INTERNATIONAL STANDARD

ISO 17874-1

Second edition
2010-01-15

Remote handling devices for radioactive materials —

Part 1: General requirements

Dispositifs de manipulation à distance pour matériaux radioactifs —

Partie 1: Exigences générales

Reference number
ISO 17874-1:2010(E)

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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 17874-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

This second edition cancels and replaces the first edition (ISO 17874-1:2004), which has been technically revised.

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 mainly with multipurpose remote handling devices for nuclear applications.

These devices replace hands and arms in areas inaccessible to personnel (mostly behind shielding walls).

There are special remote handling devices designed for narrow fields of application or for special purposes only, but these are beyond the scope of this part of ISO 17874.

Multipurpose remote handling devices have five to ten, or even more, possibilities of movement in order to cope with the planned range of tasks.

Four categories of such remote handling devices are used worldwide for the handling of radioactive materials. These categories are the following:

— mechanical master-slave manipulators;

— electrical master-slave manipulators;

— power manipulators;

— remote handling tongs.

Various special designs, hydraulic or pneumatic machines, prototypes, experimental devices and obsolete types cannot be assigned to any category or do not correspond to all requirements of this part of ISO 17874. These devices are not covered by this part of ISO 17874.

The main applications of the different categories are explained in Clause 4.

Remote handling devices were originally developed for hot cells designed for research and development in nuclear power reactor fuel elements. They are now also in widespread use in other nuclear installations, such as plants for fabrication or reprocessing of fuel elements, waste treatment stations and decommissioning of nuclear facilities.

Remote handling devices are sometimes used for non-nuclear applications. This part of ISO 17874 does not address the special requirements of any of these fields, although designers can take advantage of standardized components from the nuclear sector to achieve cost-effective designs for other purposes, where appropriate.

Remote handling devices for radioactive materials —

Part 1: **General requirements**

1 Scope

This part of ISO 17874 describes requirements concerning devices for remote handling of radioactive materials. The classification of these devices (categories and different designs within a category) and the distribution in the different parts are shown in Figure 1.

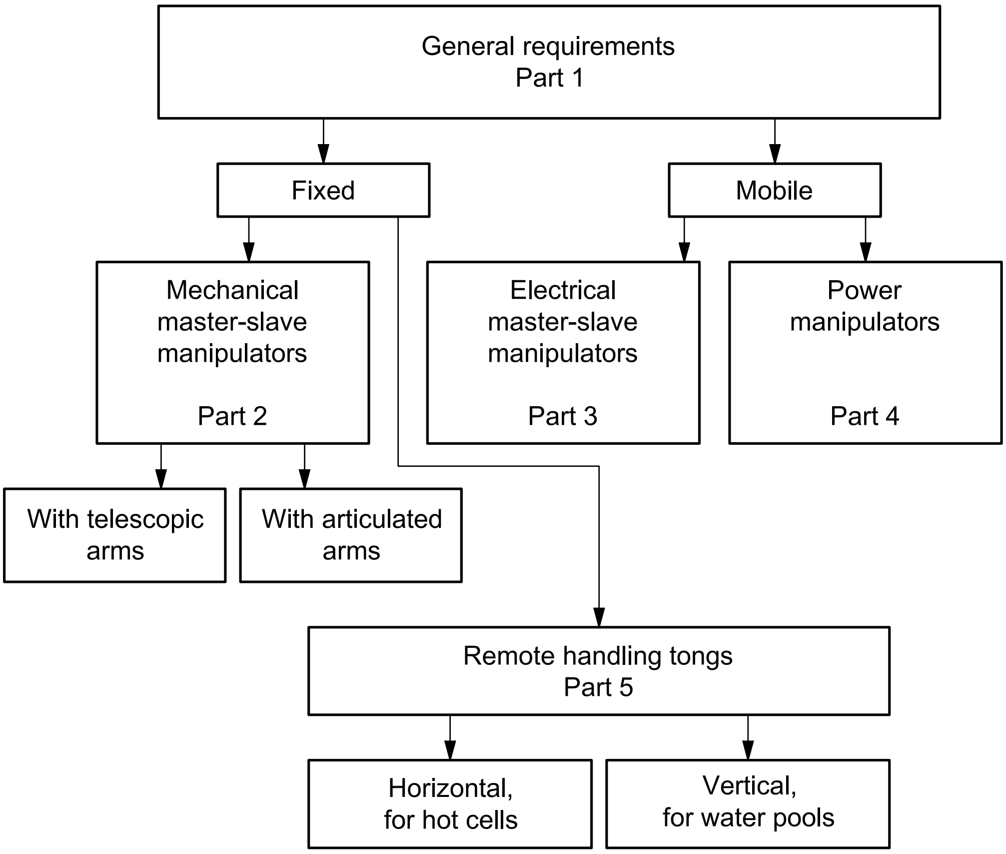


Figure 1 — Categories of remote handling devices and location in all parts of ISO 17874

Concerning the working volume, two principal designs are to be considered.

a) Fixed remote handling devices:

these devices are fitted in the shielding wall or sometimes in the ceiling of hot cells and accordingly can function only in a rather limited volume. Such devices are mechanical master-slave manipulators and remote handling tongs.

b) Mobile remote handling devices:

these devices are fitted on a transporter (e.g. a moveable bridge or a vehicle on the ground). The working volume depends mainly on the possible motion of the transporter. Such devices are electrical master-slave manipulators and power manipulators.

NOTE This part of ISO 17874 is intended to provide assistance to designers of nuclear process plants, as well as manufacturers, users and licensing authorities.

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 7212, *Enclosures for protection against ionizing radiation — Lead shielding units for 50 mm and 100 mm thick walls*

ISO 9404-1, *Enclosures for protection against ionizing radiation — Lead shielding units for 150 mm, 200 mm and 250 mm thick walls — Part 1: Chevron units of 150 mm and 200 mm thickness*

ISO 11933-1, *Components for containment enclosures — Part 1: Glove/bag ports, bungs for glove/bag ports, enclosure rings and interchangeable units*

ISO 11933-2, *Components for containment enclosures — Part 2: Gloves, welded bags, gaiters for remote-handling tongs and for manipulators*

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

ISO 17874-3, *Remote handling devices for radioactive materials — Part 3: Electrical master-slave manipulators*

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

ISO 17874-5, *Remote handling devices for radioactive materials — Part 5: Remote handling tongs*

3 Terms and definitions

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

3.1
mechanical master-slave manipulator
manipulator reproducing the movements of the hand and arm of the operator by means of isokinematic master and slave arms with back-drivable mechanical transmissions

NOTE The manipulator is generally mounted on a shielding wall.

3.2
electrical master-slave manipulator
manipulator reproducing the movements of the 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).

3.3
power manipulator
manipulator driven by switch-operated motors

3.4
remote handling tongs
mechanical device consisting of a gripper, a handle and a rod between them

NOTE Remote handling tongs are either installed in a shielding wall by using a mounting device or hung on a carrying system for use in a water pool or carried by an operator.

3.5
isokinematic
property of a manipulator, where from base to free end, master arm and slave arm, presents the same type of motion (rotation or translation) in the same order and with the same relative orientations

4 Application of multipurpose remote handling devices

4.1 General

The different categories of remote handling devices are used for various applications, as described in this clause.

4.2 Mechanical master-slave manipulators

4.2.1 Mechanical master-slave manipulators with telescopic arms

These manipulators allow the transmission of forces up to the maximum magnitude required for the tasks to be achieved manually by an unaided operator. Depending on the type of manipulator, maximum load capacities up to 45 kg can be reached (see 7.2). They are suitable for complicated tasks and are usually installed in pairs on a working station. They are designed for hot cells of all sizes with shielding walls of concrete or also of lead in some cases. They constitute the main working devices in such kinds of cells.

Different lengths of arms are available according to the size of the hot cell to be equipped. However, versions with short arms provide higher forces and, reversely, versions with long arms reduce the forces to be applied. There also exist compact manipulators with a double telescope in the slave arm, available for hot cells with restricted height.

