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Robotics — Performance criteria and related test methods for service robots —

Part 4: Lower-back support robots

Robotique — Critères de performance et méthodes d'essai correspondantes pour robots de service

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 299, *Robotics*.

A list of all parts in the ISO 18646 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is intended to facilitate understanding of performance of lower-back support robots (see Annex B). This document defines the important performance characteristics and describes how to specify them and how to test them.

The characteristics for which test methods are given in this document are those considered to affect robot performance significantly. The user of this document selects which performance characteristics to test, in accordance with the specific requirements.

The performance criteria specified in this document are not intended to be interpreted as the verification or validation of safety requirements. The verification and validation of safety requirements are specified in other standards developed by ISO TC 299.

The International Organization for Standardization (ISO) draws attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning the test apparatuses of the performance of wearable robots for lower-back support referred to throughout the document.

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Robotics — Performance criteria and related test methods for service robots —

Part 4:
Lower-back support robots

1 Scope

This document describes methods of specifying and evaluating the performance of lower-back support robots.

This document applies regardless of the purpose and application of lower-back support robots and the driving methods (e.g. electric, hydraulic and pneumatic). This document does not apply to medical robots, although the test methods specified in this document can be utilized for medical robots.

This document is not intended for the verification or validation of safety requirements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 8373, *Robots and robotic devices — Vocabulary*

ISO 13482, *Robots and robotic devices — Safety requirements for personal care robots*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8373, ISO 13482 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
robot
programmed actuated mechanism with a degree of autonomy, moving within its environment, to perform intended tasks

Note 1 to entry: A robot includes the control system and interface of the control system.

Note 2 to entry: The classification of robot into industrial robot or service robot is done according to its intended application.

[SOURCE: ISO 8373:2012, 2.6, modified — The words “actuated mechanism programmable in two or more axes” have been replaced with “programmed actuated mechanism”.]

3.2
wearable robot
robot that supplements or augments personal capabilities while attached to a human during use

Note 1 to entry: Wearable robots are referred to as restraint-type physical assistant robots in ISO 13482:2014.

3.3
lower-back support robot
wearable robot to reduce the load in the lower back of the user by its assistive force or torque

3.4
user
person who wears a wearable robot on his/her body and directly receives its assistive force or torque

3.5
restraint part
part of the wearable robot binding a corresponding attached body part of the user to transmit an assistive force or torque

3.6
assistive torque
output torque of the wearable robot to assist a user to perform required tasks

3.7
attached body part
part of the user's body on which the restraint part of the wearable robot is attached

3.8
input method
interface allowing the user to control the assistive force or torque of the wearable robot by an appropriate input signal

3.8.1
biological input
input method where biological signals that are in correlation to the force or torque the user exerts at his/her body part intended for assistance are used as the input

Note 1 to entry: Biological signals include bioelectrical signals such as myoelectric signals.

3.8.2
kinematic input
input method where movement and/or posture of the user's body parts intended for assistance are used as the input

Note 1 to entry: Biological input and kinematic input are mutually exclusive.

3.8.3
command input
any input method other than biological input or kinematic input

Note 1 to entry: Command input includes the use of commanding devices, breath switches or voice input.

Note 2 to entry: Command input includes the use of biological signals that are not in correlation to the force or torque the user exerts at the body part intended for assistance.

Note 3 to entry: Command input includes movement and/or posture of the user's body parts not intended for assistance.

3.9
assistive torque index
ATI
measure of how much the output torque of the user is reduced when the user performs a specific movement during a specific time range using the lower-back support robot

Note 1 to entry: ATI is an absolute quantity with respect to the average torque during the specific time period of a specific test motion profile. It can be helpful for the relative comparison between robots.

3.10
lumbar compression reduction
LCR
measure of how much the compressive force on the user's lumbar disks is reduced when the user performs a specific movement during a specific time range using the lower-back support robot

3.11
normal operating conditions
range of environmental conditions and other parameters which can influence robot performance (such as electrical supply instability, electromagnetic fields) within which the performance of the robot specified by the manufacturer is valid

Note 1 to entry: Environmental conditions include, for example, temperature and humidity.

