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Thermographic Criteria of Evaluation of Technical Condition of Machinery and Equipment

Abstract

Infrared thermography is used for the diagnosis purposes of various machines and devices. Despite the huge potential of thermography as a diagnostic tool, beginning thermographers are not always able to correctly assess and classify condition of the investigated object. The article presents an overview of current standards, and characterizes the methods and criteria for assessing the condition of machines and equipment.

Keywords: infrared thermography, machinery, devices, diagnostics, methodology, criteria.

1. Introduction

Infrared thermography is an invaluable tool of maintenance services, which allows to determine the condition of various machinery and devices. Despite the enormous potential of thermography there is still a large degree of uncertainty in the assessment of the condition of machinery and devices due to a lack of clear criteria of the condition evaluation based on the results of thermographic inspections. The article presents an overview of methods of diagnosis and currently used criteria for assessing the technical condition of machines and mechanical and electrical devices.

2. Thermographic diagnostics

Application of infrared thermography in the condition monitoring and diagnostics of machinery and devices is an extensive issue and may be carried out using active and passive methods. Passive thermography is most commonly used due to the ability to quickly detecting anomalies in the temperature distribution resulting from changes in the technical condition of an investigated object. The popularity of passive thermography is also due to the wide application of low-cost thermal imaging cameras dedicated to maintenance services. Despite the enormous potential of passive thermography, beginning thermographers are encountering difficulties in the interpretation and evaluation of the captured IR images. The problem in the correct assessment of the object condition on the basis of infrared images is much more severe when inspection is non-recurring and/or investigated object has non-standard construction and/or location. In addition, problems in the assessment of the technical condition can be multiplied due to erroneously prepared and carried out thermographic inspections.

A few years ago knowledge how to conduct properly the thermographic diagnosis was not widely available.

Currently, due to the high activity of thermographers and willingness to share their experiences on training courses, conferences and in numerous articles, a number of useful guidelines and criteria for thermographic assessment of the technical condition of machinery and devices were proposed.

The most important guidelines and criteria of thermographic inspections for the assessment of mechanical and electrical equipment were collected and published in several documents and standards issued by various international institutions [1].

2.1. Thermographic Standards

Documents relating to general principles of conducting thermographic inspections, personnel certification and criteria for evaluation of the technical condition of machinery and equipment were published by the International Organization for Standardization (ISO) and a few American organizations like American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM) or InterNational Electrical Testing Association (NETA).

From the point of view of thermographic diagnostics of machines and devices two relatively new standards are important: ISO 18436-7:2014 [8] which defines the requirements for qualification and assessment of personnel conducting thermographic diagnostic inspection and ISO 18434-1:2008 [7] which specifies general procedures of thermographic diagnostic of machines.

Guidance on the qualifications and certification of the personnel who uses thermography in non-destructive testing also formulated in the PN-EN ISO 9712:2012 [15].

In the American standard ASTM E1934 - 99a (2014) [3], one can find detailed advice and recommendations concerning the procedure for conducting thermographic inspection of electrical and mechanical equipment.

One can also indicate several documents which define clear recommendations and criteria for condition evaluation of the machines and equipment based on the results of thermographic inspections.

For example NETA (International Electrical Testing Association) has developed standard [2], approved by ANSI (American National Standards Institute), which defines the criteria for thermographic evaluation of the electrical equipment. Also, the Infraspection Institute (US) which trains staff in the use of thermography for the diagnosis and NDT has developed its own standard for infrared inspection of electrical and mechanical devices [6]. The standard links practical guidelines of various American thermographers. In Europe, for the inspection of electrical equipment guidelines developed by the Danish Technological Institute [14] are used.

It is worth to say that in the ISO ongoing work on the next thermographic standards. In preparation are: standard for examination of electrical installations [9], standard with requirements for infrared systems and equipment dedicated to non-destructive testing [10] and standard concerning the interpretation of thermo-graphic images [11].

