
**Remote handling devices for radioactive
materials —**

**Part 3:
Electrical master-slave manipulators**

Dispositifs de manipulation à distance pour matériaux radioactifs —

Partie 3: Télémanteurs maître-esclave électriques



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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.

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 17874-3 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

ISO 17874 consists of the following parts, under the general title *Remote handling devices for radioactive materials*:

- *Part 1: General requirements*
- *Part 2: Mechanical master-slave manipulators*
- *Part 3: Electrical master-slave manipulators*
- *Part 4: Power manipulators*
- *Part 5: Remote handling tongs*

Introduction

This part of ISO 17874 deals with electrical master-slave manipulators used for nuclear applications. These are multipurpose remote handling devices used to replace hands and arms in areas hazardous or inaccessible to personnel (typically behind shielding walls).

Electrical master-slave manipulators were originally developed for large hot cells designed for research and development of fuel elements for nuclear reactors. They are now commonly used for other nuclear purposes, such as reprocessing, accelerator plants and decommissioning of redundant nuclear facilities. A different field of application features manipulators mounted on vehicles for use, e.g. in situations involving recovery of radioactive sources or contaminated objects from incidents and accidents.

Electrical master-slave manipulators can be modified or specially designed for non-nuclear applications. This part of ISO 17874 does not address the special requirements of such fields, although designers might be able to take advantage of the standardized features and components from the nuclear sector to achieve efficient and cost-effective designs for other applications, where appropriate.

This part of ISO 17874 is intended to provide assistance to designers of nuclear process and research plants and their equipment, as well as to manufacturers and users of electrical master-slave manipulators and associated regulatory authorities.

Remote handling devices for radioactive materials —

Part 3: Electrical master-slave manipulators

1 Scope

This part of ISO 17874 specifies the main features of electrical master-slave manipulators intended to be used for nuclear applications. It outlines basic principles which relate to the design features of electrical master-slave manipulators for applications both inside and outside nuclear plant buildings.

This part of ISO 17874 does not address prototypes, experimental devices and obsolete types, involving variations in design which omit one or more essential features of electrical master-slave manipulators (e.g. force reflection). Examples of such devices and special features are given in Annex A.

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 17874-1:2010, *Remote handling devices for radioactive materials — Part 1: General requirements*

ISO 17874-2:2004, *Remote handling devices for radioactive materials — Part 2: Mechanical master-slave manipulators*

ISO 17874-4:2006, *Remote handling devices for radioactive materials — Part 4: Power manipulators*

3 Terms and definitions

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

3.1

electrical master-slave manipulator

system reproducing the movements of hand and arm of the operator by means of isokinematic master and slave arms with bilateral electrical position control (force reflection)

NOTE 1 The word “bilateral” refers to the property of the system to be indifferently moved by acting on the master arm or on the slave arm.

NOTE 2 The slave arm is generally mounted on a transporter (mobile).

3.2

arm

component reproducing the functions of a human arm, respecting in most cases the same distribution and corresponding articulations

NOTE The corresponding articulations include shoulder pivot, upper arm, elbow pivot, forearm and wrist pivot.

3.3

axis

direction of a Cartesian coordinate system defined from the operator's standpoint, considered as the origin of the system

NOTE The following axes are considered:

- axis X: from the right to the left along the shielding wall;
- axis Y: forward into the shielded cell;
- axis Z: towards the ceiling of the shielded cell.

3.4

balancing

characteristic allowing the manipulator to be maintained with negligible forces applied by the operator in stable positions throughout the whole operating volume by electrical or mechanical means (e.g. counterweights)

3.5

gaiter

specially profiled flexible sleeve designed to protect the slave arm from contamination

NOTE This component is also called a booting (US).

3.6

handle

component fixed at the end of the master arm and gripped by the operator, facilitating the control of the movement of the manipulator

3.7

indexing motion

X, Y and Z motion

adjustable electrical displacement between the slave arm position and the corresponding master arm position, to enlarge the operating volume and minimize operator strain

3.8

jaws

components fixed on the end of the tongs which facilitate the handling of the objects

NOTE The jaws can be disconnectable.

