Analysis of micro- and macrocavities in non-deformable anisotropic solid media by non-destructive testing

Ryazhskikh Viktor Ivanovich
Doctor of Technical Sciences, Full Professor
Voronezh State Technical University
Krasnov Andrey Andreevich
Postgraduate
Voronezh State Technical University

Abstract. The most problematic issue in various industries is the determination, depth and classification of micro- and macrocavities in non-deformable anisotropic solid media.

Keywords: anisotropy of solids, heat flux, thermal non-destructive testing.

The dependence of the equilibrium physical properties of a solid on the direction is determined by the anisotropy of the solid.

The quantities describing the macroscopic properties of matter are divided into scalars, pseudoscalars, vectors, and tensors of various ranks. A scalar characteristic (for example, the average density of a substance, temperature, heat capacity, entropy) is given by one numerical value, which is not associated with the concept of direction in space and does not change during rotation. Such a characteristic of a homogeneous body in a state of equilibrium cannot have anisotropy. Pseudoscalar characteristics, for example, the specific rotation of the plane of polarization, are also isotropic, since their numerical value is retained when the body or coordinate system is rotated (but they change sign when reflected). To specify a vector quantity (for example, the average magnetization of a crystal), it is required to indicate 3 components of the vector in a certain coordinate system. These components are the projections of the vector on the coordinate axes, they change when the coordinate system is rotated.

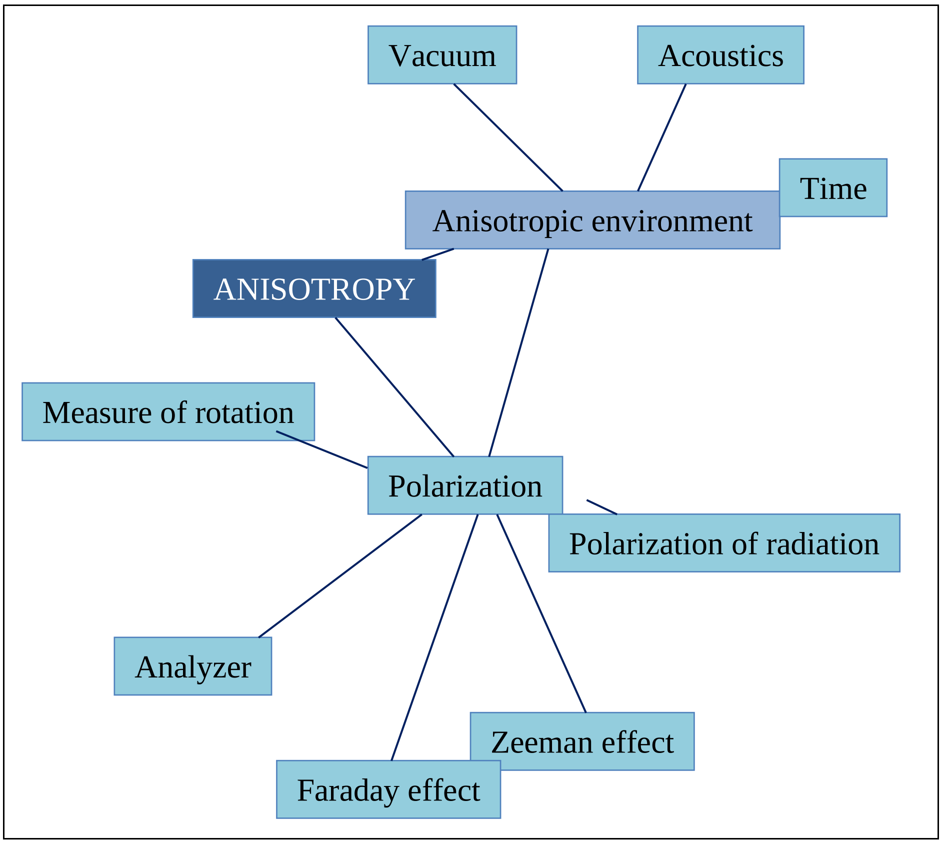

Figure 1 - Anisotropy

The law of thermal conductivity for anisotropic bodies takes into account the tensor nature of heat transfer, it can be represented as:

$$q\ M,t = -\Lambda grad\ u - \tau_p \frac{\delta q\ M,t}{\delta t} \qquad (1)$$

From the representation of the heat flux in form 1 for anisotropic bodies, we can conclude that the terms depending on the heat flux are the first two terms of the expansion of the function qq M,t÷τ_p in powers of the relaxation time τ_p,i.e. the heat flux depends not only on the rate $\tau_p \cdot \delta q$ M,t / δt of its change, but also on the acceleration $\tau_p^2 \delta^2 q$ M,t / δt^2 /2, on the third derivative, etc. Thus, now the heat flux can be represented in the form of the classical Fourier law, with a lagging argument in time equal to the relaxation time [1]:

$$q\ M,t + \tau_p = -\Lambda grad\ u \qquad (2)$$

Non-destructive testing methods, such as X-ray, thermal, ultrasonic, allow to identify the structure of micro- and macrocavities in objects of study at a great depth of occurrence without damage. X-ray and ultrasonic methods of non-destructive testing have a number of research limitations in terms of the depth of occurrence and the shape of the resulting discontinuities. The thermal method of non-destructive testing makes it possible to obtain a thermal spot identical to the shape of the investigated discontinuities.

