INTERNATIONAL STANDARD

ISO 20958

First edition
2013-08-15

Condition monitoring and diagnostics of machine systems — Electrical signature analysis of three-phase induction motors

Surveillance et diagnostic des systèmes de machines — Analyse de la signature électrique des moteurs triphasés à induction

Reference number
ISO 20958:2013(E)

Contents

Page

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, www.iso.org/directives.

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received, www.iso.org/patents.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The committee responsible for this document is ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

Introduction

This International Standard provides guidance for online condition monitoring and diagnostics of machines in the field of electrical signature analysis of three-phase induction motors.

In order to clarify the situation and direct attention towards the latest developments in this field, this International Standard presents an overview of well-established condition monitoring techniques, together with an indication of some which are expected to be less well known.

Condition monitoring and diagnostics of machine systems — Electrical signature analysis of three-phase induction motors

1 Scope

This International Standard sets out guidelines for the online techniques recommended for the purposes of condition monitoring and diagnostics of machines, based on electrical signature analysis. This International Standard is applicable to three-phase induction motors.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

3 Terms and definitions

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

3.1
current analysis
analysis of the three supply currents to a motor for magnitude, balance, and harmonic content

3.2
current signature analysis
spectral analysis performed on the line current to the motor to determine if there are currents at specific frequencies that can indicate component defects

Note 1 to entry: Traditionally, this has been focused on a single phase, but newer techniques such as Park's vector and voltage and current systems that analyse all three phases simultaneously can provide additional information.

3.3
induction motor
asynchronous AC machine that comprises a magnetic circuit interlinked with two electric circuits or sets of circuits rotating with respect to each other and in which power is transferred from one circuit to another by electromagnetic induction

Note 1 to entry: There are two basic types: squirrel-cage (SCI) and wound-rotor induction motors.

3.4
squirrel-cage induction motor
induction motor in which the secondary circuit consists of usually un-insulated rotor bars in core slots shorted together by end rings connected to both ends of each bar

Note 1 to entry: The most common bar and end ring materials are copper, aluminium, or alloys of these materials.

3.5
wound-rotor motor
induction motor in which the secondary circuit consists of polyphase windings made from insulated multi-turn coils, with each winding phase connected to a slip ring

Note 1 to entry: Control of stator and rotor current during starting and motor torque and speed during running is achieved by connecting external resistances, or a solid-state converter to each rotor winding phase by means of slip rings and brushes.

Note 2 to entry: This type of motor is also known as a slip-ring induction motor.

4 Electrical signature analysis of three-phase induction motors

4.1 General

The vast majority of motors used in industry are induction machines.

Reliability surveys show that the most vulnerable parts of an induction motor are the bearings, the stator winding and core pack, and the rotor cage winding.

There is a lot of published material about a group of monitoring and diagnostic techniques, collectively referred to as electrical signature analysis, that can be used for condition monitoring of induction motors. In general, these techniques are based on the analysis either of signals available at the motor terminals or obtained through appropriate transducers fitted to the structure. Several of these techniques are presented in 4.2 to 4.8.

The purpose of condition monitoring applied to three-phase induction motors is to assess the integrity of the motor and to provide early warning of possible faults. As an aid to this end, it is possible to obtain information about the health and integrity of an induction motor through analysis of its electrical signature. The variations in electric current, voltage, and power can equally be caused by the driven equipment, not just the motor; hence, the requirements of this International Standard, and electrical signature analysis, also apply to assessing the mechanical condition of the driven equipment.

If a motor is supplied from a variable voltage and frequency converter, care must be taken to account for current and voltage components in the output of such devices that could be misdiagnosed as resulting from motor defects. For techniques such as stator current analysis (4.2) and partial discharge (PD) analysis (4.5), it is advisable to lock the converter frequency and voltage while performing these tests.

4.2 Stator current analysis

4.2.1 General

Stator current analysis refers to measurements of the stator current. However, as the stator current is also affected by air gap fluxes and the rotor current, stator current analysis is capable of detecting problems in the rotor and the driven equipment.