3.9

master arm

arm located outside a hot cell and equipped with an operator handle on which the operator acts

3.10

range of motion

range over which a motion can be executed by a sub-assembly

3.11

orientation motion

rotation motion around certain axes of the tongs

NOTE Depending on the axis considered, three rotational motions are distinguished:

- tilt (α),
- twist (β), and
- swivel or azimuth motion (γ).

3.12**operating volume****operating range**

space in which the operation of the tongs is possible, considering all the positions in which the different components of the slave arm of a manipulator can be moved

3.13**positioning motion**

motion affecting a displacement of the tongs (or end effector)

NOTE Depending on the axis considered, three different motions are distinguished: X, Y and Z.

3.14**PLZT****lead (Pb) lanthanum zirconium titanate**

electro-optical crystal medium used to switch rapidly between orthogonal linear polarizations in three-dimensional visualization systems

3.15**slave arm**

arm located inside a hot cell, for example, and equipped with tongs to grip objects or tools, or mounted on a transporter

3.16**tongs**

gripping device fixed at the end of the slave arm and consisting of a hand assembly including the jaws

3.17**transmission element**

mechanical element which transmits motive force or torques from the drive unit(s) to the arm sub-assemblies to be moved

3.18**transporter**

kinematic system for moving and positioning the slave arm or slave unit within the operating volume

3.19**isokinematic**

property of a manipulator where, from base to free end, the master arm and slave arm present the same type of motion (rotation or translation) in the same order and with the same relative orientations

4 Field of application

Electrical master-slave manipulators are typically used inside buildings, in large hot cells for research, nuclear fuel reprocessing plants, waste treatment plants, accelerators, fusion research machines and large enclosures for other purposes where high radiation levels or radioactive contamination are encountered.

The tasks to be performed include normal operations, maintenance, repair, exchange of process components, interventions, recovery and decommissioning.

Electrical master-slave manipulators are suitable for complicated high-dexterity tasks similar to those for which a mechanical master-slave manipulator would be used, but with the possibility to reduce the force perceived by the operator. Their operating volume can be greatly increased by means of a transporter. Electrical master-slave manipulators combine most of the advantages of mechanical master-slave manipulators (particularly dexterity, see ISO 17874-2) and power manipulators (notably mobility, see ISO 17874-4). Accordingly, they can be used for work in areas that cannot be reached by fixed mechanical master-slave manipulators. Heavy objects can be handled more easily than with mechanical master-slave manipulators by using servo assistance, and in a shorter time than with power manipulators by employing isokinematic master-slave control.

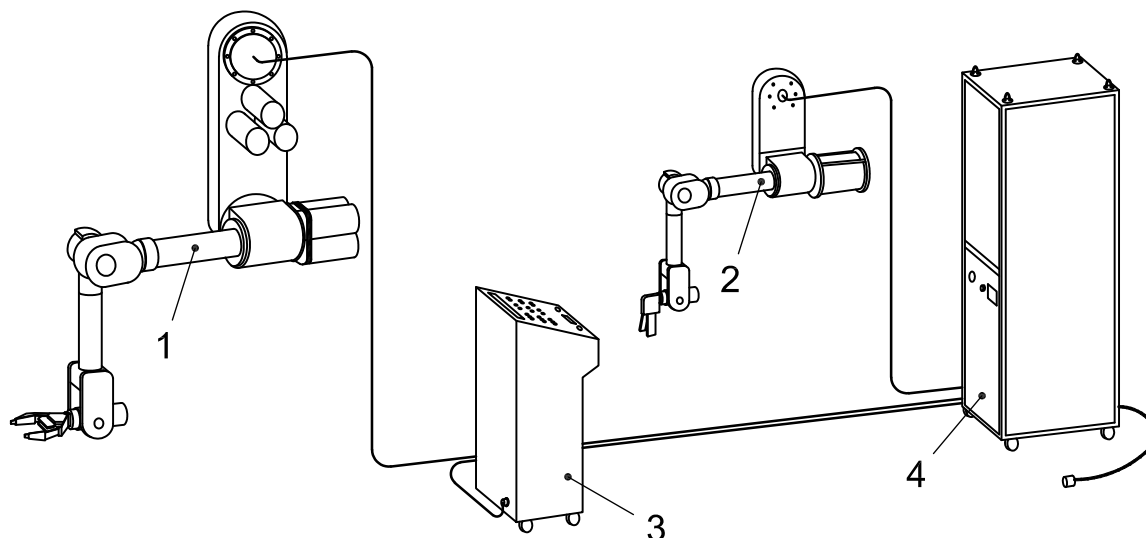
One pair of electrical master-slave manipulators can advantageously be installed instead of several pairs of mechanical master-slave manipulators in a hot cell with shielding windows, if it is not necessary to operate on many of the working stations (windows) at the same time.

