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ISO 17874-2

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Remote-handling devices for radioactive materials —

Part 2:
Mechanical master-slave manipulators

Dispositifs de manipulation à distance pour matériaux radioactifs —

Partie 2: Télémanipulateurs maître-esclave mécaniques

Reference number
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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 17874-2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation 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 mechanical master-slave manipulators used for nuclear applications.

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

Mechanical master-slave manipulators were originally developed for hot cells, which were designed for research and development for nuclear power reactor-fuel elements. They are now also in use in other nuclear installations, such as fabrication or reprocessing plants for fuel elements, waste-treatment stations and decommissioning of nuclear facilities.

This part of ISO 17874 should be of assistance to designers of nuclear plants, as well as to manufacturers, users and license authorities.

Remote-handling devices for radioactive materials —

Part 2: Mechanical master-slave manipulators

1 Scope

This part of ISO 17874 specifies the criteria for the selection, installation and use of a mechanical master-slave manipulator, for remote handling of radiaoactive materials in a nuclear facility.

This part of ISO 17874 deals only with the technical aspects related to the manipulator and its interface with the nuclear facility in which it is intended to be installed.

In particular, the process apparatus and the manipulator features need to be studied in parallel in order to optimize all the functionalities of the manipulator.

However, this part of ISO 17874 does not cover the fundamental design criteria of the nuclear facility (e.g. the process involved, maintenance of the process equipment, intervention for other purposes).

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 11933-1:1997, *Components for containment enclosures — Part 1: Glove/bag ports, bungs for glove/bag ports, enclosure rings and interchangeable units*

ISO 11933-2:1997, *Components for containment enclosures — Part 2: Gloves, welded bags, gaiters for remote-handling tongs and for manipulators*

ISO 10648-2:1994, *Containment enclosures — Part 2: Classification according to leak tightness and associated checking methods*

ISO 17874-1:2004, *Remote-handling devices for radioactive materials — Part 1: General requirements*

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 effects of the hand and arm movements of the operator by means of mechanical transmission elements, installed in a shielding or a containment wall

3.2
arm
effectively reproduces the functions of a human arm, respecting in most cases the same distribution and corresponding articulations

NOTE 1 The corresponding articulations are shoulder, upper arm, elbow, forearm, wrist joint, etc.

NOTE 2 The motions of a manipulator master arm and its associated slave arm are generally parallel.

3.3
master arm
arm located outside a hot cell and equipped with a handle on which the operator acts

3.4
slave arm
arm located inside a hot cell and equipped with tongs to grip the work-piece

3.5
axis
directions of a Cartesian coordinate system defined from the operator's standing point, considered as the origin of this system

NOTE The following axes are considered: Axis X: from right to left along the shielding wall; Axis Y: forward into the shielded cell; Axis Z: up towards the ceiling of the shielded cell.

3.6
balancing
characteristic allowing the manipulator to be maintained with negligible forces applied by the operator in stable positions throughout the whole operating volume by mechanical means (e.g. counterweights)

3.7
connection tube
component mounted inside the through-wall tube, which transmits the motions of the master arm to the slave arm by rotation and by internal mechanical elements

NOTE The connection tube can be withdrawn into the operating room.

3.8
disconnection
mechanical operation allowing the separation of two assembled elements, such as the disconnection of a slave arm or a master arm from the connection tube

3.9
extended reach (Z-motion)
a motorized mechanical extension of the slave arm, by a double telescope, serving to adjust the working length and hence to extend the reach across the working volume

3.10
gaiter of a manipulator
booting US
specially profiled flexible sleeve designed to protect the mechanical parts of the slave arms of a manipulator from contamination or to provide continuity of the leak-tightness of a hot cell

3.11
handle
component fixed at the end of the master arm and gripped by the operator, facilitating the control of the movement of the manipulator

3.12
indexing motions (*X*- and *Y*-motion)
an adjustable mechanical or electrical displacement between the slave arm position and the corresponding master-arm position, to enlarge the working volume and minimize operator strain

3.13
jaws
components fixed on the end of the tongs which facilitate the handling of an object

NOTE The jaws can be disconnectable.

3.14
joint
articulation
assembly of several pieces allowing one or more rotational motions

3.15
operating volume
space in which the operation of a tong is possible, considering all the positions in which the different components of the slave arm of a manipulator can be moved

3.16
operator side removal
operation consisting of extracting a part or the whole of a manipulator from the operator side of the hot cell

3.17
orientation motion
rotation motions around certain axes of the manipulator

NOTE 1 According to the axis considered, the three following motions are distinguished: tilt (α), twist (β) and swivel or azimuth motion (γ).

NOTE 2 In articulated manipulators, the orientation motion can be accomplished around the forearm axis or around the arm axis.

3.18
tong
gripping device fixed at the slave-arm end of the manipulator and consisting of an actuator assembly and jaws

3.19
through-wall tube
cylindrical piece mounted in the wall of a hot cell and allowing the passage of the mechanical linking elements between the different parts of a manipulator from the outside to the inside of the hot cell

NOTE The through-wall tube contains the connection tube.

3.20
positioning motion
motion effecting a displacement of the tongs (or end-effector)

NOTE According to the axis considered, three different motions are distinguished: *X*, *Y* and *Z*.

4 General architecture and classification

4.1 General architecture

A mechanical master-slave manipulator is a fixed assembly mounted on a shielded enclosure wall. It comprises three main components, a master arm, a slave arm and a connection tube equipped with mechanical elements ensuring the connection between the master arm and the slave arm.

The connection tube is generally installed horizontally through the enclosure wall. It shall be constructed in such a manner that the motions, forces, and torques, executed by the hand of the operator on the handle of the master arm, are transmitted respectively to the slave arm and the tongs.

The manipulator shall ensure force reflection from the slave arm to the master arm. The transmission elements shall be reversible in motion and communicate forces and torques reversibly, in all positions.

Depending on the final use (mounting on βγ hot cells or α-βγ hot cells), the connection tube can be unsealed or sealed. In addition, the slave arm can be equipped with a gaiter, the aim of which is to realize the protection or the leak-tightness of the manipulator slave arm. The jaws of the tongs or the complete tongs assembly can be exchanged by remote control.

The master arm and slave arm are arranged to have identical kinematics. Additional components are provided on the master arm, in particular, counter-weights balancing the arms of the master-slave manipulators and, where necessary, lockable brakes and/or the control elements for motorized relative motions or off-sets between the slave arm and the master arm (i.e. indexing).

4.2 Classification

4.2.1 Introduction

As defined in ISO 17874-1, mechanical master-slave manipulators are classified into two categories (see Figure 1):

— mechanical master-slave manipulator with telescopic arms;

— mechanical master-slave manipulator with articulated arms.

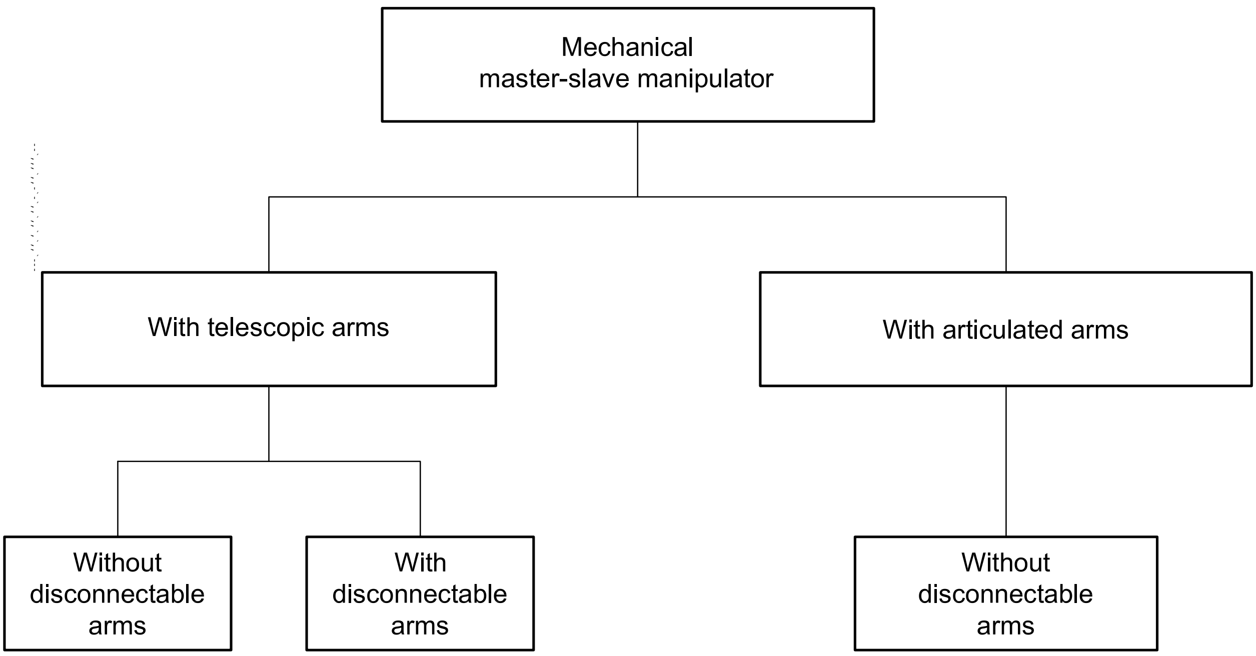


Figure 1 — Classification of mechanical master-slave manipulators

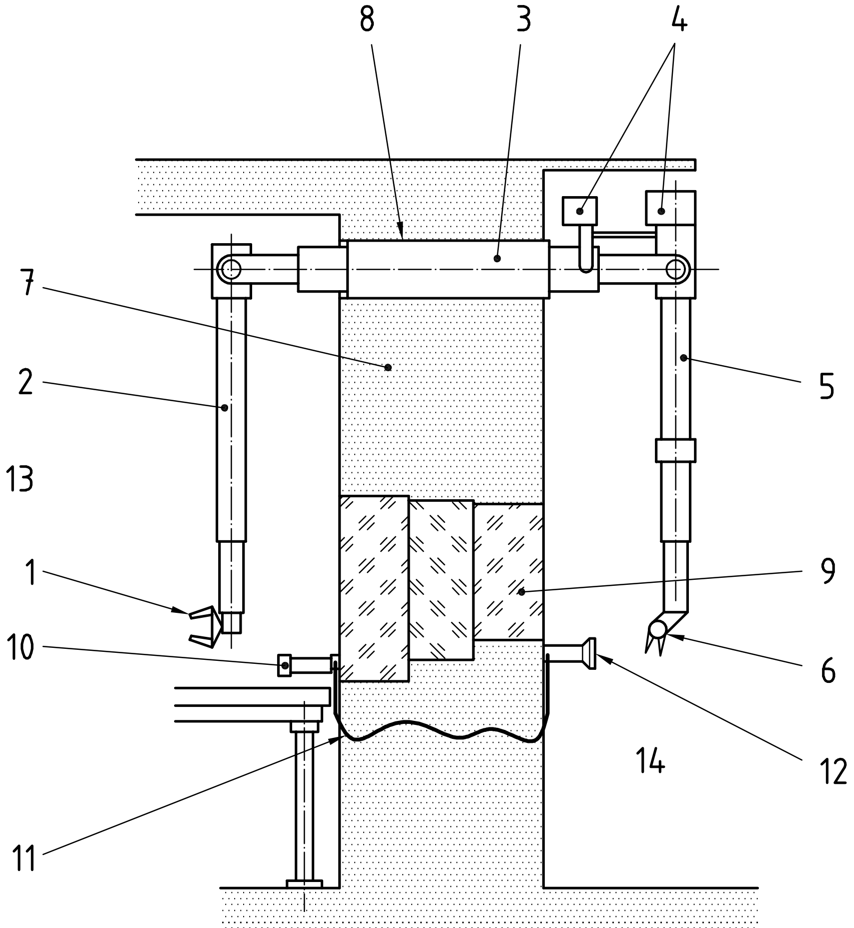
4.2.2 Mechanical master-slave manipulators with telescopic arms

Depending on the type, this kind of mechanical master-slave manipulator (see Figure 2) permits the transmission of forces up to the maximum magnitude that an operator would employ in unaided manual activity. They are suitable for complicated tasks, and are usually installed in pairs on a working station.

Manipulators with telescopic arms are designed for hot cells of all sizes with shielding walls made mainly of concrete or even of lead. They constitute the main working devices in such types of cells, which are generally of large dimensions.

A version with short arms is available, if higher forces must be executed than are possible with mechanical master-slave manipulators with articulated arms.

There are also compact manipulators with a double telescope in the slave arm, available for hot cells with a restricted height.



Key

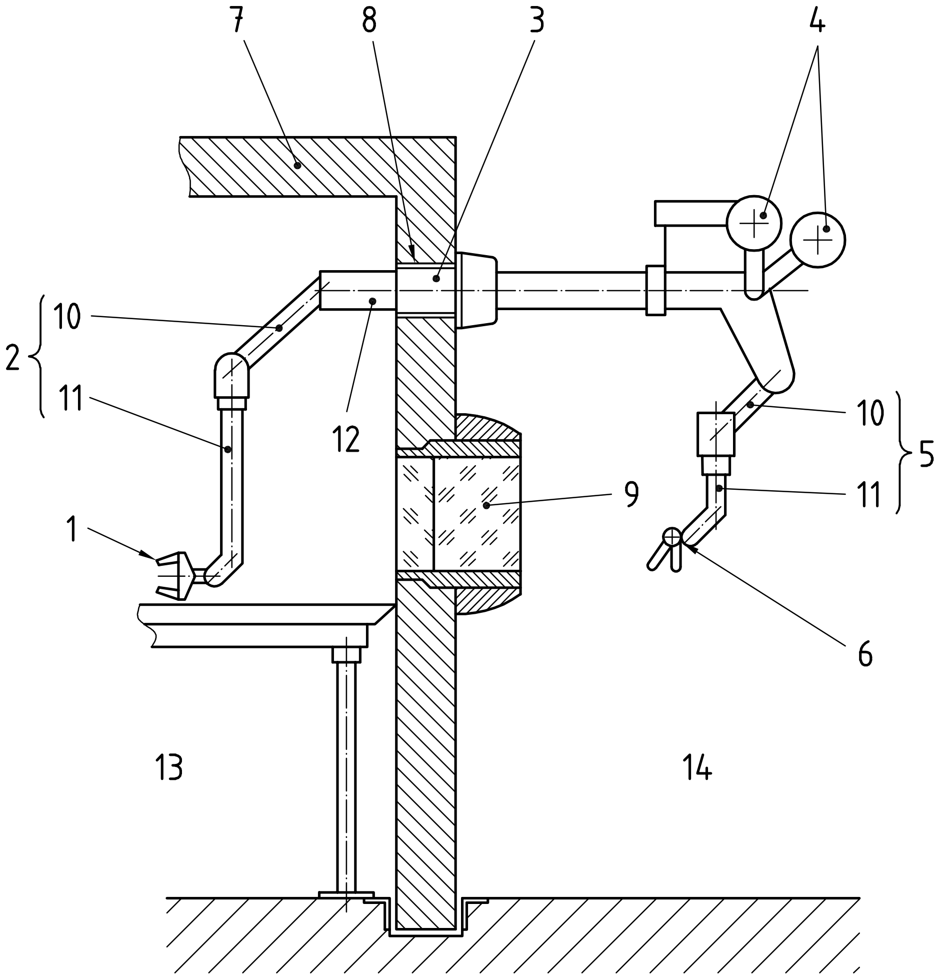
1	tong with parallel jaws	8	through-wall tube
2	slave arm	9	shielding window
3	connection tube	10	microphone
4	counter-weights	11	sound-transmission cable
5	master arm	12	loudspeaker
6	handle	13	hot cell
7	shielding wall	14	operating room

Figure 2 — Mechanical master-slave manipulator with telescopic arms

4.2.3 Mechanical master-slave manipulators with articulated arms

This kind of mechanical master-slave manipulator (see Figure 3) permits the transmission of forces up to a medium level such as an operator could easily employ repeatedly in unaided manual activity. 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 even steel.

