INTERNATIONAL STANDARD

ISO 17874-4

First edition
2006-01-15

Remote handling devices for radioactive materials —

Part 4:
Power manipulators

Dispositifs de manipulation à distance pour matériaux radioactifs

Partie 4: Télémanipulateurs télécommandés

Reference number
ISO 17874-4:2006(E)

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Published in Switzerland

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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 17874-4 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 4: Power manipulators*

— *Part 5: Remote handling tongs*

A Part 3, *Electrical master-slave manipulators*, is under study.

Introduction

This part of ISO 17874 deals with power manipulators used for nuclear applications. These manipulators consist mainly of multipurpose remote handling devices.

These devices replace hands and arms and even light hoists, depending on the model used, in areas inaccessible to personnel (mostly behind shielding walls).

Power manipulators were originally developed for hot cells designed for research and development in fuel elements for nuclear power reactors. They are now also in widespread use in other nuclear installations, such as plants for reprocessing of fuel elements, waste treatment stations, and decommissioning of nuclear facilities.

Alternative manipulators used in these fields and resulting in a wide variety of different designs are considered to be skill in an emergent phase or applied uniquely in special circumstances and are not addressed further in this current edition of this standard.

Power manipulators are sometimes modified or especially designed for non-nuclear applications. This part of ISO 17874 does not address the special requirements of any of these applications. Although designers may not be taken advantage of standardized features and components from the nuclear sector to achieve efficient and cost-effective designs for other purposes where appropriate.

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

Remote handling devices for radioactive materials —

Part 4: Power manipulators

1 Scope

This part of ISO 17874 defines the main features of power manipulators for use in ionizing radiation fields. It outlines basic principles which relate to the design and testing of power manipulators for use behind shielding walls, mainly in hot cells.

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 2768-1:1989, *General tolerances — Part 1: Tolerances for linear and angular dimensions without individual tolerance indications*

ISO 11933-5:2002, *Components for containment enclosures — Part 5: Penetrations for electrical and fluid circuits*

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
axis
directions of a Cartesian coordinate system defined from the operator 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 to the ceiling of the shielded cell.

3.2
arm
⟨manipulator⟩ component reproducing effectively the functions of an human arm, respecting in most cases the same distribution and corresponding articulations

NOTE Corresponding articulations are shoulder pivot, upper arm, elbow pivot, forearm, wrist pivot, etc.

3.3
mechanical arm
arm of a power manipulator being able to execute positioning and orientation motions and equipped with an end-effector

3.4
shoulder hook
device similar to a crane hook attached near the shoulder pivot

3.5
grip hook
end-effector with a linear motion for lifting and handling an object

3.6
disconnection
mechanical operation allowing the separation of two assembled component

EXAMPLE Disconnection of the mechanical arm from the transporter.

3.7
jaws
components fixed on the end of the tongs, which facilitates the handling of an object

NOTE The jaws can be disconnectable.

3.8
operating volume
space in which the operation of tongs are possible, considering all the positions in which the different components of the slave arm of a manipulator can be moved

3.9
gaiter
specially profiled flexible sleeve designed to protect the mechanical arm and optionally also the telescope

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

3.10
drum manipulator
simplified power manipulator designed to transport and to stack radioactive waste drums

3.11
orientation motion
rotation motions around certain axes of the manipulator

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

3.12
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.

3.13
tongs
gripping device fixed at the end of the mechanical arm and consisting of an actuator assembly and jaws

3.14
handle
component gripped by the operator, facilitating the control of the movements of the manipulator and fixed at the operating consol

3.15
transporter
kinematical system for moving and positioning the mechanical arm within the operating volume

3.16
power manipulator
manipulator driven by electrical motors (open loop in position)

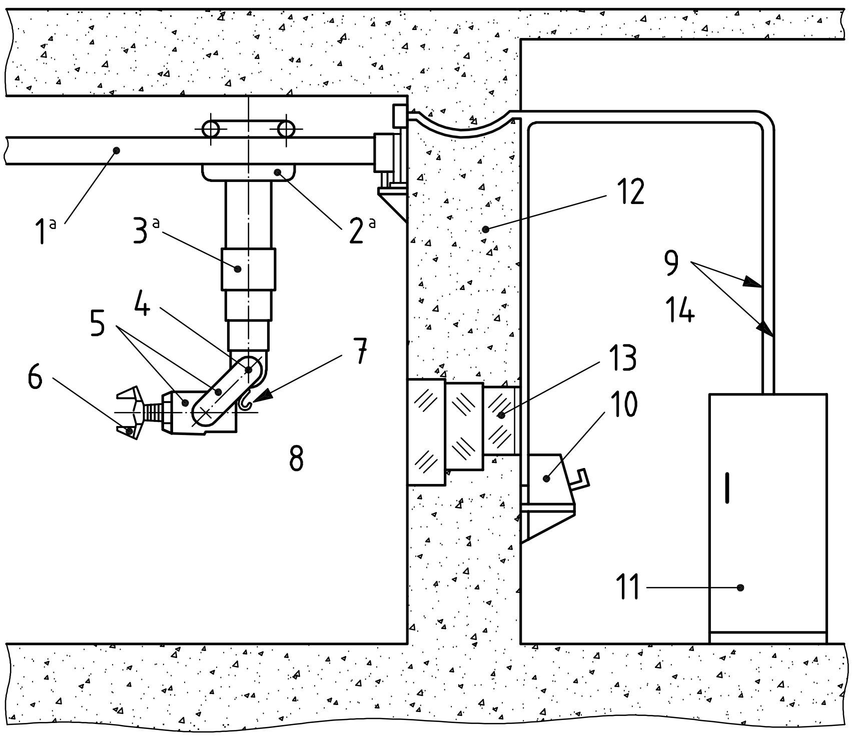
4 Applications of power manipulators

Power manipulators are used inside buildings, especially in hot cells. They consist of a mechanical arm mounted on a transporter running on rails, or sometimes on a remotely controlled vehicle. Transporters on rails usually consist of a movable bridge, a carriage and a vertical telescope (see Figure 1). The arm can also be installed on a rail vehicle on the cell floor.

They allow, in most cases, the exertion of high forces and therefore the handling of heavy objects, typifying their application. Power manipulators can be used as the only remote handling devices, but in medium-sized and large hot cells they are generally used in combination with mechanical master-slave manipulators (see ISO 17874-2). Both categories assist each other.

The mobility gives the power manipulators a large working volume, which is not offered by 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.

The relatively low working speed is one of the disadvantages of power manipulators. In addition, they are not suitable for complicated tasks.



Key

1 movable bridge
2 carriage
3 telescope with hoist
4 shoulder pivot
5 articulated arm
6 tongs
7 shoulder hook
8 hot cell
9 transmission cable
10 operating console
11 control cabinet
12 shielding wall
13 shielding window
14 operating room

[a] The movable bridge, the carriage and the telescope with hoist constitute the transporter.

Figure 1 — Power manipulator — Design for hot cells

5 General features

A power manipulator, within the meaning of this part of ISO 17874-4, is an electric motor-driven handling device operated remotely using speed control achieved by switches or potentiometers and analogue control (traditionally) or digital control. As a general rule, it exhibits the following characteristics: it has an articulated mechanical arm which is located on a positioning system, called a transporter (see Figure 1).

The arm is in most cases fitted with a tong with parallel jaws, by means of which objects can be handled and forces and torques exerted. The tongs are to be arranged to rotate without limit. The tongs can be exchanged (in some cases remotely) for other gripper types (typically a grip hook) or mechanical or electrically driven tools by means of in-cell fixtures. With the aid of a lifting hook on the articulated shoulder (called a shoulder hook), it is possible to lift substantially heavier objects than can be lifted with the tongs [see Figure 2 a)].

The transporter in most cases consists of a movable bridge, a cross-travel carriage and a vertical multiple telescope with a hoist for application in hot cells (see Figure 1). The functions of a light crane can be made available as a result of the load capacity of the hoist of the vertical telescope.

The speed of each motion can be fixed, controlled in several steps or continuously adjustable depending on the manipulator model. The operational forces are currently not directly reflected, but the gripping force can be transmitted to the operator by appropriate means. The gripping force can be measured and limited by steps, or by pre-selection or by means of an indicator and a variable sound.

