184

# INTERNATIONAL STANDARD

# ISO 9283

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## Manipulating industrial robots — Performance criteria and related test methods

*Robots manipulateurs industriels — Critères de performance et méthodes d'essai correspondantes*



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## Contents


| | | Page |
|---|---|---|
| 1 | Scope | 1 |
| 2 | Normative references | 1 |
| 3 | Definitions | 1 |
| 4 | Units | 1 |
| 5 | Abbreviations and symbols | 2 |
| 5.1 | Basic abbreviations | 2 |
| 5.2 | Quantities | 2 |
| 5.3 | Indices | 2 |
| 5.4 | Other symbols | 2 |
| 6 | Performance testing conditions | 3 |
| 6.1 | Robot mounting | 3 |
| 6.2 | Conditions prior to testing | 3 |
| 6.3 | Environmental and operating conditions | 3 |
| 6.4 | Displacement measurement principles | 3 |
| 6.5 | Instrumentation | 4 |
| 6.6 | Load to the mechanical interface | 4 |
| 6.7 | Test velocities | 4 |
| 6.8 | Definitions of poses to be tested and paths to be followed | 5 |
| 6.9 | Number of cycles | 10 |
| 6.10 | Test procedure | 10 |
| 7 | Pose characteristics | 10 |
| 7.1 | General description | 10 |
| 7.2 | Pose accuracy and pose repeatability | 12 |
| 7.3 | Distance accuracy and repeatability (applicable only to robots with the facility for explicit programming) | 17 |






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7.4 Pose stabilization time ..... 20
7.5 Pose overshoot ..... 21
7.6 Drift of pose characteristics ..... 22
8 Path characteristics ..... 23
8.1 General ..... 23
8.2 Path accuracy (AT) ..... 23
8.3 Path repeatability (RT) ..... 26
8.4 Cornering deviations ..... 26
8.5 Path velocity characteristics ..... 28
9 Minimum positioning time ..... 29
10 Static compliance ..... 30
11 Test report ..... 30

**Annex**

A Example of a test report ..... 32

## 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.

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.



International Standard ISO 9283 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*.

Annex A of this International Standard is for information only.

## Introduction

ISO 9283 is part of a series of International Standards dealing with manipulating industrial robots. Other International Standards cover such topics as safety, general characteristics, coordinate systems, terminology, and mechanical interfaces. It is noted that these International Standards are interrelated and are also related to other International Standards.

ISO 9283 is intended to facilitate understanding between users and manufacturers of robots and robot systems. It defines the important performance characteristics, describes how they shall be specified and recommends how they should be tested. An example of how the test results should be reported is included in annex A of this International Standard. The characteristics for which test methods are given in this International Standard are those considered to affect robot performance significantly.



The selection of tests given in this International Standard is not addressed by the standard; it is intended that the user of this International Standard selects which performance characteristics are to be tested, in accordance with his own specific requirements.



The tests described in this International Standard may be applied in whole or in part, depending upon the robot type and requirements.

Future International Standards will deal with application oriented and comparison testing.

Annex A of this International Standard provides a recommended format of the test report including the minimum required information and the summary of the test results.

# Manipulating industrial robots — Performance criteria and related test methods

## 1 Scope

This International Standard describes methods of specifying and testing the following performance characteristics of manipulating industrial robots:

- unidirectional pose accuracy and pose repeatability;
- multi-directional pose accuracy variation;
- distance accuracy and distance repeatability;
- pose stabilization time;
- pose overshoot;
- drift of pose characteristics;
- path accuracy and path repeatability;
- cornering deviations;
- path velocity characteristics;
- minimum positioning time;
- static compliance.

This International Standard does not specify which of the above performance characteristics are to be chosen for testing a particular robot. The tests described in this International Standard are primarily intended for developing and verifying individual robot specifications, but can also be used for such purposes as prototype testing, type testing or acceptance testing.

This International Standard applies to all manipulating industrial robots as defined in ISO/TR 8373. However, for the purpose of this International Standard the term "robot" means manipulating industrial robot.



## 2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO/TR 8373:1988, *Manipulating industrial robots — Vocabulary.*

ISO 9787:1990, *Manipulating industrial robots — Coordinate systems and motions.*

ISO 9946:—[1], *Manipulating industrial robots — Presentation of characteristics.*

## 3 Definitions

For the purposes of this International Standard, the definitions given in ISO/TR 8373 and the following definitions apply.