5 General features

An electrical master-slave manipulator generally consists of four typical sub-assemblies (see Figure 1):

- one slave arm,
- one master arm,
- an operating desk or console, and
- a control cabinet.

The slave arm and the master arm are usually built with different load capacities. In special applications, two control cabinets are provided, one each for the slave arm and the master arm, e.g. if the control for the slave arm needs to be located remotely.



Key

- 1 slave arm
- 2 master arm
- 3 operating desk (or console)
- 4 control cabinet

Figure 1 — Electrical master-slave manipulator — Sub-assemblies

In the standard mode of working, a force or a displacement is applied on the master arm, with a corresponding effect on the slave arm. However, the master and slave arms shall both be back-drivable, i.e. if a force or a displacement is applied to the slave arm, the master arm shall follow. Consequently, the actuator transmissions shall be mechanically back-drivable and the electric motor drive system shall provide “force reflection” of load on the slave arm to the operator, via the handle of the master arm. It shall be possible to introduce a ratio in the force reflection so that the slave arm executes higher forces than are felt by the operator.

The slave arm shall be electrically coupled to the master arm in such a manner that the differences of velocities and displacements between the corresponding components of the master arm and the slave arm remain very small. The motions the operator makes with the handle of the master arm and the forces and torques that he supplies to the handle shall be transmitted to the slave arm with a delay imperceptible to the operator for the task concerned.

The slave arm is generally installed on a transporter in order to attain a large operating volume, where a wide range of positions is to be achieved. The transporters are generally designed to run on rails, typically located overhead. The slave arm can also be installed on a remotely controlled vehicle running on the ground for use inside or outside buildings. Electrical master-slave manipulators can be installed in pairs to carry out complicated tasks.

6 Requirements

6.1 General aspects

Electrical master-slave manipulators shall meet a number of general technical requirements in addition to the specific features above.

Each motion of the master arm of an electrical master-slave manipulator shall be connected by a bilateral position control circuit (see 6.11) to the equivalent motion of the slave arm.

The friction force the operator has to overcome when he moves the manipulator in the no-load condition shall be kept as low as possible in order not to reduce the dexterity or to tire the operator unnecessarily (see 6.7).

The deflections due to loading of the slave arm sub-assemblies shall be kept small compared to the changes made in the orientation of the corresponding sub-assemblies of the master arm, in order not to reduce the dexterity (see 6.8). This means that a compromise shall be found between low friction and minimized backlash and elastic deflection under load.

The drive unit inertia shall be kept sufficiently low to limit operator fatigue when moving the mass of the arms quickly. The resistance to motion of the master arm felt by the operator when moving the arm at normal speed should not be perceptibly larger than the frictional and inertial forces of the master arm alone.

It shall be possible for the slave arm to follow the motions of the master arm at speeds up to 1 m/s for translations and 1 r/s for orientation motions (see 6.9), each with imperceptible lag.

