# INTERNATIONAL STANDARD

# ISO 18434-1

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## Condition monitoring and diagnostics of machines — Thermography —

## Part 1:
## General procedures

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

*Partie 1: Procédures générales*

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# Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18434-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machines*.

ISO 18434 consists of the following parts, under the general title *Condition monitoring and diagnostics of machines — Thermography*:

— *Part 1: General procedures*

Image interpretation and diagnostics is to form the subject of a future Part 2.

# Introduction

This part of ISO 18434 provides guidance on the use of infrared thermography (IRT) as part of a programme for condition monitoring and diagnostics of machines. IRT 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.

IRT 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. IRT 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.

An important advantage of radiation thermometers over contact thermometers is their speed of response. The measured energy travels from the target to the sensor at the speed of light. The response of the instrument can then be in milliseconds or even microseconds. Another advantage is the sensitivity of the instruments in that they can detect and display a thermal “picture” composed of the very subtle temperature differences of the target.

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 machines — Thermography —

# Part 1: General procedures

## 1 Scope

This part of ISO 18434 provides an introduction to the application of infrared thermography (IRT) to machinery condition monitoring and diagnostics, where "machinery" includes machine auxiliaries such as valves, fluid and electrically powered machines, and machinery related heat exchanger equipment. In addition, IR applications pertaining to machinery performance assessment are addressed.

This part of ISO 18434:

— introduces the terminology of IRT as it pertains to condition monitoring and diagnostics of machines;

— describes the types of IRT procedures and their merits;

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

— outlines methods and requirements for carrying out IRT of machines, including safety recommendations;

— provides information on data interpretation, and assessment criteria and reporting requirements;

— provides procedures for determining and compensating for reflected apparent temperature, emissivity and attenuating media.

This part of ISO 18434 also encompasses the testing procedures for determining and compensating for reflected apparent temperature, emissivity and attenuating media when measuring the surface temperature of a target with a quantitative IRT camera.

NOTE It is intended that future parts will address application-specific analysis guidelines.

## 2 Normative references

The following referenced documents are indispensable for the application 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 13379, *Condition monitoring and diagnostics of machines — General guidelines on data interpretation and diagnostics techniques*

ISO 13381-1, *Condition monitoring and diagnostics of machines — Prognostics — Part 1: General guidelines*

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

ISO 18436-7, *Condition monitoring and diagnostics of machines — Requirements for qualification and assessment of personnel — Part 7: Thermography*

ASTM E1897, *Standard test methods for measuring and compensating for transmittance of an attenuating medium using infrared imaging radiometers*

## 3 Terms and definitions

For the purposes of this document the terms and definitions given in ISO 13372 and the following apply.

**3.1**
**apparent temperature**
uncompensated reading from an infrared thermography camera containing all radiation incident on the detector, regardless of its source

**3.2**
**attenuating media**
windows, filters, atmospheres, external optics, materials or other media that attenuate the infrared radiation emitted from a source

**3.3**
**black body**
ideal perfect emitter and absorber of thermal radiation at all wavelengths

NOTE This is described by Planck's law.

**3.4**
**emissivity**
$\varepsilon$
ratio of a target surface's radiance to that of a black body at the same temperature and over the same spectral interval

**3.5**
**infrared thermography camera**
**IRT camera**
instrument that collects the infrared radiant energy from a target surface and produces an image in monochrome (black and white) or colour, where the grey shades or colour hues are related to target surface apparent temperature distribution

NOTE Such images are sometimes called *infrared thermograms*.

**3.6**
**image processing**
converting an image to digital form and further enhancing the image to prepare it for computer or visual analysis

NOTE In the case of an infrared image or thermogram this could include temperature scaling, spot temperature measurements, thermal profiles, image manipulation, subtraction and storage.

**3.7**
**infrared**
**IR**
that portion of the electromagnetic continuum extending from the red visible wavelength, 0,75 μm, to 1 000 μm

NOTE Because of instrument design considerations and the infrared transmission characteristics of the atmosphere, most infrared measurements are made between 0,75 μm and 15 μm wavelengths.

**3.8**
**isotherm**
enhancement feature applied to an image, which marks an interval of equal apparent temperatures

**3.9**
**infrared thermography**
**IRT**
acquisition and analysis of thermal information from non-contact thermal imaging devices

**3.10**
**radiation, thermal**
mode of heat flow that occurs by emission and absorption of electromagnetic radiation, propagating at the speed of light

NOTE Unlike conductive and convective heat flow, it is capable of propagating across a vacuum. A form of heat transfer which allows IRT to work since infrared energy travels from the target to the detector by radiation.

**3.11**
**reflectivity**
$\rho$
ratio of the total reflected energy from a surface to total incident energy on that surface

NOTE 1 $\rho = 1 - \varepsilon - \tau$; for a mirror, reflectivity approaches 1,0; for a black body, $\rho = 0$.

NOTE 2 Technically, reflectivity is the ratio of the intensity of the reflected radiation to the total radiation; reflectance is the ratio of the reflected flux to the incident flux. In IRT, the two terms are often used interchangeably.

**3.12**
**reflected apparent temperature**
$T_{\mathrm{refl}}$
apparent temperature of other objects that are reflected by the target into the infrared thermography camera

**3.13**
**repeatability**
⟨infrared thermography⟩ capability of an instrument to repeat exactly a reading on a fixed target over a short- or long-term interval

NOTE Repeatability is expressed in ± degrees or a percentage of full scale.

**3.14**
**signal processing**
manipulation of a temperature signal or image data for the purposes of enhancing or controlling a process

EXAMPLE 1 For infrared radiation thermometers: peak hold, valley hold, sample hold and averaging.

EXAMPLE 2 For scanners, cameras and imagers: isotherm enhancement, image averaging, alignment, image subtraction and image filtering.

**3.15**
**spatial measurement resolution**
measurement-spot size in terms of working distance

NOTE In an infrared radiation thermometer this is expressed in milliradians or as a ratio of the target-spot size (containing 95 % of the radiant energy, according to common usage) to the working distance. In scanners, cameras and imagers it is most often expressed in milliradians.

**3.16**
**target**
object surface to be measured

**3.17**
**thermogram**
thermal map or image of a target where the grey tones or colour hues represent the distribution of infrared thermal radiant energy over the surface of the target

**3.18**
**transmissivity**
**transmittance**
$\tau$
proportion of infrared radiant energy impinging on an object surface, for any given spectral interval, that is transmitted through the object

NOTE 1 $\tau = 1 - \varepsilon - \rho$

where

$\tau$ is transmissivity;

$\varepsilon$ is emissivity;

$\rho$ is reflectivity.

NOTE 2 For a black body, $\tau = 0$. Transmissivity is that fraction of incident radiation transmitted by matter.

**3.19**
**working distance**
distance from the target to the instrument, usually to the primary optic

# 4 Thermography techniques

There are several recognized IRT techniques in use throughout industry. *Comparative thermography* is the most common technique and it is normally used to provide the best available data in lieu of ideal, or absolute, thermal measurements. When encountering changing machinery operating conditions, the ability to perform rough emissivity estimates, and the ability to differentiate emissivity differences on machinery equipment, provides useful information for the condition monitoring and diagnostics of the machine under the less-than-ideal circumstances frequently encountered in the field. The confidence level of the information obtained depends on the IRT equipment used, the training and experience of the thermographer, and the detection method applied.