The maximum velocities of different power manipulator models vary in a wide range. For power manipulators designed for use in hot cells, the following characteristics are available:

— rotation of the tongs: 10 r/min;

— inclination of hand, forearm and upper arm: 1 r/min;

— arm rotation: 5 r/min;

— lifting, carriage and bridge travel: 5 m/min.

6 Requirements

6.1 General aspects

Power manipulators have to meet a number of technical and safety specifications and in addition requirements concerning the operating environment (e.g. the presence of contamination, ionizing radiation, corrosive atmosphere, excessive humidity or temperature). Four classes of load capacity can be distinguished: light, medium, heavy and super-heavy, as given in Table 1.

Table 1 — Classes of power manipulators defined by load capacity

Class of load capacity	Load capacity, m kg			
	Tong	Grip hook		Shoulder hook [c]
	Horizontal arm position [a]	Arm position		
		Horizontal [a]	Vertical [b]	
Light	$20 \leqslant m < 50$	—	—	$250 \leqslant m < 500$
Medium	$50 \leqslant m < 125$	$50 \leqslant m < 125$	$50 \leqslant m < 1\,000$	$500 \leqslant m < 1\,000$
Heavy	$125 \leqslant m < 300$	$125 \leqslant m < 300$	$125 \leqslant m < 3\,000$	$1\,000 \leqslant m < 3\,000$
Super heavy	$300 \leqslant m < 500$	$300 \leqslant m < 500$	$300 \leqslant m < 5\,000$	$3\,000 \leqslant m < 5\,000$

[a] The load capacities for arms in the horizontal position are derived from the strength of the drive mechanisms.

[b] The additional load capacities in the vertical position are optional; they should be defined according to the operational requirements and are achieved by appropriate design of the pivots, hoists and transporter mechanism.

[c] The load capacities of the shoulder hooks are based on the capacities of the hoist and transporter mechanism.

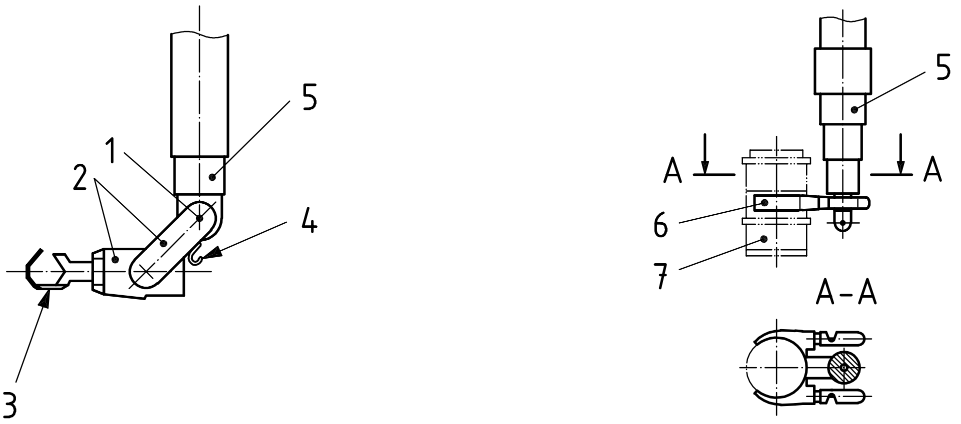
In addition to the preferred transporters for hot cells which consist of a movable bridge, a carriage and a vertical telescope (see Figure 1), there are transporters with different designs in use, e.g. movable mountings on a sidewall with a boom, movable portals, swivelling stands and other special designs.

There are also simplified manipulators for special purposes which are derived from power manipulators. Three common simplified manipulators are the following:

a) drum manipulators designed to transport and to stack radioactive waste drums, having a large gripper that can be tilted [see Figure 2b)] instead of an articulated arm;

b) manipulators intended for exchange of process components, having a double-grip hook instead of an articulated arm at the lower end of the vertical telescope;

c) remotely operated cranes, derived from power manipulator transporters, having no vertical telescope.



a) **Power manipulator with a grip hook** b) **Drum manipulator**

Key

1 shoulder pivot

2 articulated arm

3 grip hook

4 shoulder hook

5 multiple telescope with hoist

6 gripper for drums

7 waste drum

Figure 2 — Power manipulators — Examples

6.2 Materials

Since power manipulators are generally large, heavy units of equipment that are difficult to access safely, it is important to minimize the frequency of intervention for their maintenance and repair. Accordingly, the materials of component parts with exposed surfaces shall be protected against corrosion, ensuring compatibility with their function; corrosion can be promoted by ionizing radiation. All surfaces shall be designed to facilitate a high standard of decontamination. The decontamination processes envisaged shall not significantly degrade the functionality of the components, even when used repeatedly (e.g. the compatibility of the detergent type with the material of construction).

If different materials are bonded to one another, any contact corrosion shall be prevented by suitable measures. In certain cases, organic materials have to be used for specific applications (e.g. cable installations, bearing seals, lubricants). In this case, the material selected shall take into account the predicted radiation field, so as to avoid significant degradation between normal maintenance intervals.

6.3 Surface treatment

Aluminium alloys shall be anodized. Steels that are not rust-resistant shall be painted in a manner to facilitate decontamination (typically one coat of primer and two top coats), and if the surfaces are subjected to mechanical stress, they shall be suitably plated (e.g. in hard chrome). Stainless steels shall be subjected to an appropriate surface treatment, e.g. they shall be pickled and passivated. Depending on the environmental conditions, other surface treatments may be applied (e.g. painting or galvanization of carbon steel surfaces).

6.4 Design features

6.4.1 Main features

The mechanical arms of power manipulators have four to eight motions including one to three pivots. A highly movable arm (eight motions including three pivots), as compared to the preferred design (five motions including two pivots), meets the requirements of ISO 17874-1:2005, Clause 6, concerning remote handling devices for multiple purposes (see Figures 3 and 4). In most cases, the arms have five to seven motions. Each motion is provided with one motor.

6.4.2 Design concepts

As far as the arrangement of the drives for the pivots is concerned, there are three different designs with different properties, as described in a) to c), below.

a) Distributed drives

In this design, all of the drives are located adjacent to the point of application which facilitates modular design and a rapid dismantling capability of the components of the arm. For example, the elbow motor is placed in the upper arm and directly drives the elbow pivot. If the arrangement of the wrist assembly, forearm and upper arm is staggered, continuous rotation of the pivots is allowed (see Figures 5 and 6).

Mechanical arms with distributed drives, dependant on the model, have a wide range of load capacity (30 kg to 500 kg, generally 50 kg to 200 kg). The mechanical arms are between 0,45 m and 3,0 m long, in most designs 0,9 m to 1,7 m.

b) Drives in a central housing

In this design, all drives are located in a central housing, similar to slave arms of electrical master-slave manipulators. These designs are especially suitable for use with computer-controlled systems (see 7.6).

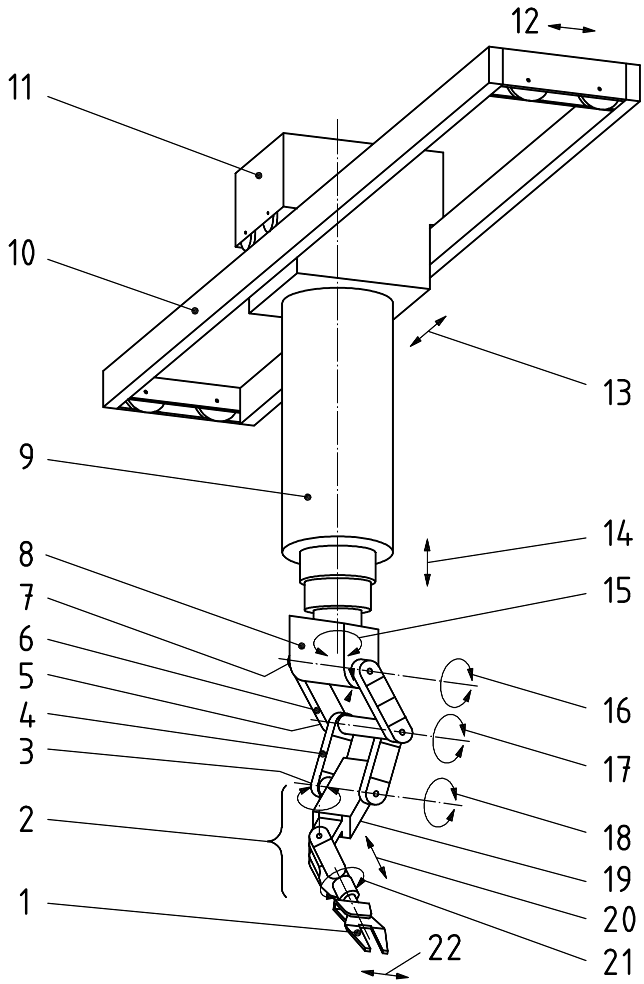
The drive units shall be located above the shoulder pivot in a central drive housing [see Figure 7 a)]. This design makes the arm slender. Concentric hollow shafts are used for transmission of movements and torques from the drive units to the arm links. The pivots of these mechanical arms can perform unlimited rotations, because of the staggered arrangement of the wrist, forearm and upper arm [see Figure 7b)].

