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Agricultural machinery and tractors — Safety of higher voltage electrical and electronic components and systems —

Part 1: General requirements

Tracteurs et matériels agricoles — Sécurité des composants et des systèmes électriques et électroniques haute tension —

Partie 1: Exigences générales

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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).

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 (see 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.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 3, *Safety and comfort*.

ISO 16230 consists of the following parts, under the general title *Agricultural machinery and tractors — Safety of higher voltage electrical and electronic components and systems*:

— *Part 1: General requirements*

Introduction

Electrification is an enabling technology regarding increased power density and greater flexibility in machine form packaging. Customer benefits are increased fuel economy through efficiency gains and enhanced power delivery options not possible with current mechanical systems.

Agricultural machinery electrical systems have traditionally been in the 12 V DC range. Electrification is introducing significantly higher voltages to the Agricultural machinery and mobile equipment sector (see scope definition) usually observed only in industrial/building applications and other transportation sectors. Increased voltage potential requires special safety considerations in this new environment.

The purpose of this standard is to provide direction on safety of electrical systems as defined in the scope (50 V AC to 1000 V AC and 75 V DC to 1500 V DC) on Agricultural machinery and tractors.

In addition, this part of ISO 16230 defines requirements that can apply to the electrical equipment of agricultural tractors and machines. Example areas include, but are not exclusive to the following:

— protection against electric shock;

— wiring practices;

— marking warning signs — safety symbols;

— operator manual considerations.

Supporting electrical equipment standards like IEC 60204-1 and ISO 6469 were considered. Additional parts of this International Standard are expected to deal with external machine interface (power distribution and communication).

This part of ISO 16230 is a type-C standard as defined in ISO 12100.

When requirements of this type-C standard are different from those stated in type-A or B standards, the requirements of this type-C standard take precedence over the requirements of the other standards for machines that have been designed and built according to the requirements of this type-C standard

Agricultural machinery and tractors — Safety of higher voltage electrical and electronic components and systems —

Part 1: General requirements

1 Scope

This part of ISO 16230 is applicable to tractors and self-propelled ride-on machines, mounted implements, and towed implements used in agriculture and forestry. This part of ISO 16230 specifies general requirements that relate to the protection and safety of operators and bystanders on machines with on-board voltages in the range of 50 V AC to 1000 V AC and 75 V DC to 1500 V DC. This part of ISO 16230 applies to electrical equipment and parts of the electrical equipment on such machines and includes general requirements related to the protection and safety of operators, bystanders, and first responders.

This part of ISO 16230 deals with significant hazards, hazardous situations, and events, as listed in Annex A, relevant to this agricultural machinery when used as intended and under the conditions of misuse foreseeable by the manufacturer during normal operation and service.

This part of ISO 16230 is not applicable to the following:

— specific design elements of external interfaces (e.g. the interface between a tractor and implement);

— externally powered equipment (e.g. line powered equipment, equipment without on-board power generation);

— purpose built forestry machines;

— stationary electrical generators.

This part of ISO 16230 is not applicable to machines which are manufactured before the date of its publication.

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 3864-1, *Graphical symbols — Safety colours and safety signs — Part 1: Design principles for safety signs and safety markings*

ISO 6469-3:2011, *Electrically propelled road vehicles — Safety specifications — Part 3: Protection of persons against electric shock*

IEC 60204-1:2005 + AMD1:2008, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60364-4-41, *Low-voltage electrical installations — Part 4-41: Protection for safety — Protection against electric shock*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems — Part 1: Principles,*

IEC 61140:2009, *Protection against electric shock — Common aspects for installation and equipment*

ECE R100, *Protection against electric shock*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
barrier
part providing protection against *direct contact* (3.7) from any usual direction of access

3.2
basic insulation
insulation applied to *live parts* (3.15) for protection against *direct contact* (3.7) under fault-free conditions

Note 1 to entry: Basic insulation does not necessarily include isolations used exclusively for functional purposes.