*Non-contact thermometry* using infrared thermal cameras is used when it is essential to know as precisely as possible the true temperature of a target. However, this technique is not normally used for condition monitoring and diagnostics.

Comparative thermography is normally used as part of a condition-monitoring process when such a process is implemented in accordance with ISO 17359. IRT can also be used as a primary or secondary technique for diagnosis and prognosis when these processes are carried out in accordance with ISO 13379 and ISO 13381-1 respectively.

# 5 Comparative thermography

## 5.1 Types of comparative thermography

Comparative thermography can be either *quantitative* or *qualitative*. The *quantitative* technique requires the determination of a temperature value to distinguish the severity of a component's condition. This value is determined by comparing the target's temperature to that of similar service equipment or baseline data. For high emissivity surfaces both temperature, $T$, and temperature difference, $\Delta T$, values are typically reliable provided good measurement techniques are followed. $T$ and $\Delta T$ values of low emissivity surfaces are often unreliable due to surface and environmental variations. In addition, many applications also require assigning values to observed thermal patterns for the purposes of analysis, trending, designating severity levels and assigning priorities.

However, there are many applications where quantitative data are not required to monitor the condition of machinery, or to diagnose a problem and recommend the appropriate corrective action. In these cases, *qualitative* techniques may be more than adequate.

## 5.2 Comparative quantitative thermography

The comparative quantitative thermography method is an accepted and effective method for evaluating the condition of a machine or component by determining approximate temperatures. It is very difficult to determine precisely the actual temperatures of a component using IRT in the field. This is due to a certain extent to the physics of IRT which must take into consideration the multiple parameters that enable a true absolute temperature measurement. These IRT considerations are: emissivity, reflectivity and transmissivity. As a result, estimates of these IRT considerations can be readily made to obtain a component's approximate temperature, which, in most cases, is more than sufficient to determine the severity of an adverse condition.

An example of comparative quantitative thermography would be that, if two or more machines are operating in the same environment and under the same load conditions, and one is experiencing an elevated temperature, this is usually an indication that a deteriorating condition may exist. However, the determination of the temperature difference would then assist in establishing the severity of the condition. In this example, a 5 °C differential would be considered minor, whereas a 100 °C differential may be considered to be critical. Also, knowing the approximate value of the elevated temperature would provide an indication that the temperature limit of a component may be approaching published values. Therefore, while qualitative measurements can also detect deficiencies, it is the quantitative measurements that have the capability of determining severity.

Since it is not always practical to determine the exact temperature, or even emissivities, of each machine surface, the alternative use of comparative thermography becomes more practical. Comparative measurement, unlike qualitative measurement, identifies a thermal deficiency by comparing the temperatures obtained using a consistent emissivity value, $\varepsilon_{\text{default}}$, for those surfaces of similar emissivity, i.e. across the surface of a single machine or between the surfaces of similar machines. The temperature *differential* between two or more identical or similar surfaces is measured numerically. Assuming that the environmental conditions and surface properties for both components are similar, the differential temperature for the given piece of equipment is recorded as being the amount above the normal operating temperature of the similar equipment.

The comparative measurement technique uses quick emissivity estimates, reflected apparent temperature and component distance measurements. The emissivity factors of the materials are obtained through experience.

It is possible to check the emissivities of the most commonly encountered materials in a plant to assign default values that can then be used when inspecting components with these materials.

Each plant must develop its own set of default values, as similar components in different plants may have different environments (such as cleanliness), or the equipment may have different surface finishes, and these varying conditions will result in different default values. Once emissivities, distances, and reflected apparent temperatures are estimated, these values are entered into the IRT camera to indicate a temperature value for each component. This type of measurement is effective when surveying many components. It is quick and it provides useful information for determining the severity of a component's condition.

## 5.3 Comparative qualitative thermography

Comparative qualitative measurement compares the thermal pattern or profile of one component to that of an identical or similar component under the same or similar operating conditions. When searching for differing thermal patterns or profiles, an anomaly is identified by the intensity variations between any two or more similar objects, without assigning temperature values to the patterns. This technique is quick and easy to apply, and it does not require any adjustments to the infrared instrument to compensate for atmospheric or environmental conditions, or surface emissivities. Although the result of this type of measurement can identify a deficiency, it does not provide a level of severity.

This IRT technique is used throughout most industries. It is very effective in identifying hot bearings or other abnormally hot machine components, hot spots in electrical equipment, undesirable hot electrical connections, leaking or blocked fluid heat exchange equipment and components (tubes), and fluid leaks from pressure vessels, pipes and valves.

## 6 Non-contact thermometry using infrared thermography cameras

The determination of the corrected temperature of a target using IRT can be difficult because of the many technical and environmental factors involved. As a result, absolute IRT measurements are done only if very precise temperature values, or small temperature differentials, are critical to a process. These determinations are normally attempted only under extremely controlled conditions. This type of measurement using IRT cameras is not normally used for condition monitoring.

## 7 Baseline measurements

For both comparative and absolute techniques, it is strongly recommended that baseline measurements be taken of critical plant equipment for diagnostic and prognostic reference. This is very important when making later IRT surveys of machines or components and comparing them with previous thermograms of the same machines operating under the same load and environmental conditions. This condition monitoring procedure is useful for identifying developing problems early, thus preventing major maintenance operations or catastrophic failures. Some examples of baseline measurements are contained in Annex C.

## 8 Safety

Prior to the commencement of work, minimum safety rules and guidelines shall be established in accordance with applicable local or national standards and regulations and particularly where hazardous environments may exist. An example of minimum safety rules and guidelines is contained in Annex B.

## 9 Calibration

Thermographers shall have IRT cameras calibrated to original equipment manufacturers' guidelines, or established industry practice. Documented calibration checks should be carried out using a traceable black-body reference in accordance with manufacturer's recommendations, client specification or any applicable industry standard. Quick calibration checks are recommended to be performed prior to each inspection or survey.

NOTE A quick check can be made, for example, by using the human face tear duct, boiling water or a melting ice cube, using the correct emissivities under ideal conditions.

## 10 Data collection

Data collection shall be carried out in accordance with the following.

a) Infrared inspections should be performed when environmental and physical conditions such as solar, wind, surface and atmospheric conditions and heat transfer are favourable to gathering accurate data.

b) The operating and environmental conditions under which data are acquired should be repeatable and consistent with normal conditions.

c) The thermographer shall ensure that all emissivity and reflected apparent temperature determinations are carried out in accordance with Annex A.

d) The thermographer shall ensure that the target size is within the spatial measurement resolution of the camera.

e) The thermographer shall have sufficient knowledge of the design, manufacturing, installation, operation and maintenance principles of the machine, the typical faults associated with each principle and their resultant thermal anomalies in order to accurately interpret the observed patterns of radiation.

f) The thermographer shall use IRT and/or measurement equipment with capabilities sufficient to meet the inspection requirements.

g) Whenever possible, after repair, or when requested by the end user, each anomaly should be re-inspected to ensure that its operating temperature is normal and the potential problem corrected.