**3.1 cluster:** Set of attained poses, corresponding to the same command pose, used to calculate the accuracy and the repeatability characteristics (shown diagrammatically in figure 6).

**3.2 barycentre:** For a cluster of n points, defined by their coordinates ($x_j - y_j - z_j$), the barycentre of that cluster of points is the point whose coordinates are the mean values $\bar{x}$, $\bar{y}$ and $\bar{z}$ calculated by formulae given in 7.2.1.

1) To be published.

## 4 Units

Unless otherwise stated, all dimensions are as follows:

- length in millimetres (mm)
- angle in radians or degrees (rad) or (°)
- time in seconds (s)
- mass in kilograms (kg)
- force in newtons (N)
- velocity in metres per second, degrees per second or radians per second (m/s), (°/s) or (rad/s)

## 5 Abbreviations and symbols

For the purpose of this International Standard, the following abbreviations and symbols apply:

### 5.1 Basic abbreviations

| | |
|---|---|
| A | Accuracy |
| R | Repeatability |
| v | Variation |
| F | Fluctuation |
| d | Drift |
| P | Pose |
| D | Distance |
| T | Path |
| V | Velocity |

### 5.2 Quantities

| | |
|---|---|
| *a*, *b*, *c* | Orientation (angular components) about the *x*-, *y*-, *z*-axis |
| *x*, *y*, *z* | Linear coordinates along the *x*-, *y*-, *z*-axis |
| *n* | Number of measurement cycles |
| *m* | Number of measurement points along the path |
| *S* | Standard deviation |
| *D* | Distance between two points |
| *l* | Distance between the attained pose and the barycentre of the attained poses |
| *v* | Path velocity |
| AP | Unidirectional pose accuracy |
| RP | Unidirectional pose repeatability |
| vAP | Multi-directional pose accuracy variation |
| AD | Distance accuracy |
| RD | Distance repeatability |
| *t* | Pose stabilization time |
| dAP | Drift of pose accuracy |
| dRP | Drift of pose repeatability |
| AT | Path accuracy |
| RT | Path repeatability |
| CR | Cornering round-off error |
| CO | Cornering overshoot |
| SPL | Stabilization path length |
| AV | Path velocity accuracy |
| RV | Path velocity repeatability |
| FV | Path velocity fluctuation |



### 5.3 Indices

| | |
|---|---|
| *a*, *b*, *c* | Indicates an orientation characteristic about the *x*-, *y*-, *z*-axis |
| *x*, *y*, *z* | Indicates a positioning characteristic along the *x*-, *y*-, *z*-axis |
| c | Command |
| *i* | Indicates the *i*-th abscissa |
| *j* | Indicates the *j*-th cycle |
| *k* | Indicates the *k*-th direction |
| *h* | Indicates the *h*-th direction |
| 1, 2 ... | Indicates the pose number 1, 2 ... |
| e | Corner point |
| g | Point where the robot performance falls within the specified path characteristics |

### 5.4 Other symbols

| | |
|---|---|
| $C_1$ to $C_8$ | Corners of the test cube |
| $E_1$ to $E_4$ | Corners of the rectangular plane for the measurement of path characteristics |
| G | The barycentre of a cluster of attained poses |
| $O_c$ | Origin of the measurement system coordinates |

NOTE 1 Further symbols are explained in the respective subclauses.

## 6 Performance testing conditions

### 6.1 Robot mounting

The robot shall be mounted in accordance with the manufacturer's recommendations.

### 6.2 Conditions prior to testing

The robot shall be completely assembled and fully operational. All necessary levelling operations, alignment procedures and functional tests shall be satisfactorily completed.

Prior to testing, the robot motions shall be restricted to those necessary for setting up the measuring instruments.

The tests shall be preceded by an appropriate warm-up operation, if specified by the manufacturer, except for the test of drift of pose characteristics which shall start from cold condition.

If the robot has facilities for adjustment by the user that can influence any of the tested characteristics, the condition used during the test shall be specified in the test report and shall be kept constant during each test.