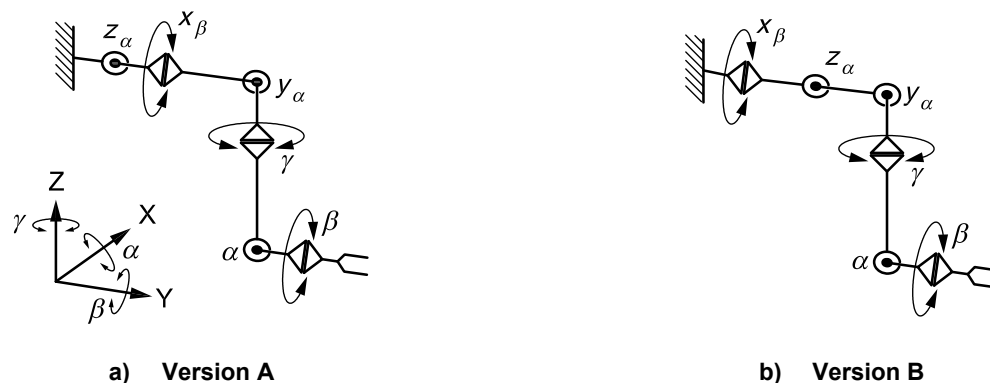
The dead weight of the sub-assemblies of the slave arm and the master arm shall be compensated. This is necessary at least for the following motions:

- inclination of upper arm,
- rotation of upper arm, and
- inclination of forearm.

Electrical master-slave manipulators also need to satisfy plant safety requirements regarding the operating environment (e.g. the presence of contamination, ionizing radiation, corrosive atmosphere, excessive humidity or temperature).

6.2 Motions

Electrical master-slave manipulators shall have seven motions (three positioning motions, three orientation motions and one gripping motion) accommodated by the master arm and the slave arm and corresponding to the requirements of ISO 17874-1:2010, Clause 4, for multipurpose remote handling devices. The kinematics of the electrical master-slave manipulators shall correspond to ISO 17874-1:2010, 6.2 (see Figure 2).



NOTE The difference between versions A and version B is the exchange of the motions Z_α and X_β . With version B, the operating volume is increased by the rotation of the shoulder pivot.

Figure 2 — Electrical master-slave manipulator — Slave arm (kinematics diagram)

6.3 Load capacity

Depending on the model of the electrical master-slave manipulator, the load capacity of the slave arm ranges from under 10 kg up to 100 kg. Three classes concerning the maximum load, defined as that handled by the tongs, shall be distinguished:

- light-capacity electrical master-slave manipulators: up to 10 kg;
- medium-capacity electrical master-slave manipulators: from 10 kg to 45 kg;
- heavy-capacity electrical master-slave manipulators: from 45 kg to 100 kg.

The slave arm shall be able to handle the maximum load in any position and orientation to which the operator can move the master arm.

It should be noted that when accelerating the load, the operator and the master-slave equipment have to accommodate the inertial forces (even if the dead weight has been compensated).

The slave arm shall be able to hold stationary (at any position and orientation) an object with a weight equal to the maximum load, for at least 30 min, without using any brakes.

6.4 Length of the slave arms

The length between the wrist pivot and the shoulder pivot of a slave arm lies typically within the range of 1,0 m to 1,9 m.

The usual length for each of the different classes is as follows:

- light-capacity electrical master-slave manipulators: from 1 000 mm to 1 200 mm;
- medium-capacity electrical master-slave manipulators: from 1 050 mm to 1 900 mm;
- heavy-capacity electrical master-slave manipulators: from 1 400 mm to 1 800 mm.

The hand assembly introduces an additional length, which ranges from 150 mm for light manipulators to 350 mm for heavy manipulators.

With regard to the dexterity, the hand assembly should be as short as possible.

6.5 Forces, torques and lengths

Table 1 specifies the minimum lengths, forces and torques characterizing a seven-motion electrical master-slave manipulator.

Table 1 — Forces, torques and lengths

Parameter	Manipulator class			
	Light capacity	Medium capacity		Heavy capacity
		(a)	(b)	
Maximum load, kg	10	24	45	100
Upper arm length, mm	460	700	700	800
Forearm length, mm	560	900	900	800
Force of inclination of upper arm, daN	10	24	45	100
Force of rotation of upper arm, daN	10	24	45	100
Force of inclination of forearm, daN	10	24	45	100
Force of rotation of forearm, daN	1,4	4,5	8	24
Force of inclination of tongs, daN	1,5	4	7,5	24
Force of rotation of tongs, daN	1,4	4	7,5	20
Gripping force, daN	14,5	30	60	130
NOTE If the arms are lengthened or shortened compared to the lengths quoted in this table (e.g. for special applications), the load capacity and the forces of inclination and rotation of the upper arm and the forces of inclination of the forearm will be reduced or increased respectively.				

