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Condition monitoring and diagnostics of machine systems — Thermography —

Part 2:
Image interpretation and diagnostics

Surveillance et diagnostic de l'état des systèmes de machines — Thermographie —

Partie 2: Interprétation d'image et diagnostic

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

A list of all parts in the ISO 18434 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides specific guidance on the interpretation of infrared thermograms as part of a programme for condition monitoring and diagnostics of machines. Thermography can be used to identify and document anomalies for the purposes of condition monitoring of machines. These anomalies are usually caused by such mechanisms as operation, improper lubrication, misalignment, worn components or mechanical loading anomalies.

Infrared thermography is based on measuring the distribution of radiant thermal energy (heat) emitted from a target surface, and converting this to a map of radiation intensity differences (surface temperature map) or thermogram. The thermographer therefore requires an understanding of heat, temperature and the various types of heat transfer as essential prerequisites when undertaking an IR programme. Thermal energy is present with the operation of all machines. It can be in the form of friction or energy losses, as a property of the process media, produced by the actual process itself or any combination thereof. As a result, temperature can be a key parameter for monitoring the performance of machines, the condition of machines and the diagnostics of machine problems. Infrared thermography is an ideal technology to do this temperature monitoring because it provides complete thermal images of a machine, or a machine component, with no physical attachments (non-intrusive), requires little set-up and provides the results in a very short period of time.

Although extremely useful, IRT has a limitation in that radiometric sensing is susceptible to unacceptable error when used on most low emissivity surfaces.

Condition monitoring and diagnostics of machine systems — Thermography —

Part 2: Image interpretation and diagnostics

1 Scope

This document provides specific guidance on the interpretation of infrared thermograms as part of a programme for condition monitoring and diagnostics of machine systems.

In addition, IR applications pertaining to machinery performance are addressed.

This document is intended to:

— provide guidance on establishing severity assessment criteria for anomalies identified by IRT;

— outline methods and requirements for carrying out thermography of machine systems, including safety recommendations;

— provide information on image interpretation, assessment criteria and reporting requirements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*

ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*

ISO 13379-1, *Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques — Part 1: General guidelines*

ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*

ISO 18434-1, *Condition monitoring and diagnostics of machines — Thermography — Part 1: General procedures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13372 and ISO 18434-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Thermal condition monitoring

4.1 Application of thermal imaging within condition monitoring programmes

Within typical condition monitoring programmes, thermal imaging of mechanical components of a machine system is not typically used as a primary monitoring technique. The exceptions to this are when heat generation or transfer characteristics are a primary indicator of impending failure or performance deterioration or where rapid scanning using thermal imaging is more economical and efficient. Another exception is when applied heat is a primary cause of failure.

4.2 Correlation with other technologies

Typically, thermal imaging is used in a condition monitoring programme to detect thermal characteristics of failure modes previously identified by another technology. In this scenario, thermal imaging can be used both to confirm the presence of a failure mode and to validate its severity. Exceptions to this occur when the primary symptom of failure is heat generation or heat loss such as bypassing reciprocating compressor valves, leaking or blocked heat exchangers, insulation failure, refrigerant leaks or electrical faults.

4.3 Performance monitoring

Thermal imaging is also applicable in the field of performance monitoring of a process and the machine at the machine/product interface. Typically, such application also involves the use of thermal imaging in a product quality assurance and/or control role whereby machine failure is identified via deterioration in product quality.

Examples of this are when the production process involves exothermic reactions such as foam manufacturing or high temperature applications such as plastic extrusion.

5 Equipment choice

5.1 Lens choice

Infrared (IR) cameras with fixed lenses can have limitations with respect to resolution and field of view and might not be suitable for all applications. For IR cameras where different lenses can be used, there is normally a choice of lenses including standard, wide angle, telephoto and macro.

For machine condition monitoring, wide angle lenses are particularly useful for gaining images containing the maximum machine surface area for comparison of apparent temperature. If wide-angle lenses are not available then IR cameras with a larger field of view (FOV) are more suitable. This allows the comparison of multiple components in a single image. This lens type is also useful in confined space areas where the standoff distance can be very small.

Telephoto lenses are useful for remote component locations such as elevated conveyors and equipment, vessels and outdoor substations. They may also be used for small items.

IR camera FOV, instantaneous field of view (IFOV) and detector characteristics should be considered in conjunction with lens characteristics to ensure thermal resolution is appropriate.

Macro lenses are not typically used for machine condition monitoring but can be used for product quality monitoring. An example is monitoring the quality of glass fibre optics.

5.2 Infrared windows and sight glasses

Infrared windows or sight glasses can be used for internal inspection of electrical cabinets, some mechanical equipment, high temperature applications such as boilers and furnaces, or where access through doors and panels is required.

5.3 IR camera characteristics

5.3.1 General

When selecting an IR camera, the condition monitoring application shall be considered to ensure the suitability of the equipment. Smaller, less expensive IR cameras might not be suitable for many applications due to their thermal, optical and image processing limitations.