4.2.2 Mechanical master-slave manipulators with articulated arms

These manipulators allow not only the execution of forces equivalent to those an unaided operator can achieve, but also forces up to a much higher level. Depending on the type of manipulator, maximum load capacities up to 100 kg can be reached (see 7.2). They are suitable for complicated tasks, and are usually installed in pairs on a working station. They are designed for hot cells of all sizes with shielding walls typically of lead or also of cast iron in some cases. They are also used in containment enclosures. They have small dimensions and therefore provide a relatively small working volume. They are used instead of remote handling tongs as described in 4.5, if a larger working volume and/or more dexterity are needed.

4.3 Electrical master-slave manipulators

These manipulators allow not only the execution of forces equivalent to those an unaided operator can achieve, but also (depending on the type) forces up to a much higher level. They are suitable for complicated tasks, and often they are installed in pairs. They allow the performance of complicated work throughout the whole volume of large hot cells and not only near the operation walls, by means of the mobility of the slave arm. As a result of their load capacities they can be used also in place of light and medium load capacity power manipulators. They can be used, not only inside facilities, but also on vehicles (also in the open air).

4.4 Power manipulators

These manipulators allow the execution of high forces and therefore the handling of heavy objects, typifying their application. According to the load capacity of their hoist, they can also be used like a crane of light load capacity. They are not suitable for complicated tasks. They are used in medium-sized or large hot cells. Normally, they have large dimensions and are used to assist mechanical master-slave manipulators. They are used for tasks to be performed in areas that cannot be reached by mechanical master-slave manipulators and for transportation of objects over significant distances. They can also be used on vehicles (also in the open air).

4.5 Remote handling tongs

4.5.1 Remote handling tongs, used horizontally

These devices allow the transmission of forces of a low level, which any operator working unaided would consider small. They can be used only if a moderate level of dexterity and a small working volume are required. In the horizontal mode of use, remote handling tongs are mostly installed in pairs. They are typically used in hot cells with shielding walls made of lead. The installation on the shielding wall is realized using standardized ball mountings called sphere units (see ISO 7212 and ISO 9404-1).

NOTE These remote handling tongs can also be used without any mounting and shielding. In this case, protection is achieved by the operator maintaining an appropriate distance from the radioactive sources.

4.5.2 Remote handling tongs, used vertically

These devices allow the transmission of forces up to a high level (depending on the type), close to the maximum magnitude that an operator would employ in unaided manual activity. They can be used if dexterity only up to a moderate level is required. In this mode of use, remote handling tongs are typically installed above water pools. They can be handled manually by the operator or fixed in a carrying system, which would typically have three positioning motions.

NOTE To facilitate understanding in this part of ISO 17874, only the four common categories of remote handling devices listed above and their usual applications are considered. This does not exclude the development of equipment with more specialist features.

5 Kinematic systems for multipurpose remote handling devices

A multipurpose remote handling device shall have several possibilities of movement (termed motions) so as to be able to achieve a great variety of remotely handling tasks. The motions are executed mechanically either by the hands and arms of the operator or by electric motors.

A fully articulate remote handling device, which should in principle not be limited concerning its motions, shall have at least seven independent motions. It shall be able to execute three independent translation movements (and forces) on an object in the directions of the three coordinate axes throughout the working volume. It shall also be able to execute three independent rotation movements (and torques) on an object around the three coordinate axes without any special prior adjustment, again throughout the working volume. The seventh motion corresponds to the gripping movement.

NOTE Specific aspects of kinematic systems for handling are described in Annex A.

6 General requirements concerning the different categories of multipurpose remote handling devices

6.1 Mechanical master-slave manipulators

A mechanical master-slave manipulator shall consist of three main components: a master arm and a slave arm connected by a connection tube incorporating mechanical transmission elements (see Figures 2 and 4). The master arm and the slave arm shall have the same number, geometry and arrangement of motions. The connection shall be made in such a manner that the motions, forces and torques respectively executed by the hand of the operator on the handle of the master arm are transmitted faithfully to the slave arm.

The manipulator shall have seven motions: three positioning motions, three orientation motions and one gripping motion, corresponding to the requirements of Clause 5. The manipulator shall ensure force reflection between the slave arm and the master arm. The transmission elements shall communicate motions, forces and torques reversibly. The connection tube can be unsealed for β-γ-hot cells or sealed for α-γ-hot cells. The jaws of the tong and/or the complete tong shall be exchangeable remotely.

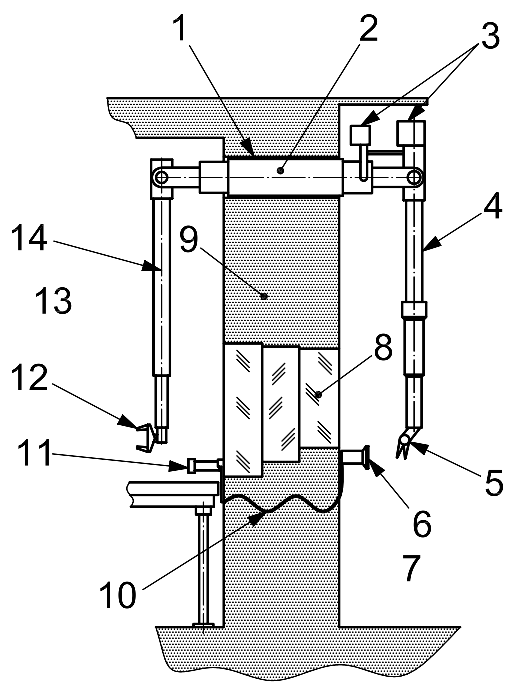
The slave arm can be equipped with a gaiter (American: booting). Gaiters are already standardized in ISO 11933-2. Concerning mechanical master-slave manipulators, two different designs shall be distinguished: master-slave manipulators with telescopic arms and master-slave manipulators with articulated arms. Both constructions are typically installed in shielding walls (see Figures 2 and 4).

Mechanical master-slave manipulators shall conform to ISO 17874-2.

NOTE For task observation during work carried out inside a hot cell, shielding windows are used and viewing geometry constraints can be considered in the overall design.

6.1.1 Mechanical master-slave manipulators with telescopic arms

The kinematics of mechanical master-slave manipulators with telescopic arms shall correspond to Figure 3. Depending on the type of manipulator, the load capacities range from 4,5 kg to 45 kg.



Key

1 through-wall tube
2 connection tube
3 counterweights
4 master arm
5 handle
6 loudspeaker
7 operating room
8 shielding window
9 shielding wall
10 sound signal transmission cable
11 microphone
12 tong with parallel jaws
13 hot cell
14 slave arm

Figure 2 — Mechanical master-slave manipulator with telescopic arms

The positioning motions for the x and y directions of the slave arm should be adjustable relative to the master arm by electrically actuated indexing to enlarge the working volume and minimize operator strain. Extended reach versions feature a double telescope in the slave arm with an additional electrically actuated positioning motion in the z direction.

In some types, the slave arm can be disconnected and removed remotely.

For hot cells with restricted height (and/or with a small working volume), compact types are required, with a manually operated double telescope in the slave arm.

In addition to visual feedback, transmission of sound from the hot cell into the operating room can be helpful.