## 11 Customer responsibilities

The customer of the IRT service should:

a) provide or help develop an inventory of the equipment to be inspected in a logical and efficient route through the facility;

b) provide a qualified assistant(s) who is/are knowledgeable of the operation and history of the equipment to be inspected when required; this person(s) should accompany the infrared thermographer during the inspection and shall be qualified and authorized to:

   1) gain access to the equipment to be inspected and should notify operations personnel of the inspection activities;

   2) open and/or remove all necessary covers immediately before inspection by the infrared thermographer;

   3) close and/or replace these cabinet and enclosure covers immediately after inspection by the infrared thermographer;

   4) operate any equipment as required if possible;

   5) assure that the equipment to be inspected is under adequate load, create satisfactory loads when necessary and allow sufficient time for recently energized equipment to produce stable thermal patterns;

   6) measure electric loads when requested by the infrared thermographer;

   7) take full responsibility for consequences resulting from actions taken, or not taken, as a result of information provided by an infrared inspection;

   8) provide information on the results of repair and inspection activities.

## 12 Field measurements of reflected temperature and emissivity, and attenuating media

In many instances field measurements of reflected apparent temperature and emissivity need to be carried out in order to obtain correct absolute temperatures. These measurements shall be carried out in accordance with Annex A as well as established industry standards and practices, normative references and manufacturers' guidelines.

Testing procedures for measuring and compensating for attenuating media shall be in accordance with ASTM E1897.

# 13 Temperature severity assessment criteria

## 13.1 Establishing severity assessment criteria

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

The severity assessment criteria can take two forms:

a) organized into general categories that identify temperature levels, or zones, versus levels of criticality;

b) applied to specific machines or components, or to like groups of machines or components.

In either case, the levels are established through experience and the accumulation of data.

In practice no singular severity assessment criterion is universally applicable to the variety of items existing in industry. Consequently, severity assessment criteria must be developed for each category of equipment based upon its design, manufacture, operating, installation and maintenance characteristics and its failure modes and criticality.

Severity assessment criteria can be established on individual machines or components. This method is based on many factors, including: safety of personnel; temperature rise versus historical data that establishes rate of deterioration and time to failure; criticality of the machine or component to the overall process; location with respect to other materials/equipment should a fire result; environmental conditions, etc. Applications could include temperature rises of critical machines, mechanical components, bearing temperature rises, electrical supply or connection rises, fluid leakage losses, or even the number of tubes clogged in fluid heat transfer-type equipment.

The infrared thermographer may use $\Delta T$ criteria or classify the temperature severity of mechanical system anomalies. These $\Delta T$ criteria are usually reported as the temperature rise of the anomaly above the temperature of a defined reference.

By taking multiple measurements of similar components over time, under similar operating and environmental conditions, statistical analysis can be used to set operational limits for trending and predicting the temperature performance of these components.

A $\Delta T$ system may be used in conjunction with these absolute temperature criteria to rate the temperature severity of an anomaly above the maximum permissible temperature.

## 13.2 Temperature difference criteria

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.

Assessment criteria should be based on temperatures specified by manufacturers, of similar items or groups of equipment, or of components located on the same shaft. It should be understood that such criteria should not be universally applied to similar machine types due to local variations in application, process, environment, duty cycle, etc.

## 13.3 Maximum permissible temperature criteria

The infrared thermographer may use absolute maximum permissible temperature criteria based on published data to identify mechanical system anomalies. It shall be well understood that there are two categories of criteria being material and design:

a) *material* criteria are used where the integrity of the material itself is of concern and is the focus of monitoring;

b) *design* criteria are used where the design integrity is the major concern and is the focus of the monitoring; d*esign* criteria should always be used in preference to *material* criteria as *design* criteria normally incorporate material requirements and *design* criteria are usually cognisant of performance, operation, reliability and capacity criteria rather than just component material integrity.

When an anomaly is heating several adjacent system components and a *material* criterion is used, the component material having the lowest temperature specification should be referenced as the alarm criterion.

**WARNING — In most machine cases, the lubricant will have the lowest temperature specification. The maximum permissible temperature should be stated as the temperature above which an unacceptable loss of component life will be experienced due to a loss of lubricant characteristics. Such reductions in characteristics may be immediate (viscosity) or long term (additive depletion). Such criteria will tend to be design rather than material based. This will require application-specific temperature criteria despite the possible use of common lubricants.**

In many instances the infrared thermographer cannot directly measure the surfaces of actual components. Care and good judgement must be used when applying any severity specifications to actual field temperature measurements as they must take into account any losses or errors due to conduction paths, convection and radiation. Such losses or errors may result in the measured values being insensitive to actual change in component condition thereby reducing the effectiveness of any trending.

## 14 Profile assessment criteria

Profile assessment is a process of comparing temperature differences and patterns across a surface. As in any severity assessment process the absolute and differential temperatures and profiles need to be determined for two key conditions being the “as new” and the “failed” conditions. Severity assessment is the subsequent process of determining the condition of the equipment between these two conditions.

The key areas of profile assessment are temperature gradients, changes in profile, historical changes, localized differences, absolute temperatures, and location of anomalies or profile characteristic relative to the item.

Severity assessment of temperatures and profiles should be carried out in accordance with Clause 13.

## 15 Diagnosis and prognosis

### 15.1 Survey intervals

Survey intervals should be determined cognisant of the rate of deterioration of the expected fault and the behaviour, over time, of temperature as a representative symptom of the fault. The determination of survey interval is primarily necessary for prognosis accuracy rather than fault identification.

### 15.2 Image interpretation

From a machinery viewpoint, thermal image interpretation is essentially a process of comparing apparent surface temperatures and temperature profiles against those representative of the ideal design, manufacture, installation, operation and maintenance criteria.

When using IRT for machinery-condition monitoring purposes the operating conditions of the machine at the time of each survey need to be known in detail as many changes in thermal profile are operating in a condition-dependent manner.

The design of a machine is essential to understanding component loading, which, in turn, is the primary contributor to thermal profile. When using IRT to assess a machine condition, the machine shall be viewed as a whole. Each image shall be analysed as part of a series rather than an individual representation of a localized condition.

## 15.3 Fault identification process

A typical fault identification process that may be used is as follows:

a) determine the expected temperature and profiles when the machine is operating under “as-designed” conditions;

b) develop severity assessment criteria associated with the “as-designed operating condition”;

c) determine the expected temperature and profiles with the machine operating under “existing” operating conditions;

d) develop severity assessment criteria associated with the “existing operating condition”;

e) determine whether the temperatures and profiles are either caused by the operating condition or a fault condition;

f) develop fault diagnosis;

g) develop prognosis if required;

h) issue report.

NOTE An example of this is locating versus non-locating bearings whereby the locating bearing normally sustains an axial as well as a radial load and subsequently can be expected to run hotter than the non-locating bearing that only sustains a radial load. Conversely if the non-locating bearing is running hotter than the locating bearing this may indicate that it is not floating and is therefore sustaining axial loading above design.