This design of mechanical arm has generally seven motions (three positioning motions, three orientation motions and one gripping motion), according to the requirements of Clause 5 in ISO 17874-1:2004 (see Figure 8).

Mechanical arms with drives in a central housing, dependant on the model, have a wide range of load capacity (25 kg to 240 kg). The mechanical arms are between 1,0 m and 5,0 m long.

This mechanical arm can also be installed in a through-wall or through-roof tube configuration.

NOTE Assemblies consisting of multiple computer-controlled mechanical arms can also be used for combined operations, e.g. two mechanical arms of design 6.4.2 b), which provides increased dexterity, or a combination of two arms [one of design 6.4.2 b) and one of design 6.4.2 a)], which provides, when associated, increased dexterity and load capacity.



Key

Components

Mechanical arm:

1 tongs
2 wrist assembly
3 wrist pivot
4 forearm
5 elbow pivot
6 upper arm
7 shoulder pivot
8 shoulder housing

Transporter:

9 multiple telescope with hoist
10 movable bridge
11 carriage

Motions

12 bridge travel (X)
13 carriage travel (Y)
14 lifting/lowering (Z)
15 arm rotation
16 inclination of upper arm
17 inclination of forearm
18 inclination of tongs
19 swivelling of tongs
20 extraction / retraction of tongs
21 rotation of tongs
22 gripping

NOTE The preferred design has no motions 18, 19 and 20 (see Figure 9).

Figure 3 — Power manipulator with synergistic drives and a highly movable arm for hot cells — Subassemblies and motion possibilities

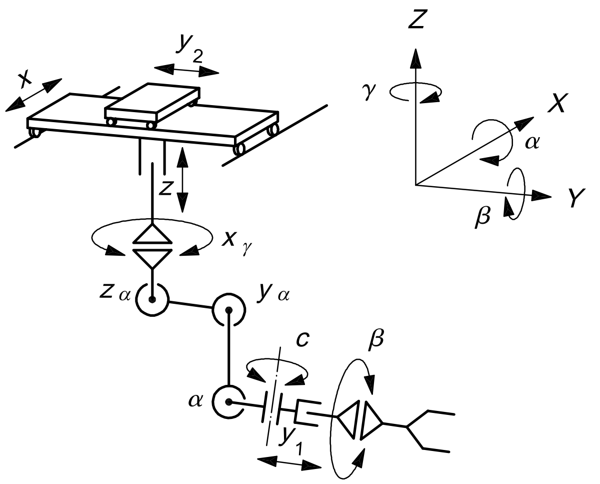


Figure 4 — Power manipulator with synergistic drives and a high movable arm — Kinematic diagram

Key

Components

Mechanical arm:

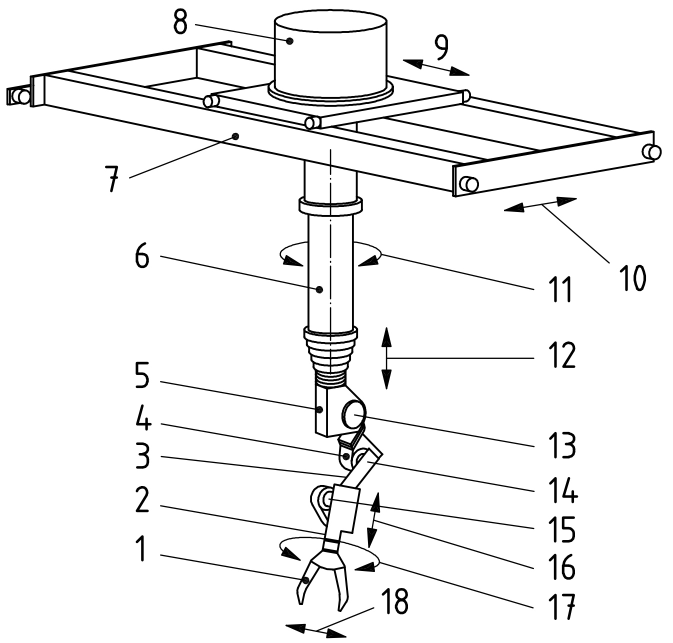
1 tongs
2 wrist assembly
3 forearm
4 upper arm
5 shoulder housing

Transporter:

6 multiple telescope with hoist
7 movable bridge
8 carriage

Motions

9 carriage travel (Y)
10 bridge travel (X)
11 arm rotation (by telescope rotation)
12 lifting/lowering (Z)
13 inclination of upper arm
14 inclination of forearm
15 inclination of tongs
16 extraction and retraction of tongs
17 rotation of tongs
18 gripping



NOTE The mechanical arm of this example has seven motions.

Figure 5 — Power manipulator with distributed drives and three pivots for hot cells — Subassemblies and motion possibilities

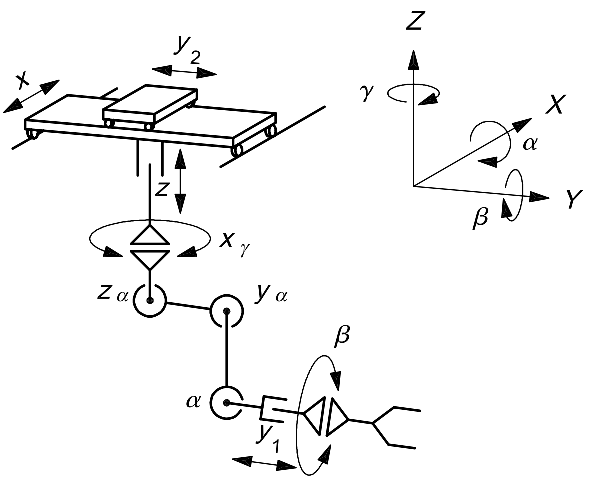


Figure 6 — Power manipulator with distributed drives and three pivots — Kinematic diagram

c) Mixed arrangement of drives with some synergistic features

This design option consists of a combination of distributed drives and drives located in a central housing. In other terms, mixed arrangement means that the drives units for the pivots are designed in such a manner that they share the total torque. The other drive units conform to the design in 6.4.2 a).

In this configuration, the drives of the elbow pivot and/or of the wrist pivot are placed above the shoulder pivot. The necessary transmission elements are located in the upper arm end forearm. The remaining drives are located in a distributed manner.

Typically, roller-chains are used for the elbow and wrist pivots, arranged such that the forearm and the wrist assembly will retain their orientation in space as the upper arm is moved (see Figures 3, 9 and 10). This corresponds to the synergistic movement of the human arm, with which operators are familiar. If small angles of adjustment are made at the shoulder pivot, with the upper arm near the vertical position and the forearm near the horizontal position, then the end-effector and wrist can be moved approximately forwards or backwards, with a simple translation motion. This arrangement, by distributing the total torque to be produced, reduces the total drive power required and permits the use of the same type of drive unit for each pivot.

Mechanical arms with synergistic drives, dependant on the model, have a wide range of load capacity (20 kg to 500 kg, generally 50 kg to 200 kg). The mechanical arms are between 0,7 m and 5,8 m long and in most designs 1 m to 2 m.

6.4.3 Housings

The housings can be made of aluminium or carbon steel (appropriately painted) or stainless steel, and with seals, depending on the operational requirements. An option is to use gaiters over the pivots and the telescope of the transporter, if necessary with a small positive pressure if the leakage is acceptable.

For electrically driven tools an electrical socket shall be provided; this should be mounted on an appropriate position on the arm, e.g. at the wrist assembly near the tong. Connection devices shall be designed for remote operation.

The carriage of a transporter shall be equipped with housing for some of the drive units and a drum for the cable or chain of the hoist.