Thermal sensitivity, spatial resolution, temperature range and time response should be carefully considered with respect to the intended applications.

5.3.2 Image capture speed

For applications that involve video capture, high surface speeds and/or rapid changes in apparent temperature, the use of a high speed IR camera can be required.

5.3.3 Wavelength choice

For most machine condition monitoring applications, both long-wave (approximately 8 µm to 14 µm) and mid-wave (approximately 3 µm to 5 µm) IR cameras are suitable.

In some specific applications, such as monitoring thin film plastic extrusion equipment, a short-wave (approximately 0,8 µm to 3 µm) or a mid-wave IR camera with specific filters can be required. Such IR cameras are also useful for internal inspections of boilers and furnaces and gas leak detection. Short-wave cameras are particularly necessary for material testing at very high temperatures (>1 000 °C). For gas leak detection, the wavelength required depends on the gas.

5.3.4 Camera lens filters

For some specific failure modes, lens filters can be required. Examples include monitoring of thin plastic films, boilers and furnaces, and gas leaks.

6 Data collection

6.1 Thermogram and photograph content

For condition monitoring applications, it is typical that many component locations are required in a single image in order to facilitate rapid comparison of multiple component temperatures. This means that it is advisable to acquire as much of the machines surface as possible in a single image.

Such image acquisition often requires

— large standoff distances,

— image acquisition at angles to the machine normally at the corners,

— elevated viewing locations.

Examples of good images with sufficient machine surface coverage are given in Figure 1.

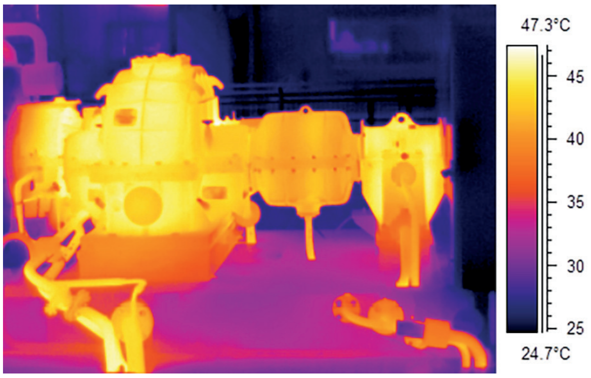


Figure 1 — Single drive train thermogram

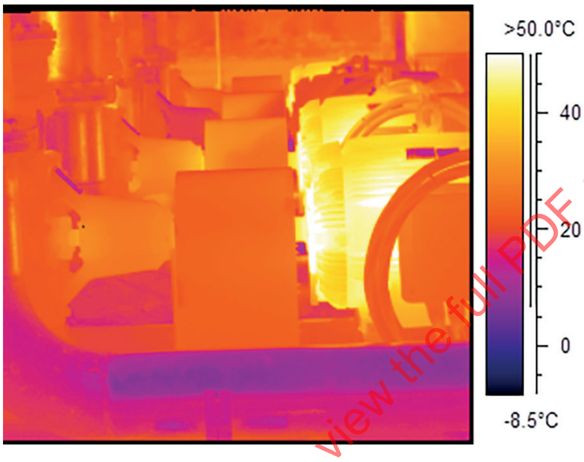


Figure 2 — Multiple machines (pump sets) comparison thermogram

Some systems also have the capability of image montage allowing the production of a single large image from many smaller ones, which can be advantageous when analysing large machine trains.

It can also be useful to include within the same image an adjacent identical machine in order to determine if any variation between them can reveal the presence of a failure mode (Figure 2). If a difference exists, further investigation can be undertaken and additional comparison of the machines operating conditions, behaviour and history can prove useful for diagnostics.

To aid with image identification and interpretation, photographs should be acquired from exactly the same location, orientation and subject content as the thermal image.

6.2 Error sources, accuracy and repeatability

6.2.1 IR camera location

Images should be acquired from locations that minimize errors caused by other sources, such as background reflections and solar reflections. For condition monitoring of machines, the image location should include as much of the machine as possible to allow for comparison and pattern analysis in a single image (Figure 1). Typically, such positions can include the acquisition of multiple machine faces in a single thermogram from a 45° angle to the corner. Determination of reflected apparent temperatures shall be in accordance with ISO 18434-1.

6.2.2 Emissivity

Where temperature alarm criteria are used, all the emissivity of any anomalies shall be correctly determined in order to ensure the accuracy of the temperatures displayed, the derived severities and the subsequent recommendations. Determination of correct emissivity shall be in accordance with ISO 18434-1.

6.2.3 Focus, range and distance

All images shall be in focus. Appropriate IR camera and image settings, i.e. range, level, span, contrast and sensitivity, shall be selected for the application. These settings may differ between that necessary for the determination of component load zone and thermal patterns as opposed to those necessary for accurate temperature determination. The standoff distance shall be appropriately selected to ensure adequate thermal and spatial measurement resolution of the anomaly.