# 16 Test report

The thermographer shall provide reports for *all infrared inspections*. Unless otherwise agreed with the customer, the report shall contain, but not be limited to, the following information:

a) the name of each thermographer;

b) the qualification of each thermographer;

c) the name and address of the customer;

d) the name of each assistant accompanying the infrared thermographer during inspection, if applicable;

e) the manufacturer, model and date of calibration for the infrared equipment used;

f) a list of all the equipment to be inspected and notations of the equipment from the list that was not inspected;

g) details of all thermal anomalies detected;

h) details of the operating and environmental conditions for each machine at the time of inspection;

i) the date(s) and time(s) of the inspection(s);

j) the date when the report was prepared.

When performing a *qualitative* infrared inspection, the thermographer should provide the following information for each anomaly identified:

k) the exact location of each anomaly;

l) a description of each anomaly;

m) details of any attenuating media;

n) when significant, the environmental conditions surrounding the anomaly; e.g. the air temperature, wind speed, wind direction and the weather conditions;

o) hardcopies of thermogram(s) of the anomaly(-ies) and corresponding visible-light image(s);

p) details of any windows, filters or external optics used;

q) an evaluation rating or a statement of the importance of the anomaly to the safe and continuous operation of the system;

r) reference to, or statement of, the assessment criteria used;

s) any other information or special conditions that may affect the results, repeatability or interpretation of the anomaly.

When performing a *quantitative* infrared inspection, the thermographer should provide the following additional information:

t) the distance from the IRT camera to the anomaly;

u) whenever possible, the maximum rated load of the item and its measured load at the time of the inspection;

v) the emissivity, reflected apparent temperature and transmission values used to calculate temperatures;

w) when using $\Delta T$ criteria, the surface temperature of the item, the temperature of a defined reference, and their relative temperature difference.

In addition to the above technical content the report should also contain a notation of any unsafe conditions or practices observed and actions undertaken.

## 17 Qualification of personnel

Thermographers shall be qualified and assessed in accordance with ISO 18436-7. The thermographer's required category shall be agreed upon by the customer and service provider prior to the commencement of any work.

# Annex A
(normative)

# Field measurements of reflected apparent temperature and emissivity

## A.1 How to measure reflected apparent temperature

### A.1.1 Equipment requirements

In order to measure target reflected apparent temperature the following equipment is required:

a) a calibrated quantitative IRT camera that allows the thermographer to input reflected apparent temperature, $T_{\text{refl}}$, and emissivity, $\varepsilon$, values;

b) an infrared reflector such as a crumpled and re-flattened piece of aluminium foil placed shiny side up on a piece of cardboard.

### A.1.2 Reflector method

The procedure for determining the reflected apparent temperature, $T_{\text{refl}}$, using the reflector method shall be as follows.

a) Set the IRT camera's emissivity control to 1,00 and distance to 0.

b) Place the IRT camera at the desired location and distance from the target to be measured. Aim and focus the IRT camera on the target.

c) Place the reflector in the field-of-view of the IRT camera. The reflector shall be placed in front of, and in the same plane as, the target surface (see Figure A.1). Maintain a safe working distance from any energised or potentially dangerous targets.

d) Without moving the camera, measure the apparent surface temperature of the reflector with the camera. Note this temperature, which is the reflected apparent temperature, $T_{\text{refl}}$, of the target.

e) For greater accuracy, repeat procedures b) to d) a minimum of three times and average the temperatures.

f) Compensate for the reflected apparent temperature by entering the averaged reflected apparent temperature in the IRT camera under the $T_{\text{refl}}$ input (sometimes referred to as “TAM”, “amb. temp.”, “reflected apparent temperature” or “background temperature”).


**Key**

1 IRT camera
2 reflected heat source
3 reflector parallel to target
4 target

**Figure A.1 — Reflector method**

### A.1.3 Direct method

The procedure for determining the reflected apparent temperature, $T_{\mathrm{refl}}$, using the direct method shall be as follows.

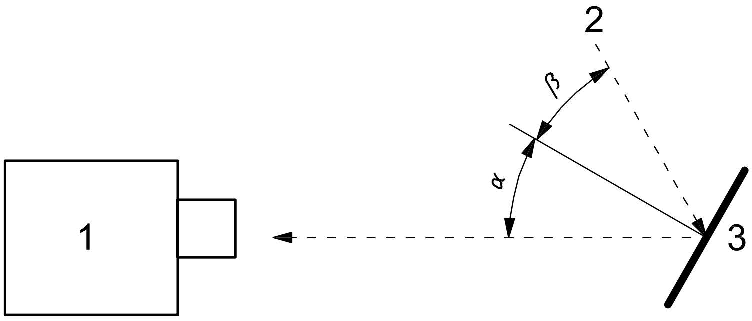
a) Set the IRT camera's emissivity control to 1,00.

b) Place the IRT camera at the desired location and distance from the target. Estimate the angle of reflection, $\alpha$, and the angle of incidence, $\beta$, when viewing the target with the camera from this location (see Figure A.2).

c) Position the IRT camera so that it is at the angle of reflection from the target, $\alpha$, and view the sources reflected by the target (see Figure A.3).

d) Measure the average apparent temperature of these sources with the camera. Use any camera features available (such as area averaging) that average these reflected apparent temperatures. Note this temperature, which is the reflected apparent temperature, $T_{\mathrm{refl}}$, of the target.

e) For greater accuracy, repeat procedures b) to d) a minimum of three times and average the temperatures.

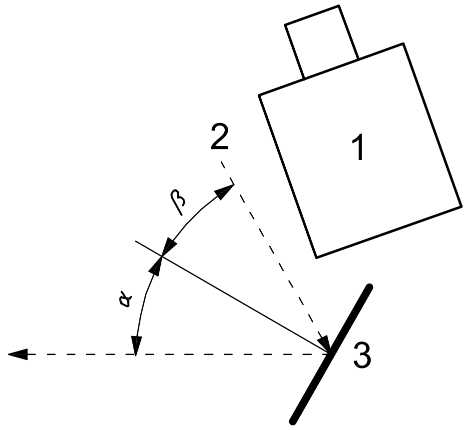



**Key**

1 IRT camera
2 reflected heat source
3 target

$\alpha$ angle of reflection
$\beta$ angle of incidence
$\alpha = \beta$

**Figure A.2 — Direct method step b)**




**Key**

1 IRT camera
2 reflected heat source
3 target

$\alpha$ angle of reflection
$\beta$ angle of incidence
$\alpha = \beta$

**Figure A.3 — Direct method step c)**

Compensation for the reflected apparent temperature can be made by entering the averaged reflected apparent temperature in the IRT camera under the $T_{\text{refl}}$ input (sometimes referred to as “TAM”, “amb. temp.”, “reflected apparent temperature”, or “background temperature”).

Thermographers can test for the significance of reflected apparent temperatures by shielding the target from various angles and observing any visual or temperature changes shown in the thermal image. Errors caused by hot or cold sources of reflected radiation can also be reduced by shielding the target from these sources.

Reflections produced by a point source (such as the sun) can often be avoided by moving the camera position and angle relative to the target. It should also be remembered that reflected apparent temperatures can be lower than ambient temperatures.