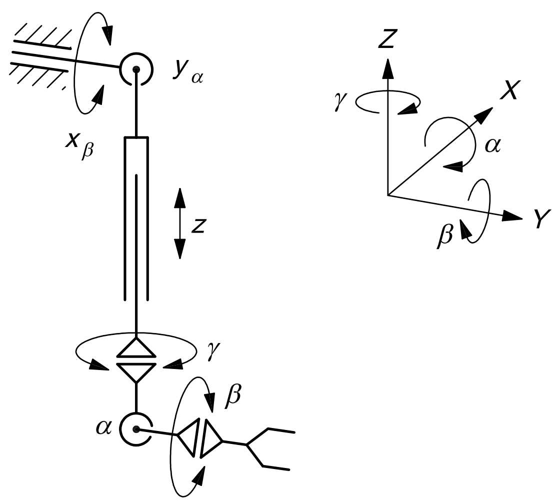
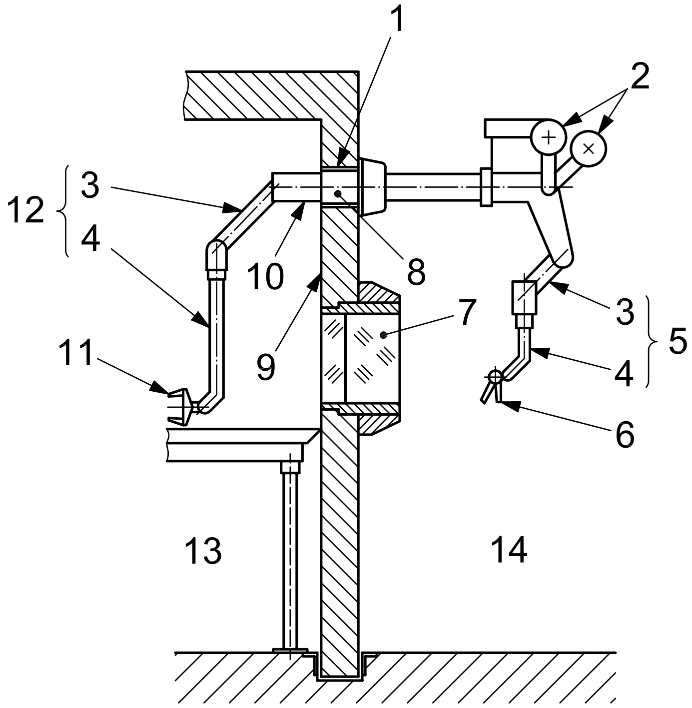


Figure 3 — Mechanical master-slave manipulators with telescopic arms (kinematic diagram)

6.1.2 Mechanical master-slave manipulators with articulated arms

The kinematics of mechanical master-slave manipulators with articulated arms shall correspond to Figure 5. Depending on the type of manipulator, the load capacities range from 2,3 kg to 12 kg.



Key

1 through-wall tube
2 counterweights
3 upper arm
4 forearm
5 master arm
6 handle
7 shielding window
8 connection tube
9 shielding wall
10 overhang
11 tong with parallel jaws
12 slave arm
13 hot cell
14 operating room

Figure 4 — Mechanical master-slave manipulator with articulated arms

The master arm may have the same length as the slave arm or may be shorter than the slave arm.

A lever at the handle may be provided to lock the gripping motion. Brakes may be provided to lock the positioning and orientation motions.

Electrically actuated indexing of the inclination of the upper arm of the slave arm may also be provided by a switch-operated electric motor, to minimize operator strain. The overhang of the slave arm in the hot cell can be varied in some types to increase the reach by moving the whole manipulator along the axis of the through-wall tube.

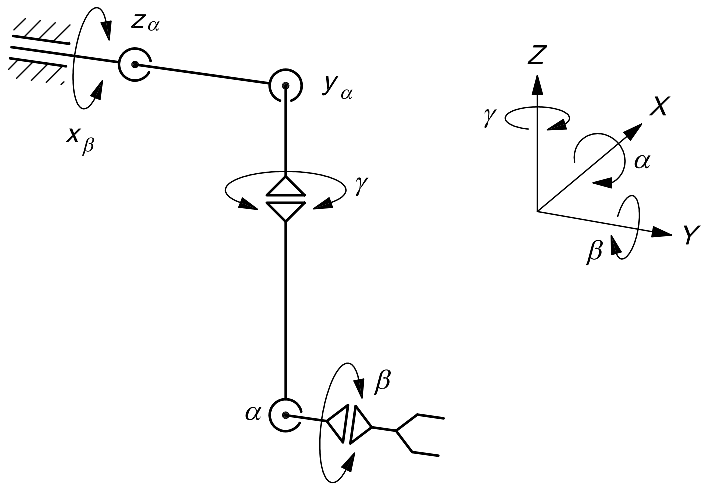
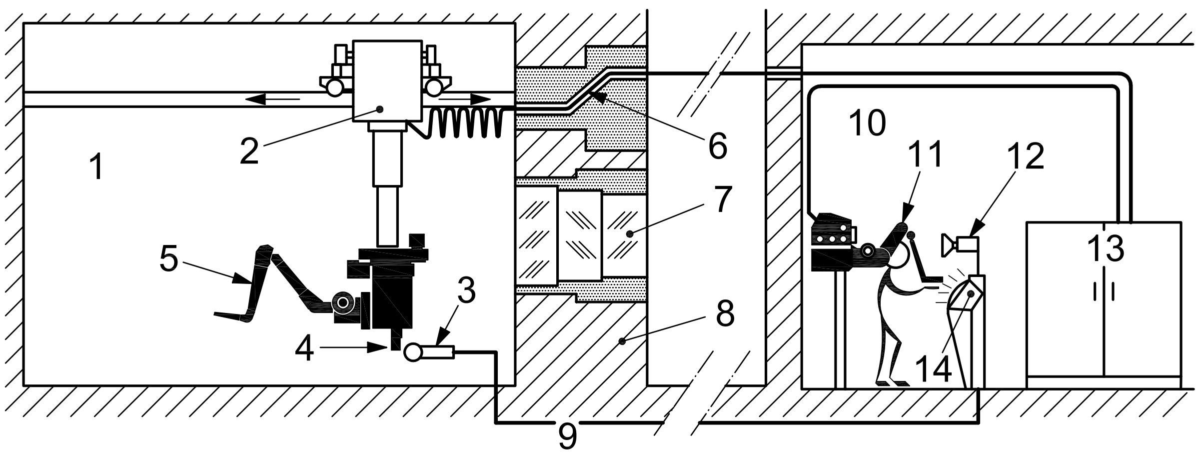


Figure 5 — Mechanical master-slave manipulator with articulated arms (kinematic diagram)

6.2 Electrical master-slave manipulators

An electrical master-slave manipulator shall consist of a master arm and a slave arm connected by an electrical system, including electric motors and a control computer (see Figure 6).



Key

1 hot cell
2 transporter for slave arm
3 microphone
4 TV camera
5 slave arm
6 transmission cables for manipulator and transporter
7 shielding window
8 shielding wall
9 sound signal transmission cable
10 operating room
11 master arm
12 loudspeaker
13 control cabinet for manipulator and transporter
14 TV monitor

Figure 6 — Electrical master-slave manipulator

The motions of the operator's hand on the handle of the master arm shall be transmitted to the slave arm. The electrical system shall feature feedback of the load as force reflection felt by the operator at the master arm and this shall be reversible. Depending on the type of manipulator, the load capacities range from 10 kg to 100 kg.

The forces executed on the master arm can be amplified on the slave arm. In order to achieve a wide range of positions inside the working volume, the slave arm is generally installed on a transporter. The operating room can be located at some distance from the hot cell.

Like mechanical master-slave manipulators, electrical master-slave manipulators shall each have seven motions accommodated by the master arm and the slave arm, corresponding to the requirements of Clause 5. The master arm and the slave arm shall be connected by bilateral position controls.

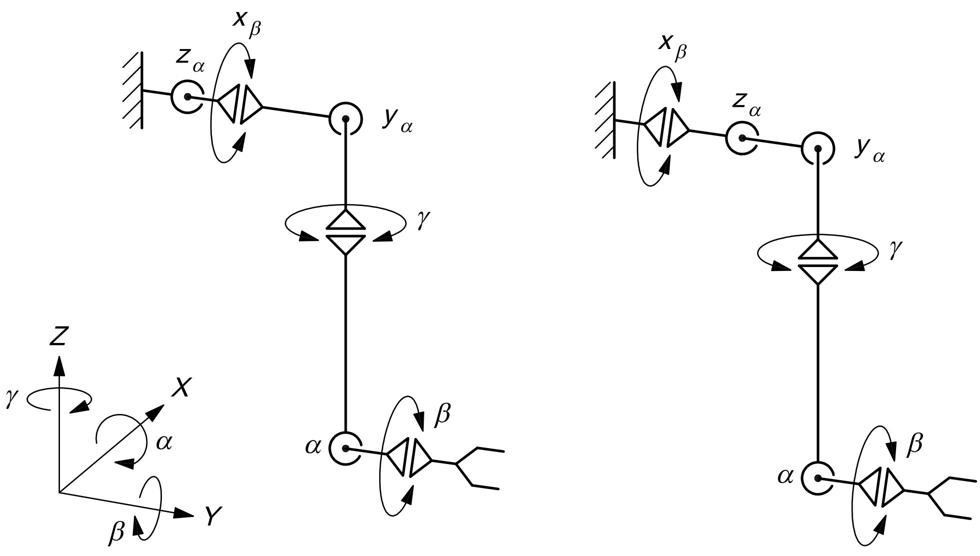
The kinematics of the electrical master-slave manipulators shall correspond to Figure 7. The difference between versions A and B is the exchange of the motions z_α and X_β. The transporter typically has four additional electrically switch-operated motions, (x, y, z and γ).