4.2.2 Spectral analysis

Current signature analysis (CSA) has the capability of detecting the following problems in squirrel-cage and wound-rotor induction motors, where applicable:

— cracked rotor bars;

— cast rotor windings with large internal voids;

— broken bar-to-short circuit ring connections;

— cracked short circuit rings;

— excessive air gap eccentricity;

— rolling element bearing defects;

— coupling misalignment;

— stator winding shorted turns;

— problems in the driven equipment.

From this list, the most significant and damaging of these are rotor cage winding problems, eccentric air gaps, and rolling element bearing defects. Rolling element bearing defects are included since CSA can identify these defects that may also be identified by vibration monitoring.

Conventional CSA is done online at or close to normal full load. The current on one motor phase is analysed for its current frequency content by measuring it with a clip-on current transformer around a motor supply cable (see Figure 1) or around the secondary side of a current transformer (CT) (see Figure 2). Newer approaches can analyse all three phases and also look at the relation between current and voltage.

Care should be taken when interpreting the results of stator spectral analysis when the motor is driving a time-varying mechanical load since different phenomena can lead to similar characteristic frequencies showing up in the stator current. Some additional means of discriminating between the possible different causes may be required.

4.2.3 Rotor cage defects

CSA monitoring has revolutionized the detection of broken rotor bars and cracked short circuit rings in squirrel-cage induction (SCI) motor rotors. Specific frequencies in the current indicate the presence of defective rotor windings during normal operation of the motor. The detection of broken rotor bars by CSA can sometimes also be confirmed by bearing vibration analysis. References [19] and [27] independently pioneered current signature analysis in the late 1970s.

In simple terms, the current flowing in the stator winding not only depends on the power supply and the impedance of the stator winding, but also includes current induced in the stator winding by the magnetic field from the rotor. That is, the stator winding is a probe or “transducer” for problems in the rotor. The key issue is separating currents that flow through the stator to drive the rotor from the currents that the rotor induces back into the stator if there is a problem. This separation is accomplished by measuring current components at frequencies other than power frequency, using a high-resolution frequency spectrum analyser.

The additional frequency components, due to rotor defects, are seen as sidebands to the fundamental frequency component at frequencies given by Formula (1):

$$f = (1 \pm 2ks) f_1 \qquad (1)$$

where

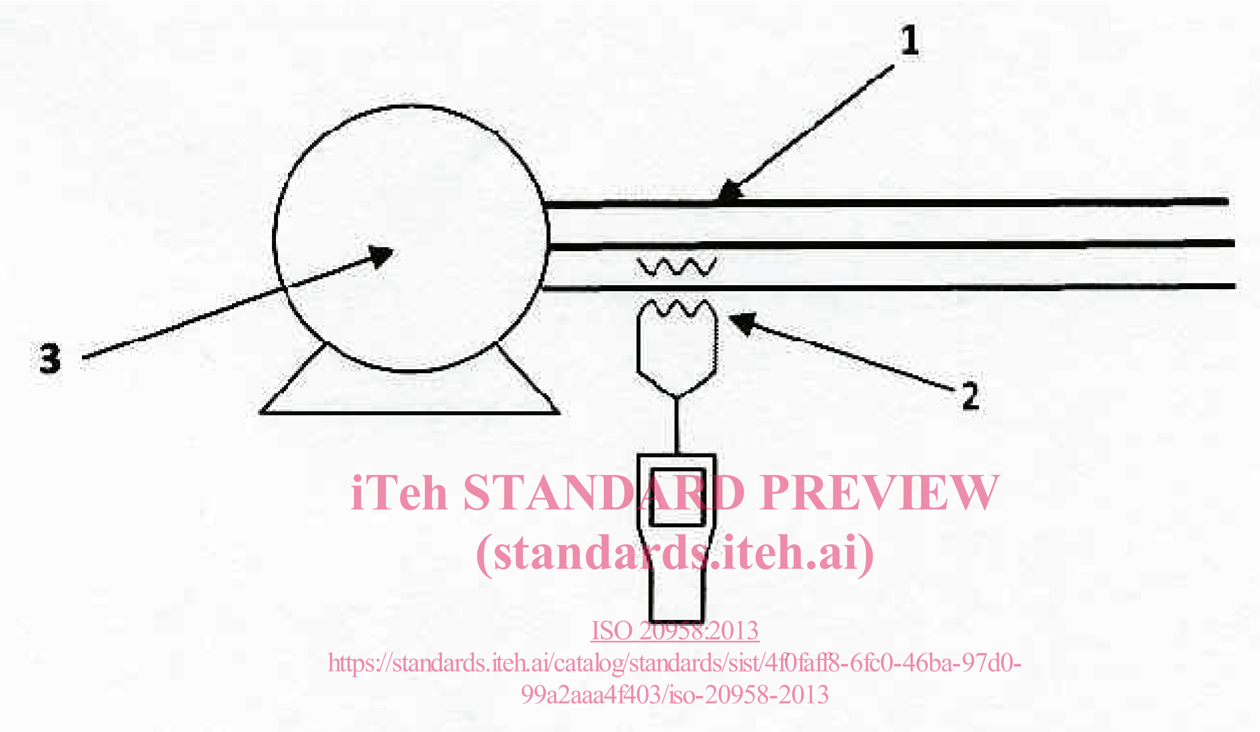
s is the per unit rotor slip;