Thermographers should also be aware that the direct method usually does not include the heat from the thermographer’s body as a source of reflected radiation, which, in some cases, can create a significant error.

## A.2 How to measure the emissivity of a target

### A.2.1 Equipment requirements

In order to measure target emissivity the following equipment is required:

a) a calibrated quantitative IRT camera that allows the thermographer to input reflected apparent temperature, $T_{\text{refl}}$, and emissivity, $\varepsilon$, values; and

b) a natural or induced means of heating or cooling the target at least 20 °C above or below the reflected apparent temperature such that the target temperature is stable and close to the temperature of the target(s) to be measured; and

c) a calibrated contact, non-contact, or mirrored thermometer; or

d) a surface-modifying material such as paint or tape with a known high emissivity in the waveband of the IRT camera being used and at a temperature close to that of the target.

### A.2.2 Contact method

The procedure for determining the emissivity, $\varepsilon$, using the contact method shall be as follows.

a) Place the IRT camera at the desired location and distance from the target to be measured.

b) Measure and compensate for the target's reflected apparent temperature.

c) Aim and focus the IRT camera on the target and, if possible, freeze the image.

d) Use an appropriate camera measurement function (such as spot temperature, cross hairs or isotherms) to define a measurement point or area in the centre of the camera's image.

e) Use a contact or mirrored thermometer to measure the temperature of the point or area just defined by the camera's measurement function. Note this temperature.

f) Without moving the camera, adjust the emissivity control until the indicated temperature is the same as the contact temperature just taken. The indicated emissivity value is the emissivity of this temperature target measured with this waveband camera.

g) For greater accuracy, repeat procedures b) to f) a minimum of three times and average the emissivity values.

h) Compensate for emissivity by entering the averaged emissivity value in the IRT camera under the emissivity input (commonly referred to as "$\varepsilon$", "emissivity").

### A.2.3 Reference emissivity material method

The reference emissivity material method is as follows.

a) Place the IRT camera at the desired location and distance from the target to be measured. Aim and focus the IRT camera on the target.

b) Measure and compensate for the target's reflected apparent temperature.

c) Apply the surface-modifying material on or immediately adjacent to the target you are measuring. Make sure the surface modifying material is dry and/or in good contact with the target.

d) Enter the known emissivity of the surface-modifying material in the emissivity input.

e) Aim and focus the IRT camera on the surface-modifying material, allow enough time for the temperatures to stabilize, freeze the image, and measure and note the indicated temperature.

f) Aim and focus the IRT camera on the target immediately adjacent to the surface-modifying material, or remove the surface-modifying material and aim and focus the camera on the previously modified surface. Be sure to allow enough time for the temperature to stabilize, freeze the image, and measure and note the indicated temperature.

g) Using the frozen image, adjust the emissivity control until the indicated temperature is the same as the just taken, non-contact temperature of the surface-modifying material. The indicated emissivity value is the emissivity of this temperature target measured with this waveband camera.

h) For greater accuracy, repeat procedures b) to g) a minimum of three times and average the emissivity values.

i) Compensate for emissivity by entering the averaged emissivity value in the IRT camera under the emissivity input (commonly referred to as "$\varepsilon$", "emissivity").

## A.3 General

Both methods of measuring emissivity require contact with the target surface.

Whenever possible, temperature measurements should be verified with other thermometers.

These methods are valid only for target surfaces that are opaque in the waveband of the IRT camera.

# Annex B
(informative)

# Example safety rules and guidelines

This annex gives an example of safety rules and guidelines which should be observed by all parties concerned (see Clause 8).

The thermographer shall comply with the safety guidelines, rules and regulations of the customer at all times.

Prior to commencement of work the following minimum safety rules and guidelines should be followed:

a) a site safety induction should be completed where deemed appropriate by the customer;

b) full personal protective equipment (PPE) to be worn to site standards;

c) carry out a job hazard assessment (JHA);

d) ensure a site standby person is present at all times within clear sight;

e) if an injury occurs, the standby person must notify the site safety response services;

f) report any incidents via an appropriate incident report system.

**IMPORTANT — Unless the necessary qualifications/licenses are held, or dispensation by the customer granted, the thermographer shall not perform any tasks that are normally done by qualified personnel including:**

**g) removal or replacement of covers;**

**h) opening or closing cabinets containing electrical or mechanical equipment;**

**i) measurement of electric loads of the equipment;**

**j) physical contact with any inspected equipment unless totally necessary, e.g. for temperature measurement using the contact method;**

**k) operation of any equipment.**

**The thermographer or any accompanying person shall not alter or modify any safety cabinets, guards, enclosures or barriers or defeat any safety devices, interlocks or systems in any way. Any such modifications, alterations or defeats should be immediately reported to the appropriate person responsible for occupational health and safety.**

# Annex C
(informative)

# Case history examples

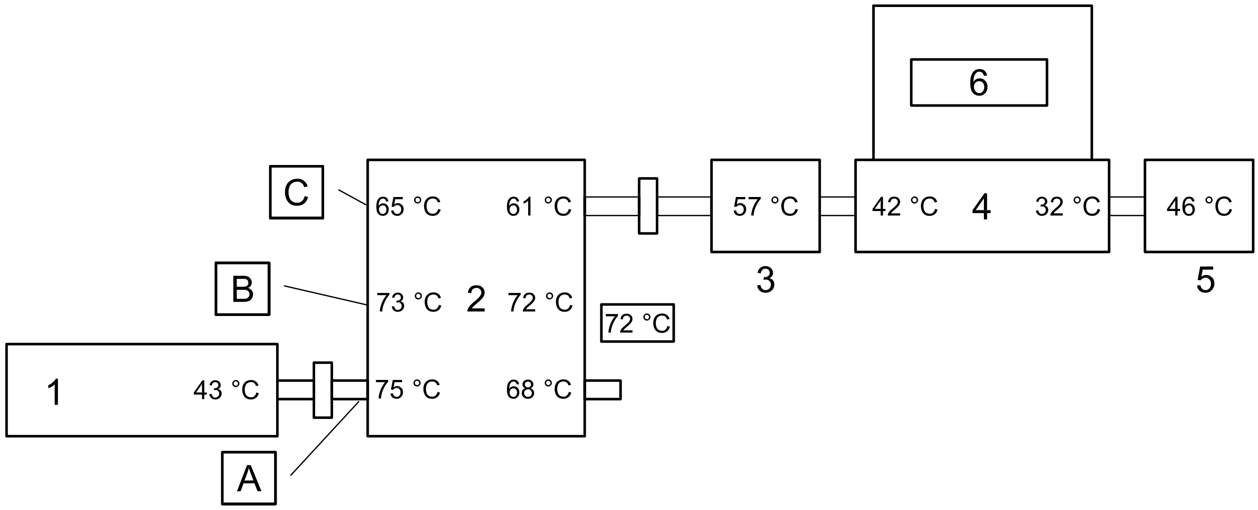
## C.1 Mill drive train misalignment

**Figure C.1 — Mill drive train misalignment**

Case History 1 involves a grinding mill drive train in a gold mine consisting of a motor, a 3 shaft reduction gearbox, 2 pinion bearings and a pinion gear. All bearings were rolling element types with the mill drive pinion gear bearings being double row spherical roller bearings. The photographs and thermal images are contained below.