3.3
basic protection
protection against *direct contact* (3.7) with *live parts* (3.15) under fault-free conditions

3.4
conductive part
part capable of conducting electric current

3.5
connector
assembly of contacts and housing which terminates conductors for the purpose of providing connection and disconnection to a suitable mating connector

3.6
creepage distance
shortest distance along a surface of a solid insulating material between two *conductive parts* (3.4)

3.7
direct contact
contact of persons with *live parts* (3.15)

3.8
double insulation
insulation system comprising both *basic insulation* (3.2)and *supplementary insulation* (3.22)

3.9
electric shock
physiological effect resulting from an electric current passing through a human body

3.10
equipotential bonding
provision of electric connections between *conductive parts* (3.4), intended to achieve equipotentiality

3.11
exposed conductive part
conductive part (3.4) of the electric equipment that can be touched by a test finger according to IPXXB after removing *barriers* (3.1)/enclosures that can be removed without using tools and that is not normally live, but which can become live under fault conditions

Note 1 to entry: Protection degrees (e.g. IPXXB) are defined in ISO 20653.

3.12
higher voltage
HV
in a machine that contains systems with more than one voltage range, higher voltage refers to systems in the ranges of 50 V AC-1000 V AC and 75 V DC-1500 V DC

3.13
isolation-resistance monitoring system
system which periodically or continuously monitors the *isolation resistance* (3.14) between *live parts* (3.15) and the electric chassis or *exposed conductive parts* (3.11)

3.14
isolation resistance
resistance between *live parts* (3.15) of *higher voltage* (3.12) electric circuit and the electric chassis or *exposed conductive parts* (3.11) as well as the *lower voltage* (3.16) system

3.15
live part
conductor or *conductive part* (3.4) intended to be electrically energized in normal use

3.16
lower voltage
in a machine that contains systems with more than one voltage range, lower voltage refers to systems with maximum voltage of <50 V AC and <75 V DC

3.17
maximum fault current
highest value of a.c. current or of d.c. current that can occur in an electric system under fault conditions according to manufacturers' specifications

3.18
potential equalization
electric connections of *exposed conductive parts* (3.11) of the electric equipment to minimize differences in potential between these parts

3.19
protection degree
protection provided by a *barrier* (3.1)/enclosure related to the contact with *live parts* (3.15) by a test probe, e.g. a test finger (IPXXB) or a test wire (IPXXD)

Note 1 to entry: Protection degrees (e.g. IPXXB, or IPXXD) are defined in ISO 20653.

3.20
reinforced insulation
insulation of *live parts* (3.15) for protection against *electric shock* (3.9) equivalent to *double insulation* (3.8)

Note 1 to entry: Reinforced insulation does not imply that the insulation shall be a homogeneous piece. The reinforced insulation can comprise several layers which cannot be tested individually as supplementary or basic insulation.

3.21
socket
connector (3.5) intended to mate with a plug-in device

3.22
supplementary insulation
independent insulation applied in addition to *basic insulation* (3.2) for protection against *electric shock* (3.9) in the event of a failure of the basic insulation

3.23
VAC
AC voltage as measured using RMS (Root-Mean-Square)

3.24
wiring
system of wires providing electric circuits and including cables and *connectors* (3.5)

4 General requirements

4.1 Standards

The safety standards for tractors and agricultural machinery, e.g. ISO 4254, ISO 26322, and ISO 25119 shall be applied in addition to the requirements provided in this part of ISO 16230.

4.2 Component selection

Component design and selection shall follow IEC 60204:2009, 4.2.1 for major system functional components (e.g. inverter selection, etc.)

5 Protection of persons against electric shock

5.1 General

The electrical equipment shall provide protection of persons against electric shock. Such protections shall consist of basic measures against direct contact and measures for protection under single-fault conditions (indirect contact).

If any of the protective measures in 5.2 and 5.3 are not practical, equivalent measures from IEC 61140 or other appropriate standards can be used.

5.2 Protection against direct contact

The higher voltage electric system on agricultural machinery and tractors shall be designed such that a person is protected against direct contact with live parts.

The following electrical safety requirements apply to higher voltage equipment or buses in a closed vehicle system or a combination of vehicle and attachment or implement system.

5.2.1 Protection measures

At least one or a combination of the following protection measures against direct contact with live parts shall be applied:

— basic insulation of live parts;

— enclosures according to 5.2.2;

— barriers, protecting against direct contact with live parts of the higher voltage system from any common direction of access.

The design of the protection measures shall also consider the connection between the vehicle and external equipment (e.g. implement, attachment, or towed machinery).

5.2.2 Enclosure requirements

Enclosures are deemed to meet the requirements of 5.2 if they meet one or more of the following.

— Live parts within the operator workplace shall be contained within enclosures compliant with IPXXD in accordance with IEC 60529.