Another design option allows the carriage to be split into two components, a chassis and housing for the drive units, which can be disconnected and reconnected remotely. In this design, the mechanical arm and the telescope, together with all the drives, can be removed from the hot cell and replaced quickly using a suitable flask and transfer system in the ceiling.

Housings, telescopes, and mechanical arms can be sealed for underwater applications.

6.4.4 Maintenance

Power manipulators shall be easy to maintain; this applies in particular to bearings, couplings and gears.

Power manipulator subassemblies and components shall be easy to mount and dismantle. Motors, gears and electric cables shall be easy to replace. Subassemblies of the same nominal type shall be interchangeable. Similarly, it should be possible to interchange elementary component. If the equipment available in the hot cells does not offer any alternative recovery option, then suitable devices shall be provided for the adjustment or shifting of the movable components concerned in the event of failure any of the drives.

Additional recommendations are addressed to the following particular components:

a) housings: special attention shall be taken in designing of housings in order to obviate the retention of contamination during operation and maintenance phases;

b) electrical motors: when they are protected from contamination by pressurized air, care shall be taken to add special remote handling filter;

c) electrical cables: their friction properties shall guarantee a low sliding effort within cable carrier chains.

6.4.5 Safety

Regarding cable drives, at least 1,5 turns shall remain wound on the cable drum when the telescope is completely extended. Chains used as a means of suspension shall be stressed only to one quarter of their breaking load. Suitable devices shall be provided to prevent cables from running off the cable pulleys or chains running off the sprocket wheels. Screwed connections shall be secured against spontaneous slackening.

Intermittent welds and spot welds shall be avoided in the travelling rails and the components of the power manipulator. All welds should avoid poor alignment of the edges, should be free of cracks and other defects in order to maximize safety.

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

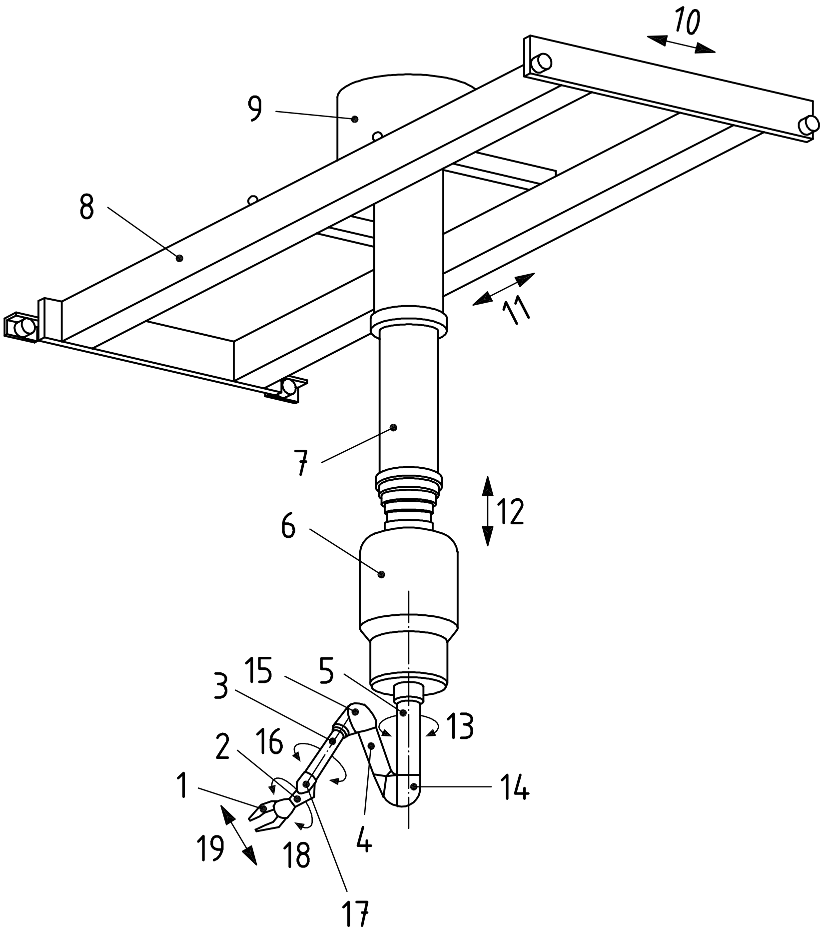
The deflection of the transporter at the nominal load shall be suitably matched to the operating conditions. In the case of movable bridges with a span-to-wheel axes distance ratio exceeding approximately 3, the travelling wheels at both ends of the span should be driven in a manner that prevents misalignment of the bridge. Energy absorbing buffers shall be provided to limit the travelling motions of the bridge and of the carriage.

Overload protection shall be provided for the mechanical components of the kinematic systems (e.g. slipping clutch, overload cut-out device, current limitation).

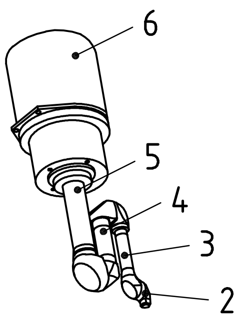
Failure-recovery strategies shall be elaborated in the overall design for those failures identified in the safety analysis and operational requirements of the plant as being of significant hazard and/or risk. In particular, automatic breaking or self-locking gear trains should be considered for all the motions to accommodate power failures.

At least one creeping speed shall be provided for each movable bridge and carriage when the nominal speeds are in excess of 5 m/min. A creeping speed is also necessary for the hoisting unit when the nominal speed is in excess of 3 m/min. The lifting and lowering speeds of the hoisting unit shall not deviate by more than 20 % from the rated speeds at the nominal load. At the articulated joints, the lowering speed at the nominal load shall not exceed the lifting speed by more than 40 %. With power manipulators that can exert a gripping force with the parallel jaw tong in excess of 100 daN at half opening width, provision for force indication or force preselection is necessary. The gripping surfaces shall be grooved to assist the holding of objects.

Power manipulators have the capability to inflict damage on other equipment in the cell, which is located in areas with limited viewing possibilities. In the case of specific requirements, it shall be possible to prevent potential damage either by physical limitations of the work envelope (e.g. by limit switches) or by programming areas by means of the control system to be inaccessible areas.



a) Complete assembly



b) Detail showing possibility of unlimited joint rotations

Key

Components

Mechanical arm:

1 tong
2 wrist
3 forearm
4 upper arm
5 mast
6 central housing with drives

Transporter:

7 multiple telescope with hoist
8 movable bridge
9 carriage

Motions

10 bridge travel (X)
11 carriage travel (Y)
12 lifting/lowering (Z)
13 arm rotation
14 inclination of upper arm
15 inclination of forearm
16 rotation of forearm
17 inclination of tongs
18 rotation of tongs
19 gripping

Figure 7 — Power manipulator with drives in a central housing and with a bridge transporter — Subassemblies and movement possibilities

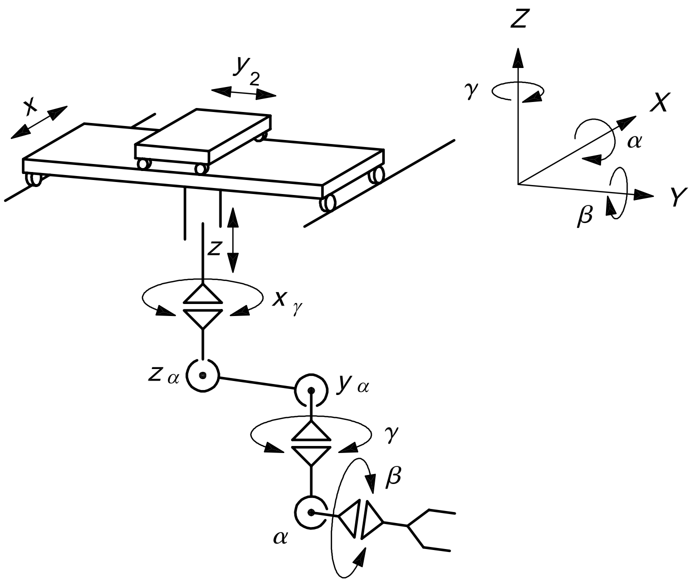


Figure 8 — Power manipulator with drives in a central housing — Kinematic diagram

6.5 Electrical equipment

Components used in the transmission of electrical energy to, from or within a hot cell, are generally chosen from manufacturers catalogues. However, special nuclear-safety applications can require the modification of such “off-the-shelf” products.