### 6.3 Environmental and operating conditions

The performance characteristics, as specified by the manufacturer and determined by the related test methods in this International Standard, are valid only under the environmental and normal operating conditions as stipulated by the manufacturer.

#### 6.3.1 Operating conditions

The normal operating conditions used in the tests shall be as stated by the manufacturer.

Normal operating conditions include, but are not limited to, requirements for electrical, hydraulic and pneumatic power, power fluctuations and disturbances, maximum safe operating limits (see ISO 9946).

#### 6.3.2 Environmental conditions

##### 6.3.2.1 General

The environmental conditions used in the tests shall be as stated by the manufacturer, subject to the requirements of 6.3.2.2.

Environmental conditions include temperature, relative humidity, electromagnetic and electrostatic fields, radio frequency interference, atmospheric contaminants, and altitude limits.

##### 6.3.2.2 Testing temperature

Where the ambient temperature of the testing environment can be controlled, it shall be maintained at

a) $(20 \pm 2)$ °C; or

b) $(\theta \pm 2)$ °C;

where

1) $\theta$ °C is between 5 °C and 40 °C;

2) $\theta$ °C is as stated by the manufacturer.

Where the ambient temperature of the testing environment is not 20 °C, it shall be stated in the test report.

The robot and the measuring instruments shall have been in the test environment long enough (preferably overnight) so that they are in a thermally stable condition before testing. They shall be protected from draughts and external thermal radiation (e.g. sunlight, heaters).

### 6.4 Displacement measurement principles

The measured position and orientation data (coordinates $x_j$, $y_j$, $z_j$, $a_j$, $b_j$, $c_j$) shall be expressed in a co-ordinate system, the axes of which are parallel to those of the base coordinate system (see ISO 9787).

The measurement point shall lie at a distance from the mechanical interface as specified by the manufacturer. The position of this point in the mechanical interface coordinate system (see ISO 9787) shall be recorded (see figure 5).

The sequence of rotation used when calculating the orientation deviation shall either be rotation about moving axes $Z$, $Y'$, $X''$ or rotation about stationary axes $X$, $Y$, $Z$.

Wherever possible, a non-contact measurement method shall be used.

When a part of the measuring instrumentation is attached to the robot, its mass and position shall be considered as part of the test load.

Unless otherwise specified, the measurements shall be taken after the attained pose is stabilized.

For path characteristics measurements, the data acquisition equipment sampling rate shall be high enough to ensure that an adequate representation of the characteristics being measured is obtained.

## 6.5 Instrumentation

The measuring instruments used for the tests shall be calibrated and the uncertainty of measurement shall be estimated and stated in the test report. The following parameters should be taken into account: instrumentation errors including repeatability and freedom from bias; systematic errors associated with the method used; calculation errors. The total uncertainty of measurement shall not exceed 25 % of the magnitude of the characteristic under test.

## 6.6 Load to the mechanical interface

All tests shall be executed at 100 % of rated load conditions (mass, position of centre of gravity, moments of inertia) according to the manufacturer's specification.

To characterize robots with load dependent performances, additional optional tests can be made with the mass of rated load reduced to 50 %, as indicated in table 1, or some other value as specified by the manufacturer.

The position of the centre of gravity of the test loads used shall be the same for all tests.

## 6.7 Test velocities

All pose characteristics shall be tested at the maximum velocity achievable between the specified poses, i.e. with the speed override set to 100 %, in each case. Additional tests could be carried out at 50 % and/or 10 % of this velocity.

For path characteristics, the tests shall be conducted at 100 %, 50 % and 10 % of rated path velocity as specified by the manufacturer for each of the characteristics tested (see table 3). The velocity specification shall be such that the robot is able to achieve this velocity over at least 50 % of the length of the test path (cornering overshoot and round-off test excepted) and that the related performance criteria shall be valid during this time.

A summary of the test velocities is given in table 2 and table 3.