The following temperatures were recorded:

| Position | Temperature<br>°C |
|---|---|
| Motor drive end bearing | 43,1 |
| Gearbox input shaft drive end bearing | 75,4 |
| Gearbox input shaft non-drive end bearing | 67,8 |
| Gearbox input shaft non-drive end shaft | 78,3 |
| Gearbox intermediate shaft drive end bearing | 72,7 |
| Gearbox intermediate shaft non-drive end bearing | 71,4 |
| Gearbox output shaft drive end bearing (locating) | 64,9 |
| Gearbox output shaft non-drive end bearing | 61,0 |
| Pinion drive end bearing (locating) | 56,8 |
| Pinion non-drive end bearing (non-locating) | 45,5 |
| Pinion gear drive end flank | 42,2 |
| Pinion gear non-drive end flank | 31,9 |




**Key**

1 motor
2 gearbox
3 bearing
4 pinion gear
5 bearing
6 girth gear

A high-speed shaft
B intermediate shaft
C low-speed shaft

**Figure C.2 — Gearbox temperatures**

The temperature of the gearbox intermediate shaft (B) can normally be expected to be slightly greater (1 °C to 2 °C) than the high-speed shaft (A) and moderately greater (3 °C to 5 °C) than the low-speed shaft (C) as it is in double mesh at any one time and hence receives more heat input. In this particular case the average temperature rise was approximately 8,5 °C above the low speed shaft and approximately 3,5 °C above the high-speed shaft, which was considered above normal.

The above temperatures and profiles were indicative of a misalignment between the motor and gearbox, a misalignment between the gearbox and the mill drive pinion gear, and a misalignment between the mill drive pinion gear and driven girth gear. The combined motor to gearbox and gearbox to mill drive pinion misalignments have resulted in a loss of end float within the gearbox trapping the intermediate shaft gear. The 10,3 °C temperature difference across the mill drive pinion gear was also considered excessive and indicative of severe pinion to girth gear misalignment.

The misalignment conditions, gear loading and bearing distress were all confirmed using vibration analysis. Subsequent overhaul and re-alignment of the drive train reduced the temperatures to acceptable levels.