Such components may be considered suitable for most applications, but only provided they comply with the requirements of ISO 11933-5. Where specifically nuclear demands need to be met (e.g. resistance to high levels of radiation or specific leak tightness), the materials and components shall be specially adapted or “nuclearized”. The components used for special applications related to nuclear safety, or such as those involving remote handling, shall be developed as needed.

NOTE Specific aspects of electrical equipment are described in Annex A.

6.6 Dimensions of tongs with parallel jaws (standard tongs)

Tongs with parallel jaws shall be dimensioned according to Table 2, corresponding to the load capacity of the articulated arm in the horizontal position. Currently, tongs are manufactured to the designs illustrated in Figures 11 a) and 11 b). Design 11 a) shall be used for load capacities, m, such that 50 kg $\leqslant m <$ 200 kg and from 300 kg $\leqslant m <$ 500 kg. Design 11 b) shall be used for load capacities from 200 kg $\leqslant m <$ 300 kg.

NOTE The dimensions of the tongs for small power manipulators are not standardized, as there are a large number of special applications.

Key

Components

Mechanical arm:

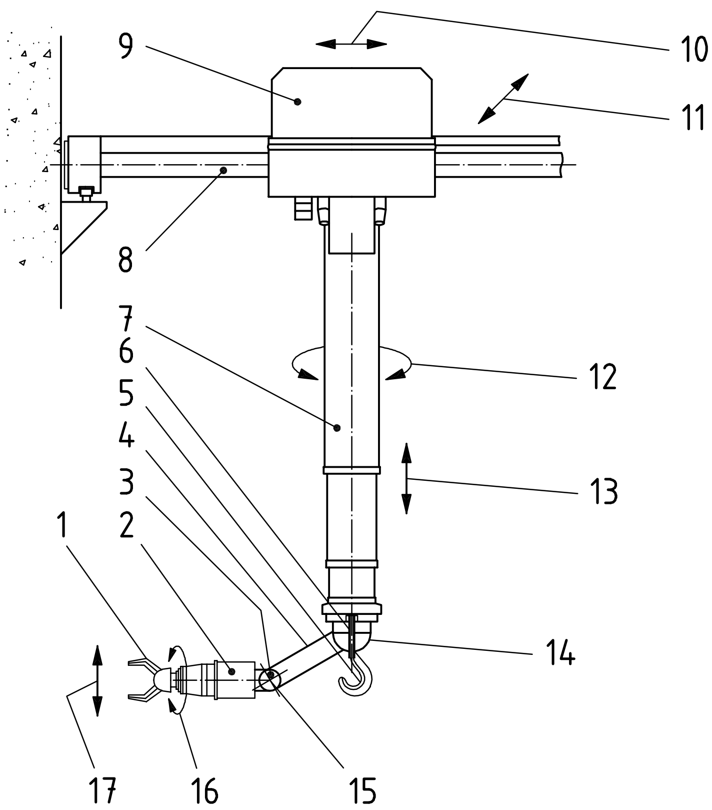
1 tong
2 forearm
3 elbow pivot
4 upper arm
5 shoulder hook
6 shoulder pivot

Transporter:

7 multiple telescope with hoist
8 movable bridge
9 carriage

Motions

10 carriage travel (*Y*)
11 bridge travel (*X*)
12 arm rotation (by telescope rotation)
13 lifting/lowering (*Z*)
14 inclination of upper arm
15 inclination of forearm
16 rotation of tong
17 gripping



NOTE The preferred design is often operated by means of two joysticks.

Figure 9 — Power manipulator with synergistic drives — Subassemblies and motion possibilities and preferred design for hot cells

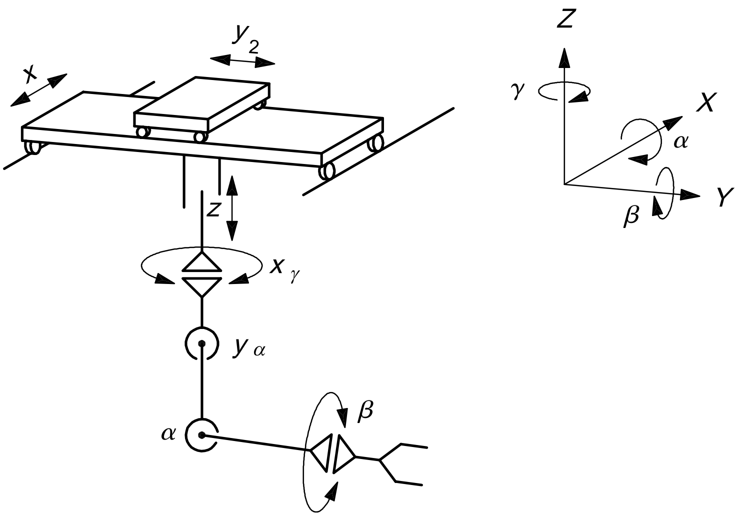
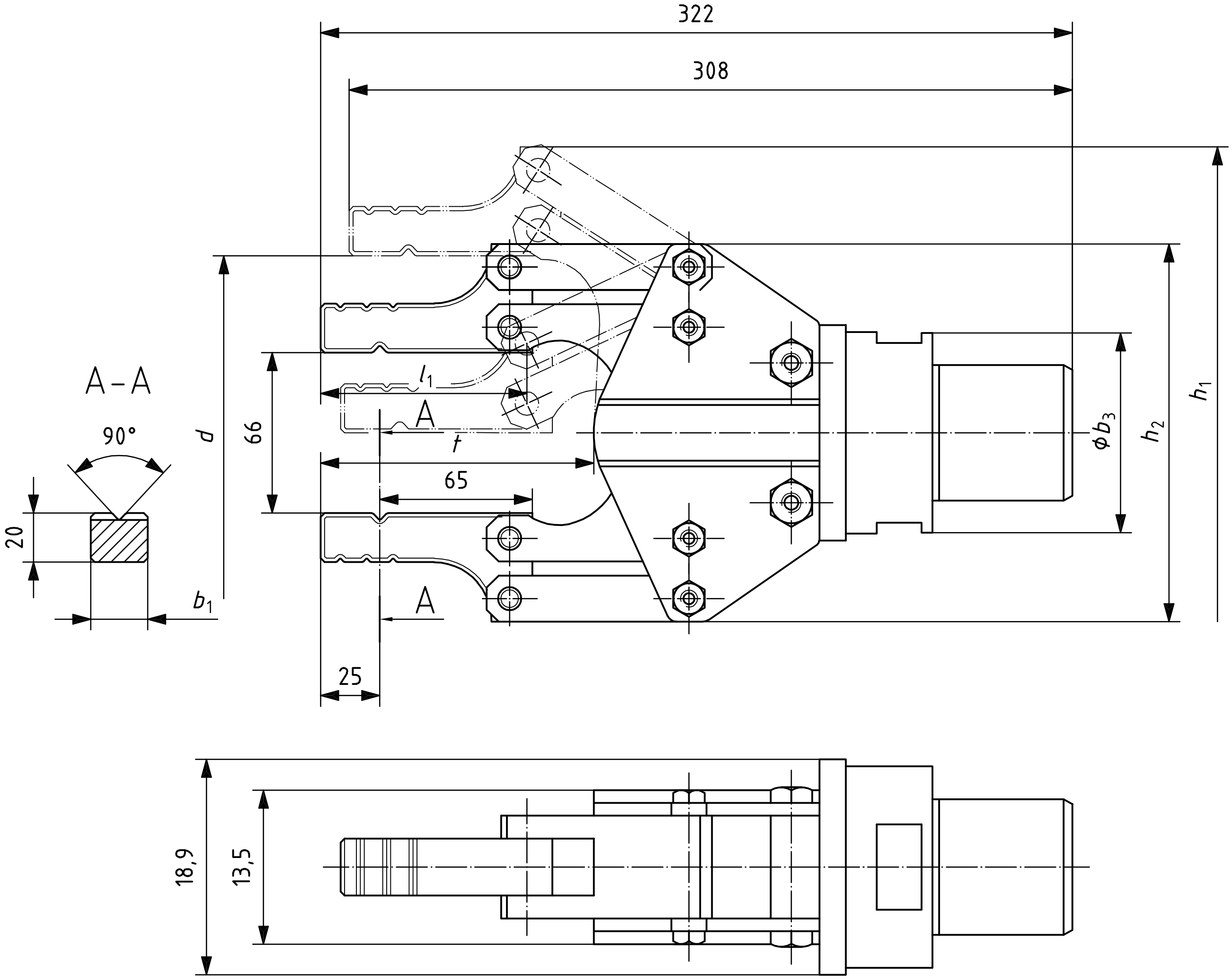
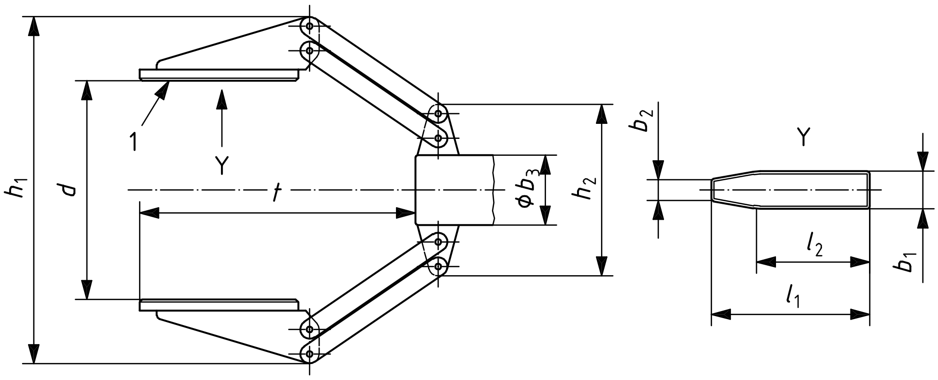