The parallel jaws of the tong or the complete tong shall be exchangeable remotely.

The gripping motion shall be capable of being locked by a switch at the handle. The positioning and orientation motions shall be able to be locked by brakes. A pair of slave arms is often installed on each transporter, in order to increase the dexterity.

In addition to visual and tactile feedback, there should be a system for transmitting sounds from the hot cell to the operating room.

Electrical master-slave manipulators shall conform to ISO 17874-3.



a b

Figure 7 — Electrical master-slave manipulator (kinematic diagram)

NOTE 1 The motions of the transporter are only used for positioning the slave arm.

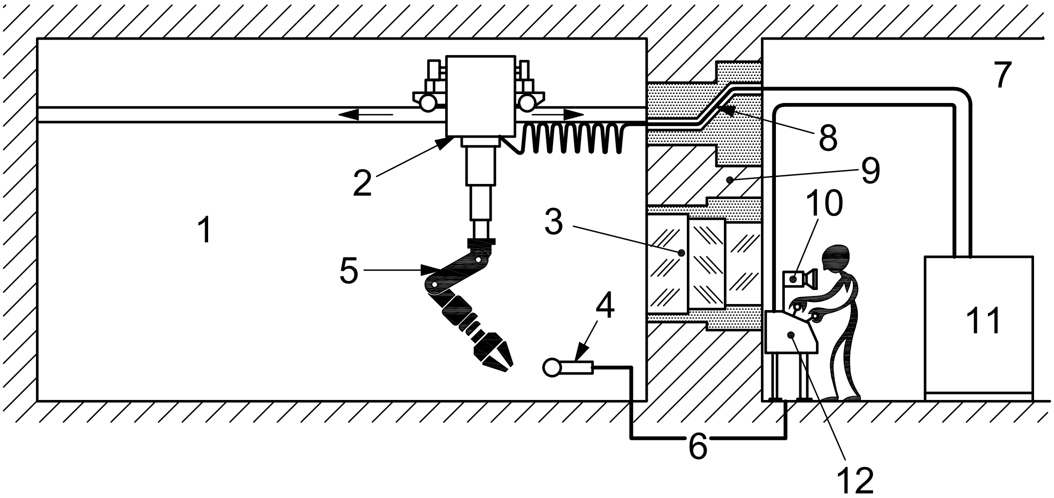
NOTE 2 For task observation during work carried out inside the hot cell, TV cameras or in some cases shielding windows are generally used.

6.3 Power manipulators

A power manipulator consists of a mechanical arm combined with a transporter. The manipulator is driven by electric motors and operated by switches or potentiometers and speed control. Different designs of operating devices are in use: press buttons, single switches for one motion each, joysticks for two to four motions and in a few cases one device for six motions. In contrast to the electrical master-slave manipulators, power manipulators have no master arm to transmit force reflection.

For hot cell applications, the operating console and the control cabinet are located in an operating room (Figure 8). A transmission cable passing through the shielding wall connects the power manipulator in the hot cell and the control console.

The mechanical arm, including the transporter, typically has seven to ten motions for designs appropriate to hot cells (see Figures 9 and 10).



Key

1	hot cell	7	operating room
2	transporter	8	transmission cable
3	shielding window	9	shielding wall
4	microphone	10	loudspeaker
5	mechanical arm	11	control cabinet
6	sound signal transmission cable	12	operating console

Figure 8 — Power manipulator (designed for hot cells)

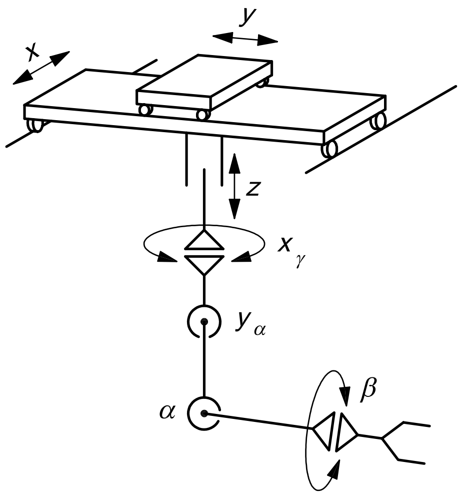


Figure 9 — Power manipulator with preferred design (kinematic diagram)

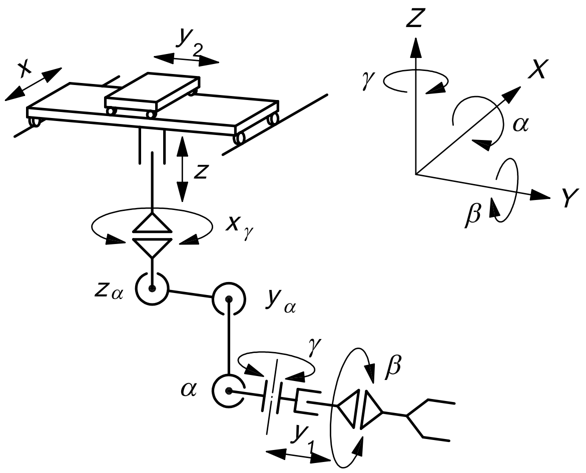


Figure 10 — Power manipulator with additional motions (kinematic diagram)

The preferred design (see Figure 9) with eight motions (the arm supporting five motions and the bridge transporter three) is available in a number of types. The most common design of the transporter consists of a moveable bridge, a cross-travel carriage and a vertical multiple telescope that provides a hoist action.

There are many different designs addressing the specific kinematics of the required system, some with more than eight motions, depending on need. The mechanical arm shown in Figure 10 fulfils the requirements of Clause 5. The load capacities of the different types have a wide range (5 kg to 500 kg, generally only 50 kg to 200 kg), as do the various physical dimensions.

The standard tong (with parallel jaws) should be exchangeable remotely, typically by means of an in-cell fixture. For several types of power manipulators, the gripping force can be controlled. In addition to visual feedback, there should be a system transmitting sounds from the hot cell to the operating room.

Power manipulators shall conform to ISO 17874-4.

NOTE 1 With power manipulators, the motions of the transporter are also used for positioning of objects.

NOTE 2 For task observation during work carried out inside the hot cell, shielding windows or in some cases TV cameras are used.

6.4 Remote handling tongs

6.4.1 General

Remote handling tongs are hand-operated. They are designed for two different applications: hot cells and water pools. They ensure one to four motions intrinsically and five to seven motions together with their mounting device. There are different classes of load capacity. Force reflection shall be ensured.

Remote handling tongs shall conform to ISO 17874-5.

6.4.2 Remote handling tongs, used horizontally

In this configuration, remote handling tongs are installed with sphere units (ball-mountings), typically in small hot cells with lead shielding walls. Two different designs are in use, with a rigid or an articulated rod (see Figures 11 and 13). Their kinematics shall correspond to Figures 12 and 14, respectively. The motions x_γ and z_α correspond to the movement possibilities of the sphere unit. The motions y and β correspond to the movement possibilities of the rod in the tube of the sphere unit.

In some types, the gripper can be exchanged remotely by means of a fixture.