They are also often used in containment enclosures with thick concrete shielding walls. They have small dimensions and therefore provide a relatively small working volume. They are used instead of remote-handling tongs, if a larger working volume is available or/and more dexterity is needed.



Key

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

Figure 3 — Mechanical master-slave manipulator with articulated arms

4.3 Kinematics

4.3.1 General

The manipulator shall have seven motions, three positioning motions (see Figure 4), three orientation motions (see Figure 5) and one gripping motion, according to the definitions given in ISO 17874-1.

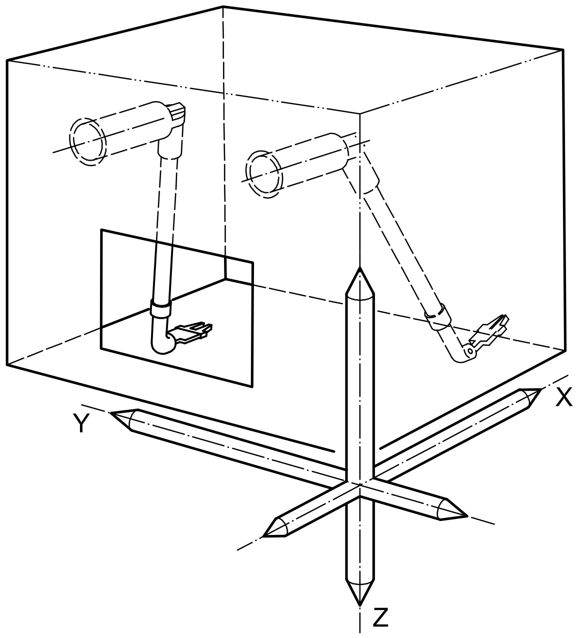


Figure 4 — Positioning motions

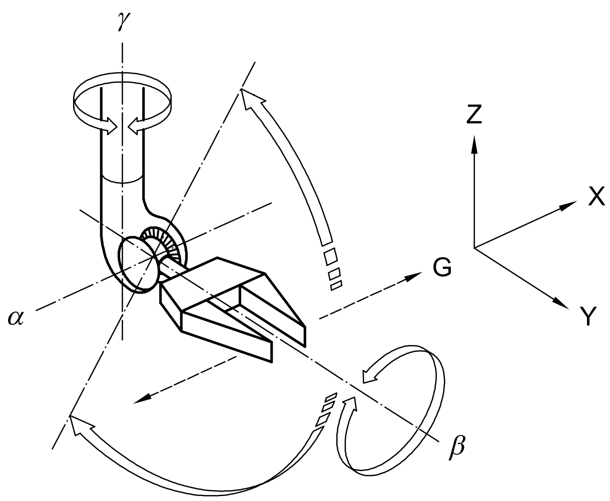
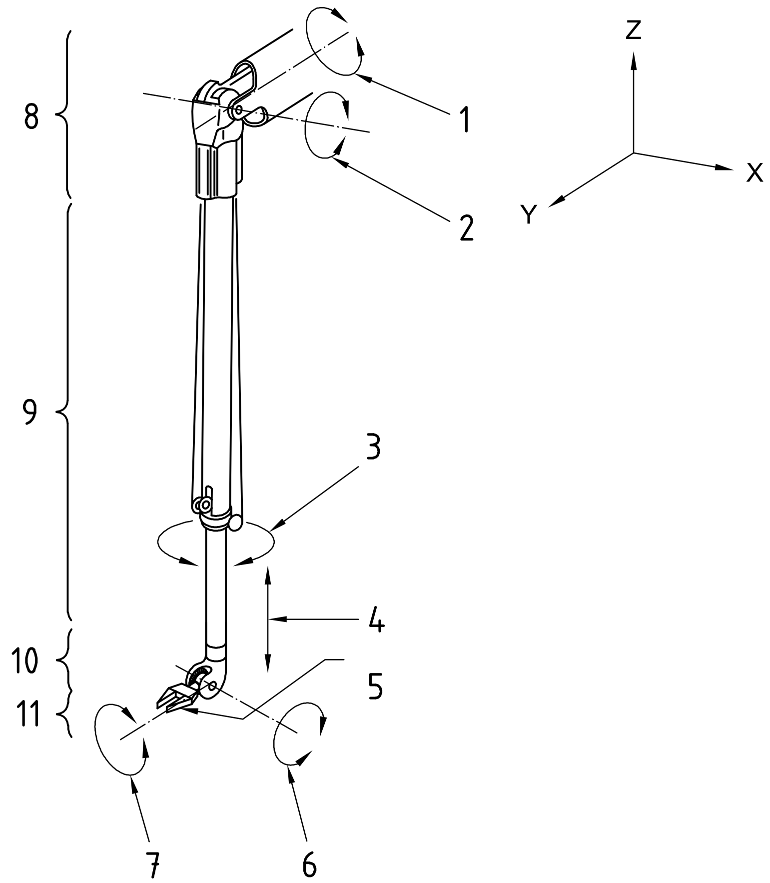


Figure 5 — Orientation and gripping

4.3.2 Manipulators with telescopic arms

For manipulators with telescopic arms, for which the motion along the Z axis is performed by translation of the tubes (see Figure 6).



Key

1 right-left motion (around the Y axis)
2 forward-backward motion (around the X axis)
3 arm rotation (around the Z axis) (swivel or azimuth motion)
4 up-down motion (along the Z axis)
5 gripping motion
6 wrist rotation (around the X axis) (tilt motion)
7 tongs rotation (around the Y axis) (twist motion)
8 shoulder
9 telescopic arm
10 wrist joint
11 handle (master side)/tongs (slave side)

Figure 6 — Mechanical master-slave manipulator with telescopic arms

This kind of manipulator shall be equipped with an electrical indexing of the Y-motion (forward-backward) and X-motion (right-left). It may also include an electrical extension of the Z-motion (up and down), consisting of a double telescopic arm. The latter is called extended reach.

The indexing allows the range of action of the slave arm to be increased, while keeping the master arm in a good ergonomic position.

Mechanical master-slave manipulators with telescopic arms are differentiated in the following way.

— Manipulators without disconnectable arms. In this case, the functional links between the master arm and the slave arm are directly realized by cables or tapes.

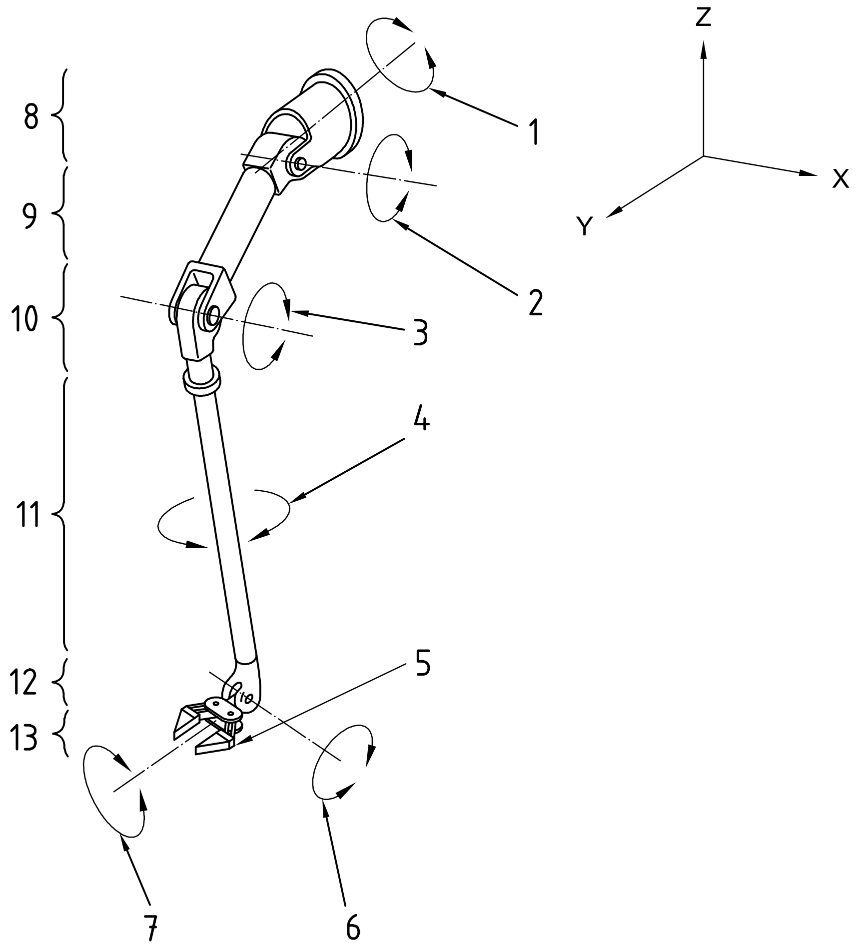
— Manipulators with disconnectable arms. In this case, the links by cables or tapes are interrupted at the level of the connection tube, where the motion transmissions are performed by rotating shafts and gears.

This solution consequently allows the disconnection of the slave arm. In many cases, the disconnection of the master arm is also possible.

4.3.3 Manipulators with articulated arms

For manipulators with articulated arms, the motion along the Z axis is performed by a combination of two rotations around the shoulder axis and the elbow axis (see Figure 7).

This kind of manipulator can be equipped with electrical or mechanical indexing of the upper arm.



Key

1 right-left motion (around the Y axis)
2 forward-backward motion (around the X axis)
3 arm rotation (around the Z axis) (swivel or azimuth motion)
4 up-down motion (along the Z axis)
5 gripping motion
6 wrist rotation (around the X axis) (tilt motion)
7 tongs rotation (around the Y axis) (twist motion)
8 shoulder
9 upper arm
10 elbow
11 forearm
12 wrist joint
13 handle (master side)/tongs (slave side)

Figure 7 — Mechanical master-slave manipulator with articulated arms

5 Basic considerations for the choice of a manipulator

5.1 General criteria

The design constraints of the manipulator determine the field of use offered by the two categories of manipulators.

Mechanical master-slave manipulators with telescopic arms

- are designed to be installed in walls of large thickness (generally about 1 000 mm),
- provide operation in relatively large volumes,
- offer generally a reduced dexterity compared to those equipped with articulated arms,
- provide a large range of load capacities (up to 45 kg),
- allow two possibilities of maintenance (operator side removal or disconnection of the slave arm inside the hot cell),
- provide a large variety of features compared to mechanical master-slave manipulators with articulated arms.

Mechanical master-slave manipulators with articulated arms

- are designed for operation in a limited working volume, generally between 100 mm and 500 mm),
- provide a restricted range of load capacities (up to 12 kg),
- provide a better dexterity than those with telescopic arms,
- impose maintenance-access constraints (operator side removal), affecting the general design of the installation.

5.2 Particular criteria

5.2.1 Introduction

This clause lists the technical characteristics which have to be specified to enable the choice of the type of manipulator.

5.2.2 Main characteristics of the manipulators

5.2.2.1 General

The characteristics of the equipment shall be chosen in accordance with Clause 7 of ISO 17874-1:2004.

5.2.2.2 Load capacity

It is necessary to define the task to be performed as precisely as possible. For this purpose, the following parameters shall be specified:

- the maximum as well as the likely weight of the loads to be handled (objects, tools)[1)];
- forces (static and dynamic) to be exerted on objects;
- torques (static and dynamic) to be applied by the rotation of the operator's hand or arm;
- the reaction provided by tools (e.g. hydraulic shear, impact wrench, vibration sources, high-pressure jets for decontamination, compressed air chisel);
- weight of the objects to be lifted[2)]. The lifting capacity may be significantly higher than the handling capacity.

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1) Handling means moving a piece in the whole space using the tongs.

2) Lifting means moving a piece in the vertical direction using a hook.

To increase the lifetime of the mechanical master-slave manipulator, its use near the limit of its maximum load capacity has to be avoided.

The key parameter dictating the choice of manipulator type is generally the maximum weight to be handled. Table 1 gives the required maximal load capacities, according to the class of the manipulators.

NOTE Because of the resultant significant decrease of dexterity, care should be taken when working in extreme positions.

Table 1 — Classification of mechanical master-slave manipulators according to their maximal load capacity (handling capacity)

Manipulator class	**Light** (L)	**Medium** (M)	**Heavy** (H)
Maximum load capacity (handling capacity) (kg)	< 10	10 - 20	> 20

5.2.2.3 Geometric characteristics

For this purpose, the following aspects shall be considered:

— the operating volume of the master arm; this parameter shall be taken into account especially regarding the layout of the front face of the shielded enclosure and any adjacent equipment or structures;

— the operating volume of the slave arm; this parameter shall be taken into account especially to guarantee the required accessibility to the process equipment; the adequacy of the operating volume in combination with the foreseen load capacity shall also be checked;

— the spaces required for the operation and the maintenance of the manipulator, as recommended by the manufacture, have also to be respected.

5.2.2.4 Dexterity

The dexterity of a manipulator characterizes the ease with which it can perform complex tasks.

The dexterity cannot readily be quantified, but is adversely affected by the no-load forces (friction, dynamic mass, etc., see 5.2.3) or excessive flexure and is improved by the provision of a smooth action, minimal backlash (or play), and good operator ergonomics (see 5.2.4).

Accordingly, it can be said that the dexterity can be increased by reducing the values of the friction to be overcome by the operator in the no-load condition. For a given manipulator, dexterity varies inversely with the load applied.

It should also be noted that, in extreme positions, the dexterity is reduced (and some complicated tasks cannot be performed) owing to loss of effective motions in one or more axes.

5.2.2.5 Reliability

For a given manipulator, the reliability depends critically on the working conditions, which in general can be foreseen. To achieve a good reliability, it is therefore necessary to avoid the use of the manipulator in extreme working conditions (e.g. frequent use at maximum load capacity, or with exposure to degradation due to a chemical atmosphere, or with inadequately trained operators, etc.).

In addition, to maximize the reliability, the maintenance intervals and procedural instructions of the manufacture have to be respected.

5.2.3 No-load forces and torques

A significant contribution to the total force to be overcome by the operator comes from the no-load forces and torques, including residual balancing errors and the spring tension of the tong (which has to open automatically when relieved of the force of the operator's hand).

Generally, the no-load forces and torques shall be as low as possible. The no-load forces and torques are influenced by the load capacities (manipulator classes), the general design of the manipulator, the tension in any cables or tapes, the presence of gaiters, seals and a number of other variables.

These no-load forces and torques shall be provided by the manufacturers upon request, using the standardized measurement methods described in Annex A.