Figure 10 — Power manipulator with synergistic drives — Kinematic diagram of preferred design for hot cells

Dimensions in millimetres



a) **Tongs for load capacities,** m**, such that** 50 kg $\leqslant m <$ 200 kg **and** 300 kg $\leqslant m <$ 500 kg



b) **Tongs for load capacities,** m**, such that** 200 kg $\leqslant m <$ 300 kg

Key

1 jaws

Figure 11 — Tongs with parallel jaws for power manipulators

Table 2 — Typical tong dimensions

Dimensions in millimetres

Load capacity, m kg	d [a, b]	b_1	b_2	l_1	l_2	b_3 [c]	h_1 [c]	h_2 [c]	t [b]
$50 \leqslant m < 200$	150	24,8	—	90	—	84	240	158	104
$200 \leqslant m < 300$	200	35	20	100	85	125	360	195	160
$300 \leqslant m < 500$	300	46	—	100	—	125	500	290	220

NOTE 1 Material of the tongs: stainless steel.

NOTE 2 General tolerances of dimensions: in accordance with class c of ISO 2768-1:1989.

[a] The tongs shall be able to be closed until $d = 0$.

[b] Minimum dimensions.

[c] Maximum dimensions.

6.7 Dimensions of grip hooks

Grip hooks (see Figure 12) are to be dimensioned according to Table 3, corresponding to the load capacity of the telescopic hoist (see Table 1).

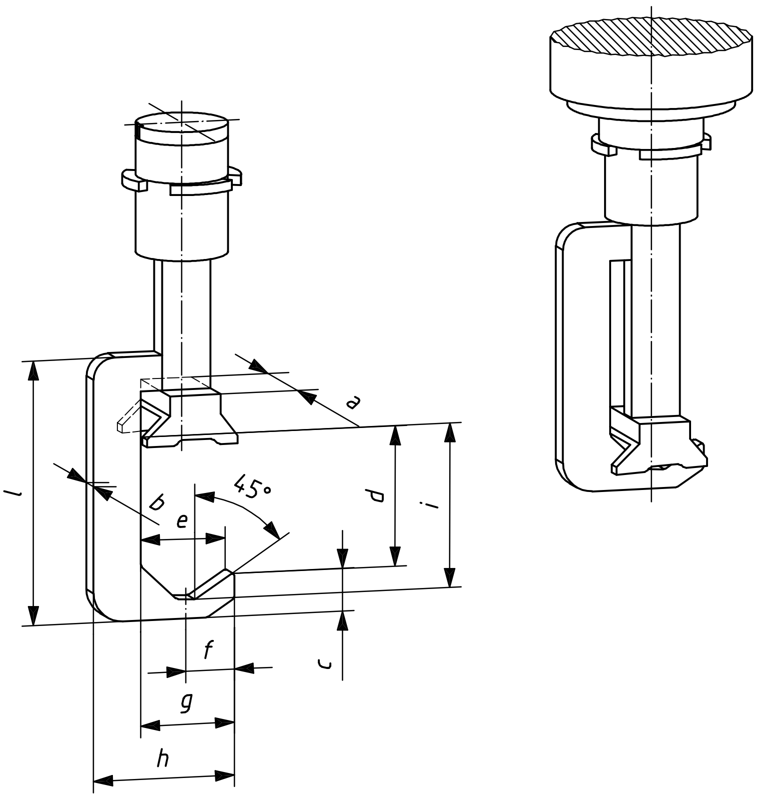


Figure 12 — Grip hook for power manipulators

Table 3 — Typical grip hook dimensions

Dimensions in millimetres

Load capacity, m kg	a	b	c	d	e	f	g	h	i	l
$m \leqslant$ 1 000	50	13	12,7	79	40	32	60	92	100	205
$m \leqslant$ 3 000	50	20	16	68	46	35	63	111	114	180
NOTE 1 Material of the grip hook: stainless steel.										
NOTE 2 General tolerances of dimensions: in accordance with class c of ISO 2768-1:1989.										

6.8 Dimensions of shoulder hooks

Shoulder hooks (see Figure 13) are to be dimensioned according to Table 4, corresponding to the load capacity of the telescopic hoist (see Table 1).

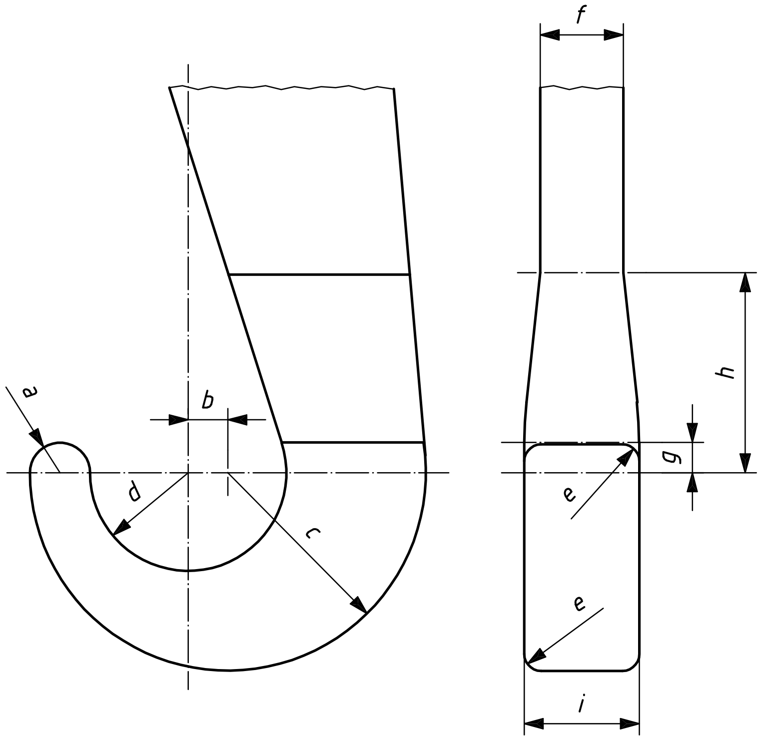


Figure 13 — Shoulder hook

Table 4 — Typical shoulder hook dimensions

Dimensions in millimetres

Load capacity, m kg	a	b	c	d	e	f	g	h	i
$m \leqslant$ 1 000	R7	10	50	25	R5	22	8	50	$\leqslant$ 30
$m \leqslant$ 3 000	R9	12	60	30	R5	26	9	60	$\leqslant$ 40
$m \leqslant$ 4 000	R9	15,5	65,5	20	R5	20	23	80	$\leqslant$ 35
$m \leqslant$ 5 000	R11	14	70	35	R5	30	10	70	$\leqslant$ 50

NOTE 1 Material of the grip hook: stainless steel.

NOTE 2 General tolerances of dimensions: in accordance with class c of ISO 2768:1989.