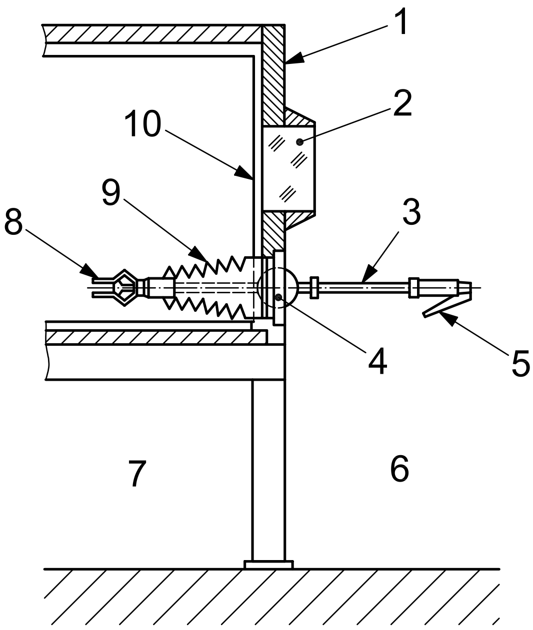
It shall be ensured that the rods provide the same shielding effect as the shielding comprising the wall.

The diameters of the rods and the sphere units corresponding to these types of remote handling tongs are standardized in ISO 7212 and ISO 9404-1. Gaiters (American: bootings) and enclosure rings for these remote handling tongs are described respectively in ISO 11933-1 and ISO 11933-2.

Special remote handling devices exist, which are derived from remote handling tongs with rigid rods equipped with different tools instead of the gripper.

Remote handling tongs featuring a rigid rod are in some cases carried and held in the working position by the operator.

NOTE For task observation during work carried out inside the shielded containment enclosure, small shielding windows are generally used.



Key

1 shielding wall
2 shielding window
3 rod (rigid)
4 sphere unit
5 handle
6 operating room
7 hot cell
8 gripper
9 gaiter
10 containment enclosure

Figure 11 — Remote handling tongs (rigid), horizontal, in a hot cell [example shown is with gaiter and containment enclosure (α–γ hot cell); options without gaiter or containment enclosure are possible]

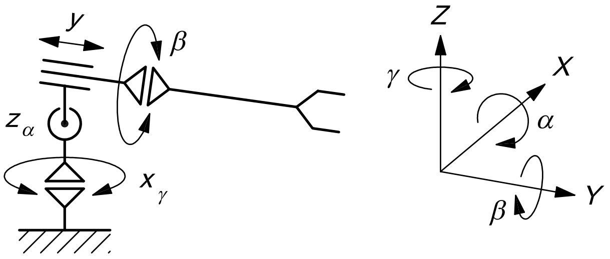
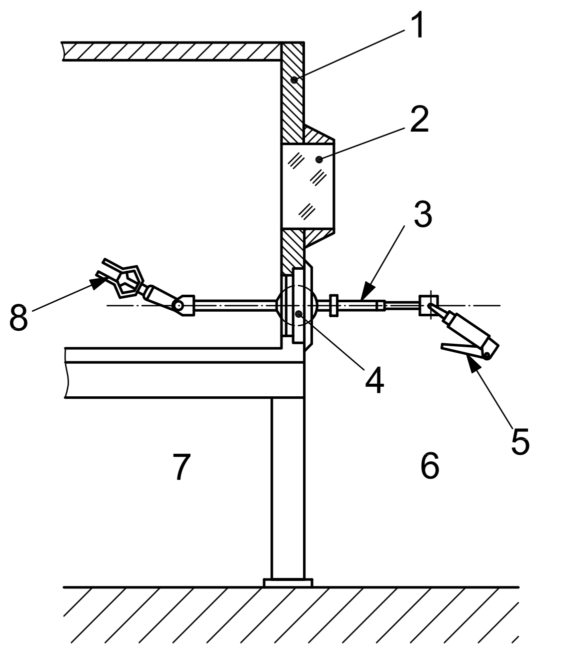


Figure 12 — Remote handling tongs (rigid), horizontal (kinematic diagram)



Key

1 shielding wall
2 shielding window
3 rod (articulated)
4 sphere unit
5 handle
6 operating room
7 hot cell
8 gripper

Figure 13 — Remote handling tongs (articulated), horizontal, in a hot cell
[example shown is without gaiter or containment enclosure (β–γ hot cell), options with gaiter and containment enclosure are also possible]

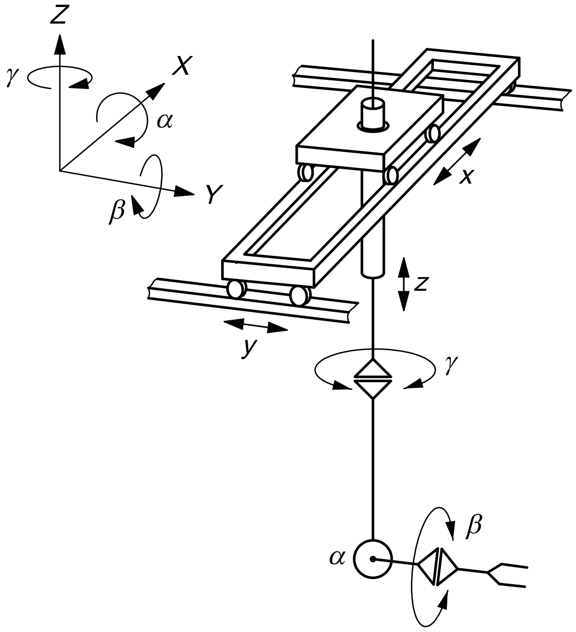
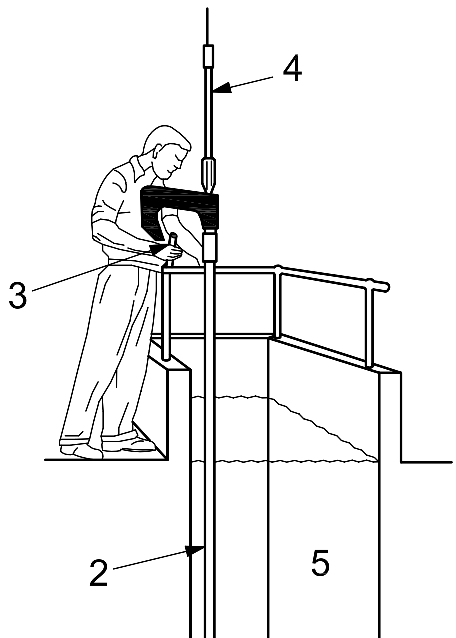


Figure 14 — Remote handling tongs (articulated), horizontal (kinematic diagram)

NOTE The motions x_γ and z_α are functionally combined in the spherical bearing of the sphere unit. The motions y and β are provided via axial and rotational movements of the rod in a tube running through the sphere unit. In Figures 12 and 14, the combined motions are drawn separately to facilitate understanding.

6.4.3 Remote handling tongs, used vertically



Key

1 gripper

2 rod (articulated)

3 handle

4 carrying system

5 water pool

Figure 15 — Remote handling tongs, articulated and with hand rotation, vertical, for water pools

In this configuration (unlike that described in the previous paragraph), the remote handling tongs are equipped with a long vertical rod between the gripper and the handle to make their use possible in water pools. These types of remote handling tongs are available in three different designs:

— with a rigid rod;

— with a simple articulated rod;

— with an articulated gripper and additional hand rotation (see Figure 15).

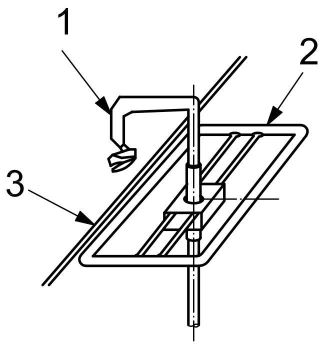
Remote handling tongs for water pools with rigid or articulated rods are similar to those intended for horizontal mounting in hot cells. The differences are only in the detailed design of the rods, which are much longer and therefore larger in diameter.

Remote handling tongs for water pools usually have a support system to carry the weight and to enable precise positioning. Such a system typically has four motions (x, y, z and γ) (see Figure 16). The kinematics are shown in Figure 17.