5.2.4 Flexures and backlashes

Although flexures and backlashes do not contribute additional forces for the operator to overcome, they adversely affect the dexterity of the manipulator by introducing a requirement for nugatory movements of the master arm and any indexing system. In addition, the flexure (that is, elastic distortion of the components of the manipulator) represents stored energy in the affected motions that may cause problems, such as spring-back if rapidly released.

Accordingly, flexures and backlashes shall be minimized while recognizing the inevitable design compromises of the increased cost and/or weight of more rigid components and the friction that can be associated with anti-backlash mechanisms. The reduction of flexures and backlashes is therefore also a compromise with respect to the increase of the no-load forces and torques described above.

The flexure and backlash behaviour of the manipulator shall be provided by the manufacturers upon request, using the standardized measurement methods described in Annex A.

5.2.5 Other criteria

Other parameters, such as those listed in ISO 17874-1, have to be considered if relevant (e.g. ease of decontamination, maintainability, resistance to radiation).

5.3 Mounting of the master-slave manipulators

5.3.1 General

The positioning of the manipulator in the enclosure wall shall take into account the following aspects.

5.3.2 Height of the connection tube axis with regard to the level where the operator stands

Concerning this variable, the following considerations apply.

- Manipulators with articulated arms and manipulators with telescopic arms, of small dimensions: the height depends on the dimensions of the type of master-slave manipulator. It shall lie between 1 850 mm and 2 500 mm.

- Manipulators with telescopic arms for shielded enclosures of large dimensions: for usual manipulators, the standard height is 3 050 mm.

The connection tube is specific to the type of manipulator. It is installed in a through-wall tube embedded in the enclosure wall. Since the established products of different manufacturers differ in the required diameter of the through-wall tube, care has to be exercised in the choice of diameter for any particular installation.

It is possible to fit size-reduction rings to accommodate smaller connection tubes in larger through-wall tubes, but not *vice versa*. The recommended range or standard dimensions of internal diameters of through-wall tubes is shown below for each type of manipulator:

— for master-slave manipulators with articulated arms: 160 mm to 170 mm;

— for master-slave manipulators with telescopic arms of small dimensions: 190 mm;

— for master-slave manipulators with telescopic arms of large dimensions: 254 mm.

5.3.3 Interaxis

A working station is generally equipped with two similar master-slave manipulators. The interaxis distance between the through-wall tubes varies from 700 mm (master-slave manipulators with small operating volume) to 900 mm (master-slave manipulators with large operating volume).

The actual value recommended by manufacturers depends on the design of the manipulator and must not be reduced when the overall hot-cell design is implemented, in order to avoid collisions during motion. Moreover, the optimal ergonomic conditions for the operator(s) are achieved with the two master-slave manipulators so installed on the working station.

5.3.4 Operating volume of the master arm

The operating volume of the master arm shall be free of obstacles. It shall be checked that items of auxiliary equipment are not installed in the front face, near the manipulator working station (e.g. ventilation ducts, service penetrations, electric cables, walk-ways, control consoles), because they would interfere with the range of action of the master-slave manipulator.

5.4 Leak-tightness and protection against contamination

5.4.1 General

In order to avoid the spread of radioactive contamination into the operator areas, a containment enclosure, shielded or unshielded, is generally provided and characterized by a total permissible leakage rate (see ISO 10648-2). This total permissible leakage rate results from the contribution of all of the local leaks due to the penetrations through the enclosure walls (doors, windows, ventilation ducts, service penetrations, etc.) as well as the contribution of all the manipulator penetrations.

It is commonly accepted that the local leakage rate due to the manipulator penetrations through the enclosure wall should be maintained at a level not higher than the leakage rate of the rest of the enclosure. In cases where a specific leak-tightness is specified by the end-user, the manufacturer has to comply with the required specification and to demonstrate the compliance with the specifications.

This leak-tightness can be obtained in two different ways, according to the chosen manipulator maintenance mode:

— unsealed connection tube, with or without a gaiter;

— sealed connection tube, typically with a gaiter.

NOTE A variation of this configuration is also available without a gaiter, in which case leak-tightness is not ensured.

The specified leakage rate of the manipulator during standard maintenance procedures shall be maintained as far as possible at a level no greater than that of normal operation.

5.4.2 Gaiters for manipulators

Gaiters for mechanical master-slave manipulators are flexible sleeves covering the slave arm. There are two categories of gaiters, according to the function intended:

- protection gaiters;
- leak-tight gaiters.

These two categories of gaiters shall be used in order to comply with the following objectives:

a) **A protection gaiter** is designed to provide some protection of the manipulator slave arm against the radioactive contamination and any physical or chemical pollutants present inside the hot cell. It does not contribute to the leak-tightness of the hot cell or of the containment enclosure, which is ensured by the sealed connection tube.

b) **A leak-tight gaiter** is designed to ensure the leak-tightness of the hot cell or the containment enclosure in the case of an unsealed connection tube. This type of gaiter also ensures a high standard of protection of the manipulator slave arm against the radioactive contamination and any physical or chemical pollutants present inside the hot cell.

A manipulator has to be equipped with only one category of gaiter, which depends upon the intended operating conditions. Gaiters shall be designed to suit the manipulator category, the gaiter interchangeability technique for maintenance, the environmental conditions (radiation exposure, mechanical damage, etc.) and the leak-tightness requirements. The leak-tightness of the hot cell or the containment enclosure shall be achieved by seals placed between the through-wall tube and the connection tube.

The choice of a manipulator equipped with a sealed or unsealed connection tube and the use of an additional gaiter depends on several operational parameters which have to be taken into account. Some of these could be contradictory, so that a compromise has to be made. These parameters are as follows:

- high leak-tightness;
- special internal atmosphere;
- presence of high temperature or aggressive atmosphere;
- necessity of maintenance of the manipulator (from inside or outside the hot cell);
- frequent use of the manipulator;
- allowed periods of disuse;
- necessity of replacement of the gaiter;
- procedure of removal of the manipulator from of the shielded cell;
- high level of radiation inside the cell;
- good dexterity (e.g. reduced no-load forces and backlashes) and maximum operating volume;
- need for a large viewing angle;
- mechanical impact by objects during work;
- need for transportation equipment for the manipulators inside or outside the hot cell;
- removal concept for damaged manipulators and likely frequency of such damage;
- acceptable decontamination efforts before any repair;
- contamination risk in the operating room.

5.4.3 Installation and replacement of gaiters

Installation and replacement of the gaiter are accomplished as follows:

a) **for leak-tight gaiters**, from the outside of the enclosure and after removal of the manipulator;

b) **for protection gaiters,** at the same time as the whole slave arm, using an auxiliary lifting device inside the hot cell.

6 Different manipulator mounting methods and associated requirements

6.1 Unsealed connection tube, with a gaiter

6.1.1 General

This solution applies to all types of mechanical master-slave manipulators. Depending on the type of gaiter used (leak-tight gaiter or protection gaiter), the slave arm is totally or partly protected.

6.1.2 Use of a protection gaiter

When a protection gaiter is used (see Figure 8), the containment of the hot cell shall be performed in a dynamic way. Accordingly, this technique is not recommended for nuclear applications where a risk of spread of radioactive contamination exists.

In this configuration, the protection gaiter is mounted on a ring which has to be fastened to the slave arm behind the shoulder pivot (see Figure 9). The slave arm is exchangeable by remote control, using a lifting device which is kept inside the hot cell.

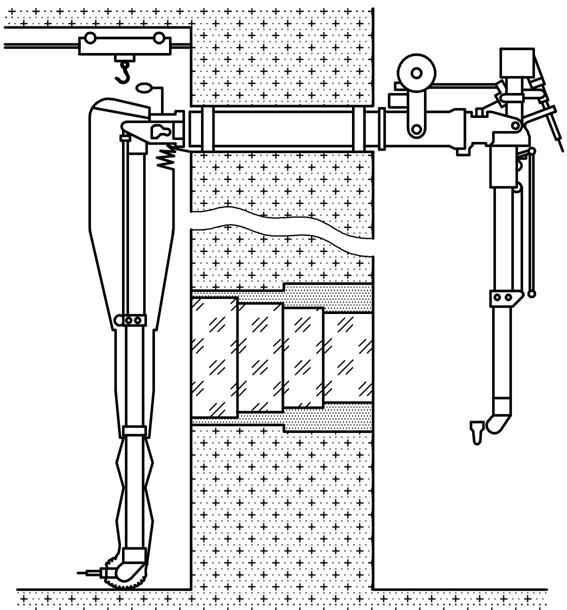


Figure 8 — Use of a protection gaiter

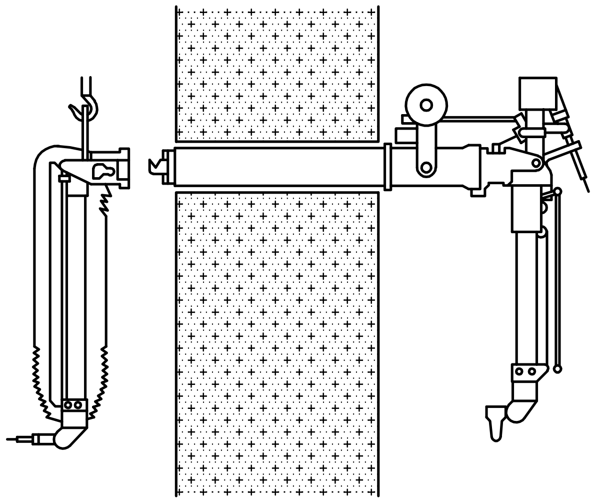


Figure 9 — Fastening of a protection gaiter

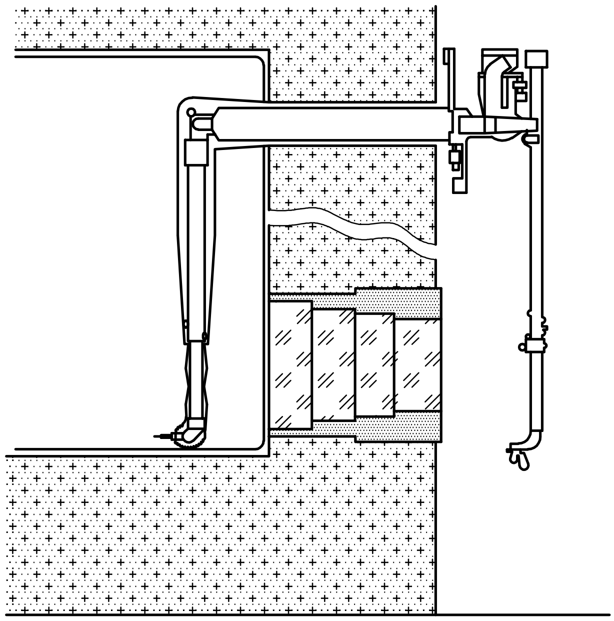
6.1.3 Use of a leak-tight gaiter

6.1.3.1 General

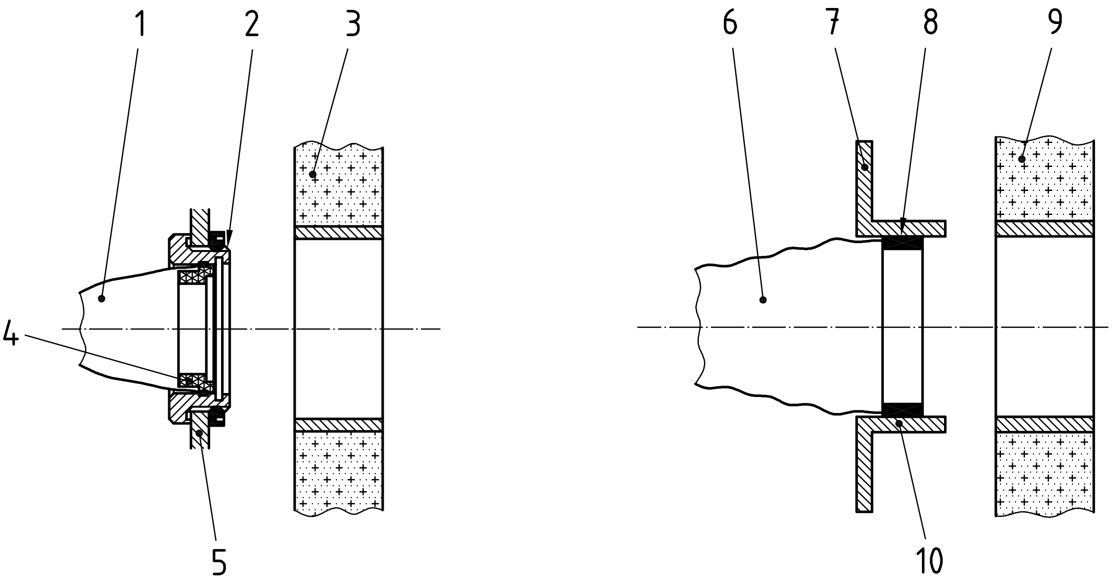
When a leak-tight gaiter is used, the continuity of the static containment of the hot cell is ensured. This technique is therefore especially recommended for highly contaminated hot cells (α-βγ or neutron hot cells).

6.1.3.2 Method 1

In this configuration [see Figure 10 a)], the gaiters are mounted on an ejectable support ring fastened to the containment enclosure wall located behind the βγ shielding wall.



a) General view



b) Gaiter mounted on a type 1 support ring, fixed on a type 1 enclosure ring

c) Gaiter mounted on a type 3 support ring, fixed on a glove port used as a type 3 enclosure ring

Key

1	gaiter	6	gaiter
2	enclosure ring	7	glove port
3	shielding wall	8	support ring
4	support ring	9	shielding wall
5	enclosure wall	10	enclosure wall

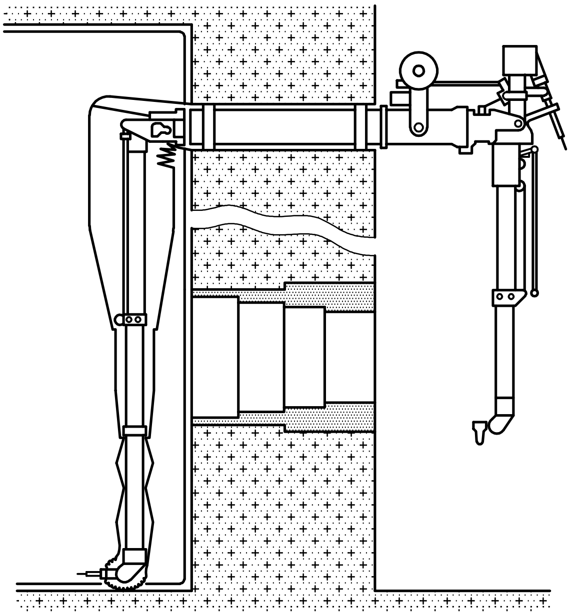
Figure 10 — Gaiter fastened on a support ring, fixed on the containment enclosure wall

The mounting is to be accomplished by one of the following options:

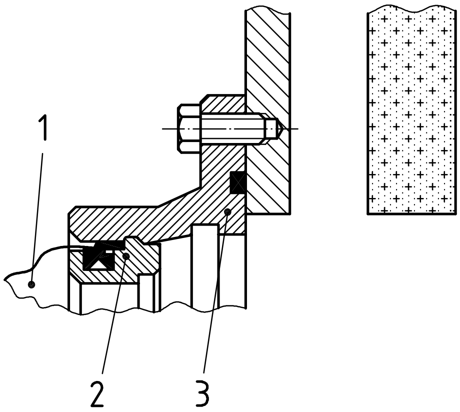
a) gaiter fixed on a type 1 support ring, mounted on a type 1 enclosure ring [see Figure 10 b)];

b) gaiter fixed on a type 3 support ring, mounted on a glove port used as a type 3 enclosure ring [see Figure 10 c)].