For condition monitoring of machine systems, the most appropriate stand-off distance may be extremely large to include the entire machine train in a single image to allow for comparison and pattern analysis. Correction for stand-off distance shall be in accordance with ISO 18434-1.

6.2.4 Machine operating conditions

When routine assessment is carried out, the machine should be operating under steady state conditions representative of normal operating conditions and after thermal equilibrium has been achieved. The conditions at the time of assessment shall be recorded.

6.2.5 Environmental conditions

In many instances, field measurements of reflected apparent temperature and emissivity need to be carried out in order to obtain correct temperatures. These measurements shall be carried out in accordance with ISO 18434-1 as well as established industry standards and practices, relevant International Standards and manufacturers' guidelines.

6.2.6 Calibration

IR cameras shall be in calibration at the time of inspection and a calibration check shall be carried out prior to image acquisition. Such requirements are stated in ISO 18434-1.

7 Machine bearing location identification convention

All machine bearing locations shall be identified in accordance with ISO 13373-1.

8 Severity criteria

8.1 Baseline measurements

Baseline temperatures and assessment criteria should be based on historical or statistically derived temperatures established from the specific item, or machine groups, when in the "ideal" condition. Establishment of severity criteria shall be in accordance with ISO 17359 and ISO 13379-1. Assessment criteria should be based on temperatures specified by manufacturers of similar items or groups of equipment. These measurements shall be carried out in accordance with ISO 18434-1 as well as established industry standards and practices, relevant International Standards and manufacturers' guidelines.

8.2 Typical guidelines

When applying infrared thermography to the condition monitoring and diagnostics of machines, and their related components, it is strongly recommended that severity assessment criteria be established.

These measurements shall be carried out in accordance with ISO 18434-1 as well as established industry standards and practices, relevant International Standards and manufacturers' guidelines.

9 Image interpretation guidelines

From a machinery viewpoint, thermal image interpretation is essentially a process of comparing apparent surface temperatures and patterns against reference images representative of the ideal design, manufacture, installation, operation and maintenance criteria. Such comparison can also be required prior to and post a maintenance activity.

Once the comparison and identification of any anomalies are completed, analysis normally takes the form of comparing temperatures and patterns with those consistent with known faults and failure modes.

When using thermography for machinery condition monitoring purposes, the operating and environmental conditions of the machine at the time of each survey need to be known in detail as many changes in thermal patterns are dependent on operating condition and/or environment.

Understanding the design of a machine is essential to understanding component loading, which can be the primary contributor to the thermal pattern. In one case, a normal loading can generate an excessive temperature while an acceptable temperature can be generated by an abnormal load application. A typical example of this is where the heat generated by friction in a bearing load zone is not excessive but is in the wrong location indicating potential faults such as incorrect assembly or drive train misalignment.

When analysing machine systems, a thermodynamic approach needs to be undertaken combined with an analytical approach that considers the machine system as a whole rather than as individual components. Such a thermodynamic approach considers the machine system from the viewpoints of heat generation, heat loss and incident heat as well as conduction, convection and radiation.

Key examples of this include heat transfer along a shaft into a bearing from another source of heat, i.e. gears, leaking steam seals/glands or hot process fluid.

Consideration of such sources, prior to determining machine or component fault characteristics, ensures that the heat balance of the machine is considered as a system rather than as a specific component fault. A table of examples relating to thermodynamic conditions is given in Annex A.

A typical fault identification process that may be used is specified within ISO 18434-1. Upon completion of that process, the following further actions can also be required by the customers:

a) apply confirmatory analysis using an alternative technique if necessary;

b) determine corrective actions.

10 Diagnosing thermodynamic problems

10.1 General principles

Diagnosing machine systems using thermography is not generally rule based. Diagnostics, therefore, requires a principle based approach where analysts use thorough understanding of the principles of heat generation, flow and control to diagnose machine systems faults. In any diagnosis process, the definition and description of "normal" is as equally important as defining and describing "abnormal".

There are generally six principles that underpin such analysis:

— sources of heat generation within a machine system;

— abnormal heat distribution;

— sources of friction control within a machine system;

— sources of external application of heat to a machine system;

— sources of heat loss from a machine system;

— principles of heat transfer that affect the heat transfer to and from a machine system.

Diagnosis of machine systems usually requires the application of all six principles to identify the source of thermal anomalies and to diagnose causes. Examples that demonstrate the principles are given in Annex A.

10.2 Heat generation

10.2.1 General

Heat generation sources may include, but not be limited to: friction, exothermic reaction, electromagnetic, electrostatic and adiabatic compression.