**Table 1 — Test loads**



| Characteristics to be tested | Load to be used | |
|---|---|---|
| | 100 % of rated load (X = mandatory) | The mass of rated load reduced to 50 % (O = optional) |
| Unidirectional pose accuracy and pose repeatability | X | O |
| Multi-directional pose accuracy variation | X | O |
| Distance accuracy and distance repeatability | X | — |
| Pose stabilization time | X | O |
| Pose overshoot | X | O |
| Drift of pose characteristics | X | — |
| Path accuracy and path repeatability | X | O |
| Cornering deviations | X | — |
| Path velocity characteristics | X | O |
| Minimum positioning time | X | O |
| Static compliance | — | See clause 10 |

**Table 2 — Test velocities for pose characteristics**

| Characteristics to be tested | Velocity | |
|---|---|---|
| | 100 % of rated velocity (X = mandatory) | 50 % or 10 % of rated velocity (O = optional) |
| Unidirectional pose accuracy and pose repeatability | X | O |
| Multi-directional pose accuracy variation | X | O |
| Distance accuracy and distance repeatability | X | O |
| Pose stabilization time | X | O |
| Pose overshoot | X | O |
| Drift of pose characteristics | X | — |
| Minimum positioning time | X | O |



**Table 3 — Test velocities for path characteristics**

| Characteristics to be tested | Velocity | | |
|---|---|---|---|
| | 100 % of rated path velocity (X = mandatory) | 50 % of rated path velocity (X = mandatory) | 10 % of rated path velocity (X = mandatory) |
| Path accuracy and path repeatability | X | X | X |
| Cornering deviations | X | X | X |
| Path velocity characteristics | X | X | X |

## 6.8 Definitions of poses to be tested and paths to be followed

### 6.8.1 Objective

This subclause describes how five suitable measurement positions are located in a plane placed inside a cube within the working space. It also describes test paths to be followed. When robots have a range of motion along one axis, small with respect to the other, replace the cube by a rectangular parallelepiped.

### 6.8.2 Location of the cube in the working space

A single cube, the corners of which are designated $C_1$ to $C_8$ (see figure 1), is located in the working space with the following requirements fulfilled:

— the cube shall be located in that portion of the working space with the greatest anticipated use;

— the cube shall have the maximum volume allowable with the edges parallel to the base coordinate system.

A figure showing the location of the cube used in the working space shall be included in the test report.