— Live parts in areas other than the operator workplace shall be contained within enclosures compliant with IPXXB in accordance with IEC 60529.

— For enclosure access, it shall not be possible to open an enclosure without having to apply a tool. If a tool is not required to open the enclosure, the power supply shall automatically be switched off if a cover of the enclosure is opened.

— The voltage of the live parts becomes equal or below 60V DC or equal or below 30V AC (rms) within 5 s after disconnection of the supply voltage in accordance with IEC 60204-1.

5.3 Connectors

Connectors are deemed to meet the requirements of 5.2 if they meet one or more of the following.

— When able to be separated without tools, connectors inside the operator station shall comply with IPXXD, and connectors outside the operator station shall comply with IPXXB.

— They are provided with a locking mechanism and other components need to be removed with the use of tools in order to separate the connector

— The voltage of the live parts becomes equal or below 60 V DC or equal or below 30 V AC (rms) within 1 s after the connector is separated in accordance with IEC 60204-1. If time exceeds 1 s, additional switching devices or an appropriate warning device shall be applied in accordance with IEC 60204-1.

NOTE For sockets connecting the vehicle with attachments or implements, see Clause 6.

5.4 Protection against indirect contact

5.4.1 IT system

The vehicle system or a combination of vehicle and implement or machine and dedicated attachment (e.g. header) shall be designed as an IT system as defined by IEC 60364-4-41.

5.4.2 General

At least one or a combination of the following measures shall be applied.

— Protective Provisions (Protection by class II construction or equivalent). To prevent the occurance of touch voltages, the electrical installation shall meet the requirements of IEC 61140:2009, 7.3 for class II equipment or equivalent requirements of other electrical safety standards.

— Protection by electrical separation. The provisions in IEC 61140:2009, 7.3.1.2 for electrical separation shall be met.

— Protection by automatic disconnection of source. Protection by automatic disconnection shall meet the requirements for IT systems, IEC 60204-1: edition 5.1 2009, 6.3.3. This only applies to chassis faults.

— IEC 60204-1 is applicable except for interruption times.

NOTE Interruption times defined by the application.

5.5 Protection by potential equalization (equipotential bonding)

5.5.1 Potential equalization for components

For protection against electrical shock which could arise from indirect contact, the exposed conductive parts, e.g. the conductive barrier and enclosure, shall be galvanically connected to the electrical chassis by connection with electrical wire or cable, welding, or by a connection using bolts, etc. so that dangerous potentials cannot be produced.

All components forming the potential equalization current path (conductors, connections) shall withstand the maximum system fault current that can occur.

The resistance of the potential equalization path between any two exposed conductive parts of the higher voltage electric circuit(including all attachments or implements) that can be touched simultaneously by a person shall not exceed 0,1 ohms at 0,2 A and at >20 A.

NOTE 1 Alternatively, the equipotential bonding can be designed and verified according to IEC 61140.

NOTE 2 Cable shielding cannot be part of the equipotential bonding system.

5.5.2 Potential equalization for sockets

Potential equalization requirements for sockets connecting the vehicle with external equipment are deemed to meet this requirement if the requirements in 5.5.1 are fulfilled.

5.6 Isolation resistance requirements

5.6.1 Electric power train consisting of separate DC or AC buses

If AC higher voltage buses and DC higher voltage buses are galvanically isolated from each other, isolation resistances shall have a minimum value of the following:

— 100 Ω/V of the nominal working voltage between the DC higher voltage bus and the electrical chassis;

— 500 Ω/V of the nominal working voltage between the AC higher voltage bus and the electrical chassis;

— 500 Ω/V of the nominal working voltage between the AC and DC buses.

The reference shall be the maximum working voltage adapted from ECE R100 5.1.3.1.

5.6.2 Electric power train consisting of combined DC- and AC-buses

If AC high voltage buses and DC high voltage buses are galvanically connected, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 500 Ω/V of the nominal working voltage.

However, if all AC high voltage buses are protected by at least one of the two following measures, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 Ω/V of the nominal working voltage:

— reinforced insulation;

— double or more layers of solid insulators, barriers, or enclosures that meet the basic insulation requirements independently;

— mechanically robust protections that have sufficient durability over vehicle service life, e.g. motor housings, electronic converter cases, or connectors.

5.6.3 Insulation monitoring

Insulation resistance testing shall be required by the manufacturer either as periodic maintenance or an automatic test on a regular basis.