10.2.2 Surface friction

Friction is caused by the interaction of two surfaces moving in relative motion whilst in contact. Relative velocity, surface roughness, relative surface hardness, materials, contaminants, lubricating films and load all influence surface friction. Thermal imaging can be used to determine the machine's thermal response to any change in these friction modifiers.

It is possible that the load on a particular surface is not representative of the total applied load as surface geometries and load characteristics can result in such applied loads being concentrated over a particular surface area. Such load concentration can result in increased heat generation over a localised area.

It is important for the analyst to have a thorough understanding of the design intent for machine component loading in order to determine abnormal load, load patterns and load distributions.

10.2.3 Fluid friction

Fluid friction is caused by the disturbance of a fluid flow over a surface. Such fluid flow disturbance can be influenced by fluid velocity, flow characteristic (laminar or turbulent), fluid density, thermal properties, surface roughness and pressure.

The heat generation within a fluid containing machine can also be concentrated over a particular surface area due to geometrical errors such as impeller-to-casing misalignment or eccentricity causing localised variation of fluid friction due to clearance variation.

Fluid friction can also be generated within hydrodynamic bearings particularly under boundary and mixed film lubrication conditions when internal friction may be higher than under normal operating conditions.

10.2.4 Electrostatic discharge heating

Electrostatic heating occurs when an electrostatic charge builds up on, or in, a component resulting in a discharge arc between components. This arcing creates heat.

This typically occurs on centrifugal compressors or fans in a dust laden environment when static electricity builds up on the impeller and discharges to earth via the bearings or seals usually in the load zone.

10.2.5 Electrical (induced current) discharge heating

Electrical (induced current) heating occurs when a current induced by a rotating magnetic field builds up on, or in, a rotating component resulting in a discharge arc between components. This arcing creates heat.

This typically occurs on various types of variable speed motors where rotating currents can be induced in the motor rotor resulting in a passage of current to earth via the bearings usually in the load zone.

10.2.6 Exothermic reaction heating

An exothermic reaction is a chemical reaction or phase change that releases energy in the form of heat. Such reactions can include combustion of fuels and lubricants (micro-dieseling) as well as industrial processes such as foam generation.

10.2.7 Electromagnetic heating

Eddy currents inside ferromagnetic components, causing the components to heat up due to molecular/atomic excitation, can cause electromagnetic heating.

This usually occurs on static components within alternating current electromagnetic field, i.e. motor control cabinet components, casings and structural components within magnetic fields.

10.2.8 Compression heating

Changes in pressure can also generate heat. Examples include gas compression in compressors, bladder pulsation dampers and adiabatic compression of entrained air in lubricants and or liquids (cavitation). This typically occurs in reciprocating compressors or hydraulic systems.

10.2.9 Material cyclic deformation heating

Cyclic deformation of some materials produces heat due to the work hardening and microstructural deformation of the material.

10.2.10 Electrical resistance heating

Heat is generated in electrical systems by the passage of current through a conductor or across contacting surfaces. The rate of heat generated power, P, expressed in watts, is proportional to the resistance, R, expressed in ohms, of the conductor or conducting path and the square of the current, I, where current is measured in amperes.

$$P = I^2 R$$

10.3 Abnormal heat distribution

Abnormal loading conditions caused by incorrect machine and component forces can result in abnormal thermal distribution patterns whilst not necessarily producing excessive heat. Examples of this include misaligned machine trains, misaligned components and internal shaft misalignment within gear trains or machines with integral gear drives, e.g. some large centrifugal multi-stage compressors.

Abnormal heat distribution sometimes occurs at incorrectly assembled machine surface interfaces whereby air gaps provide a degree of insulation. Alternatively, the loss or absence of an insulating medium can also result in abnormal heat transfer between machine surfaces.

10.4 Applied heat

Applied heat sources are generally external to the machine and require conduction, convection, radiation and induction for heat transfer to the machine. Examples typically include heat conduction along machine components, heat convection within enclosed machine spaces and heat radiation from adjacent hot surfaces.

10.5 Heat loss

Sources of heat loss can include, but not be limited to, conduction, convection and radiation by various fluids, gases and materials, as well as endothermic reactions and adiabatic cooling.

Heat loss can be intentional (i.e. cooling) or unintentional (i.e. loss of insulation). A thorough understanding of the machine system design is required to determine what represents an abnormal condition. Abnormal cooling conditions can be induced by inadequate or excessive cooling and/or inadequate or excessive insulation.

10.6 Heat transfer

Heat transfer can be either intended or unintended. Heat transfer is usually controlled by some form of insulating media. Failure of insulation results in unwanted heat flow either from or into the machine system.

Annex A
(informative)

Case examples

The following are examples only and should not be used for interpretation or analysis. These images should be interpreted by certified thermographers that are suitably experienced in the relevant machinery design and analysis principles.