3. Methods of thermographic diagnostics

In the thermographic diagnostics unquestionably the primary symptom that indicates the current condition are temperature values and their distribution visualized as an infrared image. Depending on how and when infrared images were acquired, one can distinguish two fundamental methods of thermographic diagnostics:

- Absolute methods
- Relative methods

Indicated methods are considered in the existing standards and a number of guidelines relating to the thermographic diagnostics of machines and devices.

3.1. Absolute methods

Absolute methods mainly rely on contactless measurement of absolute temperatures on the surface of diagnosed object using an infrared camera. Due to the high uncertainty of temperature measurement using an infrared camera under industrial conditions, these methods should be used with caution paying particular attention to the metrological conditions. Absolute methods in some cases may be the only effective way of assessing the current object condition.

Absolute temperature measurements can be used e.g. in the case of a single thermographic examination of an object for which previous inspections have not been conducted and there are no other running object of similar design. In this case, the only criteria for assessing of the object conditions can be determined based on absolute temperature limits of objects machine or device parts.

The limits of permissible temperature values can often be found in the operational manuals, catalogues or standards relating to a specific parts mounted in a machine or device.

It is recommended that during the thermographic examination of an object, the object has several adjacent components with different limits of operating temperatures (e.g. Bearings, sealing, grease), the lowest temperature component specification should be used for assessment of object condition.

In the machines, in most cases allowable temperature of the applied lubricants is lower than temperature of the other components of the machine. Thus the lubricant temperature is an indicator of machine condition. In the case where it is not possible to find a limit temperature value for a particular component, it could be assumed the lowest known temperature limit for similar component. Most of the maximum permissible temperature values given in standards and documentation is determined for the rated operating conditions.

It is worth to mention that in case of electrical devices, one can find three temperature limits: rated ambient temperature limit, allowable increase in temperature and maximum allowable operating temperature, which can be considered as the sum of rated ambient temperature and allowable temperature rise. These limits refer to devices operating at rated load and a specified ambient temperature.

However during a thermographic inspection electrical devices not always operate at rated load. In order to take into account a reduced operating load of electrical devices in determining the maximum allowable temperature, the following formula could be taken into consideration [5]:

$$T_{\max_{corr}} = \left(\frac{I_m}{I_z}\right)^2 T_{zw} + T_{om} \quad (1)$$

where:

$T_{maxcorr}$ - corrected maximum allowable temperature,

I_m – measured load current, A,

I_z – rated load current, A,

T_{zw} – rated temperature rise (from standard),

T_{om} – measured ambient temperature.

The maximum allowable temperature for the exemplary components used in mechanical devices are presented in Table 1.

Tab. 1. Example of maximum allowable temperatures of machines components

Machine component	T_{max}, °C
Bearing races	125
Bearing steel cage	300
Bearing plastic cage	120
Bearing felt seal	100
Silicone lip seal	180
PTFE lip seal	180
Lead base babbitt	149
Cadmium and lead bronze base	260
Mineral oils without EP additives	120
Lithium base grease	110
Polysulfide rubber seal	107
Polyurethane seal	93
Silicone rubber seal	232

Absolute temperature values for mechanical systems can also be defined in general terms on the basis of the results of statistical analysis of historical measurements. Table 2 presents the temperature limits applied when assessing machinery in the company Dunaferr Steelworks [12]. Presented temperatures were not the only criterion for evaluation of the state, also took into account the parameters of mechanical vibration (RMS, ENV).

Tab. 2. Absolute temperature criteria for machine inspections (based on [12])

T, °C	Condition class	Action
0-40	Good	Operation
>40-50	Satisfactory	Conditional operation control
>50-65	Unsatisfactory (standby)	As soon as possible check or fix
>65	Unacceptable	Immediately check and fix or stop

3.2. Relative methods

The fundamental and most commonly used method of evaluation of the machines and devices condition by the use of infrared thermography is to compare the results of thermographic observations with reference data. Such diagnostic approach is based on relative data and due to the type of reference data, we can talk about comparative quantitative or qualitative thermography.