NOTE 1 The motions z and γ are provided by independent arrangements, via axial and rotational movement of the rod in a tube passing through the cross-travel carriage.

Variations from the arrangement shown in Figure 17 are possible, e.g. remote handling tongs with a rigid rod (which have no α- and β-motion) or with an articulated rod (in which case there is no β-motion). In every case, it shall be ensured that the rods have the same shielding effect as the water they displace (e.g. a gas-filled hollow structure would not generally be advisable).

NOTE 2 Observation of the working region is made by direct sight, taking advantage of the transparency of the shielding water or by TV cameras.



Key

1 remote handling tongs

2 carrying system

3 walk-way railing

Figure 16 — Example of carrying system for vertical remote handling tongs

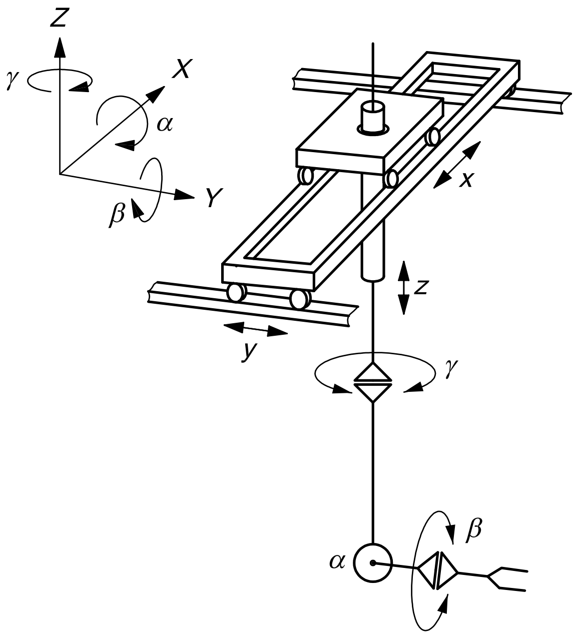


Figure 17 — Remote handling tongs, articulated and with hand rotation, vertical (kinematic diagram)

7 Principal criteria for the selection of multipurpose remote handling devices

7.1 General

This subclause explains how to select manipulators or remote handling tongs of different designs. One or other (or both) of the following methodologies can be adopted.

a) The process equipment in the hot cell is designed and procured independently of remote handling considerations. Subsequently, the remote handling system components are specified to achieve the required overall functionality. Remote handling devices are selected from available proprietary items and/or by modification or by the design and construction of bespoke components.

b) The required handling devices are selected from available proprietary items. The design of the hot cell and process equipment is modified and/or adapted to suit the end-effectors, motions, load capacities, working volumes, etc. of the selected remote handling device.

To be able to perform a task, three criteria are paramount:

— load capacity;

— dexterity (considering the number of motions and the no-load forces);

— reliability.

Besides these, many other features of the remote handling devices, the accessories, the assisting devices and the boundary conditions have a strong influence on the operational efficiency of remote handling systems. Some of these are addressed in Clause 8.

7.2 Load capacities of remote handling devices

For each task, it is a prerequisite to analyse the stress to be applied on the remote handling devices:

- the maximum weights of the loads (objects, tools) to be handled or lifted, including acceleration effects;
- the forces to be exerted;
- the torques to be applied by hand rotation or the arm;
- the reaction forces of tools (e.g. hydraulic shears, impact wrenches, high pressure jets for decontamination, compressed air chisels and any sources of vibration).

Based on the results of this analysis, choices concerning the load capacities of the necessary remote handling devices are made.

To increase the reliability and effective lifetime of remote handling devices, it is recommended to keep the normal working loads at no more than two thirds of the maximum load capacities specified by the manufacturer, apart from a few exceptional cases. The maximum load capacities reached in the different categories of remote handling devices are shown in Figure 18.

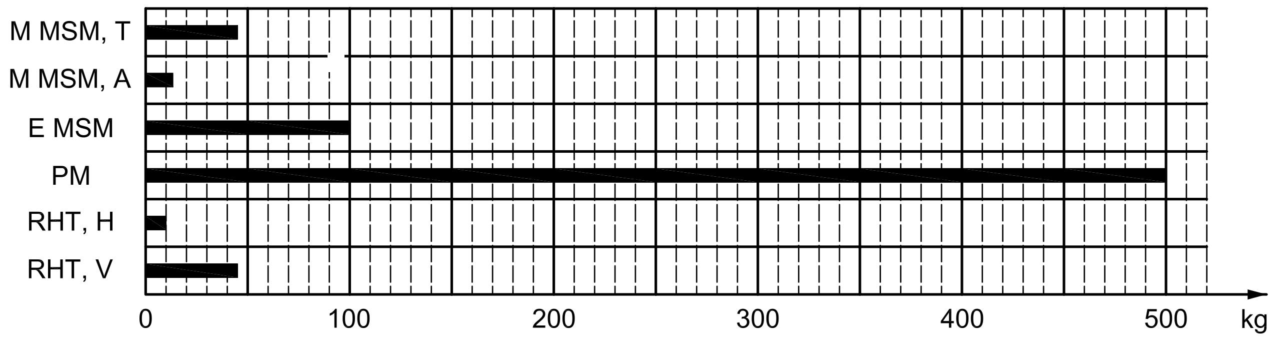


Figure 18 — Maximum load capacities in the tong of remote handling devices reached in the different categories

Abbreviations used:

M MSM, T	Mechanical master-slave manipulator with telescopic arms
M MSM, A	Mechanical master-slave manipulator with articulated arms
E MSM	Electrical master-slave manipulator
PM	Power manipulator
RHT, H	Remote handling tongs, horizontal
RHT, V	Remote handling tongs, vertical

7.3 Dexterity of remote handling devices

The dexterity of a remote handling device is the ability to execute tasks up to a defined level in a scale of tasks with different degrees of difficulty. The dexterity achieved in remote handling systems is a complex property, in which a series of parameters shall be considered, including a few that are independent of the remote handling devices themselves. The dexterity depends upon the following factors:

- the principles of the control system and the operating devices;
- the way of executing the motions:
  - sequential (one motion after the other, e.g. power manipulators);
  - combined (several simultaneous motions, e.g. mechanical or electrical master-slave manipulators);
- the design of the kinematic system (number, type and arrangement of the motions);
- the design of the tong (in particular the shape and size relative to the objects to be handled);
- the forces to be overcome when moving the manipulator in the no-load condition (only a concern with master-slave manipulators);
- the number of remote handling devices located in the working station (whether two devices, normally of the same type, or only one device is available);
- the quality of visual feedback (which depends upon distance, angle and the intensity, spectral characteristics and any flicker or irregularity of the illumination);
- the qualifications and experience of the operators.

The choices concerning the necessary dexterity of the remote handling devices should be made on the basis of the requirements and characteristics of the considerations mentioned above.

The addition of a second remote handling device increases the dexterity of the overall system, but provides no other new feature, in terms of load capacities. However, the use of two remote handling devices can be necessary in some cases needing no high dexterity, e.g. for holding the workpiece.

The dexterity of the various categories of remote handling devices is very different and is qualitatively indicated in Figure 19.

Increase of dexterity →

PM < RHT < MSM

Figure 19 — Dexterity of remote handling systems

Abbreviations used:

PM Power manipulator

MSM Master-slave manipulator (mechanical or electrical)

RHT Remote handling tongs

7.4 Reliability of remote handling devices

Although the reliability of the remote handling equipment is a very important feature of the system, it is not readily possible to evaluate the reliability deterministically. Therefore, it is essential that the user specifies the conditions and accordingly the requirements, defining the intended application as precisely as possible, e.g.:

- the load profile (forces and occurrence frequencies over a typical operational year);
- the number of load changes for critical component parts, which shall be admissible under defined loads;
- the admissible maintenance intervals;
- the environmental conditions (radiation, corrosion, etc.).

The experiences learned by the manufacturers in different applications as well as those of established users are very important and should be considered in the selection process.

The selected manufacturer should furnish a maintenance plan specific to the intended use, i.e. accounting for the conditions listed above.