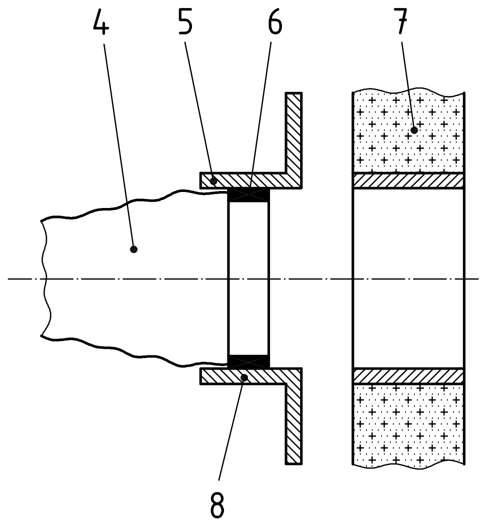
The only permissible variation of this system is described in the following configuration, where the gaiter is mounted on the inner liner of a highly contaminated hot cell (see Figure 11).



a) General view



b) Gaiter mounted on a type 1 support ring, fixed on a type 1 enclosure ring



c) Gaiter mounted on a type 3 support ring, fixed on a type 3 enclosure ring

Key

1 gaiter
2 support ring
3 enclosure ring
4 gaiter
5 glove port
6 enclosure ring
7 shielded wall
8 inner liner

Figure 11 — Gaiter fixed onto the inner liner of a leak-tight concrete hot cell

Depending on the type of support ring, the gaiter is either:

— fixed directly on a type 3 support ring, which is attached to a glove port used as a type 3 enclosure ring thus terminating the inner liner, or

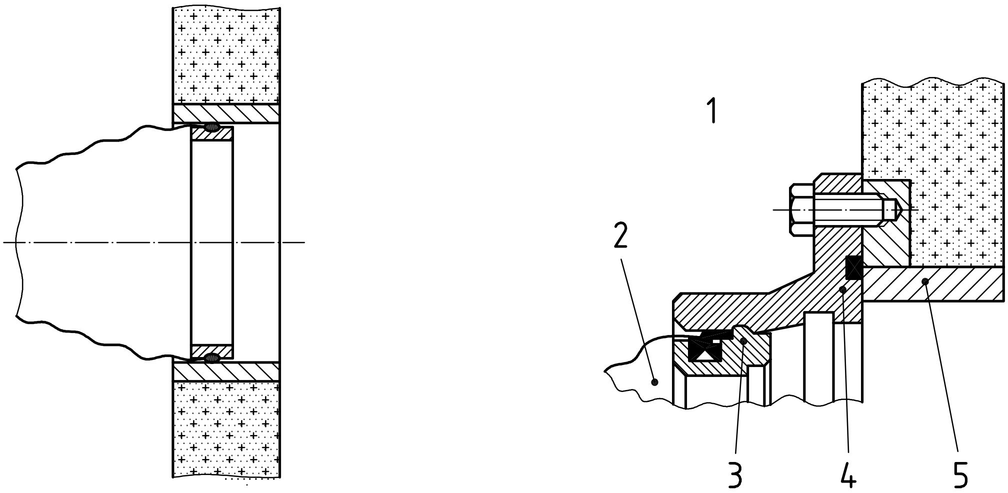
— mounted on a type 1 support ring, fixed on a type 1 enclosure ring, which is screwed onto a flange located at the termination of the inner liner.

NOTE References to type 1, type 2 and type 3 support rings and enclosure rings are derived from ISO 11933-2.

6.1.3.3 Method 2

In this configuration, the gaiters shall be mounted on a support ring fixed at the inner end of the through-wall tube (on the side opposite to the operator).

The support ring is to be mounted either directly on the through-wall tube [when a type 3 support ring is used, [see Figure 12 a)], or indirectly through a containment enclosure ring [when a type 1 support ring is used, see Figure 12 b)].



a) Gaiter mounted on a type 3 support ring, fixed on a trough-wall tube

b) Gaiter mounted on a type 1 support ring, fixed on a type 1 enclosure ring

Key

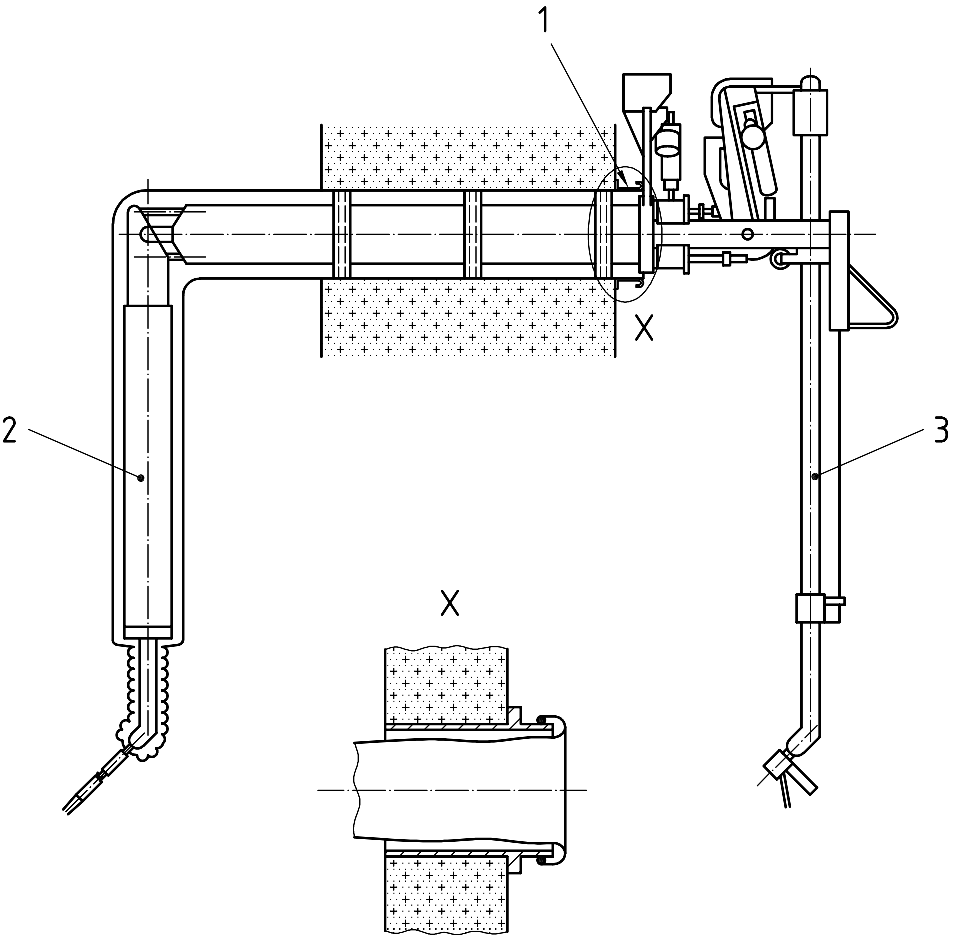
1 inside enclosure
2 gaiter
3 support ring
4 enclosure ring
5 through-wall tube

Figure 12 — Gaiter fixed to a through-wall tube

6.1.3.4 Method 3

In this relatively primitive configuration, the gaiters were mounted directly on the flange of a glove or bag port fixed on the shielding wall at the operator side (see Figure 13).

WARNING — This solution is no longer recommended, because it entails a breach of containment during mounting and removal of the manipulator for maintenance, etc.



Key

1 gaiter terminated in a bead and sealed at the wall flange using a clamping system

2 slave arm

3 master arm

NOTE No longer recommended.

Figure 13 — Mounting of a gaiter fixed on a glove/bag port on shielding wall at the operator side

6.1.3.5 Additional requirements

In the two recommended configurations, the gaiters maintain the leak-tightness of the containment enclosure, when the manipulator is removed from the wall from the operator side (see Figure 14).

Exchanges of leak-tight gaiters are generally made by remote control, using an ejecting device. The different techniques for exchanging such gaiters are described in ISO 11933-2.

Profiles, designs, material of construction and additional recommendations concerning gaiters for manipulators are also described in ISO 11933-2.

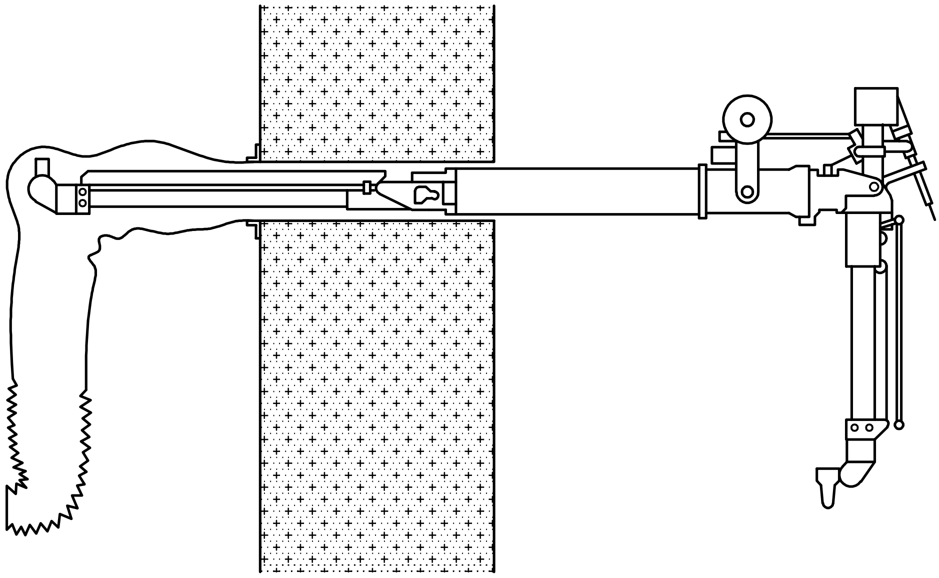


Figure 14 — Example of exchange of a manipulator, removal from the operator side

6.2 Unsealed connection tube, without gaiter

This technique is only applicable for βγ hot cells, with no contamination. This solution applies to all categories of mechanical master-slave manipulator with disconnectable arms. The three components of the manipulator (the master arm, the slave arm and the connection tube) are exchangeable by remote control.

The containment of the hot cell can only be realized dynamically.

NOTE This technique has frequently been used in the past for some nuclear applications, but because it does not offer a continuity of the static leak-tightness of the hot-cell wall, it is no longer recommended for use in nuclear installations where any risk of contamination may occur.

6.3 Sealed connection tube

In this solution (see Figure 15), the leak-tightness between the connection tube and the through-wall tube is ensured by seals. Generally, the connection tube is itself leak-tight by construction, so this technique ensures the continuity of the leak-tightness of the enclosure of the hot cell.

For continuous monitoring of the leak-tightness, the through-wall tube can be provided with a double-seal system, with an interspace as a control medium.

This solution applies only to mechanical master-slave manipulators with disconnectable arms. The slave arm is exchangeable by remote control.

Gaiters associated with this technique will be of one of the following types.

— A protection gaiter for protecting the slave arm to some extent against the contamination and possible corrosive atmosphere of the containment enclosure. Protection gaiters are identical to those described in 6.1.2;

— A a leak-tight gaiter (e.g. when a high level of containment or protection of the slave arm is required). Care shall be taken in this case, to avoid excessive overpressure or underpressure of the volume between the gaiter and the slave arm during operation. Leak-tight gaiters are identical to those described in 6.1.3.

The inclusion of a HEPA filter permits breathing of the volume enclosed by the gaiter while controlling the associated contamination path (see Figure 16).

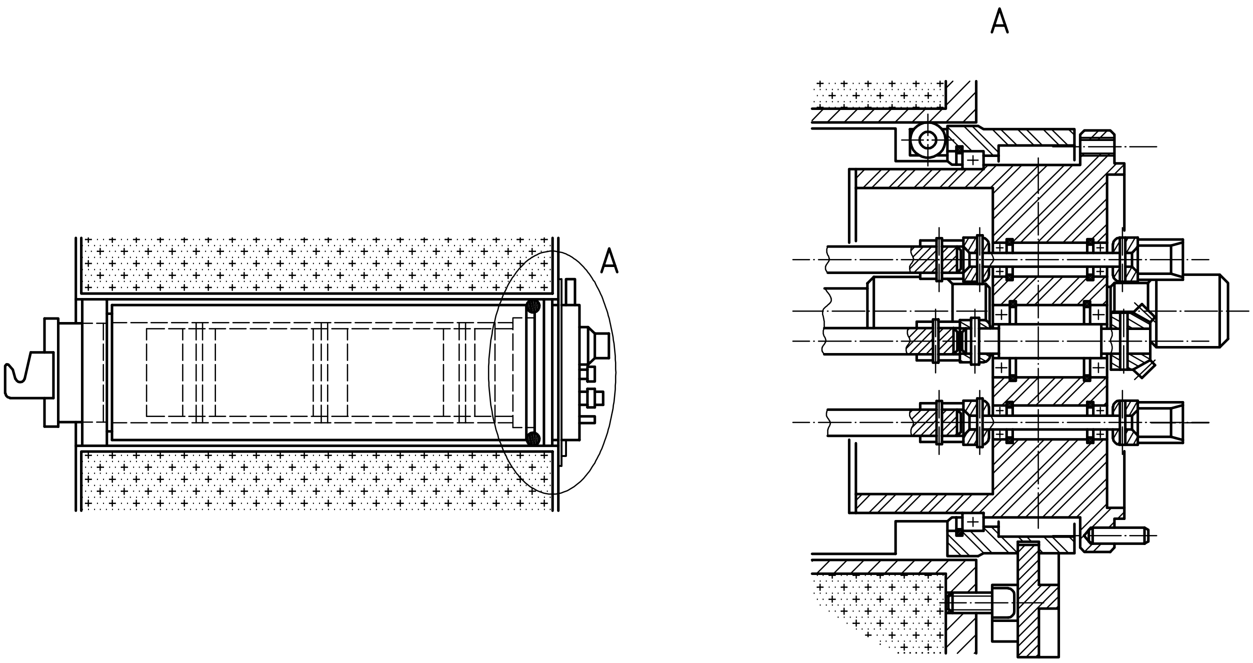


Figure 15 — Principle of a sealed connection tube
(Detail "A" is enlarged in the insert on the right)

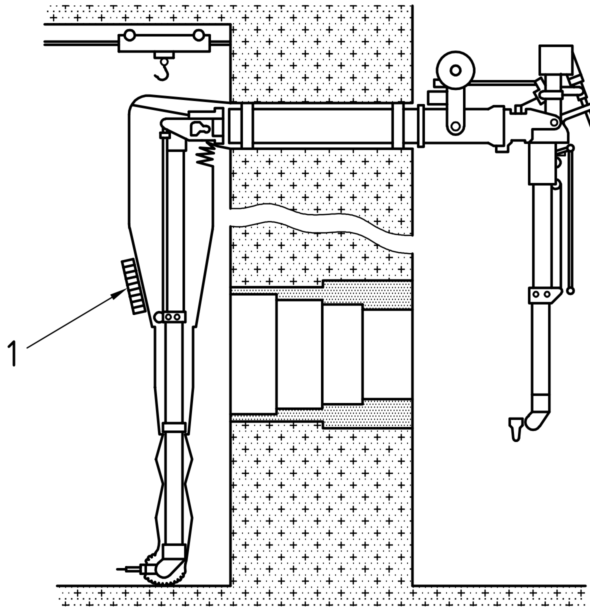
6.4 Design of the lower end of the gaiters

6.4.1 General

The nature of the work to be done and the constraints imposed by the manipulator model shall be considered in the design of the lower end of the gaiter. Parameters considered shall include the following.