7 Operating devices and control systems

7.1 General

The following types of operating elements are used:

— push-buttons (each for one speed of one motion direction);

— operating elements for movement (each for one individual motion);

— joysticks (for two to four motions each);

— six motion-operating devices;

— computer-based systems.

All operating devices shall be equipped with features requiring positive operator actions to maintain motions of the manipulator. For example, push buttons should be equipped with a spring in order to stop the motion if the operator releases the push-button.

Specific provisions for each category are detailed in 7.2 to 7.6.

7.2 Push-buttons

Push-buttons are used in conjunction with controls which make it possible to execute the manipulator motions in one or more speed steps. For this purpose, one or more push-buttons, depending on the number of speed steps, shall be provided for each of the two directions of a motion.

7.3 Operating elements for one motion

With some models, operating elements for one individual motion can be actuated in both directions. The speed shall increase continuously with deviation from the “off” position. Three different variants are in use.

a) Elements with a rotary actuation are used for all kinds of motions.

b) Pure rotation motions (arm and tong rotation) are operated by elements with rotary actuation and for all other motions (translation motions, pivots, swivelling of tong and gripping) elements with linear actuation are used.

c) Often two elements with a rotary actuation are used per motion, one for both directions of the movement and the other one for the force variation. They are arranged on the operating console within a schematic figure of the manipulator.

7.4 Joysticks

A reduction in the number of operation elements can be achieved by the use of joysticks. Two joysticks are often used for operating power manipulators of the preferred design (eight motions, see Figure 5). With the right joystick, the four motions of the arm are operated with gripping covered by an additional three position switch. The three motions of the transporter are operated by means of the left joystick. The directions of joystick actuation shall coincide with the directions of the manipulator motions starting from the basic positions. It is then possible, after a very short training period, to operate the manipulator with the two joysticks, while watching only through a shielding window without looking at the control box.

7.5 Six-motion operating devices

Operating devices for the six motions of a mechanical arm and gripping allow the operation of a power manipulator with only one hand or one hand and the arm, respectively. The actuation of the manipulator is made by different features depending on the type of the operating device. With devices operated by one hand corresponding to the Cartesian coordinate system, generally three forces and three torques must be applied. Such devices usually have the form of a sphere or a handle. With a variant in handle design, three small translation motions and three torques must be applied. Gripping is actuated by an additional switch.

Joy arms are operated by one hand and the arm. The six motions of a mechanical arm that can be executed are divided into two groups (orientation and positioning motions). A switch is used for gripping.

With operating devices for six motions, the forces, torques or deflections applied on the operating devices shall be executed very precisely to avoid drifting of other motions when these are not intended to move simultaneously.

7.6 Computer controlled systems

Computer-controlled systems are capable of providing all types of controls described in 7.2 to 7.6. In addition, a programmable automatic point-to-point control can be made available for operations which must be repeated. The primary control mode is speed-control, remotely operated.

Computer control can provide a relatively simple interface, allowing the operator to carry out movements in any direction, while the computer coordinates the six rotation and pivot motions of the arm automatically to achieve the desired effect. For example, translation motions in the directions of the coordinate axes (x, y and z) can be performed while the tong remains in its orientation in space. Another example is to provide rotation motions around coordinate axes (x, y and z) centred at the tong. For these features, an appropriate number of position transducers shall be installed in the mechanical arm.

Six-motion operating devices operated with one hand or one arm (see 7.5) are advantageous. It shall be possible to limit the gripping force and the torques of all other motions by current-limiting.

Also, single switches for one motion each, touch-screen or a PC with keyboard are used.

Speed may be selected in an appropriate range according to the operational requirements.

A PC is generally used for programming.

8 Manipulator vehicles

A special transporter category for power manipulators is that of vehicles which can be moved independently on the ground. Manipulator vehicles are used for interventions if radioactive sources must be handled or in radioactive contaminated areas or after accidents with radioactive material or in nuclear plants. Manipulator vehicles are also used for decommissioning operations in nuclear facilities.

Small, medium-sized and large manipulator vehicles shall be distinguished as follows.

a) Manipulator vehicles of small sizes generally have the following dimensions: length: 0,9 m to 1,3 m, width: 0,6 m to 1,0 m. They can pass through door apertures in buildings. Mostly, they have two tracks, although some types have four tracks with a geometric variable chassis to enhance the mobility. They are remotely controlled either by cable or via radio with storage batteries on board. The power manipulator arm typically has a load capacity of 20 kg to 100 kg. Observation is made by TV (see Figure 14).

   For safe manipulation and manoeuvring, a vehicle should have at least four TV cameras, one each on a pan-tilt head, on the gripper, on the body for travelling forward and on the body for travelling backwards.

   It is desirable to allow the sides of the vehicle to be viewed as well. For that purpose, the use of a stereo TV camera system with zoom-lenses on the pan-tilt head is advantageous.

b) Medium-sized manipulator vehicles have dimensions similar to those of a small passenger car. They have two tracks and are remotely controlled via radio. They are equipped either with storage batteries or with an engine and generator. The power manipulator arm generally has a load capacity up to 250 kg. Drive and work observation are achieved by means of a number of TV camera views, as for the small class of such vehicles.

c) Typically, manipulator vehicles of large sizes are equipped with a manned shielded cabin and one or two power manipulator arms.

The control system is similar to that of a power manipulator in a hot cell.

9 Special tongs and tools

Large-size power manipulators can be fitted with a number of special tongs and tools, such as those described in a) and b) below:

a) end-effectors interchangeable with the standard tong, such as

   — special tongs: 90° angle tong, pipe tong, double pipe tong, combination pliers, tong for interior surface gripping,

   — tools adapter for socket wrenches,

   — tools which are operated by gripping drive: shears, pincers, side cutting pliers, cutting hook, and

   — electric tools: impact wrench, 90° angle impact wrench, drilling machine, bow saw, disk saw, parting-off grinder, hammer, cutting hook, shears, nibbler.

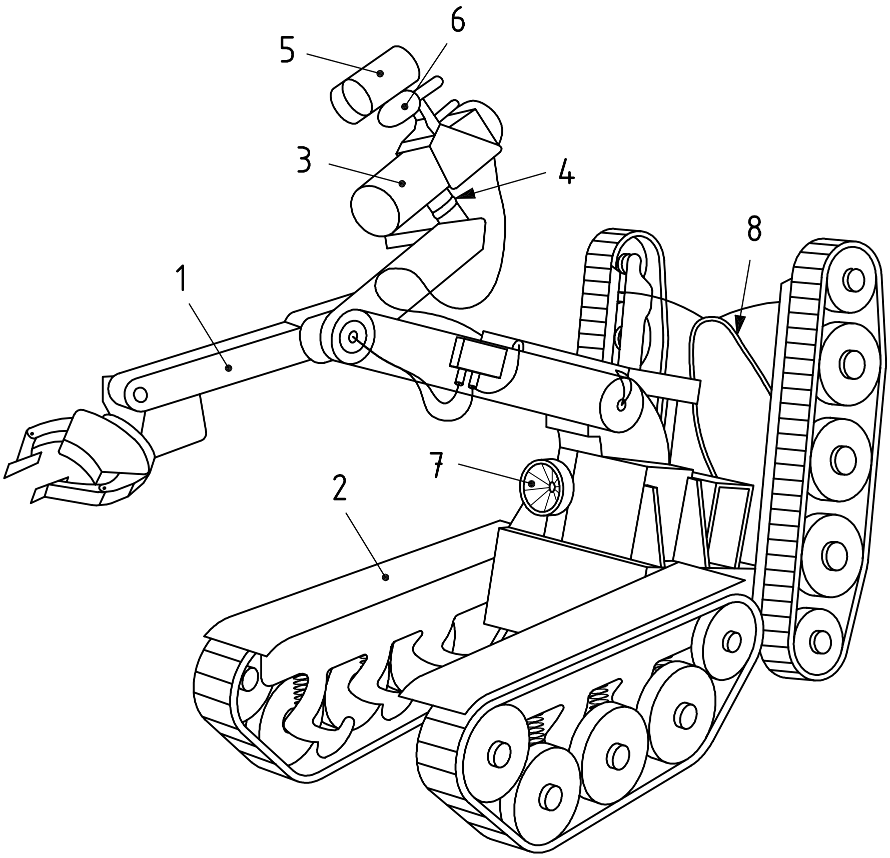
b) tools adapted for gripping by the standard tong, such as

— electric tools-impact wrench, disk saw, parting-off grinder, mechanical shears,

— hydraulic shears, and

— for treatment of concrete, pneumatic chipping hammer, percussion drill, hydraulic split off device.