Concerning the reliability of the manipulators, the following additional aspects shall be taken into account:

- intended use in laboratories;
- intended use in production installations.

For various reasons, such as fatigue of the operators and limited reliability of the equipment, mechanical and electrical master-slave manipulators and power manipulators should not be used for very repetitive operations (such as industrial-scale mass production). The use of manipulators in production processing systems should be reserved for maintenance and intervention operations.

There are, however, two possible methods to enhance the reliability:

- the design can incorporate greater margins between the intended operational loads and the manufacturer's recommended maximum loads (but designers should note remarks in 7.3 concerning dexterity, particularly no-load forces);
- more intensive development can be undertaken to eliminate weak points (identified in a design and/or as a result of proving trials of prototypes).

In addition, the value of properly respected maintenance schedules and more sophisticated maintenance techniques, such as ongoing failure mode analysis and condition monitoring (where appropriate), should not be underestimated.

8 Other criteria

8.1 General

Apart from the principal criteria (Clause 7), there are many other issues influencing the overall efficiency of remote handling systems and accordingly playing a role in the selection process. These other issues can be divided into two sets, concerning the remote handling devices themselves (mostly in the working zone) and the peripheral/auxiliary provisions.

8.2 Working zone

The issues of interest are the following.

a) **Dimensions of the remote handling devices**: some key dimensions shall be fixed to suit the corresponding dimensions of any existing hot cells, e.g. the arm length of mechanical master-slave manipulators or the width of the moveable bridge of a power manipulator. Consistent with 7.1, the alternative approach is to fix the dimensions of new hot cells in the design stage, to suit the standard dimensions of available remote handling devices.

b) **Working speed**: the necessary working speed depends on the quantity of work to be performed in a given time. Overall system output may be improved by sharing the task stream between more hot cells, reducing the speed demanded in any one of them.

c) **Handling safety**.

d) **Minimized operator fatigue**.

e) **Leak-tightness of the housings and of the containment structure**.

f) **Ease of decontamination**.

g) **Maintainability**: these features c) to g) shall be given careful consideration and appropriate tests shall be carried out where prior knowledge is insufficient.

h) **Durability**: materials shall be specified which are resistant to (or protected from) the corrosive fluids, radiation, etc. anticipated in the working environment.

i) **Accessibility**: it shall be possible to mount and to remove mechanical master-slave manipulators and remote handling tongs for horizontal use safely from the operator side. With master-slave manipulators equipped with a sealed connection tube, it shall also be possible to remount the slave arm from the inside of the hot cell. When electrical master-slave manipulators or power manipulators are used in a ceiling of a hot cell, suitable transfer systems and/or airlocks are necessary to move them in and out safely.

j) **Necessary working volume including lay-down areas**: the remote handling system shall permit tasks to be undertaken in a good situation. The objects to be handled shall be in the working volume of any mechanical master-slave manipulator intended to be used. Accordingly, it should be possible to transport the workpiece objects and any relevant tools into the working volume. The working volume shall be kept clear of objects which do not require maintenance, and should incorporate space to lay down tools and components of the workpiece, as appropriate.

k) **Manoeuvring space**: in the case of mobile manipulators, it shall be possible to move them safely to the objects to be handled.

l) **Working environment on the operator side**: when using a mechanical master-slave manipulator, it is important to ensure that the movements of the master arm are not limited by other equipment such as instruments, monitors, electrical conduit and junction boxes, lights, ventilation ducts and so on.

8.3 Peripheral and auxiliary provisions

Issues concerning the auxiliary equipment and the periphery region that are to be considered within the system design include the following:

a) **Visibility of the tasks**: the spectral characteristics of the working volume illumination and viewing system should suit the colours of the workpieces and tools intended, to ensure good reflectance and transmission of the view. The relative light intensities of the operator's view of the working zone and immediate operator-side environment should be appropriately balanced to avoid problems of glare.

b) **Quality of visual feedback**: further to the consideration of 8.2, the design process should also address the adequacy of viewing angles, resolution of optical trains, cameras and screens, optical distortion, build-up of dust on optical surfaces, crazing and opacifying due to radiological and chemical attack and similar image-degrading effects.

c) **Sound signal transmission**: transmission of the working zone sounds to the operator(s) will often be of benefit but care should be taken to choose an appropriate bandwidth for each element of the system, to minimize signal contamination by electronic interface or vibration of the microphone mounting, and to ensure a relatively low-noise listening environment.

d) **Special grippers and tools**: special grippers can be needed to handle particularly delicate or awkwardly-shaped workpieces or tools which cannot be replaced by more appropriate designs (see 7.1).

e) **Adaptation of the process components to the tongs, grippers and tools**: again following 7.1, the alternative approach is to (re)design the workpiece and process equipment or parts of them so that they suit available proprietary tongs, grippers and tools.

f) **Lifting devices, especially cranes**: in addition to working volume access, maintenance access and issues of operational loading versus reliability, lifting devices such as cranes introduce a range of safety considerations such as fail-safe grabs, automatic cable-drum brakes and, depending on the application, seismic qualification requirements. Control issues such as operator interfaces, visual feedback, soft-start of the crane motions and movement limit switches are also likely to be features of the design.

g) **Maintenance concepts** (rooms, equipment): maintenance issues will generally include means of access, extent of remote handling for the maintenance tasks, provision of airlocks to minimize the spread of contamination, temporary and/or mobile shielding, development of recommended spares and of holdings of consumables, schedules, failure feedback databases (as discussed above), as well as dedicated facilities as near as practicable to the hot cell for the non-local maintenance activities.

9 Design summary

From the beginning of the project, the following shall be studied in parallel:

— the remote handling equipment;

— the design of the process equipment;

— the maintenance requirements for the process equipment;

— the means for maintenance and intervention.

Before deciding on the definitive overall design of the hot cell plant and the associated process equipment, the operations planned for the manipulators should be precisely defined.

During the project, all the chosen means for manipulation should be compatible with the likely evolution of the process equipment and with the working environments. Exceptional interventions to rectify any component failures of the process equipment, workpieces, remote handling devices, tools and auxiliary systems should be planned for.

Annex A
(normative)

Kinematic systems for remote handling devices

A.1 General aspects

Although the effectiveness of motorized manipulators is determined by their control system and the operating device, an issue always of key concern is the design of the kinematic system. First of all, the numbers and types of possibilities of movement (motions) and their arrangement with respect to each other shall be determined for the required features of the kinematic system.

Figure A.1 shows the preferred coordinate system, which is based on the six degrees of freedom of an object in three-dimensional space, together with the standard nomenclature.

The coordinate system is plant oriented as usual in remote handling technology, that is the X-axis is in the direction of the longitudinal axis of the plant and the Y-axis is in the direction of the rest position of the arm of the remote handling device (see Figure A.2). Although remote handling tongs for water pools have their rods in the direction of the Z-axis, all the coordinates and their designations are the same (see Figure 17).

Since the workpieces have these six degrees of freedom in position and orientation, the manipulators to handle them shall, for full operational flexibility, feature at least six corresponding motions to position and orient the tong of the manipulator with respect to the workpiece.

Figure A.2 shows an example of a manipulator fulfilling these requirements. Each degree of freedom of the workpiece object (compare Figure A.1) is matched by one motion of the manipulator arm. The subscripts of each positioning motion designation letter indicate which type of rotation motion shall be performed to achieve that positioning motion (see A.2).

Only one definite position of each of the moveable limbs is possible in order to achieve any particular position and orientation of the tong using a kinematic system with the above-mentioned features.

In summary, it can be seen that three motions are necessary to position, for example, the centre of the tong in any point (x, y, z) of the working volume (positioning motions). In addition, another three motions are necessary to put the tong in any orientation (α, β, γ) at the chosen position point (orientation motions).

Clearly in some specialized applications, greater or smaller numbers of positioning and orientation motions may be appropriate.

NOTE 1 In the field of industrial robot technology, it is usual to exchange the designation shown here for the X-axis with that of the Y-axis.

NOTE 2 The requirements above are fundamental; they also apply to automatic and programmable handling devices.