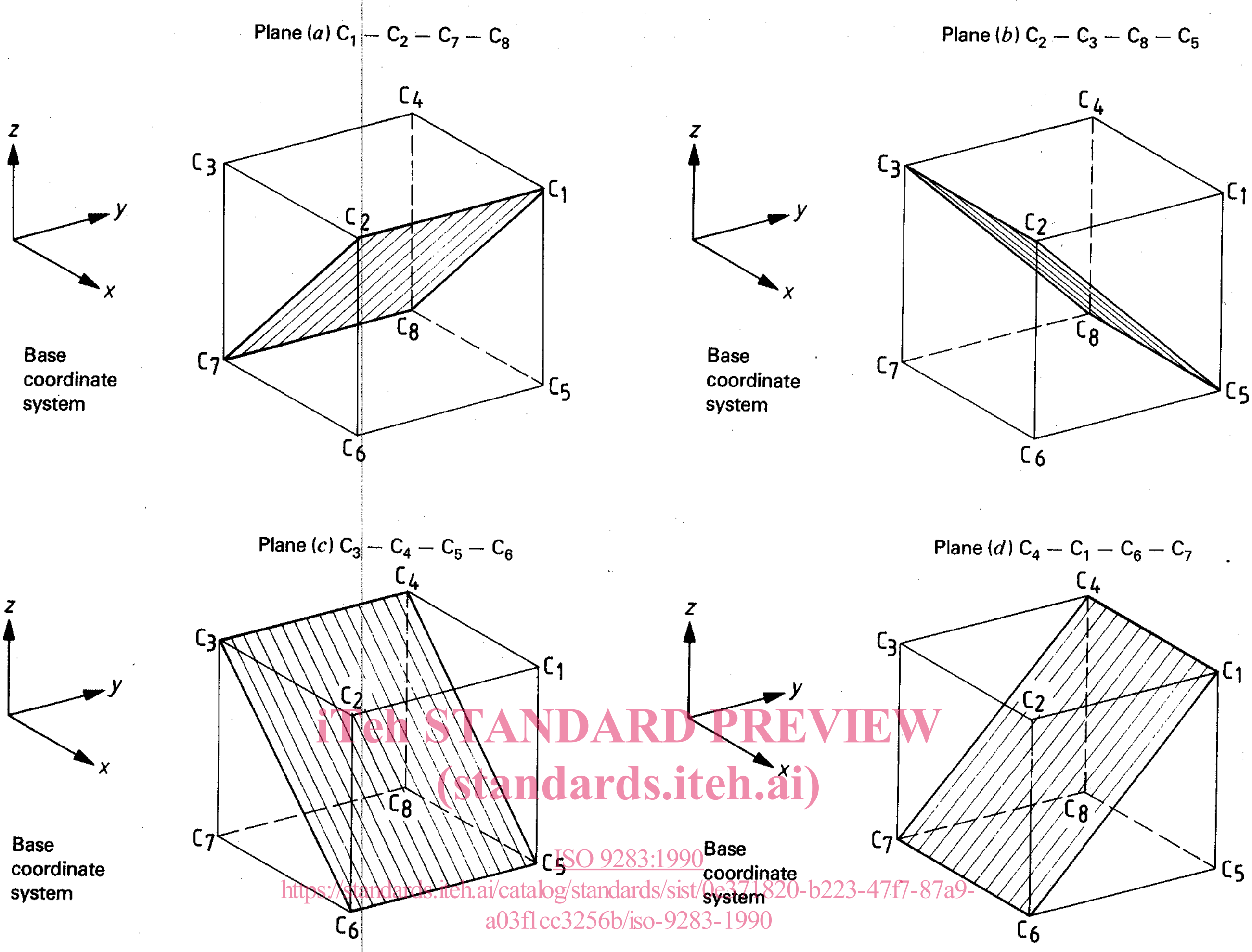





**Figure 1 — Cube within the working space**

### 6.8.3 Location of the planes to be used within the cube

One of the following planes shall be used for pose testing, for which the manufacturer has declared the values in the data sheet to be valid:

a) $C_1 - C_2 - C_7 - C_8$

b) $C_2 - C_3 - C_8 - C_5$

c) $C_3 - C_4 - C_5 - C_6$

d) $C_4 - C_1 - C_6 - C_7$

The test report shall specify which of the four planes has been tested.

### 6.8.4 Poses to be tested

Five points ($P_1$ to $P_5$) are located on the diagonals of the selected plane. These points, together with the orientations specified by the manufacturer, constitute the test poses at which the centre of the mechanical interface is placed for the test. The test poses shall be specified in base coordinates and/or joint coordinates, as specified by the manufacturer.

NOTE 2 The use of base coordinates is preferred.

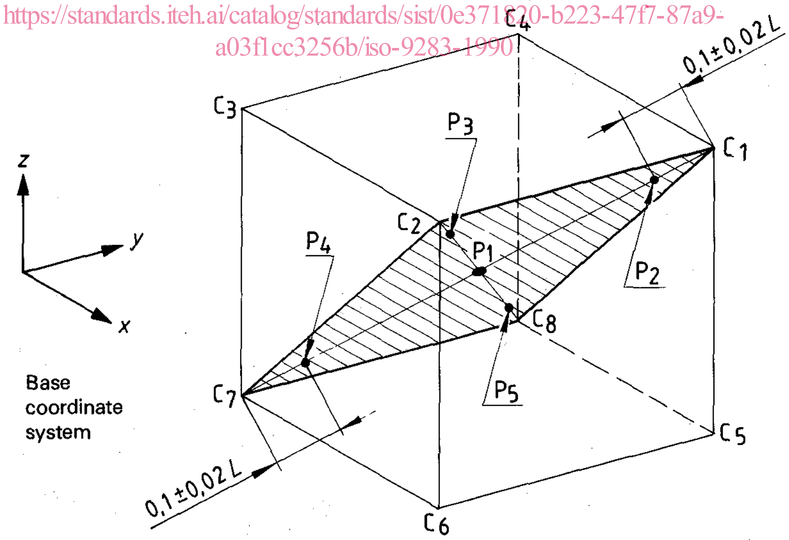
$P_1$ is the intersection of the diagonals and is the centre of the cube. The points $P_2$ to $P_5$ are located at a distance from the ends of the diagonals equal to (10 ± 2) % of the length of the diagonal (see figure 2). If this is not possible then the nearest point chosen on the diagonal shall be reported.