6.4.2 Lateral and rotational motion required for the gaiter to accomplish the work to be done

The designers shall ensure that the gaiters incorporate an adequate number and disposition of bellows segments to accommodate the full movement possible in each degree of freedom (i.e. motion) of the slave arm, with special attention to combinations of extreme movements. It shall be ensured that, at the extremes of the movements required, the material of the gaiter(s) is nowhere strained close to its elastic limit, making due allowance for ageing effects which may be accelerated by the working atmosphere, the presence of gritty particulates for elevated operational temperature, etc.



Key

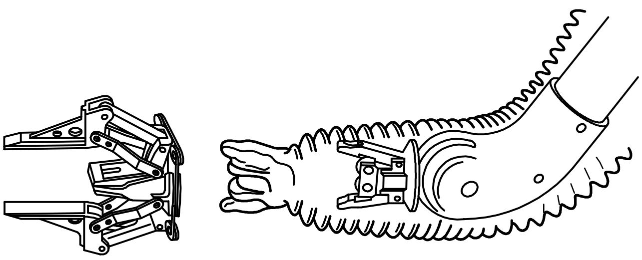
1 HEPA filter

Figure 16 — Principle of addition of a HEPA filter on a leak-tight gaiter

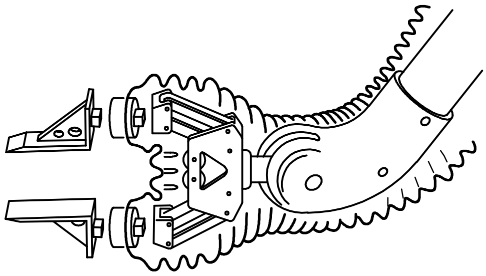
6.4.3 Forces placed upon the gaiter during operation, with respect to lifting and rotational movement and the mechanical protection of the gaiters.

Examples shown in Figure 17 b) and c) are suitable for application of a direct force. The example shown in Figure 17 a) shall be used with caution. The gaiter may be damaged while connecting the end-effector (tongs or tool) to the slave arm, and the material of the gaiter remains in the load path of the applied forces.

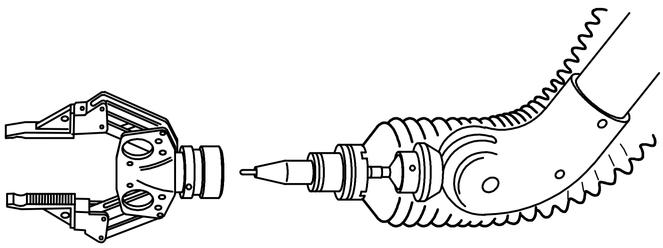
The example shown in Figure 18 applies when a protection gaiter is used.



a) Gaiter with disconnectable half-tong

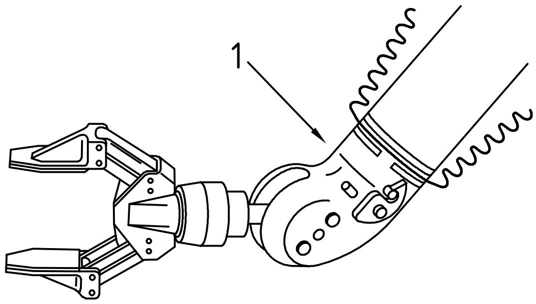


b) Gaiter with removable jaws



c) Gaiter with removable tongs

Figure 17 — Termination of a leak-tight gaiter at the tongs



Key

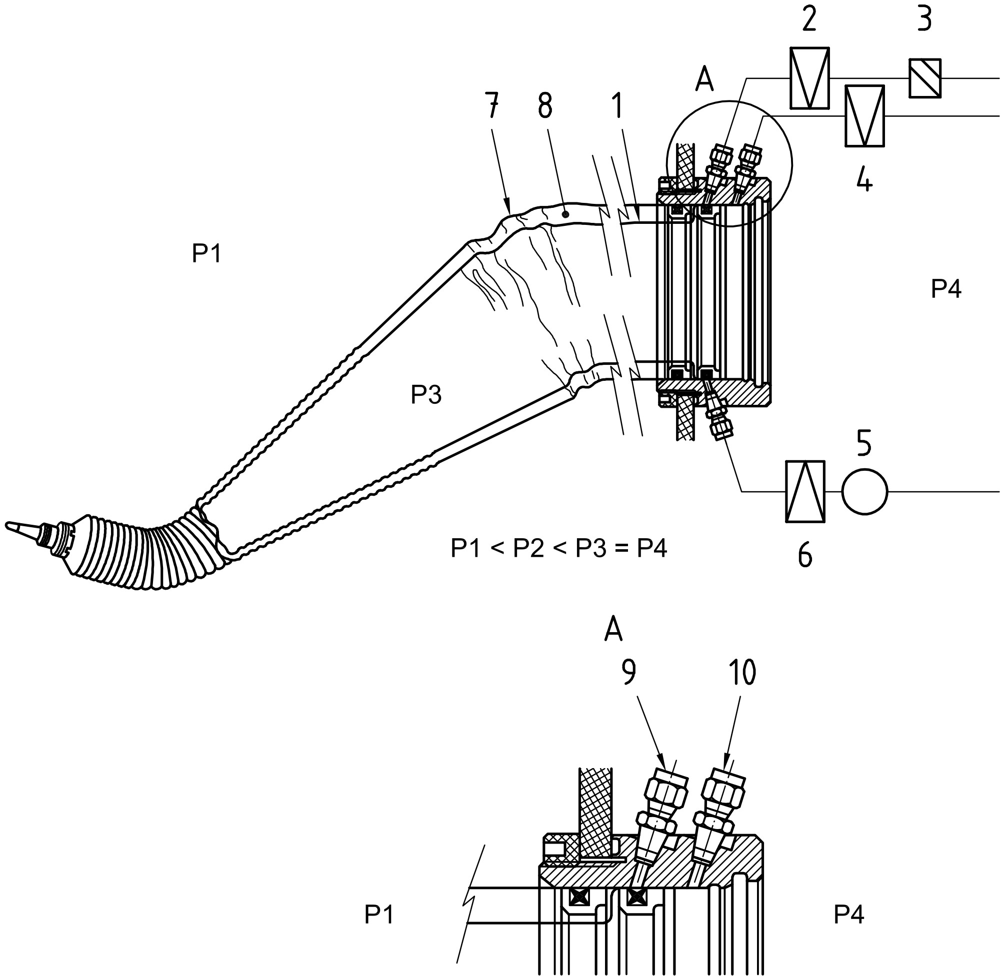
1 disconnectable wrist

Figure 18 — Termination of a protection gaiter at the tongs

6.5 Special case of double gaiters

Double gaiters may be used when a high-purity internal atmosphere in the containment enclosure is required (e.g. inert gases containing only traces of impurities of H_2O or O_2) or in the case of high α contamination (see Figure 19).

The double gaiters are fitted on two support rings, situated one behind the other, and mounted on a specially profiled enclosure ring (an enclosure ring with two or three grooves, see ISO 11933-1). At the tongs side, double gaiters are mounted in the same way as single gaiters. The use of a double-gaiter system allows a purge of the intermediate atmosphere. The space between the two gaiters is to be filled with the same gas as that desired in the containment enclosure.



Key

1 internal gaiter
2 HEPA filter
3 reservoir regulated to P2
4 HEPA filter on intermediate purge gas-line at pressure P3
5 manometer
6 HEPA filter
7 external gaiter
8 inter-sleeve pressure P2
9 circuit of inert gas
10 intermediate purge
P1 internal-enclosure pressure
P4 operator-side pressure

Figure 19 — Design of a double gaiter with intermediate purge

Maintaining a negative pressure between the two gaiters permits the detection of any leaks arising in either one of them, and the safe replacement of the leaking one. Such a double-gaiter system also reduces the risk of contamination of the slave arm.

The technique for replacement of a double-gaiter assembly is similar to that for a simple gaiter. During this procedure, the volume between the old and the new double-gaiter assembly is purged using the gas line marked 10 in Figure 19).

6.6 Replacement of manipulator gaiters

6.6.1 Leak-tight gaiters (see Figure 20)

The gaiter-replacement procedure shall be achieved as follows:

— the exchange begins by removing the jaws of the tongs, or the whole tongs, in the hot cell; the end of the gaiter is then also separated from the manipulator arm;

— subsequently, from outside the hot cell, the manipulator slave arm is removed, keeping the hot cell leak-tight [see Figure 20 a)];

— the gaiter is then exchanged, without breaking the leak-tightness of the connection, using the method appropriate to the kind of seal; for gaiters described above (methods 1 and 2 of 6.1.3), an ejection device shall be designed to suit the support ring and the through-wall tube characteristics [see Figure 20 b)];

— finally, the manipulator is replaced and the forward end of the slave arm is connected to the new gaiter; the jaws (or tongs assembly) are then re-installed.

NOTE A special ejection device is necessary to change a double-gaiter system properly.

6.6.2 Protection gaiters (see Figure 21)

Changing a protection gaiter is not possible in an active hot cell; an assistance cell or a dedicated maintenance work-shop must be used after removal of the whole slave arm. The gaiters-replacement procedure shall be achieved in the following way.

— The exchange begins by disconnection of the slave arm from the connection tube [see Figure 21 a)]. It is necessary, to avoid damage during this procedure, to be sure that the lifting operation is performed strictly using the methodology and the lifting points indicated by the manufacturer.

— The replacement operation is performed in most cases without direct visibility by the operator. The addition of a suitable viewing system is, however, recommended, such as mirrors or a TV camera. To facilitate the removal of the arm, the overall hot-cell design must make allowances for the operating volume necessary for the installation and the access requirements of the handling equipment.

— The slave arm is transported to a nearby maintenance cell using a special lifting device or to the maintenance work-shop by means of a transportation cask.

— The replacement of the connection tube, when necessary [see Figure 21 b)], is performed in the horizontal direction from the operator side towards the hot cell, the new connection tube progressively pushing ahead the old one, which is introduced into a special container installed in the hot cell.

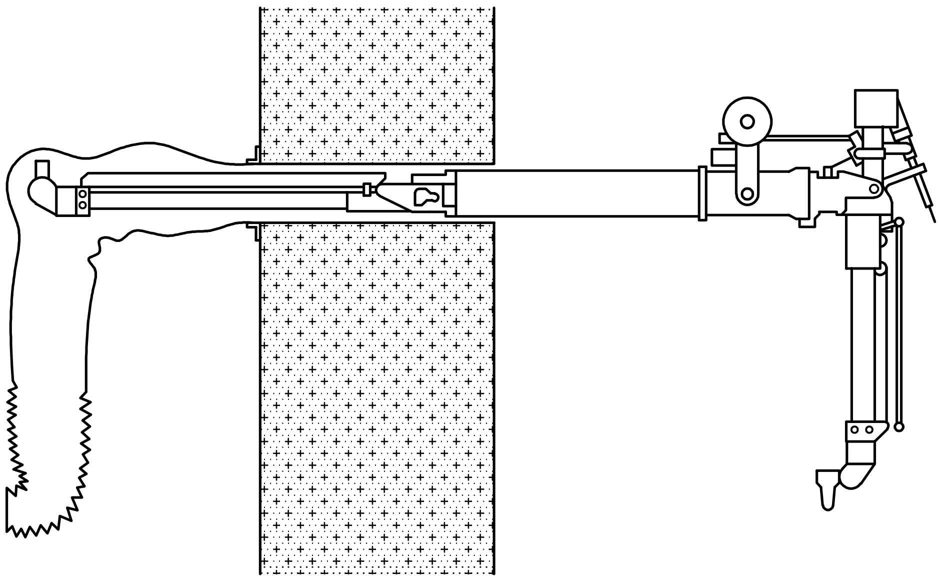
— Finally a new slave arm, or the old one after appropriate maintenance or decontamination, is connected onto the new connection tube, in a reverse manner.

Bearing in mind the tasks to be performed with the master-slave manipulator, it may be advantageous to choose a type of slave arm equipped with a wrist joint which can be disconnected by remote control. This solution allows:

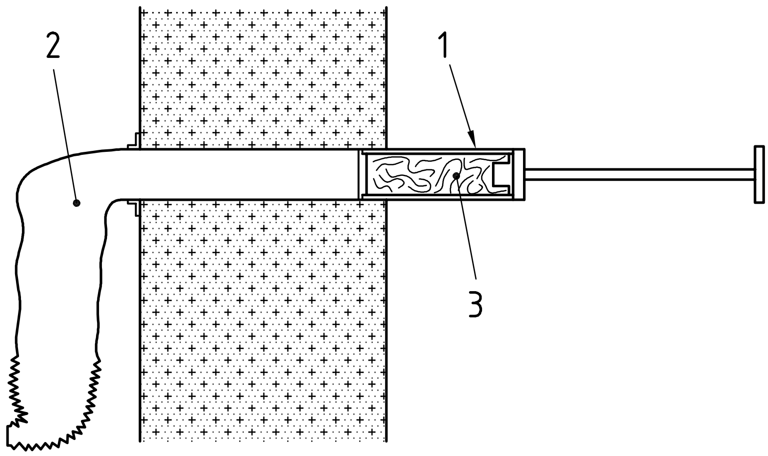
— a relatively small sub-assembly which may be strongly contaminated and/or irradiated to be left in the hot cell, and

— a standard replacement by remote operation of this sub-assembly (which may be subject to rapid degradation in a hostile atmosphere).

