where improving heat sink conditions is recommended to betatron designers.

It is worth noting that advantages of cutting-edge data processing become visually illustrative in pseudo color images which can be obtained by means of the ThermoFit Pro software.



**Fig. 3.** Temperature evolutions in time. 1–resistors in preliminary current circuit, 2–damping throttle, 3–power contour thyristors, 4–rectifying diode module.

Figure 3 shows pixel-based temperature evolutions in some points of the IR scene. In further research, the attention will be paid to the analysis of these evolutions by applying the technique of the so-called thermal tomography [11].

## 4 Conclusion

A basic conclusion from the conducted research is that IR thermography is an efficient means of evaluating operation thermal conditions in betatron power supply units. This allows elaborating a well-founded approach to the designing of power supply units thus potentially improving betatron operation reliability.

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