[SOURCE: ISO 8373:2012, 6.1]

3.12
rate of assistance
measure of the reduced torque by a lower-back support robot integrated over the time period of a specific test motion profile

Note 1 to entry: Rate of assistance is a normalized quantity with respect to the integrated torque over the time period of a specific test motion profile. It can be helpful for the relative comparison for different test motion profiles within the robot.

4 Test conditions

4.1 General

The lower-back support robot shall be completely assembled, sufficiently charged and operational. All self-diagnostic tests shall be satisfactorily completed. It should also be ensured that the robot operates in a safe manner throughout the test.

The tests shall be preceded by the preparations for operation as specified by the manufacturer, including calibration of any relevant sensors that effect on the test results.

All conditions specified in Clause 4 should be satisfied for the tests described in this document, unless it is stated otherwise in the specific clauses.

Each test described in Clause 5 and Clause 6 of this document have different test configurations which require separate test apparatuses and test procedures.

4.2 Environmental conditions

The following environmental conditions shall be maintained during all tests.

— Ambient temperature: 10 °C to 30 °C

— Relative humidity: 0 % to 80 %

If the environmental conditions specified by the manufacturer are outside the given conditions, then this shall be declared in the test results.

4.3 Operating conditions

All performance shall be measured under normal operating conditions. When the performance is measured under conditions outside the normal operating conditions, these conditions shall be specified along with the test results.

5 Test method for assistive torque index and lumbar compression reduction

5.1 Purpose

This clause describes the method of specifying and evaluating the performance of lower-back support robots.

NOTE Theoretical backgrounds and validation experiments are provided in Reference [6] which provides a rationale of focusing only on bending torques and compression forces. At the current stage of the market, there are only the products that are intended to assist sagittal movement. To keep the test apparatus and test method simple, the limitation of the test method is considered acceptable to measure a representative performance of the robots.

5.2 Relevant characteristics

5.2.1 General

Two performance indices are introduced for this test method: Assistive torque index (ATI) and Lumbar compression reduction (LCR).

By the assistive torque of the robot, the user's extension force of hip joints and that of the trunk will be reduced, and then the compressive force on lumbar disks will be reduced. Ideally, the lumbar compression can be derived from the extension torque of hip joints and the posture of the trunk. The extension torque can be reduced by the assistive torque of the robot. For the robot with such characteristics, the lumbar compression does not need to be measured because it can be inferred from the assistive torque and the posture of trunk.

For some robots for which lumbar compression could be increased because of the robot's mechanical structure, mass and mass distribution above the lumbar joint and/or actuation method (e.g. artificial muscles on user's back skin), lumbar compression should be measured together with assistive torque.

NOTE According to Reference [1], compressive force on lumbar disks can be the major cause of back injury and, therefore, often used as an index to estimate the risk of back injury. Based on this background, LCR is introduced as a performance indication of the robot.

5.2.2 Assistive torque index (ATI)

The Assistive Torque Index (ATI) consists of 5 representative values, $\mathrm{ATI}_{1\,000}^{\mathrm{Lower}}$, $\mathrm{ATI}_{200}^{\mathrm{Lower}}$, $\mathrm{ATI}_{1\,000}^{\mathrm{Hold}}$, $\mathrm{ATI}_{1\,000}^{\mathrm{Raise}}$ and $\mathrm{ATI}_{200}^{\mathrm{Raise}}$, which are calculated by the following formulae with t_1 and t_2 specified in

Table 1. The superscript and the subscript of ATI indicate a phase of reference movement and a time duration in milliseconds, respectively.

$$\mathrm{ATI}_{t_2-t_1} = \frac{1}{t_2-t_1}\int_{t_1}^{t_2} \psi\left(\tau^{\mathrm{ref}}(t),\ \tau(t)\right)dt$$

where

$$\psi(\alpha,\beta) = \begin{cases} \alpha-\beta \text{ if } \alpha \ge 0 \\ -(\alpha-\beta) \text{ if } \alpha < 0 \end{cases},$$

$\tau^{\mathrm{ref}}(t)$ is the actual output torque of the hip joints of the test apparatus (see 5.3.1) during the reference movements (without robot);

$\tau(t)$ is the actual output torque of the hip joints of the test apparatus (see 5.3.1) during the reference movements (with robot).