Table A.1 — Case examples

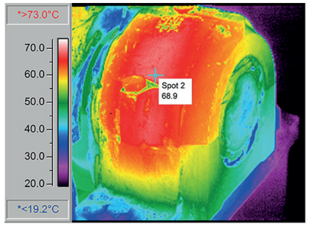
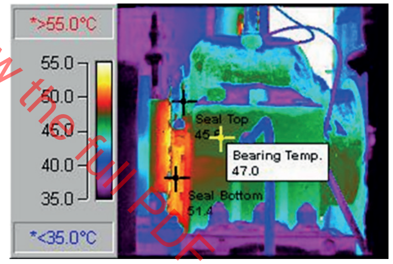
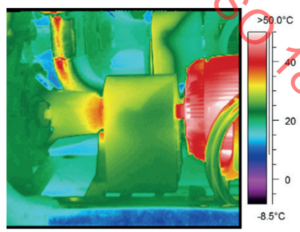
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.2 Surface friction	Large rolling element bearing	Bearing Friction in top of housing due to fretting. Note lack of conduction across housing interface.	Temperature rise above split line of the bearing appears greater in the top half. This is indicative of heat generation within the housing of fretting corrosion caused by loose housing bolts.	 **Figure A.1**	
10.2.2 Surface friction	Mine ball mill pinion bearing	Friction between lower portion of bearing housing seal rubbing on the shaft	Rubbing bearing housing seal	 **Figure A.2**	
10.2.2 Surface friction	Water pump	Pump with hot coupling side bearing and motor with hot drive end bearing and windings	Misalignment	 **Figure A.3 a)**	 **Figure A.3 b)**

Table A.1 *(continued)*

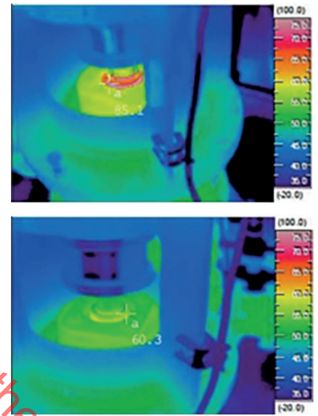
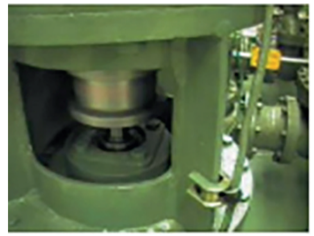
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.2 Surface friction	Water pump	Pump bearing Abnormal temperature increase of the pump bearing in continuous running. The temperature rose up to 85,1 °C (above) while the other three normal pump bearings were about 60 °C (below). Before the break down of the pump, the change of the pump to the reserve one was performed. By infrared thermographic testing, the plant output decrease was able to be evaded.	Mechanical damage	 **Figure A.4 a)**	 **Figure A.4 b)**

Table A.1 *(continued)*

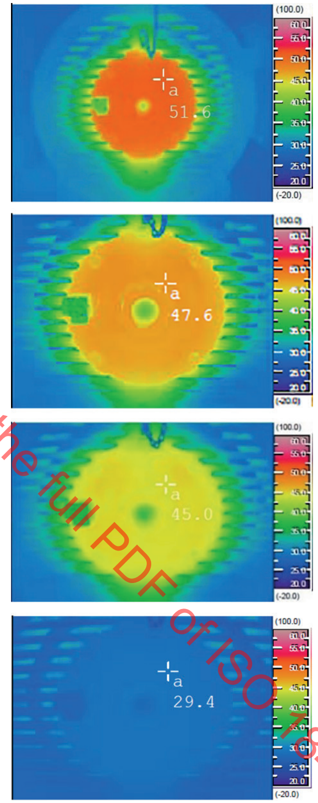
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.2 Surface friction	Electric motor	Bearing on the anti-coupling side The temperature rose up to about 51,6 °C (the first thermogram) while it was about 30 °C usually. Infrared thermographic testing had been performed for ten days after grease treatment (the second thermogram: one hour after, the third thermogram: after three days). As the temperature decreased to a normal level after ten days (the forth thermogram), it was confirmed that treatment by grease replenishment was appropriate.	Problem of lubricant (grease)	 Figure A.5 a)	 Figure A.5 b)

Table A.1 *(continued)*

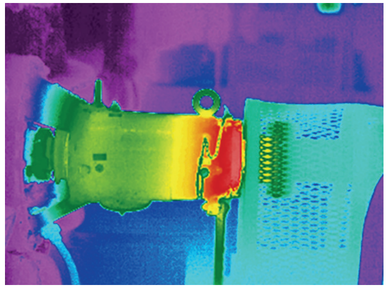
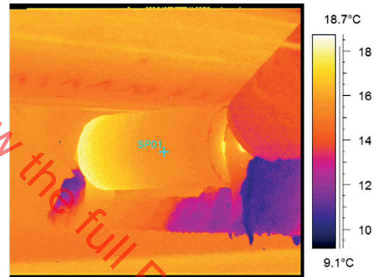
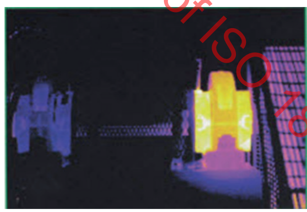
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.2 Surface friction	Pump	Pump Coupling bearing and coupling with elevated relative temperatures	Misalignment	 Figure A.6 a)	 Figure A.6 b)
10.2.2 Surface friction	Conveyor	Conveyor High friction between belt and roller and high bearing temperatures	Failed conveyor idler bearing	 Figure A.7 a)	 Figure A.7 b)
10.2.2 Surface friction	Belt driven fan	Fan High belt and belt side bearing temperatures	Overtight belts	 Figure A.8 a)	 Figure A.8 b)