NOTE Other tools can also be adapted, if they meet certain conditions imposed by the manipulator model used, especially the limits of weight and reaction forces and torques.



Key

1 mechanical arm (power manipulator with 6 motions)
2 vehicle
3 TV camera
4 swivelling unit
5 task spot-light
6 microphone
7 driving light
8 cable for signals and power

Figure 14 — Manipulator vehicle of small sizes — Example with variable chassis geometry

10 Testing

10.1 General

Power manipulators shall be submitted for testing before commissioning and during their operation time. Prior to the initial commissioning of the power manipulator, an inspection and test is mandatory. This consists of a preliminary scrutiny, a structural examination, an acceptance test, and if necessary retests. In the case of type-tested power manipulators without auxiliary equipment, the preliminary scrutiny and the structural examination may be omitted.

For final technical validation, all documents which were necessary to manufacture the power manipulator(s) shall be examined. The structural examination is concerned with ascertaining whether or not the manipulator has been competently constructed in accordance with the documents listed in the technical validation report.

10.2 Acceptance testing

The acceptance test is intended to verify that the mechanisms and appliances on the power manipulator and the safety arrangements are complete, suitable and effective. All functions shall be tested both without load and at the maximum admissible load. During the acceptance test, above all, the tests of the hoist and the associated cables or chains respectively are very important with regard of the operational safety of the unit. Requirements for testing the hoist with the load at the shoulder hook are as follows.

The test load, P, for power manipulators shall be

$$P = 1{,}25 \times P_1$$

where P_1 is the maximum admissible load (combined weights of useful load, load suspending device and slinging device).

The use of a dynamometer inserted between the power manipulator and a floor anchorage, and intended as a substitute for the test load, is not admissible.

The following items shall be tested:

a) efficiency of the braking devices: the test load shall be intercepted and held safely during the lowering motion at the nominal speed, both when the control device is switched back normally, and when the main stop switch is actuated;

b) efficiency of the overload safety devices;

c) functioning of the motorized motions (all the motions that are likely to occur in normal operation or that are possible shall be verified individually with the most unfavourable load positions, taking due care in the performance of the tests).

All these tests shall be carried out of the factory. After delivery, all functions shall be tested without and with load. After mounting in the hot cell, all functions shall be tested again without load.

10.3 Inspections and tests at regular intervals

A regular inspection shall be performed to verify that the condition of power manipulator satisfies the operational requirements, and that all the safety devices operate effectively. Power manipulators shall be comprehensively tested at least once a year. All functions shall be thoroughly tested and the results appropriately recorded.

11 Non-radioactive trial cells

11.1 General

Operational experience of power manipulators demonstrates that considerable improvements in working efficiency can be achieved if a non-radioactive trial cell (also called mock-up) is provided. This shall offer a working environment and dimensional envelope, similar to the hot cells of the plant.

The trial cell shall simulate the thickness of the shielding walls and shall be equipped with one power manipulator, mechanical master-slave manipulators in accordance with ISO 17847-2 and, if possible, with shielding window viewing and other important basic equipment (e.g. transfer-systems, lighting, ventilation, electrical installations). This can be used to address such issues as

- operator training,
- manipulator system capability,
- error and fault avoidance, and
- reliability assessments and maintenance planning.

11.2 Operator training

The main purposes of a trial cell in this connection are qualification and training of new operators and proving that operators can perform the tasks.

Power manipulators have a wide variety of functionality and control system layouts and, in combination with the particular features of the working hot cell and the intended tasks, usually possess unique operational characteristics. Since the remediation of errors in the active cells is likely to incur significant expenses in lost time and the accumulation of additional waste, thorough operator training in a non-radioactive cell is recommended.

NOTE Camera and monitor systems used as additional viewing devices also vary considerably; operator learning is generally faster with the use of multiple 2D views, 3D systems, colour views or high-definition than with normal definition or black-and-white views.

11.3 Manipulator system capability

Important are proving whether or not the tasks can be done with the manipulators and proving the suitability of the process components for remote handling.

Cells designed for simple repetitive tasks with essentially no possibility of operator error or partial equipment failure (see next section) might not benefit from inactive proving trials, but those intended for complex tasks or flexible working practices are very likely to do so. New challenges to the equipment and the operators can be resolved using accurate simulations in an inactive environment, testing and developing hardware modifications and handling processes.

11.4 Error minimization and failure recovery

Many hot cells have been designed such that normal operations are readily carried out, but certain situations encountered cannot be remedied without cell entry, depending on the design of the hot cells and their basic equipment. Items in this regard can include lighting, cameras, deployment limits of manipulators, electrical cable from the cell wall to the transporter of the power manipulator, exchange of large process components, waste air filters and obstructive support structures. The provision of a trial cell with accurate mock-ups of the in-cell equipment facilitates the identification and remediation of hardware, and/or allows practicing of particular corrective processes to minimize problems in the hot cell.

11.5 Reliability assessments and maintenance planning

Extensive proving trials of the remote handling hot-cell equipment (~ 1 000 h) will identify any weaknesses in the designs and yield failure statistics, allowing the hot-cell maintenance planning to be optimized in terms of intervention intervals and components needing preventative maintenance or pre-emptive replacement.

Annex A
(normative)

Electrical equipment for power manipulators

The conductor system shall be adopted for control circuits cabling as a protective measure against any shock hazard. In the event of a fault, the first short to earth shall be indicated by a visually or audible alarm. Items of electrical equipment shall be connected to one another by screened conductor, when the magnitude of the operating voltage exceeds a minimum value given by national regulations. In the case of three-phase current feeds via a plug-in connection, a phase sequence monitoring device shall be provided. In the event of a phase failure, there shall be no substantial increase of the lowering speed.

The operating devices shall be designed with no self-locking or operators features (thus achieving a “dead man’s switch” safety function). Multiple-step push-buttons (push-through buttons) for speed control are not admissible. Safety switches shall be positively actuated. Circuits which have the same factor of safety as safety switches are admissible.

The hoisting and travelling motions shall be limited by dual electrical limit switches. In the case of speeds lower than 10 m/min, with an installed drive-power of less than 0,5 kW, and with a non-positive drive, no limit switches are necessary for the crane travel and the carriage travel. Unless any other important safety considerations militate against this, short circuits and overloads may only exert their effect on the drives of the electrical circuit in which they occur. Electric motors shall be protected against undue overheating as a result of overloading by protective switches or equivalent devices on all poles. The telltale lamps for visual signals and the sounders for audible warnings shall be capable of being checked from each control point.

The electrical cabling for power supply and signal transmission with the transporters shall fulfil the following requirements: on a transporter with a movable bridge, three cables are necessary to allow motions in the x, y and z directions: one cable each between the hot cell wall and the bridge, the bridge and the carriage and inside or outside the telescope.

For the cable between wall and bridge, a cable drum is often used. The electrical cable between the bridge and the carriage is typically hanging in loops on a steel cable. The cable for the telescope is either a spiral inside the telescope or rolled up on a cable drum outside of the telescope. If required, the multi-core cable between bridge and carriage has plugs designed to be operated remotely for exchange of the drive housing (together with the mechanical arm and the telescope). The cable between wall and bridge should have such plugs on both ends.

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[6] DIN 25409 *Remote handling systems for use behind shielding walls —*

- *Part 1: Remote handling tongs, dimensions*1)
- *Part 2: Master-slave manipulators with 3 pivots, dimensions*
- *Part 3: Telescopic master-slave manipulators, dimensions*
- *Part 4: Telescopic master-slave manipulators, requirements*
- *Part 5: Master-slave manipulators with 3 pivots, requirements*
- *Part 6: Remote handling tongs, specifications*
- *Part 7: Power manipulators with electric drives, requirements and tests*
- *Part 8: Power manipulators, operating devices, arrangement and designation*
- Supplement: *Recommendations for use*

[7] NF E 61-005, *Manipulators — Telemanipulators — Manipulating robots — Classification*

[8] NF E 61-050, *Telemanipulators — General*

[9] NF E 61-051, *Manipulators — Master-slave mechanically controlled*

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

1) DIN 25409 is a German standard. Parts 1, 2, 3, 7 and 8 are also available in English.

ICS 13.280

Price based on 26 pages