6.6 Design features

6.6.1 Main features

The slave arm and master arm of an electrical master-slave manipulator shall be divided into four sub-assemblies:

- hand assembly (slave arm) or handle (master arm),
- forearm,
- upper arm, and
- drive system.

Depending on the model, the drive system consists either of two distinct drive blocks (see Figure 3) or of one drive housing containing all the drive units (see Figure 4). The upper arm is generally orientated horizontally and the forearm vertically, when in the basic position.

The pivots of an arm are the wrist pivot, elbow pivot and shoulder pivot (see Figure 4). Each motion of the slave arm and the master arm shall be equipped with one drive unit. Such a drive unit shall consist of one or several motors, a gearing, which provides a basic reduction, a position transducer and a brake. Optionally, a tachometer may be used in addition.

The drive units shall be interchangeable to minimize spares holding as much as possible. These drive units shall be arranged behind the shoulder pivot as seen from the tongs or handle, respectively, in order to minimize the weight of the arm sub-assemblies. This helps the realization of a slender arm, which is advantageous with regard to working in restricted spaces.

Consequently, for the orientation motions and the gripping motion, transmission elements shall run from the drive units to the associated arm sub-assemblies. These are typically steel cables and/or steel tapes.

The slave arm shall be equipped with tongs with parallel moving jaws (standard tongs), by means of which objects can be handled and forces and torques can be exerted on objects. The dimensions for standard tongs are given in 6.10. This allows the adaptation of the gripping location of objects and tools to suit the dimensions of the jaws.

For electrically driven tools, a socket for electrical current shall be provided. Optionally, a multiple coupling for electricity, welding, hydraulic and pneumatic services can be incorporated, which should be mounted on an appropriate position on the slave arm or slave unit. Connection devices shall be designed for successful remote operation in a hostile environment (e.g. with grit and corrosive chemicals present).

The parallel jaws of the tongs, or half of the tongs, or the complete tongs assembly, shall be remotely exchangeable by means of an in-cell fixture or another slave arm. If the parallel jaws are exchangeable, the complete tongs can optionally be exchanged remotely.

The slave arm can be arranged to be exchangeable remotely.

The positioning and orientation motions of the slave arm and of the master arm shall be lockable by brakes. Generally, if no force is exerted at the handle, the tongs shall be opened automatically by an appropriate means. However, the gripping motion shall be lockable by a switch at the handle in order to relieve the operator from having to sustain the gripping force.

Overload protection shall be provided for the mechanical sub-assemblies of the kinematic systems (e.g. slipping clutch, motor current limitation).

Electrical master-slave manipulators shall be easy to decontaminate and maintain; in the case of maintenance, this applies in particular to bearings, couplings, gears and motors. Electrical master-slave manipulator sub-assemblies and components shall be simple to mount and dismount. Drive units and electric cables shall be easy to replace. Sub-assemblies of the same nominally identical model shall be interchangeable. Similarly, it shall be possible to interchange sub-assembly parts within one model. If the equipment available in the hot cells does not offer any alternative recovery option, then suitable devices shall be provided for the adjustment or shifting of the motions concerned, in the event of failure of any of the drives.

To facilitate decontamination, intermittent welds and spot welds shall be avoided in the sub-assemblies of the electrical master-slave manipulators. All welds shall avoid poor alignment of the edges and be free of cracks and other defects, in order to minimize decontamination problems.

Welds which are exposed to contamination in service shall be such that the quality of the weld surface corresponds to the quality of the adjacent surfaces.

6.6.2 Design concepts

6.6.2.1 General features

The transmission elements of the motions comprising inclination of upper arm and inclination of forearm shall be designed in such a manner that they have synergistic features and support each other. Thus, the drive units for both motions can be of the same type.

The drive units for rotation of tongs and inclination of hand shall be coupled together by a differential gear in the hand assembly. Accordingly, if the rotations of these drive units have different directions, the tongs are rotated; and if they have the same direction, the tongs are inclined.