CAUTION — These replacement procedures are those recommended to be used when a master-slave manipulator equipped with a disconnectable telescopic arm is used, even if the design of this type of equipment permits the front (operator-side) removal.



a) Removal of slave-arms from the operator side



Key

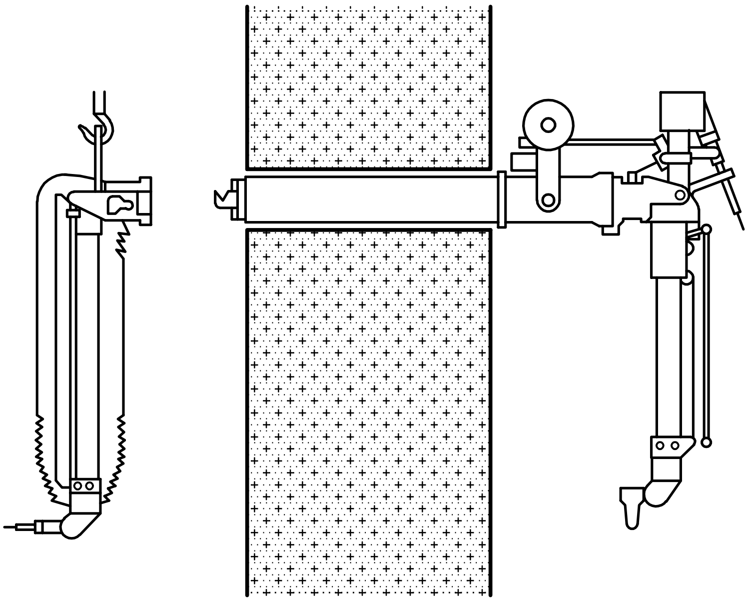
1 ejection device

2 used gaiter

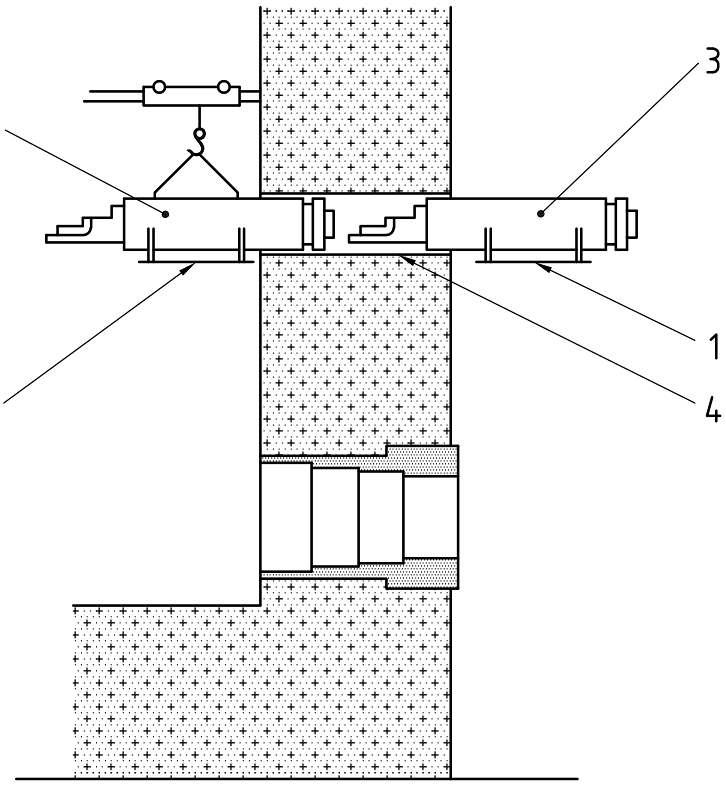
3 new gaiter

b) Exchange of gaiters using an ejection device

Figure 20 — Usual method of replacement of a leak-tight manipulator gaiter



a) Disconnection of the slave arm



Key

1 receptacle

2 old connection tube

3 new connection tube

4 through wall-tube

b) Replacement of the connection tube

Figure 21 — Usual method of replacement of a manipulator equipped with a protection gaiter on a connection tube

6.6.3 Special attention

Both of the exchange procedures described above break the radiation protection shielding (γ or neutron shielding). To avoid this risk, the radiation sources have to be removed from the hot cell before starting the operation, or a special shielded plug has to be mounted on the through-wall tube.

6.7 Attachment of leak-tight manipulator gaiters

The attachment of leak-tight manipulator gaiters is achieved using support rings which are mounted on enclosure rings.

The standard dimensions of the enclosure rings and support rings shall be in accordance with ISO 11933-1.

7 Accessories

7.1 Connection tubes with shielding

In order to ensure additional gamma or neutron shielding, connection tubes may be equipped with the following components:

— high-density material (lead, stainless steel, cast iron, etc.) which contributes additionally to the gamma flux attenuation;

— neutron-absorbing material (borated polyethylene, compressed wood, etc.), which confers additional neutron flux attenuation.

These materials are usually provided in the form of rings inserted into the connection tube. This kind of protected connection tube greatly reduces the direct shine-path for radiation.

In circumstances where very strong neutron or gamma sources are to be encountered, one or more steps in the through-wall tube diameter may be inserted to improve the shielding continuity.

7.2 Balancing

The no-load balancing of a master-slave manipulator, in all positions of the range of movements, is an important characteristic, because it allows the operator to perform a task with essentially the same dexterity in different positions and with minimal fatigue.

The balancing is generally performed with adjustable counterweights installed on the master arm, and sometimes also on the slave arm.

A master-slave manipulator can be designed with two types of balancing:

— a basic balancing (no-load, optimized in the reference position of all motions);

— extended balancing, to achieve no-load balancing in all effective positions.

In the case of master-slave manipulators with disconnectable arms, a master arm can be implemented with slave arms of various lengths. The balancing shall be then adjusted, e.g. by adding or removing appropriate weights foreseen for this purpose.

7.3 Terminations

7.3.1 Slave-arm terminations

A pair of tongs or a gripper assembly generally terminates the slave arms. Such assemblies shall be readily disconnectable from the slave arm. The disconnection is performed in the hot cell by means of a disconnection station.

The tongs are linked to the slave-arm wrist via an adaptor on the wrist-joint (see Figure 22). In the case of a fixture with a leak-tight gaiter, the tongs are linked to the leak-tight connection assembly.

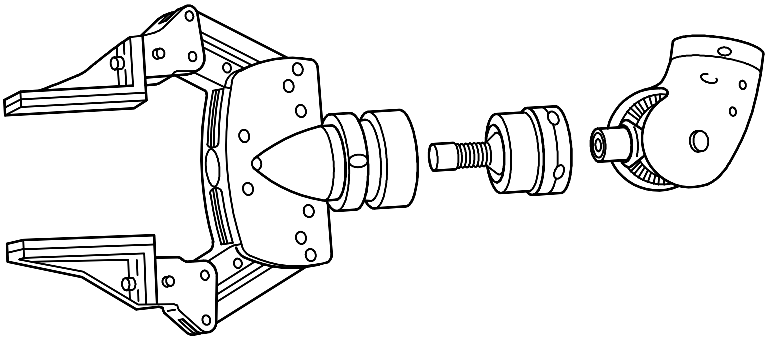


Figure 22 — Principle for the connection of disconnectable tongs

The tongs can be supplied:

— with disconnectable jaws, or

— without disconnectable jaws.

If a master-slave manipulator has to be employed in a production facility, the jaws (and/or the entire tongs or gripper assembly) are frequently used in the course of typical mechanical handling processes and are generally exposed to a high level of irradiation and contamination. They cannot be readily decontaminated. Consequently, they are often defined as consumable elements. In such cases, types with disconnectable jaws are likely to be more cost-effective overall.

Standard jaws for master-slave manipulator tongs have to follow the dimensions indicated in Figure 23. Other dimensions are available.

Dimensions in millimetres

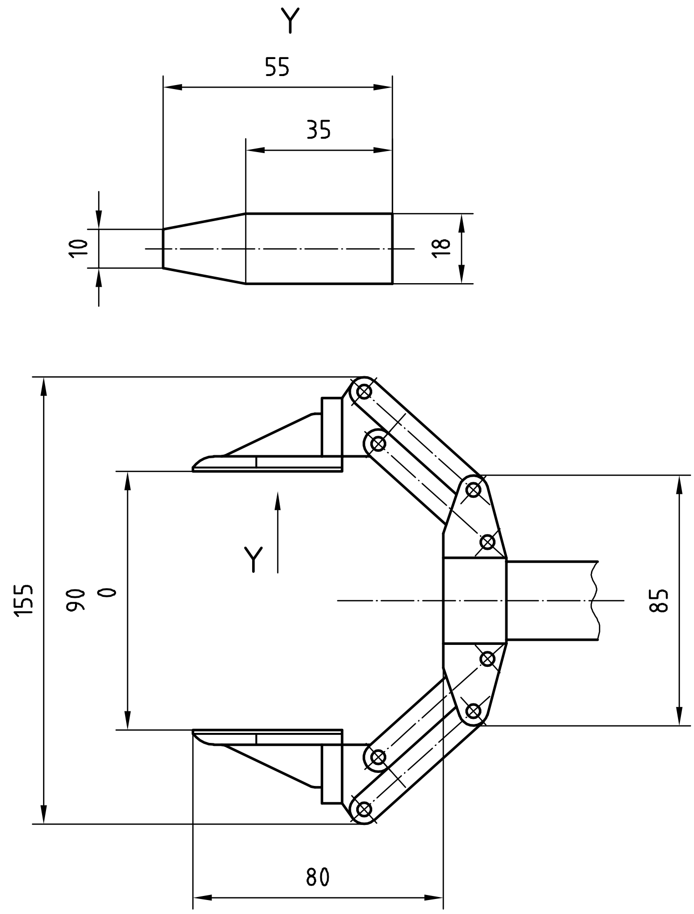


Figure 23 — Dimensions of jaws

7.3.2 Master-arm terminations

The end of the master arm is equipped with a handle, which can receive either:

— a force handle, or

— the control box for the electrically actuated motions, where present.

7.4 Electricity supply

Mechanical master-slave manipulators should be supplied with DC electricity at a low voltage, in accordance with the local regulatory requirements.

7.5 Various

7.5.1 General

The main accessories necessary for the implementation of mechanical master-slave manipulators are the following.

7.5.2 Ejection device

An ejection device is a mechanism allowing the ejection of a leak-tight gaiter and its replacement by a new gaiter without breaking the hot-cell containment (see ISO 11933-1 and ISO 11933-2).

There are various types of ejection devices for the implementation of gaiters mounted on standard support rings, which differ regarding:

- the diameter of the enclosure ring,
- the type of enclosure ring (with a single, double or triple groove),
- the thickness of the shielded wall, or
- the type of gaiter (e.g. a single- or double-gaiter system).

Ejection devices can be of the mechanical or pneumatic type.

7.5.3 Disconnection station

A disconnection station is a mechanical device installed inside the hot cell and used to connect or to disconnect, in remote operation, the different components of a master-slave manipulator (especially the wrist-joint and the tongs). It is a specific device designed to complement the master-slave manipulator work-station.

The installation of a disconnection station in a hot cell requires a suitable working area. Its operation is generally accomplished using a hook or crane. Annexe B describes some typical disconnection stations frequently in use.

Annex A
(normative)

Method of measurement of no-load forces and torques, flexures and backlashes

A.1 General

A.1.1 Introduction

The determination of no-load forces and torques, flexures and backlashes shall be carried out using the following procedure.

For the purpose of this procedure, the reference and the initial positions of the mechanical master-slave manipulator shall be defined.

A.1.2 Reference position

This corresponds to the position of the master-slave manipulator, when all the motions are in the positions indicated by the manufacturer. This position is defined for all types of manipulators in an X, Y and Z coordinate system, referred to the position of the first articulation (shoulder joint).

A.1.3 Initial position

This corresponds to the position required in order to carry out a specified test. This position is usually the reference position.

A.2 Measurements of no-load forces[3)]

A.2.1 General principle

A.2.1.1 Mechanical master-slave manipulators with telescopic arms

For this type of manipulator, master and slave arms shall be held in the vertical position, half-way between the extremities of the manual motion in the Z direction with any electrical *Z*-motion fully retracted. The other motions are to be placed in the reference position, with the braking systems released.

A.2.1.2 Mechanical master-slave manipulators with articulated arms

For this type of manipulator, master and slave forearms shall be held in a vertical position with the upper arms at an angle to be specified by the manufacturer, to achieve the normal operational reference position. The other motions shall be placed in the reference position, with the braking systems released.

A.2.2 Preparation of the equipment

Before carrying out the measurement, the following precautions shall be taken or verifications made.

---

3) In the present test method, when measuring the no-load forces and torques, residual balancing errors and the spring tension of the tong are not taken into account.

— The tension in the cables, tapes or chains shall be specified for the tests.

— Lubricants shall be as specified by the manufacturers.

— The ambient temperature during the test shall be recorded and the equipment shall be identified.

— The position of the master-slave manipulator shall be in the initial position as defined in A.1.3.

A.2.3 Methodology

A.2.3.1 General

By means of a dynamometer acting on the master arm at the initial position defined in A.1.3, a force necessary to move the master arm by about 100 mm or 15° shall be applied. The reading of the dynamometer shall be taken during a slow steady motion covering the 100 mm or 15° movement, and shall be repeated in the opposite direction, with the recorded result being the average of the results of the two directions.

A.2.3.2 *X*-motion

The point of attachment of the dynamometer and direction of the force shall be on the wrist of the master arm, at a distance d_x from the axis of the wrist to be specified by the manufacturer, the force exerted being both normal to the master arm and held within the ZX-axis plane throughout the measurement (see Figure A.1).

The wrist-rotation motion shall be locked during this test to ensure that the *X*-motion tested is solely a result of the principle *X*- (and *Z*-) motions of the arm.

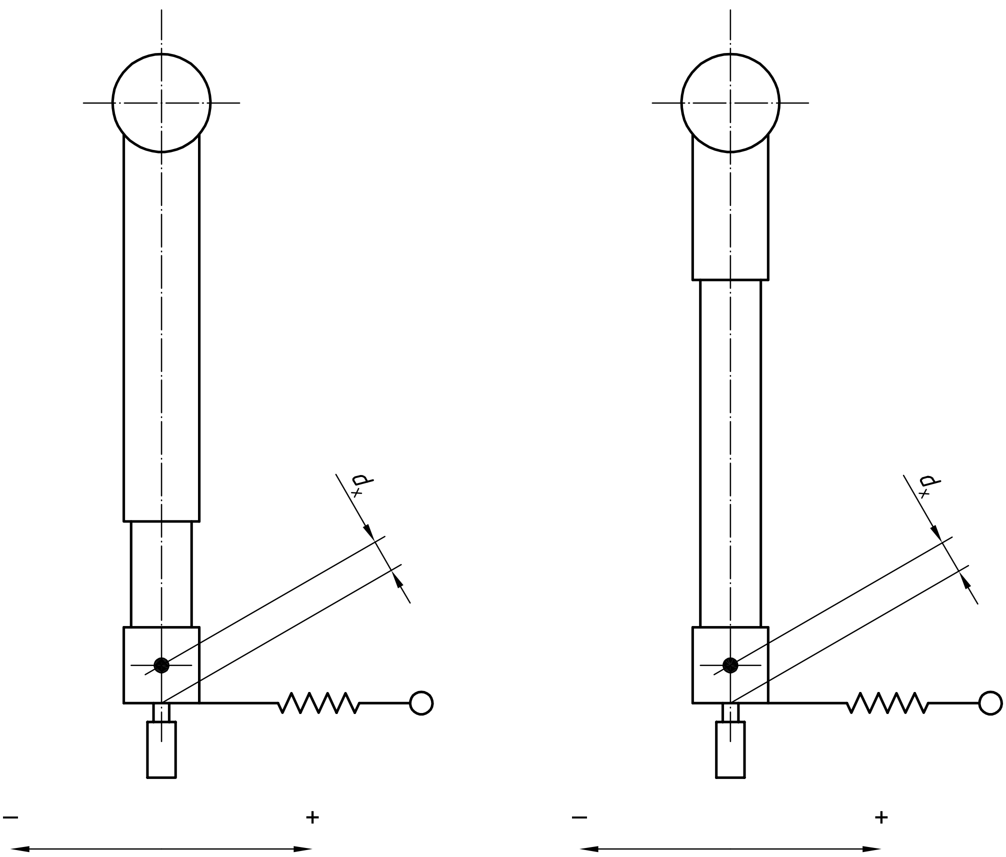


Figure A.1 — Measurement of no-load forces for the *X*-motion

A.2.3.3 *Y*-motion

In the case of manipulators with articulated arms, this part of the test shall be carried out twice, once with the shoulder articulation blocked and a second time with the elbow articulation blocked instead.