Table A.1 *(continued)*

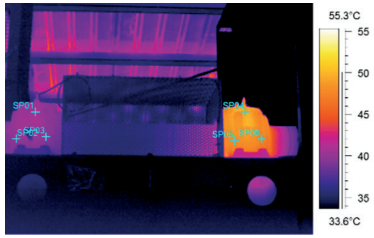
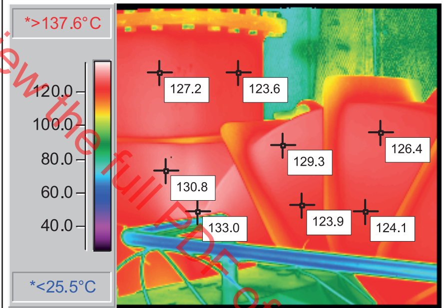
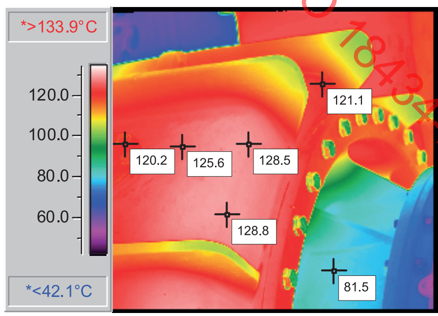
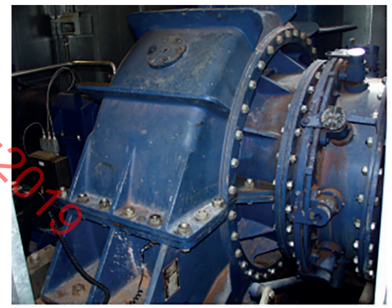
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.2 Surface friction	Belt driven fan	Fan High fan side bearing temperatures Note shaft temperature profile indicates heat generation is within the bearing.	Poor lubrication Reduced internal clearance	 **Figure A.9 a)**	 **Figure A.9 b)**
10.2.3 Fluid friction	Centrifugal air compressor	Casing Non uniform temperature profile on opposite corners	Misalignment of casing to impellor	 **Figure A.10 a)**	 **Figure A.10 b)**
10.2.3 Fluid friction	Centrifugal air compressor	Casing Non uniform temperature profile on opposite corners	Misalignment of casing to impellor	 **Figure A.11 a)**	 **Figure A.11 b)**

Table A.1 *(continued)*

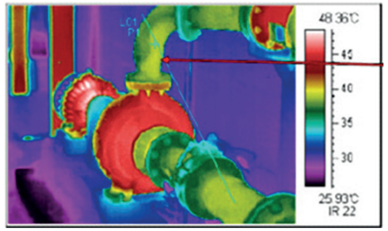
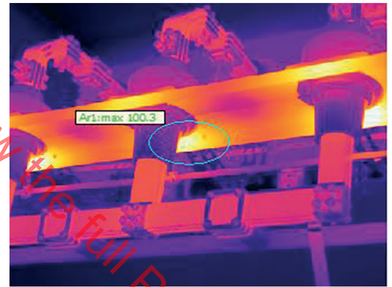
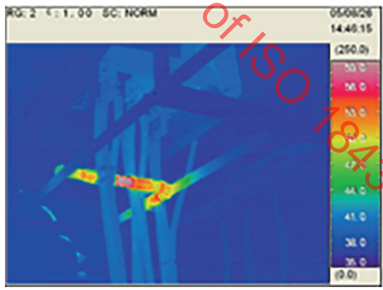
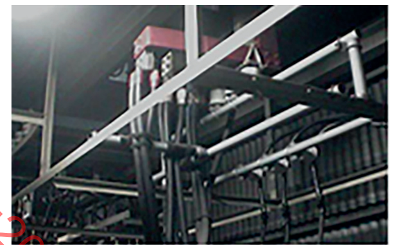
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.3 Fluid friction	Compressor cooling water pump	Cooling water pump Pump is hotter than suction or discharge indicating recirculating flow.	High backpressure due to blocked cooler downstream	 **Figure A.13 a)**	 **Figure A.13 b)**
10.2.7 Electromagnetic heating	Supporting structure of bushing	In places of bushings is overheating.	Local overheating by eddy currents	 **Figure A.14 a)**	 **Figure A.14 b)**
10.2.7 Electromagnetic heating	Distribution line	Electric wire support steel tube	Electric wire supporting steel pipe shows high temperature of over 60 °C. An improvement such as changes of the pipe position is necessary	 **Figure A.15 a)**	 **Figure A.15 a)**