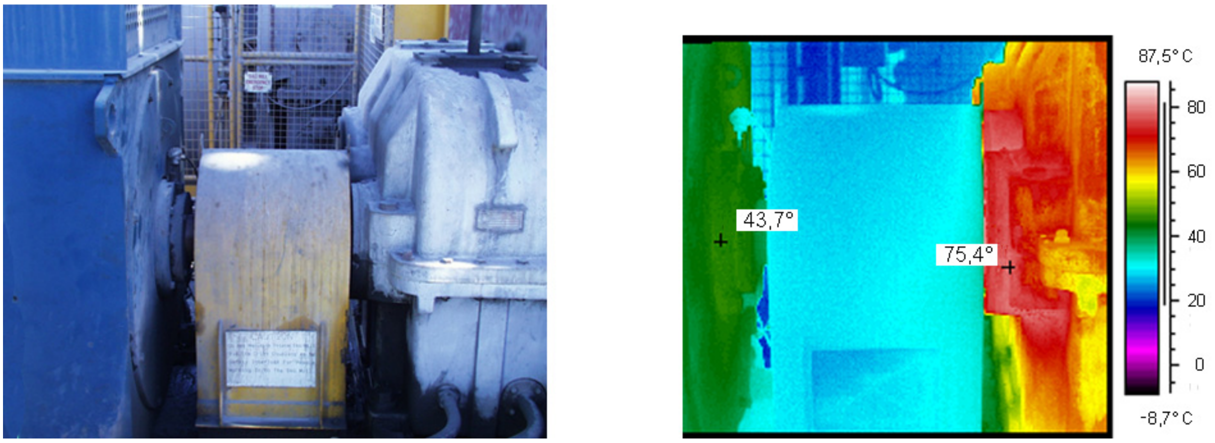



**Figure C.3 — Motor and gearbox input shaft**

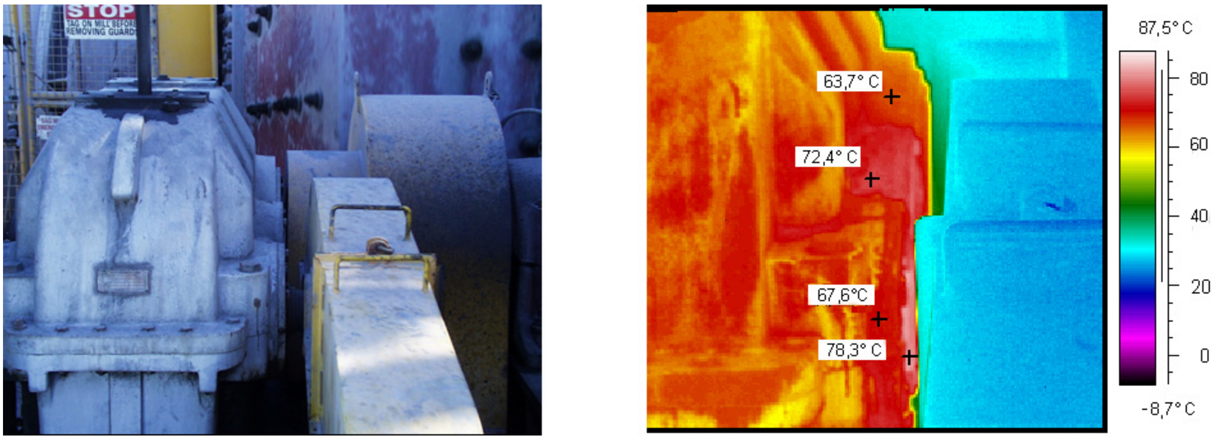



**Figure C.4 — Gearbox input shaft side**

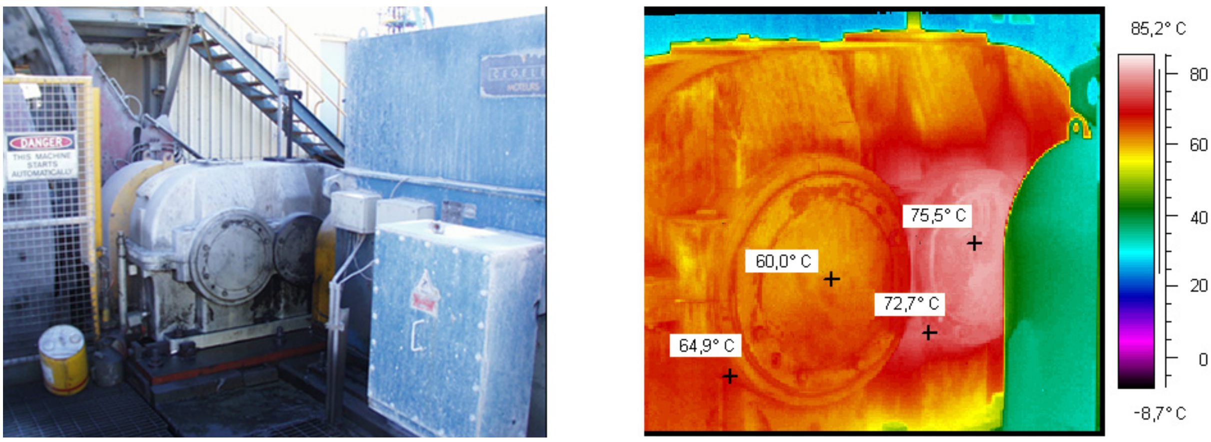



**Figure C.5 — Gearbox motor side**

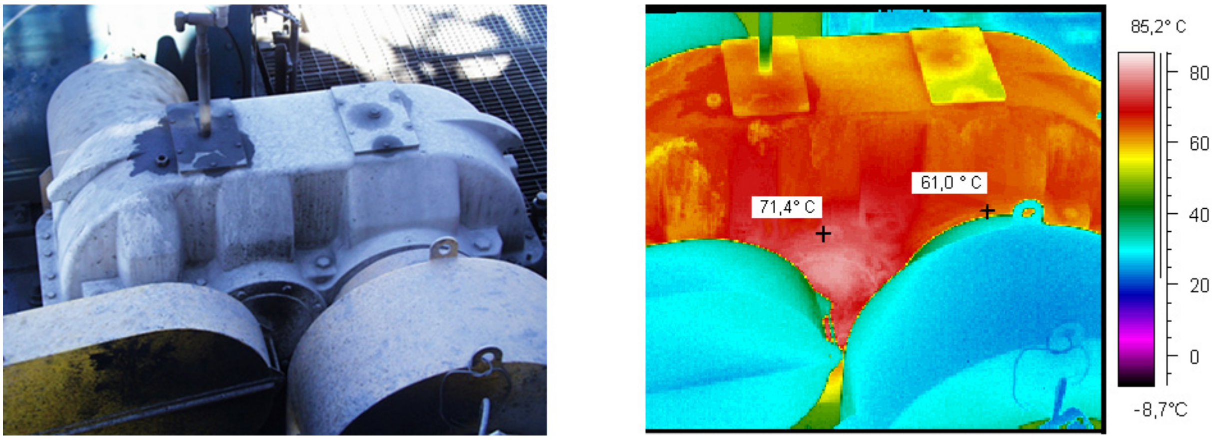



**Figure C.6 — Gearbox mill side**

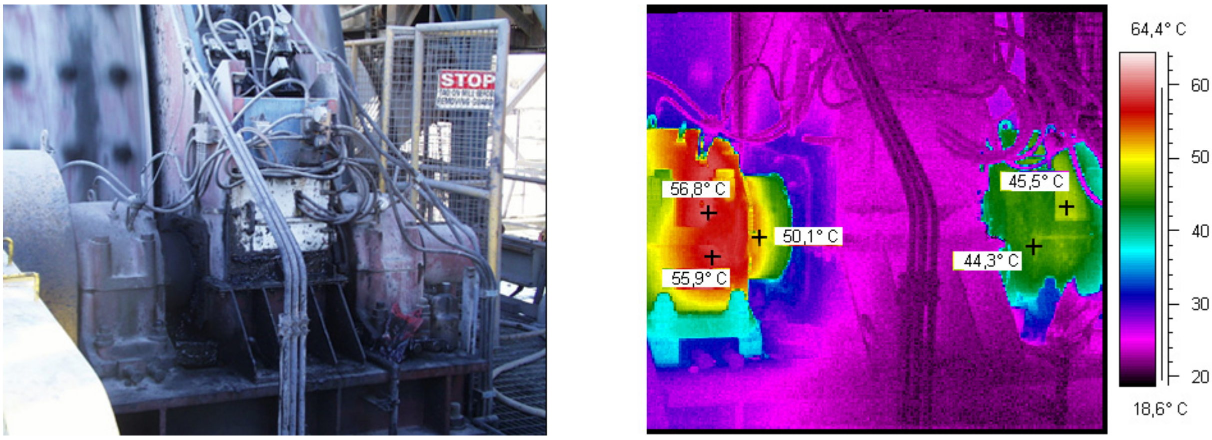



**Figure C.7 — Pinion bearings and mill drive pinion gear housing**

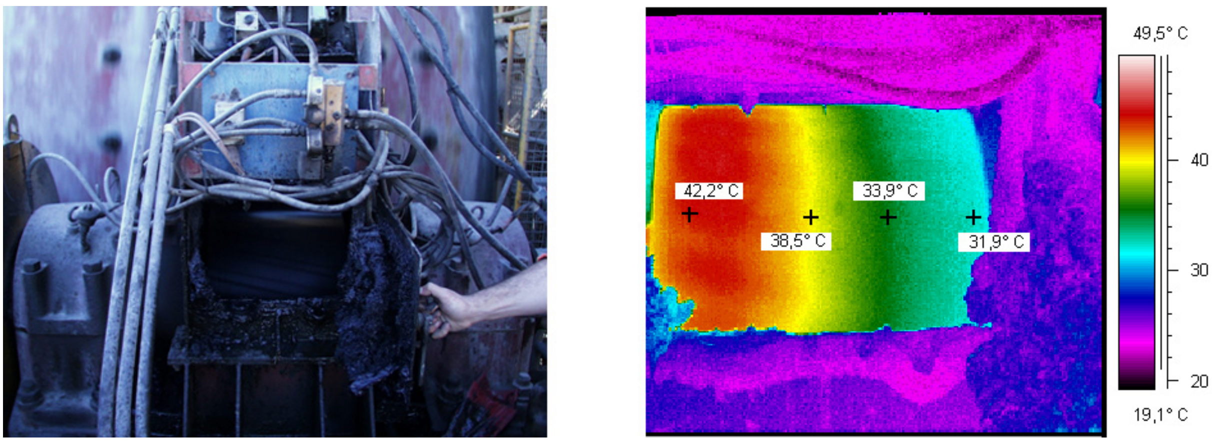
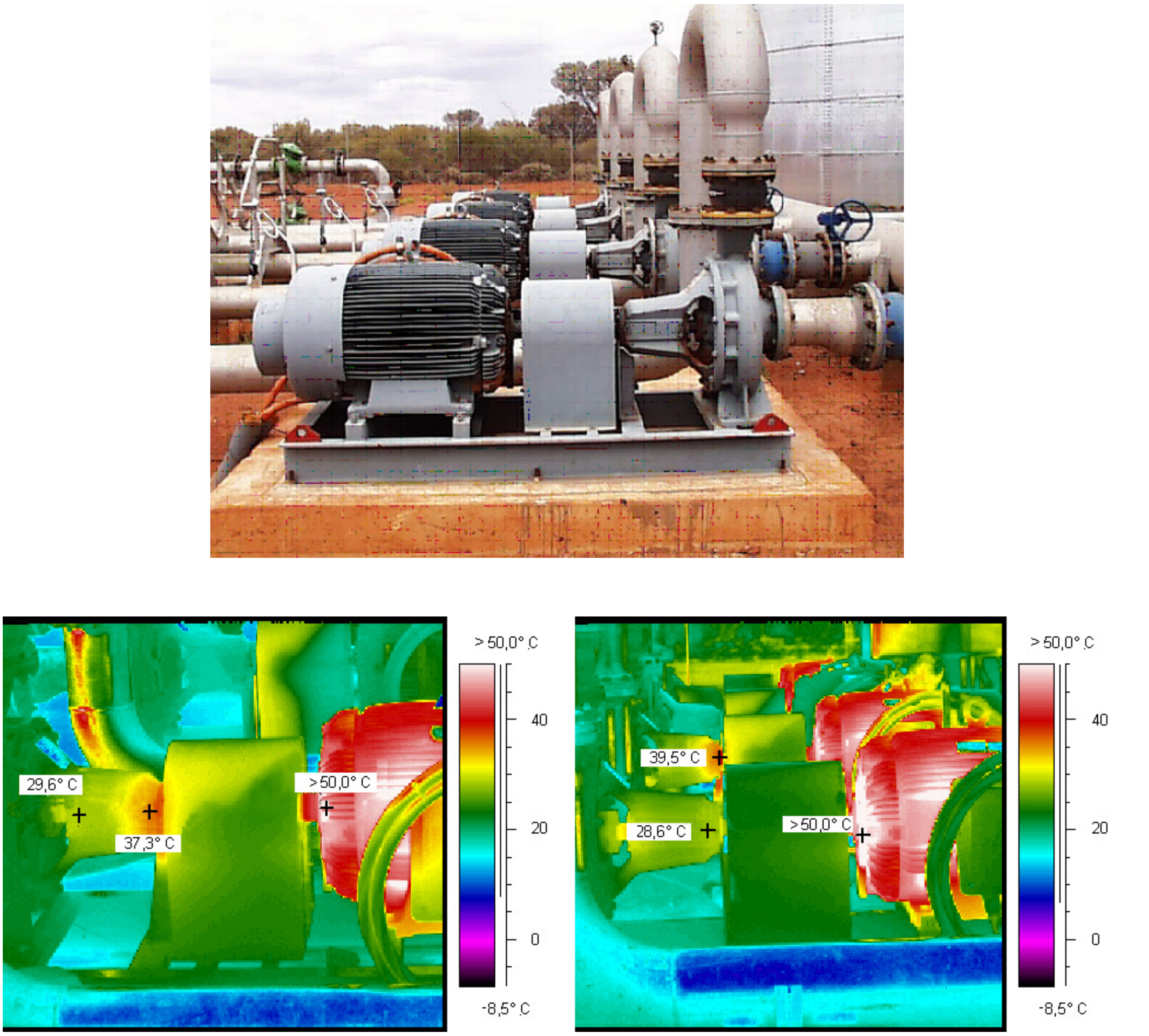



**Figure C.8 — Mill drive pinion gear**

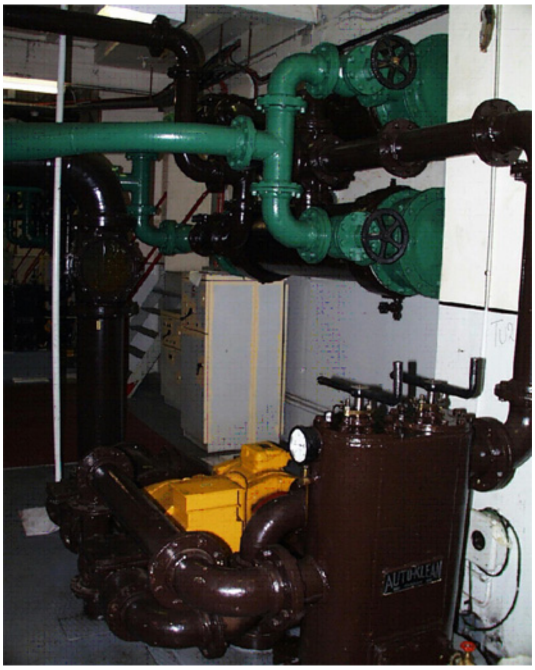
## C.2 Misaligned pumps

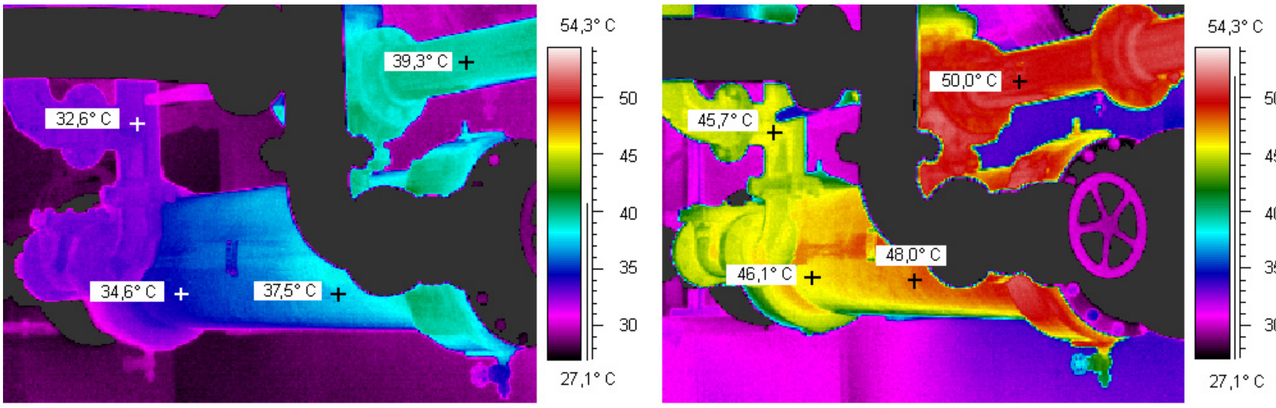



The high coupling end pump and motor bearing temperatures and the high temperature difference between the pump bearings are typical of a misaligned pump. The photograph and thermal images are taken from opposite sides of the row of pumps.

**Figure C.9 — Misaligned pumps**

## C.3 Vertical hydro-turbine oil coolers






The two hydro-turbine oil coolers of identical design demonstrate that one of the turbines has an oil cooler problem (right-hand image of turbine 2).

**Figure C.10 — Vertical hydro-turbine oil coolers**

Insufficient thermal evidence existed at the time of survey to determine whether the problem was related to oil flow, water flow, or both given that the machines were operating at identical loads.

Under identical loads and oil condition turbine No. 2 operated with consistently higher vertical (thrust) vibration due to the effects of reduced oil viscosity resulting from the higher operating temperatures.

# Bibliography

[1] ASTM E1149-90, *Definitions of terms relating to NDT by infrared thermography* 1)

[2] ASTM E1862, *Standard test methods for measuring and compensating for reflected temperature using infrared imaging radiometers*

[3] ASTM E1933, *Standard test methods for measuring and compensating for emissivity using infrared imaging radiometers*

[4] ASTM E1934, *Standard guide for examining electrical and mechanical equipment with infrared thermography*

1) Standard withdrawn in 1991.

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