The point of attachment of the dynamometer shall be on the wrist of the master arm, at a distance d_y from the axis of the wrist to be specified by the manufacturer, the force exerted being both normal to the master arm and held within the ZY-axis plane throughout the measurement (see Figure A.2).

The wrist rotation motion shall be locked during this test to ensure that the *Y*-motion tested is solely a result of the principle *Y*- (and *Z*-) motions of the arm.

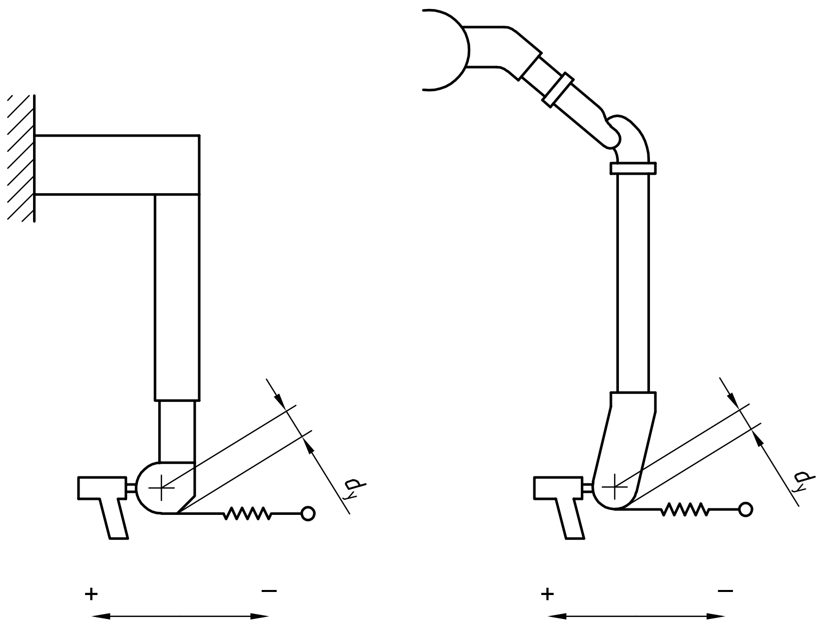


Figure A.2 — Measurement of no-load forces for the *Y*-motion

A.2.3.4 *Z*-motion

The point of attachment of the dynamometer and direction of the force shall be on the wrist of the master arm, with the force exerted remaining parallel to the master arm (at the forearm for manipulators with articulated arms) throughout the measurement (see Figure A.3).

For mechanical master-slave manipulators with articulated arms, the shoulder and elbow rotations shall be free.

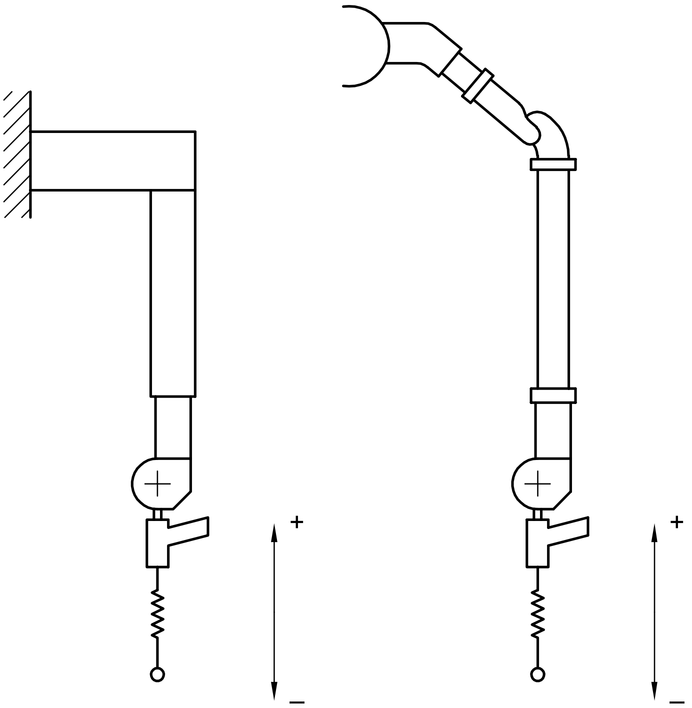


Figure A.3 — Measurement of no-load forces for the Z-motion

A.2.3.5 α-Motion

The points of action of the two forces comprising the couple which applies the torque shall be on the operation handle at a well-determined position, to allow an accurate torque (force × distance) value to be recorded (see Figure A.4).The couple shall be applied within the YZ plane.

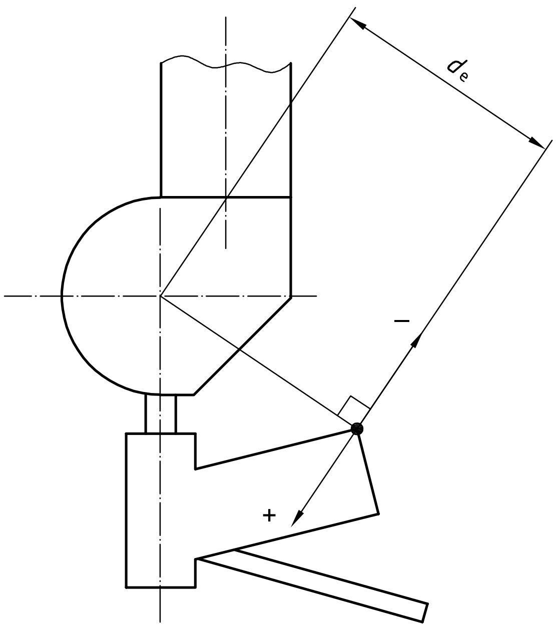


Figure A.4 — Measurement of no-load forces for the α-motion

A.2.3.6 β-Motion

The points of action of the two forces comprising the couple which applies the torque shall be on the operation handle at a well-determined position, to allow an accurate torque (force × distance) value to be recorded (see Figure A.5). The couple shall be applied within the XZ plane.

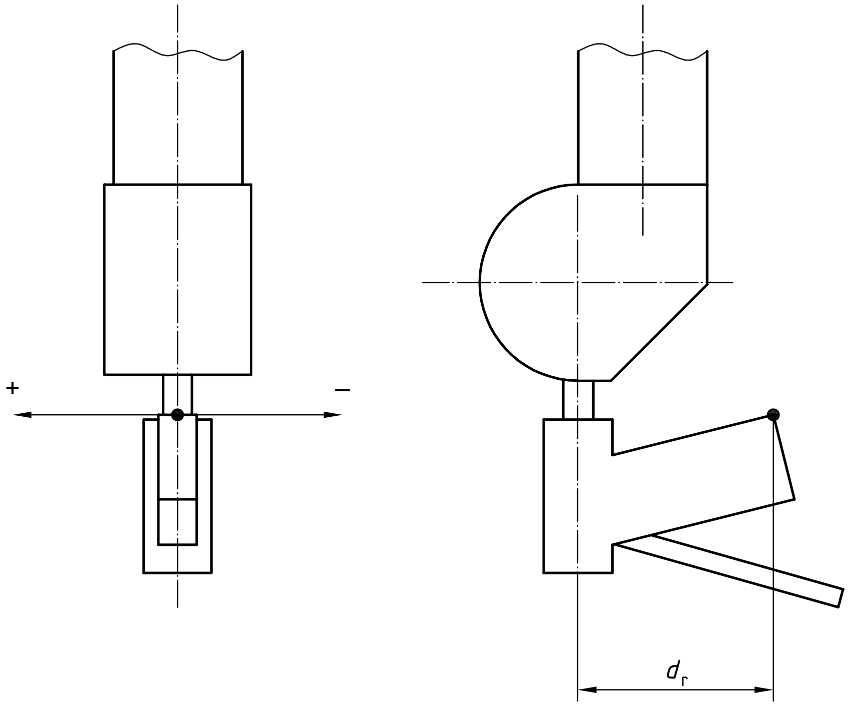


Figure A.5 — Measurement of no-load forces for the β-motion

A.2.3.7 γ-Motion

The points of action of the two forces comprising the couple which applies the torque shall be on the operation handle at a well-determined position, to allow an accurate torque (force × distance) value to be recorded (see Figure A.6). The couple shall be applied within the XY plane.

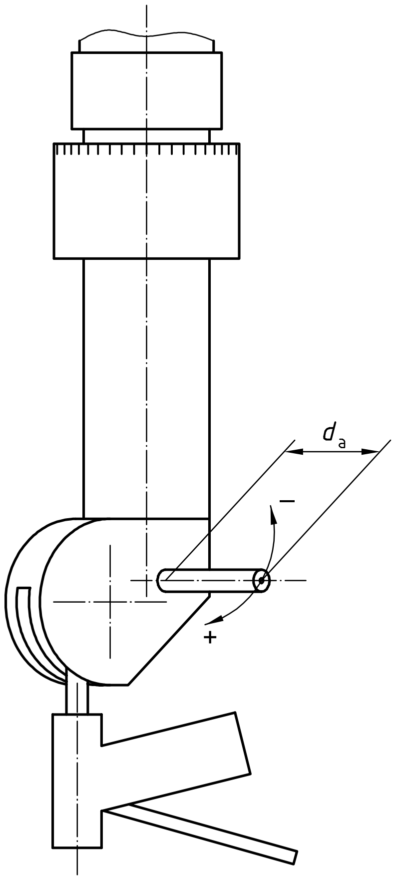


Figure A.6 — Measurement of no-load forces for the γ-motion

A.3 Flexure and backlash measurements

A.3.1 General principle

The slave arm is to be in a vertical position and, if possible, the master arm is also vertical. The tongs are perpendicular to the slave arm, the gripping motion operating in a horizontal plane.

— **For a mechanical master-slave arm with telescopic arms**, to half-way between the extremes in the Z direction manually (the electrical *Z*-motion has to be completely retracted if it exists). The other motions are to be placed in the reference position, with the braking systems released.

— **For a mechanical master-slave arm with articulated arms**, in the reference position for all the motions, with the braking systems of the motion not under test released.

A.3.2 Methodology

A.3.2.1 General

Use a graduate plate and an indicator as shown in the following drawings.

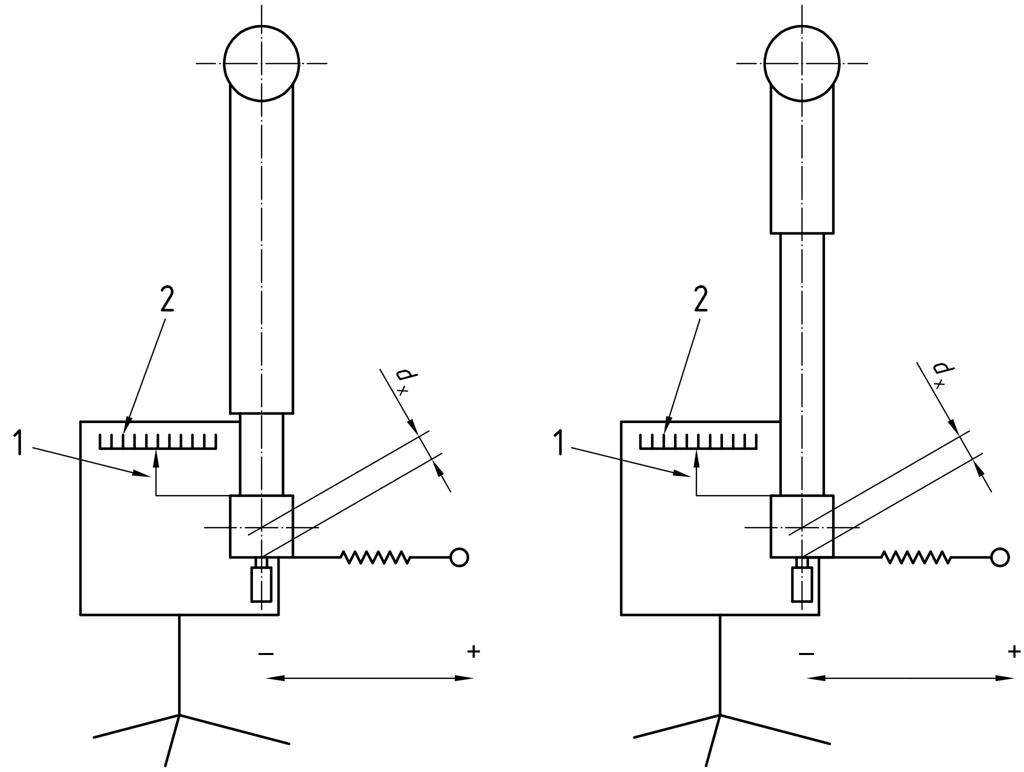
Progressively release the test force until it becomes equal to zero and note the values indicated on the graduated plate at the extrema. Repeat the measurement three times and record the resulting average extremum values for each motion tested.

Carry out a second series of measurements, now exerting the test force in the opposite direction. The flexure (including the backlash) is defined as the nugatory motion in one direction only, and accordingly corresponds to half the sum of the averages of the results obtained for the test traction in the two directions.

The backlash alone (i.e. the slack) is defined as half the sum of the averages of the results obtained with the test traction just brought to zero in the two directions.

A.3.2.2 *X*-motion

The point of attachment of the dynamometer shall be on the wrist of the master arm, at a distance d_x from the axis of the wrist to be specified by the manufacturer, along with the direction of the force. The graduated plate shall be placed in a vertical plane close to the wrist, with the indicator fixed to the wrist (see Figure A.7).



Key

1 indicator

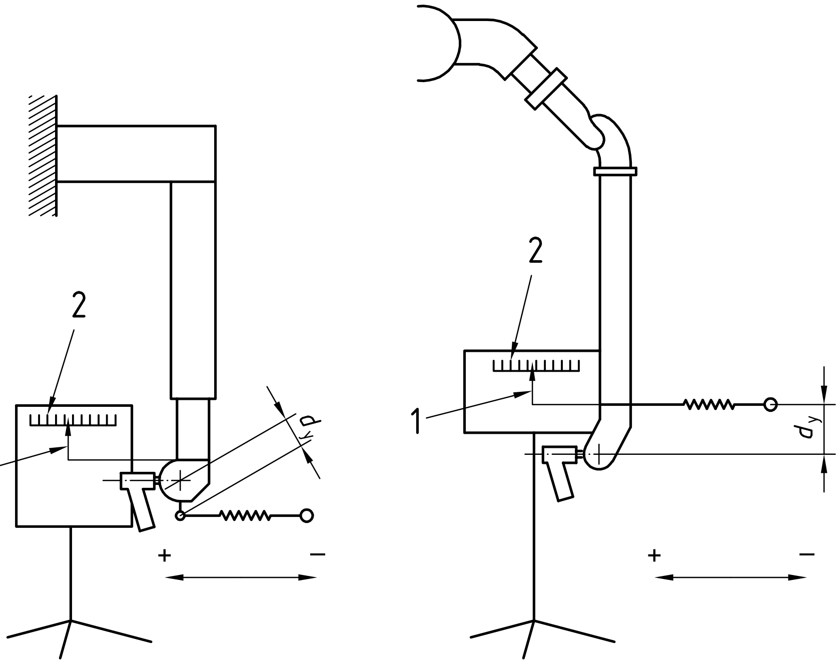
2 graduated plate

Figure A.7 — Flexure and backlash measurements for the *X*-motion

A.3.2.3 *Y*-motion

The point of attachment of the dynamometer shall be on the wrist of the master arm, at a distance d_y from the axis of the wrist to be specified by the manufacturer, along with the direction of the force. The graduated plate shall be placed in a vertical plane close to the wrist, with the indicator fixed to the wrist (see Figure A.8).