3.2.1. Comparative qualitative thermography

Comparative qualitative thermography allows us to compare features of the temperature distribution fields of two or more objects of the same design in the IR camera field of view or acquired independently at different moments of time at different thermograms.

In case of comparative qualitative thermography it is not necessary to precisely set of infrared camera correction parameters in order to obtain precise measurements of temperature values. However it is important to assume that the parameters of thermographic observation (camera settings, object load, environmental conditions) for several objects of similar design, or the same object observed independently in different moments of time should be the same.

During assessing the condition of machines and equipment based on qualitative infrared images one can use a visual analysis of shapes, sizes and pseudo colours of temperatures fields, shapes of temperature profiles, etc. When comparing two qualitative thermograms it is worth to unify the level and range of temperature values displayed on the thermogram.

An example of comparative qualitative thermography might be comparison of the temperature distribution fields of two fuses visible on single thermogram, or comparison of two thermal image of the same bearing housing recorded an interval of 3 months.

3.2.2. Comparative quantitative thermography

In the case of the comparative quantitative thermography a diagnostic symptom is temperature difference ΔT resulting from the comparison of the observed object temperature with a reference value. The reference value could be e.g. temperature of similar object operating under the same conditions (e.g. temperature of a bearing housing of the same design like observed one), ambient temperature (Fig. 1a) or the temperature of the same object at another moment of time (Fig. 1b). In this case, the symptom is the relative change of the temperature over time $\Delta T(\delta t) = \mathrm{T}(t_1) - T(t_2)$.

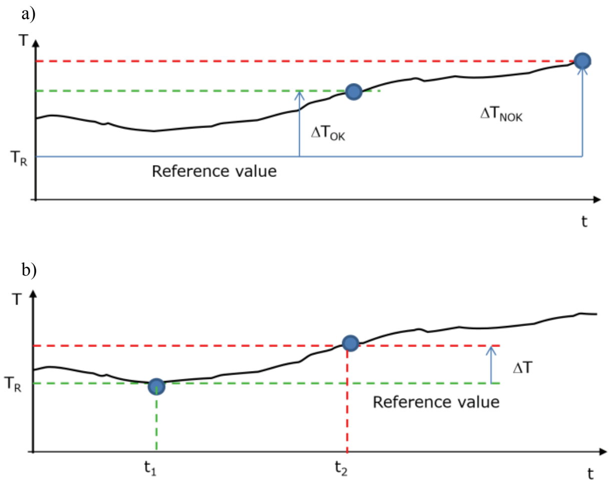

Fig. 1. Example of comparative diagnostics when a) reference value is determined arbitrarily; b) reference value depends on particular moment of operation time

4. Objects condition assessment criteria

There are a number of machines and devices which could be effectively diagnosed using infrared thermography. Examples of this are: electric motors, couplings, pumps, gearboxes, compressors, bearings, electric switching stations, overhead lines, electrical power equipment, etc.

During assessment of machine conditions one can use a criteria based on the temperature difference values between the measured and the reference temperature. Table 3 contains based on ISO 18434-1:2008 temperature difference limits and conditions classes.

Tab. 3. Temperature difference criteria for assessing the machine conditions [6, 7]

ΔT, °C	Condition class	Actions
1-10	Advisory	Corrective measures should be taken at the next maintenance period
>10-20	Intermediate	Corrective measures required as scheduling permits
>20-40	Serious	Corrective measures required ASAP
>40	Critical	Corrective measures required immediately

The reference temperature should be based on historical measurements gathered at the beginning of the operation when investigated object technical condition were very good.

Not always, is possible to record reference temperature in the initial stage of machine operation. In such case, the reference temperature could be determined based on statistical analysis of the large number of historical infrared measurements of different objects belonging to the same class and operating in similar condition as the investigated machine. Of course, values taken into account during determining of the reference value should come from machines operating in a good technical condition. This approach justifies the necessity of collection and share the results of measurements conducted during thermographic inspections.