f_1 is the fundamental supply frequency;

k is 1, 2, 3, etc.

The rotor currents in a cage winding produce an effective three-phase magnetic field, which has the same number of poles as the stator field, but is rotating at slip frequency with respect to the rotating rotor. If rotor current asymmetry occurs, then there is a resultant backward (i.e. slower) rotating field at slip frequency with respect to the forward rotating rotor. Asymmetry results if one or more of the rotor bars is broken or there are breaks in a short circuit ring preventing current from flowing through them. It can be shown that this backward rotating field is actually rotating forwards at (1 − 2s) times synchronous speed with respect to the stationary stator winding. This induces currents in the stator winding at a frequency of $f_1(1 - 2s)$, which is referred to as the lower twice slip frequency sideband due to broken bars. This current causes a cyclic variation of current that causes a rotor torque oscillation at twice slip frequency ($2sf_1$) and a corresponding speed oscillation which is a function of drive inertia. This rotor speed oscillation creates an upper side band (Reference [21]) current component at a frequency of $f_1(1 + 2s)$ that is enhanced by the third time harmonic flux. Broken rotor bars, therefore, result in current components being induced in the stator winding at frequencies given by Formula (2):

$$f_{sb} = f_1(1 \pm 2s) \quad (2)$$



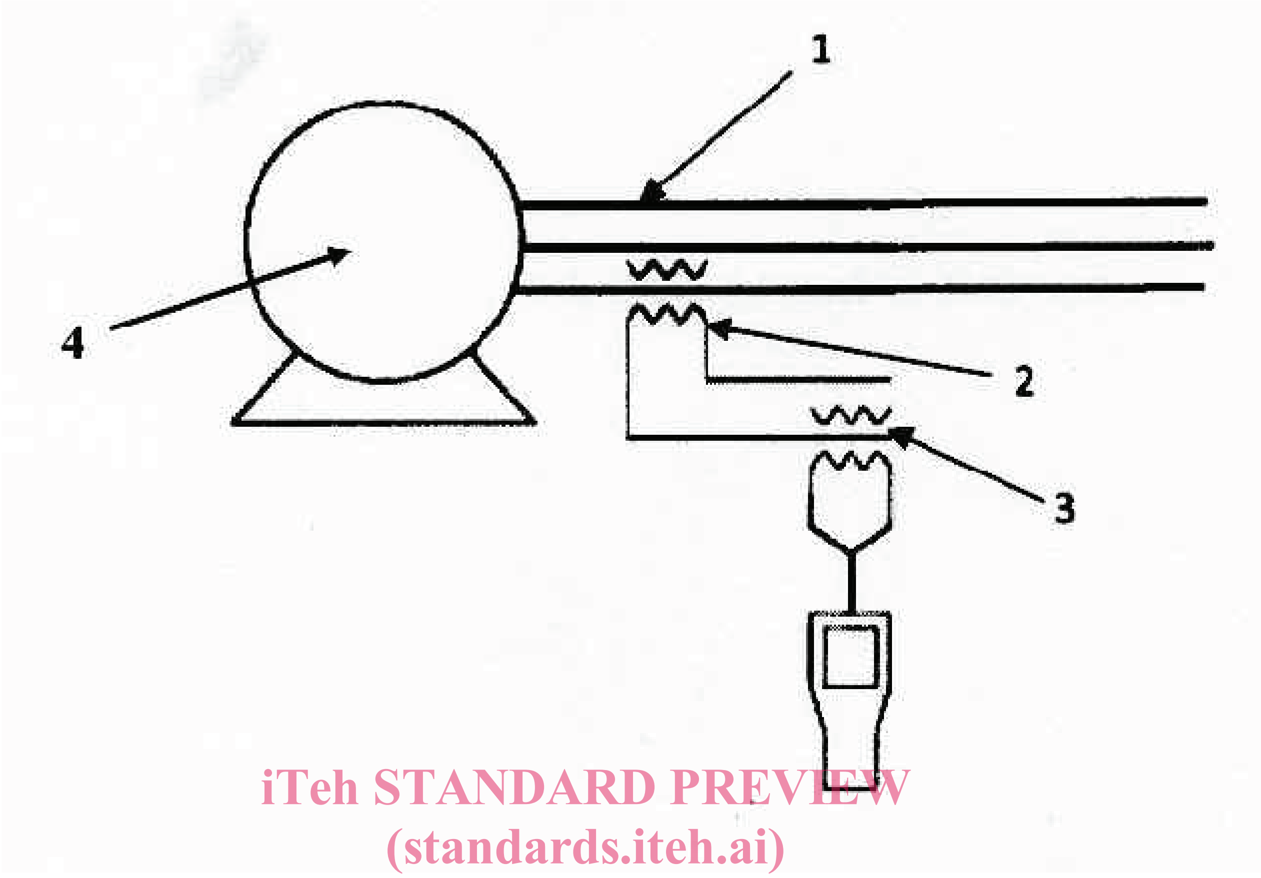
Key

1 phase lead

2 current probe, n_2

3 squirrel-cage induction motor

Figure 1 — Squirrel-cage induction motor CSA measurement on phase lead



Key

1 phase lead

2 current probe, n_1

3 current probe, n_2

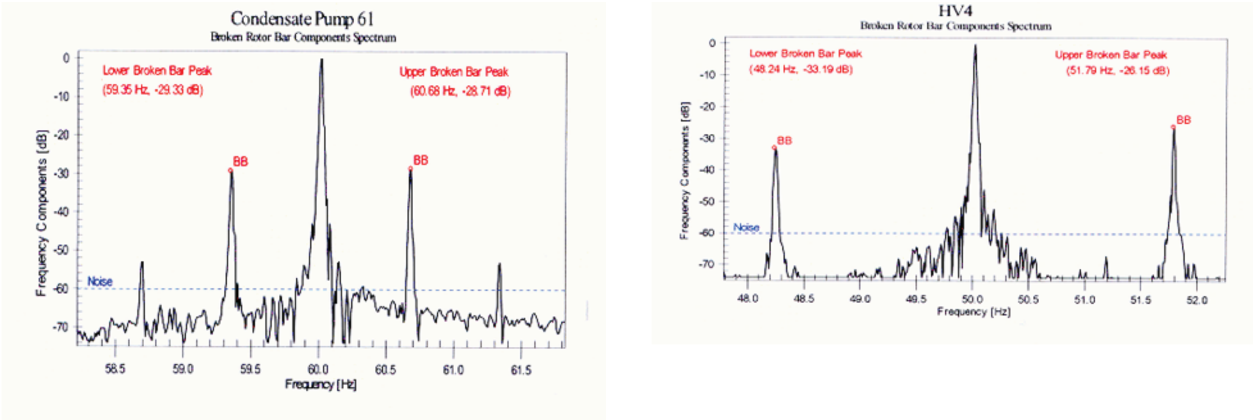
4 squirrel-cage induction motor

Figure 2 — Squirrel-cage induction motor CSA measurement from CT secondary

Current components due to broken rotor bars that appear in a logarithmic amplitude versus frequency plot (such as that shown in Figure 3) as current components that are $\pm 2sf_1$ removed from the fundamental 50 Hz or 60 Hz current component. It is important to note that if the rotor core has the same number of support spider arms as the number of stator winding poles, sidebands with the same frequencies as those from broken bars will result (Reference [16]).