Automatic testing of the insulation resistance shall be provided as preferred means. If periodic maintenance is used for the insulation resistance testing, the manufacturer shall specify the maintenance frequency in the operator's manual and in the service literature.

5.7 Parasitic coupling

Given an IT-system architecture, there shall be no electrical connection to the machine chassis with the exemption of

— capacitive couplings, e.g. caused by suppression capacitors,

— the shield of shielded cables or components, and

— insulation monitoring systems.

5.7.1 Protective measures — Parasitic coupling

Protective measures to be applied (at least one of the following):

— double or reinforced insulation;

— one or more layers of insulation, barriers, and enclosures, individually or in combination, in addition to the basic protection;

— rigid barriers/enclosures with sufficient mechanical robustness and durability, over the vehicle service life.

5.8 Test procedure for the protection against electric shock

The manufacturer shall establish a test procedure that ensures the design provisions for protection against electric shock are satisfied over the life of the machine. See reference ISO 6469-3, 7.7.2 for guidance.

6 Additional requirements for electrical sockets connecting to implements or attachments

6.1 Mated connection — General

The mated interface shall

— be water protected according to the application. A minimum of IPx7 is required, and

— ensure that the requirements of potential equalization (see 5.5) are met for machine and external equipment simultaneously.

NOTE Specifications of interface to be documented in a future International Standard.

6.2 Connect/Disconnect

The design of the plug and the socket shall ensure that the equipotential bonding contact makes before all other contacts and breaks after all other contacts. An interlock device shall be provided. It shall mate last and break first. Breaking of interlock shall disable the output as decribed below.

If socket and respective plug are disconnected, at least one of the following requirements shall be met:

— the vehicle power outlet shall de-energize within 1 s after disconnection;

— the vehicle power outlet shall de-energize in a time specified by the manufacturer and meet IPXXB.

6.3 Protection of electrical equipment

Protection requirements shall be met by each individual electrical system or, in case of an electrical connection between multiple electrical systems (e.g. harvester and harvesting head), by the combination simultaneously.

6.3.1 Short-circuits and overloads

The higher voltage electric system of the machine or tractor shall be protected against short-circuit and over-load conditions.

6.3.2 Heat generating components

Heat creating electrical components shall be located and arranged so as to avoid over-heating.

7 Conductors and cables used in higher voltage distribution — General requirements

7.1 Identification Colours

The outer covering of cables, harness, and conduits used for higher voltage circuits, not within enclosures or behind barriers, shall be marked with orange colour and voltage level. The colour shall be used the entire length of the covering.

NOTE 1 Connectors can be identified by the harnesses to which the connector is attached.

NOTE 2 Specifications of orange colour are given, e.g. in standards in the US (8.75R5.75/12.5), Japan (8.8R5.8/12.5) according to the Munsell colour system and In Europe (ECE R 100) by RAL colour system in reference with orange colour in IEC 60304.

7.2 Identification of conductors for multicore cable

The identification of each conductor shall be possible by colour of basic insulation layer or by (printed) number on the basic insulation layer.

7.3 Creepage and clearance distances

Components and vehicle higher voltage wiring shall meet the requirements for creepage and clearance in applicable clauses of IEC 60664-1.

7.4 Cable and wire insulation

Cabling insulation shall meet the requirements of ISO 6469-3:2011, 7.7.2.

7.5 Cross-sectional area

The cross-sectional area shall be selected so that during all operational conditions of the machine or tractor, the conductor temperature does not exceed the temperature rating of insulation used.

7.6 Multicore cables

Unless specially designed, multicore cables fed by circuits of different voltage shall have insulation appropriate for the highest applicable voltage.

7.7 Wiring that flexes

Wiring that flexes during normal operational functions of the machine or tractor shall be relieved of mechanical strain at their electrical termination in minimum and shall be within the limits recommended by the cable manufacturer.

7.8 Flame retardancy

It is recommend to meet or exceed IEC 60695-11-10 or equivalent specification.

7.9 Protection of cables

7.9.1 Outer covering

The outer covering for higher voltage cables should be highly resistant to abrasion, oil, and solvents which the cables can be exposed to during normal operation or service. The outer covering should meet the requirements of SAE J2192 or equivalent. This goal can be achieved by cable design or added full length covering in addition to the cable insulation.

The outer covering is to be specified for exposed environmental influences and should fulfil the following criteria:

— temperature classification of the protective material/covering shall fulfil the range for the max. surface and ambient temperature in the mounted area;

— UV resistant;

— when using added covering, provide minimum distance of 60 mm from connector body to covering end;

— when using added covering, provide minimum distance of 60 mm from harness branch to covering end.