The limit values of temperature differences for mechanical equipment published in the standard ISO 18434-1: 2008 coincide with the values proposed in the publication of Infraspection Institute [6], where additionally condition class-dependent actions for maintenance services were proposed (Tab. 3).

For the purposes of electrical systems diagnostics also developed various criteria condition [1, 2, 3, 5, 12, 14]. The criteria take into account differential and absolute temperature measurements performed by use of infrared camera.

The criterion of measured and air temperature difference is published in the standard developed by NETA/ANSI [2]. In this standard, among others, formulated limits and recommended actions during thermographic examination of electrical systems (Tab. 4).

Tab. 4. Thermographic Survey Suggested Actions Based on Temperature Rise [2]

Temperature difference (ΔT) based on comparisons between similar components under similar loading	Temperature difference (ΔT) based on comparisons between component and ambient air temperatures	Recommended action
1°C – 3°C	1°C – 10°C	Possible deficiency; warrants investigation
4°C – 15°C	11°C – 20°C	Indicates probable deficiency; repair as time permits
-----	21°C – 40°C	Monitor until corrective measures can be accomplished
> 15°C	> 40°C	Major discrepancy; repair immediately

In Polish literature one can meet the criteria of evaluation of the conditions of the electrical equipment. In [16] presented the criteria which allow to evaluate the electrical system condition based on 3 categories of faults: The first category (Cat. C) classify condition in which the temperature rise (measured relative to the average temperature of the similar object) is smaller than 5°C; it is recommended to repair during the next service. The second condition category (Cat. B) refer to the temperature difference range from 5°C to 35°C. If this condition occur a fast repair is recommended, taking into account the possibility of equipment switch-off. In the case of temperature rise higher than 35°C (Cat. A), the immediate repair is recommended. In some cases there are also accepted following temperature difference limits: <10°C, 10°C-30°C and >30°C. It is assumed that research must be conducted with a load greater than 30% of the rated load.

Another example of electrical systems assessment criteria are the one developed in Polish company ZBE ”Energopomiar” and dedicated for the assessment and classification of defects of current connections of switchgear units [17]. The criteria are based on the value of the temperature rise of the terminal above the temperature of the wire connected to the terminal. Developed temperature limits are depended on thermographic measurement conditions such as ambient temperature, wind speed or load value. It is assumed that the wind speed must not exceed 4 m/s, and load current should not be less than 30% of rated current for the switchgear or transmission line. The limit values are presented in Table 5.

Tab. 5. Criteria of assessment of connection terminals of switchgear units [17]

Measurement Conditions	ΔT, °C			
Wind speed <2 m/s	3–10	11–30	31–50	>50
Wind speed >2m/s	3–10	11–20	21–35	>35
Load current 30%–60% In*	Sufficient	Bad	Very bad	Very bad
Load current >60% In*	Sufficient	Bad	Very bad	Very bad
	Connection condition class			

*In-rated current

5. Conclusions

Thermographic diagnostic of machines and devices requires from thermographer adequate knowledge and experience. Developed standards preserve uniform and high levels of thermographic diagnosis because they contain of the requirements for personnel qualifications conducting thermographic inspections, as well as the procedures and criteria for evaluation of object condition [3, 7, 8]. Due to of the variety of machines and equipment as well as various ways of its operation quantitative criteria defined in the standards do not always reflect the real symptoms of a investigated object condition and may require adjustment. Does not change the fact that the existence of quantitative criteria is a good reference point for both beginners and experienced thermographers conducting inspections of machinery and equipment of unknown history of operation. A promising is the fact that further studies connected with standardizing of different aspects of thermographic surveys are in continuous development. One of important way of increasing of thermographic qualification is systematic practice and participation in different conferences, workshops and trainings where one can find a lot of practical and interesting tips and tricks.

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