Table A.1 *(continued)*

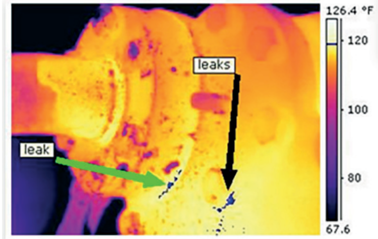
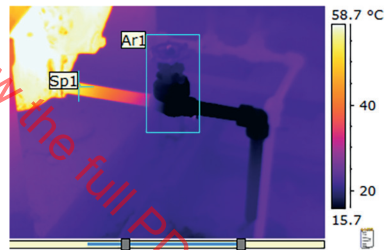
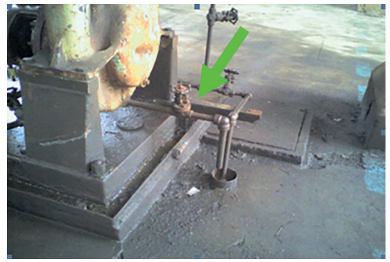
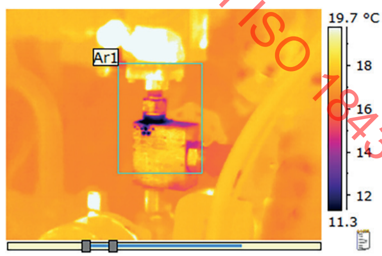
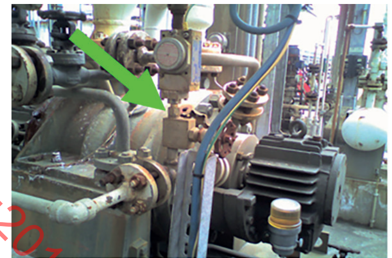
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.8 Compression heating	HVAC unit	Compressor Adiabatic decompression cooling due to leak?	**Compressor not working properly** Compressor not working properly because of a Freon leak. The leak was found with infrared due to oil leaking out with Freon.	 **Figure A.16 a)**	 **Figure A.16 b)**
10.2.8 Compression heating	MEK area	Manual discharge valve Adiabatic cooling	Gas leakage (VOC) detected due to gas expansion The valve is closed during normal operation.	 **Figure A.17 a)**	 **Figure A.17 b)**
10.2.8 Compression heating	Vacuum area	Connection Adiabatic cooling	Gas leakage (VOC) detected due to gas expansion	 **Figure A.18 a)**	 **Figure A.18 b)**

Table A.1 *(continued)*

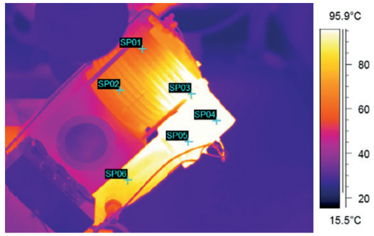
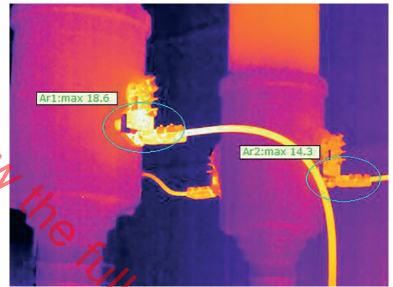
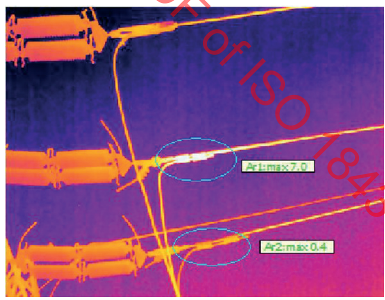
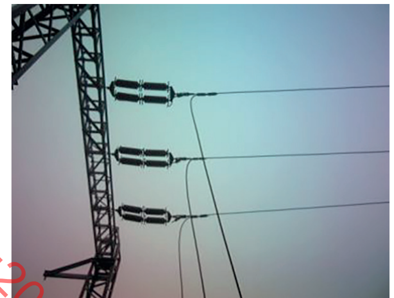
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.8 Compression heating	Reciprocating compressor	Compression heating of cylinders with abnormal temperature profile from leaking valve	Valve leak	 Figure A.19 a)	 Figure A.19 b)
10.2.10 Electrical resistance heating	Measuring current transformer	Transformer terminal	High resistance joint	 Figure A.20 a)	 Figure A.20 b)
10.2.10 Electrical resistance heating	High voltage line	Conductor terminal	High resistance joint	 Figure A.21 a)	 Figure A.21 b)