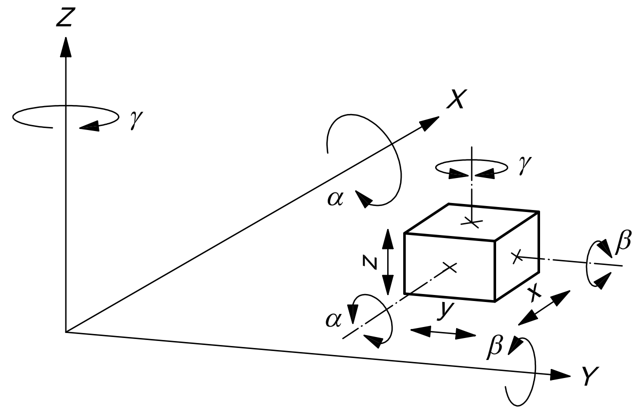


Figure A.1 — The coordinate system and the six degrees of freedom of an object in 3D space

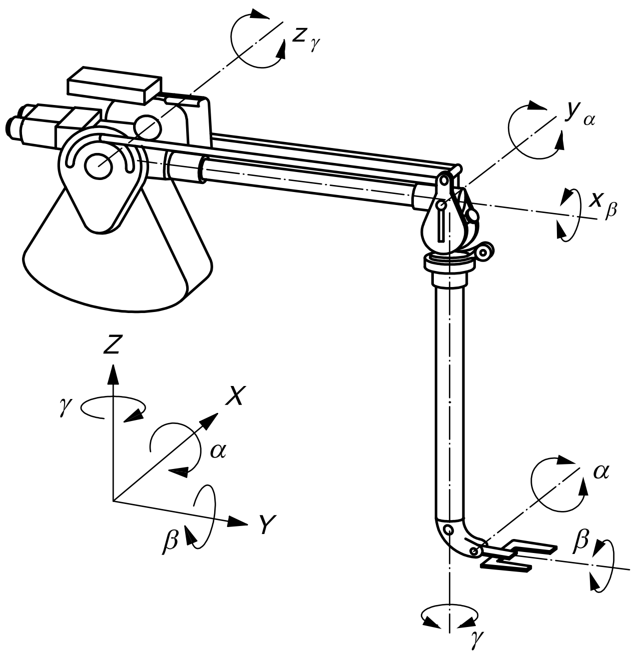


Figure A.2 — Example of possibilities of movement of a manipulator

A.2 Motions for positioning

Positioning motions can be achieved by two different kinds of movements. These are linear translation motions or rotation motions combined with long arm limbs. In the latter case, the rotation motions shall not be considered as providing any useful orientation motions, which should be minimized by appropriate selection of the arm length with respect to the dimensions of the working volume.

The features according to A.1 are fulfilled very simply, if the kinematic system has three true translation motions in the directions of the coordinate axes X, Y and Z. This is typically the case with the bridge transporter system of a power manipulator (Figure 9). The arms of manipulators have instead two (in telescopic types) or three (in articulated types) rotation motions acting on long arm limbs to achieve the corresponding number of translation motions. By this means, it is possible to achieve a large working volume relative to the overall dimensions of the remote handling device assembly, along with associated advantages in cost, maintenance and methodology.

The tong is moved on a circular path, if a rotation motion of an arm limb is made. One or two compensation motions shall accordingly be made simultaneously to perform pure translation motions. In addition, a change of the orientation of the tong happens simultaneously to the change of the tong position. These orientation changes are generally undesirable and further compensation motions are therefore usually necessary to maintain the required orientation of the tong in the working space (see A.3).

The rotation motions with long arm limbs for position change are tilt, swivel and twist motions, related to the rest position of a manipulator.

By combination of a different number of translation motions and rotation motions with long arm limbs there are 27 different kinematic chains with three motions each existing, if they are independent of the three coordinate axes and both directions of one coordinate.

A.3 Motions for orientation

The rotation motions to change the angles of orientation α, β, and γ are categorized respectively as tilt, twist and swivel motions. Different combinations of these motions are achievable depending on the categories of the remote handling devices employed. The group of orientation motions consists of one twist, swivel and tilt motion each, e.g. with power manipulators (see Figure 10), and two twist motions and one tilt motion, e.g. with master-slave manipulators (see Figures 3, 5 and 7) related to the rest positions. The elements for orientation are for practical reasons designed as a part of the forearm or the hand limb. This determines that twisting of the workpiece using only a single motion can only be carried out around the Y-axis, in the rest position of the manipulator.

Because the axes of the other two orientation motions do not run through the centre of the workpiece, circular motions with small radius are carried out instead of pure rotational motions for the X- and Z-axes. For pure rotation of a workpiece around its centre in the α and γ directions (i.e. around the X- or the Z-axis), two to five compensation motions shall be carried out, depending on the operational situation, to prevent unintended changes in the position and/or orientation about other axes.

A.4 Motion of tongs

The tongs normally have only one motion. Tongs with two parallel and simultaneously moved jaws are used for all types of manipulators. With remote handling tongs, sometimes grippers which function like scissors are used.

A.5 Kinematic system variations

While A.1 specifies the usual kinematic system with six motions, more than six motions for positioning and orientation can be necessary for certain purposes, for example:

— to enlarge the working volume;

— to enable the slave arm to work behind obstacles;

— for very precise positioning of the tong, by means of only one motion.

Example methods include the provision of additional motions of a transporter, tilting of the drive housings of electrical master-slave manipulators or adding a linear stroke of the tong to achieve a very precise positioning motion, e.g. on the hand limb of some types of power manipulator.

The arm and the transporter can be provided with more motions than necessary as a minimum to be able to work behind obstacles.

Remote handling tongs with a rigid rod or with an articulated rod have a kinematic system with less than six motions. Therefore, their operational flexibility is restricted.

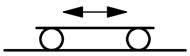
A.6 Symbols of motions for schematic diagrams

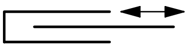
A.6.1 General

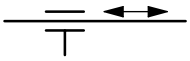
In this clause, the symbols below are used.

A.6.2 Positioning motions

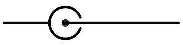
A.6.2.1 Translation motions

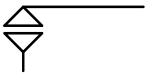

Travel motion

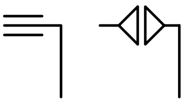

Telescopic motion (also multiple)


Push motion

A.6.2.2 Translation motions effected by rotation motions combined with long arm limbs

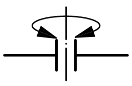

Tilt motion with long arm limb (around the X-axis)

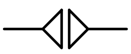

Swivel motion with long arm limb (around the Z-axis)


Twist motion with long arm limb (around the Y-axis)

A.6.3 Orientation motions (rotation motions)


Tilt motion (around the X-axis)


Swivel motion (around the Z-axis)


Twist motion (around the Y-axis)

NOTE Symbols standardized in ISO 3952 (all parts) are not used in this annex, in order to simplify the kinematic diagrams, to yield figures which are very similar to the actual mechanical structures and to facilitate recognition of the practicable motions and their classifications.

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[12] DIN 25409-1[1)], *Remote handling devices for use behind shielding walls — Part 1: Remote handling tongs, dimensions*

[13] DIN 25409-2[1)], *Remote handling devices for use behind shielding walls — Part 2: Master-slave manipulators with three pivots, dimensions*

[14] DIN 25409-3[1)], *Remote handling devices for use behind shielding walls — Part 3: Telescopic master-slave manipulators, dimensions*

[15] DIN 25409-4, *Remote handling devices for use behind shielding walls — Part 4: Telescopic master-slave manipulators, requirements and tests*

[16] DIN 25409-5, *Remote handling devices for use behind shielding walls — Part 5: Master-slave manipulators with three pivots, requirements and tests*

[17] DIN 25409-6, *Remote handling devices for use behind shielding walls — Part 6: Remote handling tongs, requirements*

1) DIN 25409-1, DIN 25409-2, DIN 25409-3, DIN 25409-7 and DIN 25409-8 are in English and German (Beuth Verlag GmbH, 10772 Berlin, Germany).

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