7.9.2 General requirements — Protection

Where wiring passes through metal parts of the frame or enclosures, the holes shall be fitted with insulating bushings or the wiring shall be protected by some other equivalent means.

All conductors shall be either effectively insulated and where necessary protected against mechanical damage or shall be so placed and safeguarded as to avoid danger when the machine or tractor is in normal operation.

8 Wiring practices — General

8.1 Fastening and clamping

Fastener and clamps shall provide proper retention, protection, and serviceability for harnesses through

— the use of deburred or additional protective surfaces to prevent wear into the harness,

— applying per manufacturer recommendation,

— bending the conduit after the use of a fastener (e.g. clamping) within the supplier recommendations, and

— preventing harness motion between clamping locations.

8.2 Routing

Prevent contact against or clamping to

— sharp edges,

— raw surfaces, and

— lines which carry flammable liquids (i.e. fuel lines).

When higher voltage cables are routed along metal tubes and fixed by clamps which are mounted to the tubes, the clamps shall be insulated.

Higher voltage cables should not be routed transversely to other cables with contact between the cables (e.g. 90°). If transverse routing is unavoidable for technical reasons, a minimum distance of 2 mm clearance between the cables shall be maintained through the usage of fasteners and clamps.

Parallel mounting of cables is acceptable.

9 System requirements

9.1 Power on/power off procedure

9.1.1 Active state

To activate the higher voltage system, the ignition switch shall need to be in the ON-Position.

9.1.2 Deactivated state

There shall be a means to de-energize the system (following in general the means and requirements of IEC 60204-1, 6.2.4). No electrical energy shall be present in a conductive part when the system is deactivated.

If the ignition key is in the OFF position, the higher voltage system shall be disabled with system de-energizing initiated.

The transition time to reach the de-energized state shall be specified by the manufacturer in the operator's manual and the service literature.

9.1.3 System state indication

When the system is "off" and there is higher voltage present in any of the conductive parts, an indication of higher voltage shall be provided.

9.2 Fault modes (indication)

System faults that require operator action or that can result in reduced system performance shall be indicated to the operator with a visual signal or audible signal or both.

Switching off the audible signal is allowed when a visible signal is still displayed.

10 Marking and symbols

The marking of electric components that fall under the scope of this part of ISO 16230 shall be used to alert service persons or others to potential live parts. This excludes wiring harnesses and cables.

The symbol ISO 7010-W012 shall appear on or near openable enclosures, removable barriers, or external interfaces (for example, connection points) where the risk of contact with voltages in the range of 50 V AC to 1000 V AC or 75 V DC to 1500 V DC is present.

ISO 7010-W012 shall be used in colour in accordance with ISO 3864-1: yellow background, black symbol, black triangular border.

11 Information for use

Information for use shall be in accordance with Clause 11 and ISO 3600.

The operator's manual shall

— specify the locations on the machine which should not be cleaned with jets of water and any special instructions related to washing the machine in general,

— provide information specific to hazards associated with the electrical system and system usage,

— designate periodic inspection and maintenance requirements for the electrical system,

— inform the operator of limitations based on working environment considerations,

— specify that service of the electrical system shall only be performed by qualified service personel, and

— the transition time to reach the de-energized state shall be specified by the manufacturer in the operator's manual and the service literature.

12 Service literature

12.1 General

General documentation requirements are addressed in ISO 4254.

12.2 Reduction of electrical hazards while servicing

Within the service literature (or equivalent), the manufacturer shall provide information to address the unique hazards associated with the electrical system and provide specific instructions related to maintaining the system integrity.

12.2.1 Description of effects of electricity on the human body

The service literature shall state the following or equivalent:

"Direct contact with electricity can cause physical harm or death. Observe all safety precautions provided in this manual while servicing this machine."

12.2.2 Statements regarding risk reduction

The service literature shall provide the following:

— information specific to hazards associated with the electrical system and special procedures for service (e.g. machine washing);

— a method for verification of discharge of residual voltages prior to servicing. Instructions to the service person to use electrical Personal Protective Equipment (PPE) to reduce the likelihood of accidental contact and the effects of arc flash and arc blast;

— instructions to verify that the residual voltage measuring device is functioning correctly and rated for the safe measurement of the voltage;