Thermal control (TC) is a type of non-destructive testing based on fixing and converting infrared radiation into the visible spectrum. The thermal method is used in all branches of industry, where the technical condition of the controlled objects can be judged by the inhomogeneity of the thermal field.

At present, the method of thermal non-destructive testing (TNC) has become one of the most popular in heat power engineering and industrial production. In Russia, an increase in interest in thermal control is largely due to the adoption of Federal Law № 261 – FZ "On Energy Saving", which regulates energy audits of facilities in order to save resources. According to the definitions given in the law, the thermal method is the basic method for monitoring the current state of industrial facilities.

The main advantages of thermal control are: versatility, accuracy, efficiency, high productivity and the ability to carry out control remotely. According to one of the classifications, the following types of thermal control can be distinguished:

- Thermal imaging control
- Control of thermal conductivity
- Temperature control
- Control of heat flux density

Passive and active thermal control are conventionally distinguished. The passive TNC does not need an external heat source. On the contrary, active TNC assumes heating of the object by external sources.

The passive method of thermal control implies that the occurrence of a thermal field in the control object occurs during its operation or manufacture. Thermal control using the passive method is the most common TC method and is widely used in almost all branches of modern industry. The main advantage of the method is the control of objects without decommissioning and the absence of the need for additional manipulations associated with heating the object. Thermal non-destructive testing devices most often used in the passive method are thermal imagers, pyrometers, infrared thermometers, heat flow meters and data loggers.

The active method of thermal control is used when, during operation, the object does not independently emit sufficient thermal radiation for conducting TC. With the active method of thermal control, the object is heated by various external sources. Typical objects inspected by this method are multilayer composites and other objects that require an external thermal load.

Depending on the method of temperature measurement, thermal control devices are divided into contact and non-contact.

Currently, the most common devices for contact temperature measurement are: thermocouples, metal and semiconductor resistances, thermal indicators, thermal pencils, manometric and liquid thermometers. Non-contact thermal control devices include thermal imagers, thermographs, quantum counters, radiation pyrometers, etc.

Among thermal control devices, thermal imagers are currently the most in demand. The share of thermal control tasks solved with thermal imagers is so large that the term thermal imaging control is often used.

Thermal imager - a device for monitoring the temperature distribution of the investigated surface. The temperature distribution is shown on the display as a color field, where a certain temperature corresponds to a certain color. In most models of thermal imagers, information is recorded in the device memory and can be processed on a PC using special software.

Observation and measuring thermal imagers are distinguished. Observing devices simply produce an infrared image of the observed object, and measuring devices can assign the corresponding temperature to the digital signal of each pixel, as a result of which a heat map of the controlled surface is obtained.

Today thermal imagers are the optimal tool used in all cases where the technical condition of the controlled objects can be judged by the inhomogeneity of the thermal field. Thermal imagers allow you to quickly and reliably identify hot spots and potential problem areas during maintenance in construction, energy, manufacturing and other industries. The thermal imager is included in the list of equipment required for certification of the NDT laboratory using the thermal method.

Pyrometers (infrared thermometers) are devices for non-contact temperature measurement of bodies. The principle of operation of the device is based on measuring the power of thermal radiation in the infrared and visible range of light. Pyrometers are used to solve problems where, for various reasons, it is not possible to use contact thermometers. Pyrometers are often used for remote thermal monitoring of incandescent objects and in other cases when physical contact with the controlled object is impossible due to its inaccessibility or too high a temperature.

Data loggers are typically used to measure temperature and humidity. The data loggers are suitable for long-term measurement and are compact devices with display, memory card, waterproof housing and programmable operating times. Some modern models have the ability to simultaneously connect several probes, allowing measurements to be taken in several rooms at once. Logger data is analyzed using special software and can be used to generate reports in graphical and tabular forms.

In addition to the listed electronic devices, various mechanical means of thermal control are widely used, such as self-adhesive labels, thermal pencils, temperature indicators, high-temperature paint, heat-dissipating paste, and others.

The use of the thermal method also allows its combined use with other methods of non-destructive testing. Supplementing thermal control with other NDT methods, as a rule, makes sense when TC is a method preceding the use of more effective NDT tools or when synthesis by various control methods gives more accurate results.

A combination of the first type is possible, for example, when detecting water in aircraft honeycomb panels, as well as impact damage and delamination in composite materials. In these cases, with the help of thermal inspection, potentially defective areas are localized, after which a more thorough inspection can be performed using ultrasonic testing. Riveted joints of aircraft panels can be inspected in a similar way, where the main inspection is usually carried out by eddy current method.

Combination of the second type is usually used to control complex objects, when the result of data synthesis is not a simple summation of individual results, but creates their new quality, the so-called synergy effect. In this case, the simultaneous combination of thermal control with other NDT methods makes it possible to obtain the resulting image, which will be processed and analyzed only once. In addition to more accurate results, such a combination can significantly reduce time and financial costs compared to the sequential application of several methods. Currently, the concept of data fusion using various sensors is actively developing and has already found its application in the military and aerospace industries.

References

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