The poses to be used for pose characteristics are given in table 4.

**Table 4 — Poses to be used for pose characteristics**

| Characteristics to be tested | Poses | | | | |
|---|---|---|---|---|---|
| | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ |
| Unidirectional pose accuracy and pose repeatability | X | X | X | X | X |
| Multi-directional pose accuracy variation | X | X | — | X | — |
| Distance accuracy and distance repeatability | — | X | — | X | — |
| Pose stabilization time | X | X | X | X | X |
| Pose overshoot | X | X | X | X | X |
| Drift of pose characteristics | X | — | — | — | — |






*L* = length of diagonal

Example showing plane *a*) $C_1 - C_2 - C_7 - C_8$ with poses $P_1 - P_2 - P_3 - P_4 - P_5$

**Figure 2 — Poses to be used**

### 6.8.5 Movement requirements

All joints shall be exercised during movement between all poses.

Care should be taken during the test not to exceed the manufacturing operation specification.

### 6.8.6 Paths to be followed

#### 6.8.6.1 Location of the test path

The cube described in 6.8.2 shall be used.

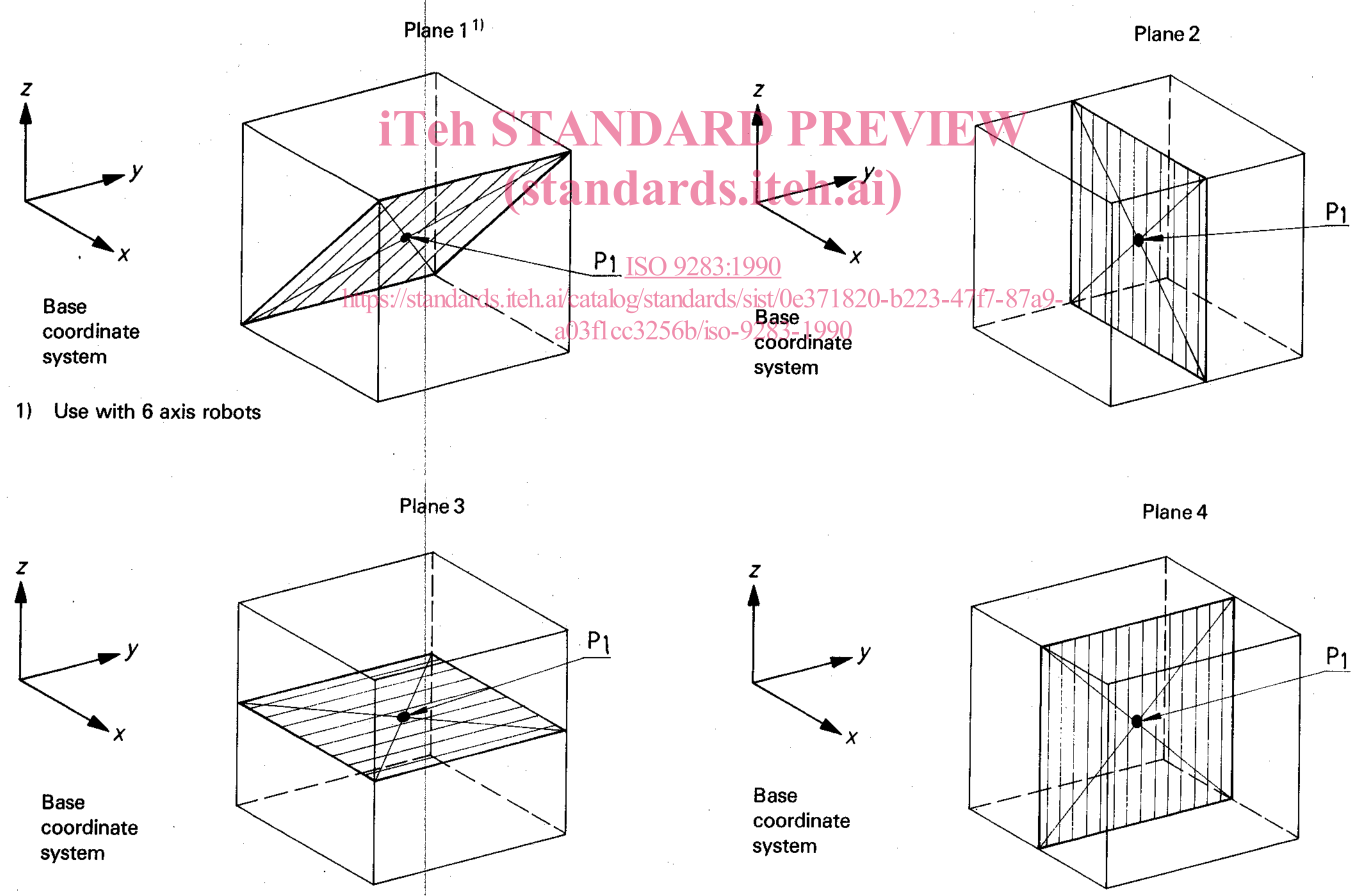
The test path shall be located on one of the four planes shown in figure 3. For six axis robots, plane 1 shall be used unless otherwise specified by the manufacturer. For robots with less than six axes the plane to be used shall be as specified by the manufacturer.