For mechanical master-slave manipulators with articulated arms, the test is to be carried out for each *Y*-motion, i.e. once while blocking the shoulder articulation, and once while blocking the elbow articulation.



Key

1 indicator

2 graduated plate

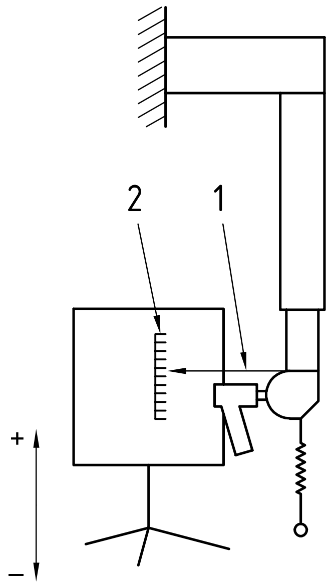
Figure A.8 — Flexure and backlash measurements for the *Y*-motion

A.3.2.4 *Z*-motion

This test is only relevant for mechanical master-slave manipulators with telescopic arms.

The point of attachment of the dynamometer shall be on the wrist of the master arm. The graduated plate shall be placed in a vertical plane close to the wrist, with the indicator fixed to the wrist (see Figure A.9).

For mechanical master-slave manipulators with articulated arms, the total *Z*-motion is the result of the combination of the shoulder and the arm rotation, measured during the *Y*-motion test mentioned above.



Key

1 indicator

2 graduate plate

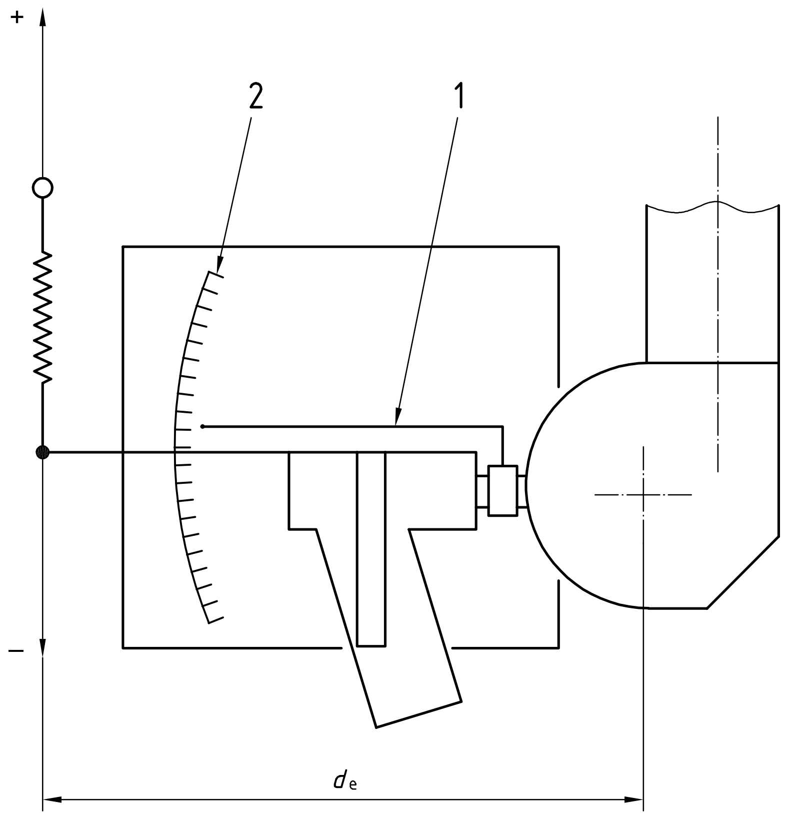
Figure A.9 — Flexure and backlash measurements for the Z-motion

A.3.2.5 α-Motion

It shall be verified that the rigid support of the tong assembly prevents twisting of this assembly in any direction. It is also advisable to clamp the XYZ position of the wrist so that the forces used to create the torques on the handle do not create linear motions confusing the angular measurements.

The point of attachment of the dynamometer shall be on a lever specially clamped to the handle assembly for these tests, this lever being maintained in the reference plane of the handle, at a distance d_e from the axis of the wrist of the master arm to be specified by the manufacturer.

The graduated plate shall be placed in a vertical plane close to the wrist, with the indicator fixed to the handle (see Figure A.10). The test force shall be specified by the manufacturer.



Key

1 indicator

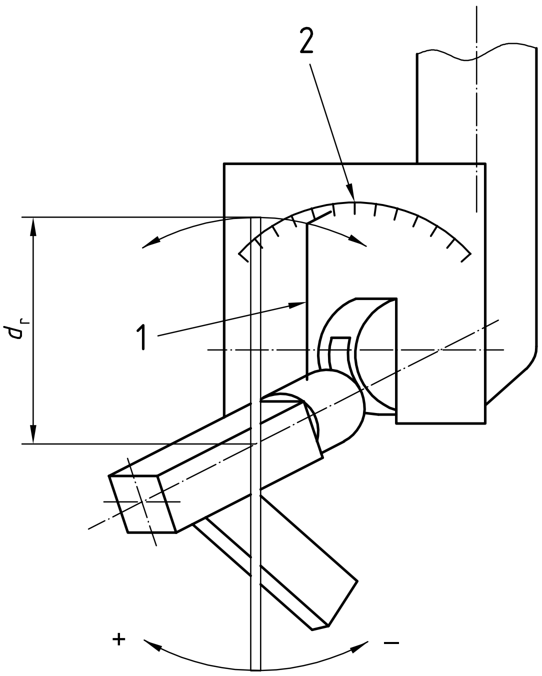
2 graduated plate

Figure A.10 — Flexure and backlash measurement for the α-motion

A.3.2.6 β-Motion

Two dynamometers are necessary, one at each end of the test lever. The dynamometers are to be placed at a distance d_r from the rotation axis of the handle, to be specified by the manufacturer.

The lever is to be fixed in the plane of the handle, in a perpendicular position compared to the rotation axis of the handle. The graduated plate shall be placed in vertical position close to the wrist, and the indicator fixed to the handle (see Figure A.11).



Key

1 indicator

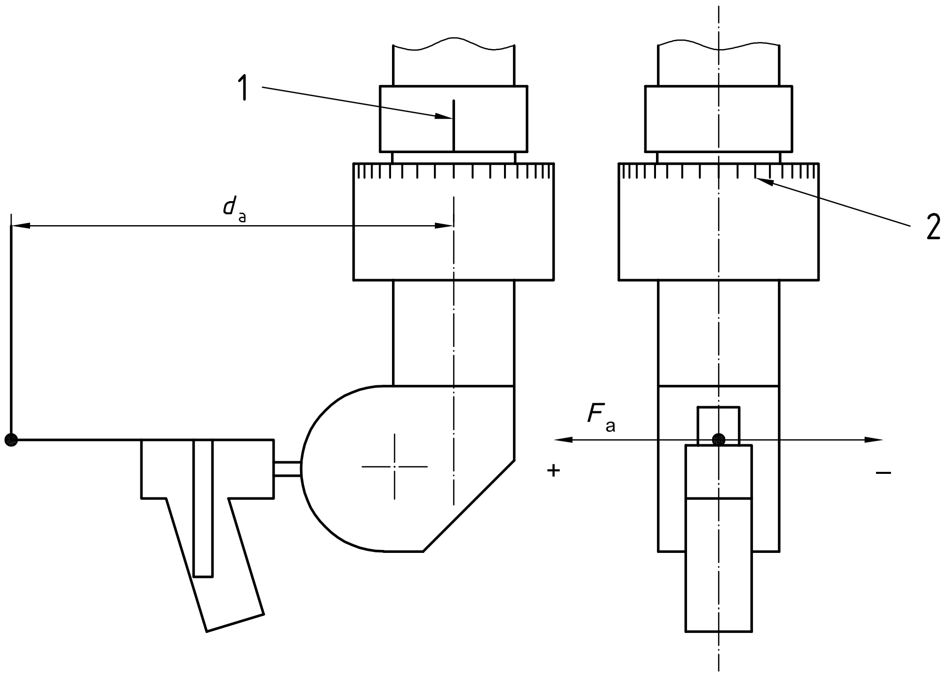
2 graduated plate

Figure A.11 — Flexure and backlash measurement for the β-motion

A.3.2.7 γ-Motion

The point of attachment of the dynamometer shall be on the lever, while the lever is to be maintained in the plane of the handle, at a distance d_a from the axis of the wrist of the master arm to be specified by the manufacturer.

The graduated plate shall be placed respectively on the forearm for mechanical master-slave manipulators with articulated arms, and on the arm for mechanical master-slave manipulators with telescopic arms. The indicator is to be fixed to the wrist (see Figure A.12). The test force shall be specified by the manufacturer.



Key

1 indicator

2 graduated plate

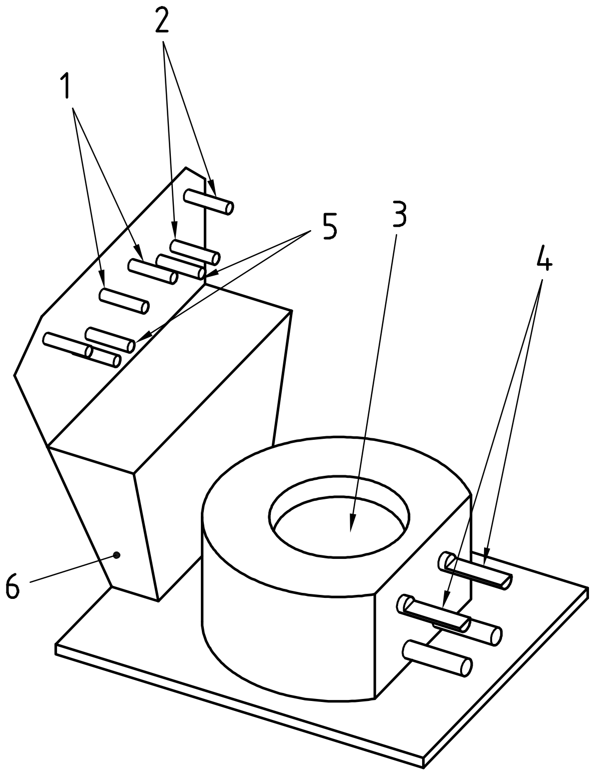
Figure A.12 — Flexure and backlash measurement for the γ-motion

Annex B
(informative)

Typical disconnection stations

B.1 Model A

Figure B.1 gives an example of a disconnection station for tongs.



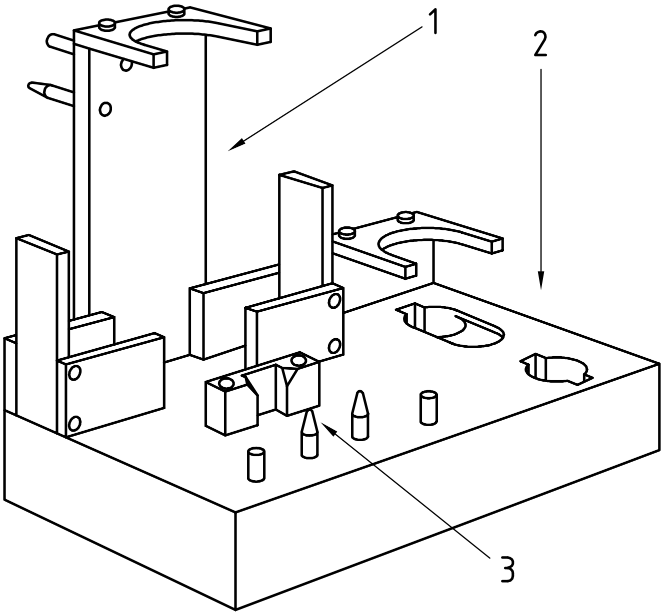
Key

1 pins for uncoupling of tongs
2 pins for uncoupling of jaws
3 gaiter coupling device
4 gaiter uncoupling device
5 pins for receiving jaws
6 pocket for tongs

Figure B.1 — Disconnection station for tongs (first model)

B.2 Model B

Figure B.2 gives another example of a disconnection station for tongs.



Key

1 zone of disconnection of the tongs
2 zone of disconnection of the leak-tight coupling
3 zone of disconnection of the jaws

Figure B.2 — Disconnection station for tongs (second model)

B.3 Model C

Figure B.3 gives another example of a disconnection station for a wrist-joint.

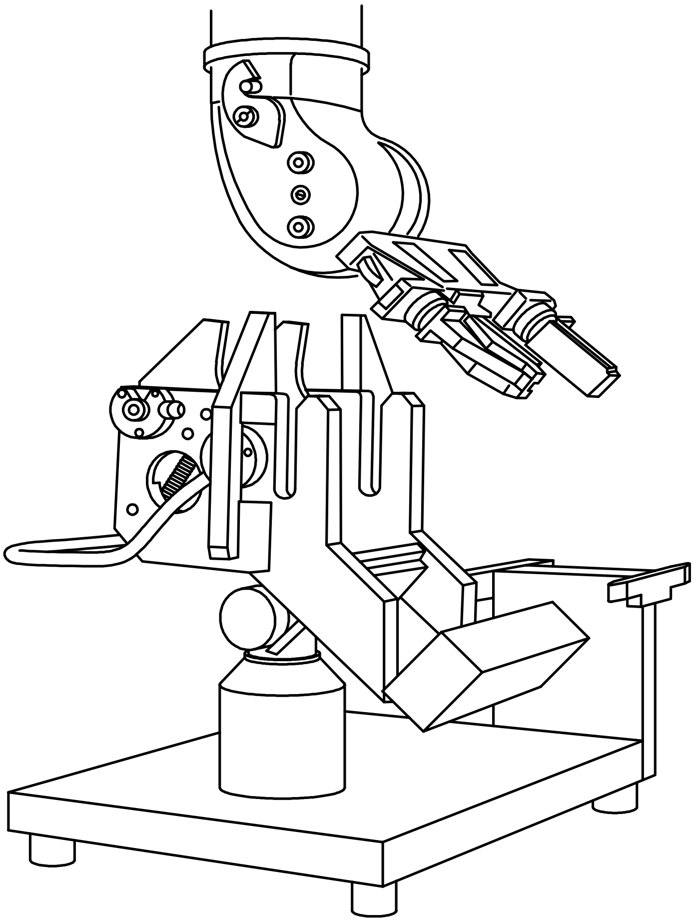


Figure B.3 — Disconnection station for a wrist-joint

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