Table A.1 *(continued)*

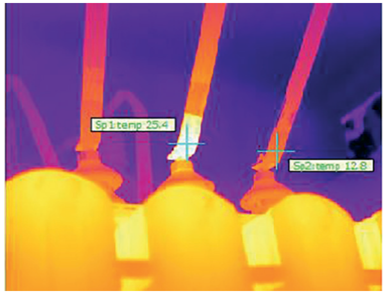
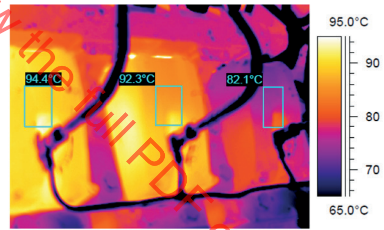
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.2.10 Electrical resistance heating	Transformer bushing	Terminal connector	High resistance joint	 **Figure A.22 a)**	 **Figure A.22 b)**
10.3 Abnormal heat distribution	Diesel engine Driven electrical power generation	V shaped 6 cylinders diesel engine Number 3 cylinder not producing power efficiently	Cylinder 3 abnormal temperature	 **Figure A.23 a)**	 **Figure A.23 b)**
10.3 Abnormal heat distribution	Coking operation	Safety relief valve Right valve hotter than similar valves on left for comparison Convection heating	Leaking SRV	 **Figure A.24 a)**	 **Figure A.24 b)**

Table A.1 *(continued)*

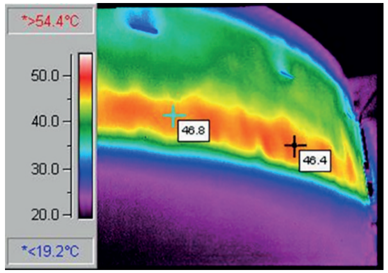
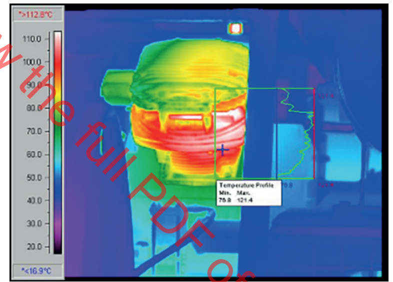
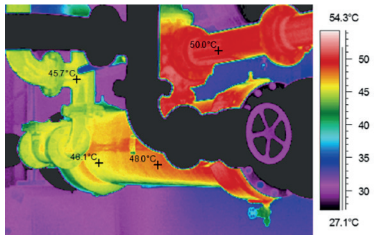
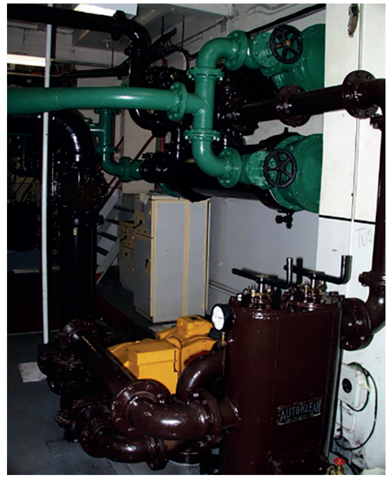
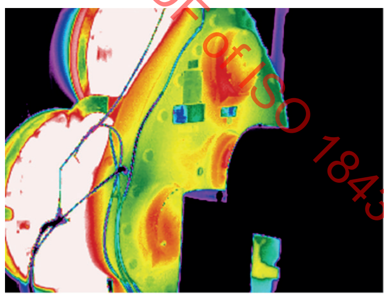
Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.3 Abnormal heat distribution	Mineral processing tank	Acid digestion tank	Failed rubber lining within tank	 Figure A.25 a)	 Figure A.25 b)
10.3 Abnormal heat distribution	Air compressor on mining equipment	Compressor cylinder Note high temperatures from air leak, however, apparent high temperatures on casing side wall due to high emissivity of blackened oil coating.	Head gasket leak	 Figure A.26 a)	 Figure A.26 b)

Table A.1 *(continued)*

Diagnostic principle and subclause	Name of the machine or system e.g., calendar, reformer, hydraulic arm, etc.	Name of the component on the machine Thermal characteristic	Degradation or problem or fault	Thermogram	Visual
10.3 Abnormal heat distribution	Hydroelectric turbine bearing cooling system	Hydro turbine bearing cooler High temperatures of water and oil pipes	Blocked cooler tubes on heat exchanger	 Figure A.27 a)	 Figure A.27 b)
10.3 Abnormal heat distribution	Multi stage high speed centrifugal air compressor	Bearing load zones not in expected direction of gear and shaft reaction forces	Bearing housing bores machined out of line resulting in bearing misalignment and overload	 Figure A.28 a)	 Figure A.28 b)