Also, devices such as gearboxes in the motor/driven equipment drive train can create symmetrical sidebands around the fundamental frequency current that can look like those from broken bars. Care should be taken to evaluate sidebands around the fundamental line current that are in the domain of those generated by breaks in rotor cage windings, since there are driven equipment defects that can generate similar patterns. In particular, the various shafts in a gearbox installed between the motor and its driven equipment can produce a series of symmetrical currents around the fundamental line current. The best way to differentiate between such currents and those from cage winding breaks is to perform tests at two significantly different loads to see if there is sideband movement that is proportional to the change in rotor slip.

Because the stator current resulting from breaks in rotor cage winding is modulated at twice the slip frequency, sf_1 is often close to about 1 Hz. This creates a “thrum” sound at this low frequency that is easily recognized by knowledgeable plant staff.



a) 60 Hz motor **b) 50 Hz motor**

Figure 3 — Current signatures of motors with broken bars

The current is analysed with a spectrum analyser or customized digital signal processing unit as shown in Figure 3, which gives examples of both 60 Hz and 50 Hz motors with broken rotor bars. Typically, the sidebands are only 0,3 to 3 Hz or so away from the very large power frequency component and the sideband currents are typically 100 to 1 000 times smaller than the main power frequency currents. The slip “*s*” depends on both the number of poles and slots of the rotor form and the nature of the material constituting the cage winding. The modulation frequency depends not only on the slip rate at rated load, but also the relative I/I_n, where I is the actual current and I_n the motor full load current. Consequently, exceptional dynamic range and frequency resolution is required to accurately measure the sideband peaks due to broken rotor bars. For this reason, current magnitudes are measured in decibels. If there are no rotor cage winding breaks, then there are no or very low-level sidebands.