During the measurement of the path characteristics the centre of the mechanical interface should lie in the plane selected, and its orientation should be kept constant to that plane.

#### 6.8.6.2 Shape and size of the test path

Figure 16 in 8.2 gives an example of a command linear path and figure 17 in 8.2 gives an example of a command circular path.

The shape of the test path should be linear or circular except for cornering deviations (see 8.4 and figure 18). If paths of other shapes are used they shall be as specified by the manufacturer and added to the test report.




1) Use with 6 axis robots



**Figure 3 — Definition of planes for location of test path**

For a linear path, the length of the path shall at least be equal to 80 % of the distance between opposite corners of the selected plane. An example is the distance $P_2$ to $P_4$ in figure 4.

For the circular path test, two different circles shall be tested. For the large circle the path shall be inside the defined plane and as large as possible.

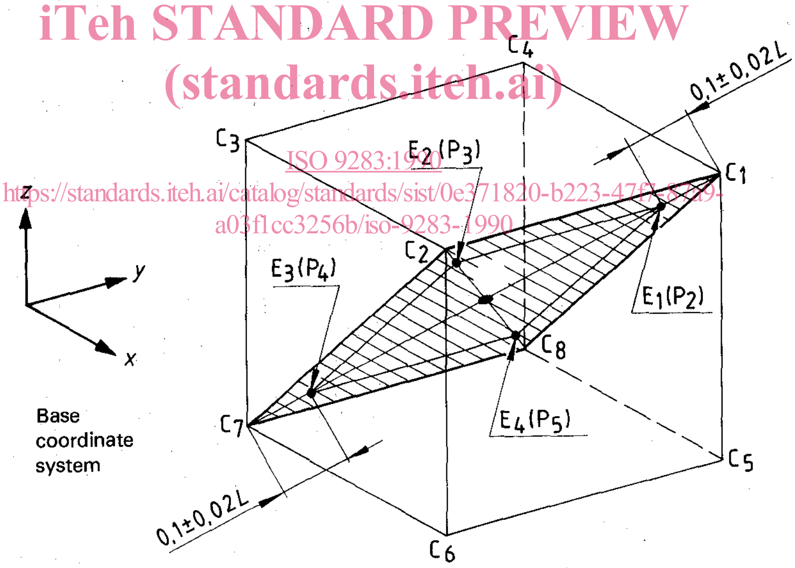
The diameter of the large circle shall be at least 80 % of the length of the side of the cube. The centre of the circle shall be $P_1$.

The small circle should have a diameter of 10 % of the largest circle in the plane or 20 mm, whichever figure is the least. The centre of the circle shall be $P_1$.

The path shall be programmed so that a minimum number of command points are used and that each command point is located along the path. The number and location of the command points and the method of programming shall be specified in the test report.

For a rectangular path, the corners are denoted $E_1$, $E_2$, $E_3$ and $E_4$, each of which is at a distance from its respective corner of the plane equal to (10 ± 2) % of a diagonal of the plane. An example is shown in figure 4 in which $P_2$, $P_3$, $P_4$ and $P_5$ coincide with $E_1$, $E_2$, $E_3$ and $E_4$ respectively.






*L* = length of diagonal

**Figure 4 — Example showing a rectangular path**