To detect cage winding breaks, it is necessary that the slip frequency be accurately known. In early “broken rotor bar” detectors, a stroboscope that directly detected the rotor speed (and thus allowed calculation of slip) was used. Alternatively, slip can be detected from an axial flux probe near the rotor winding (Reference[19]). Present-day CSA monitors may have proprietary means of estimating slip from the current itself (Reference[16]). This greatly improves the ease of performing CSA. Some of these methods are effective, but many have been shown to produce errors for small motors, motors that have a large number of poles, or those driving pulsating loads.

Basic interpretation requires comparison of the lower sideband with the power frequency stator current. Experience shows that if the sideband becomes larger than about (≤-50 dB) of the power frequency current, then cage winding breaks are likely. The greater the sideband current (that is, the larger the fraction of the power frequency current), then the more severe the rotor cage winding deterioration. As with most other monitors, it is best to trend the sideband magnitude over the years. If the sideband increases over time at approximately the same load, then it is reasonable to expect that a greater number of bars have broken in more locations. Figures 3 a) and 3 b) show decibel versus frequency plots of motors with several broken bars. At some point, there can be enough breaks in the rotor bars that the motor can fail to start or some metal may fly off the rotor, destroying the stator winding. CSA may not detect bar breaks in large two- or four-pole motors if the breaks occur under endwinding retaining rings since the retaining ring itself can allow the current to continue to flow.

Early CSA monitoring was prone to false indications (that is, indicating that a rotor had problems when it had none) and, less frequently, to missing defective rotor windings. Thus, early users of this test had low confidence in the results. However, improvements in theory, software, and spectrum analyser and