NOTE 1 In general, assistive torque of the robot interferes with the duration of the movement and the necessary force or torque of the user. This is a source of instability of the test results. Therefore, this document adopts a time average within a specific time range during the reference movements.

NOTE 2 As the reference movements defined in 5.3.2 are antigravity movements, $\tau^{\mathrm{ref}}(t)$ is expected to be always negative and the relationship $\psi(\alpha,\beta) = -(\alpha-\beta)$ always applies. However, this document defines ψ in a more general form to make ψ positive when the necessary torque for the reference movement and the torque of the robot are in the same direction. See Annex A.

NOTE 3 When ψ is positive, the torque of the robot in the antigravity direction (extension) can reduce the necessary torque of the user to achieve the reference movements. Or, in some cases, the user has to output the torque in the gravity direction (flexion) to resist the torque of the robot. When ψ is negative, the torque of the robot in the gravity direction (flexion) can increase the necessary torque of the user to achieve the reference movements. See Annex A.

5.2.3 Lumbar compression reduction (LCR)

The Lumbar Compression Reduction (LCR) consists of 5 representative values $\mathrm{LCR}_{1\,000}^{\mathrm{Lower}}$, $\mathrm{LCR}_{200}^{\mathrm{Lower}}$, $\mathrm{LCR}_{1\,000}^{\mathrm{Hold}}$, $\mathrm{LCR}_{1\,000}^{\mathrm{Raise}}$ and $\mathrm{LCR}_{200}^{\mathrm{Raise}}$, which are calculated by the following equations with t_1 and t_2 specified in Table 1. The superscript and the subscript of LCR indicate a phase of reference movement and a time duration in milliseconds, respectively.

$$\mathrm{LCR}_{t_2-t_1} = \frac{1}{t_2-t_1}\int_{t_1}^{t_2} \psi\left(F^{\mathrm{ref}}(t),\ F(t)\right)dt$$

where

$$\psi(\alpha,\ \beta) = \begin{cases} \alpha-\beta \text{ if } \alpha \ge 0 \\ -(\alpha-\beta) \text{ if } \alpha < 0 \end{cases},$$

$$F^{\mathrm{ref}}(t) = \phi\left(M_{\mathrm{y}}^{\mathrm{ref}}(t)\right) + F_{\mathrm{z}}^{\mathrm{ref}}(t)\ ,$$

$$F(t) = \phi\left(M_{\mathrm{y}}(t)\right) + F_{\mathrm{z}}(t)\ ,$$

$$\phi(\gamma) = \begin{cases} \gamma/0{,}05 \text{ if } \gamma \ge 0 \\ -\gamma/0{,}1 \text{ if } \gamma < 0 \end{cases},$$

$F_z^{ref}(t)$ is the actual lumbar compressive force of the test apparatus in z-axis direction during the reference movements (without robot);

$F_z(t)$ is the actual lumbar compressive force of the test apparatus in z-axis direction during the reference movements (with robot);

$M_y^{ref}(t)$ is the actual lumbar bending moment of the test apparatus around y-axis during the reference movements (without robot);

$M_y(t)$ is the actual lumbar bending moment of the test apparatus around y-axis during the reference movements (with robot).

The axes of the coordinate system are shown in Figure 1.

NOTE 1 In general, assistive torque of a robot interferes the duration of the movement and the compressive force on the lumbar disks of the user. This is a source of instability of the test results. Therefore, this document adopts a time average within a specific time range during the reference movements.

NOTE 2 A human would stiffen his/her muscles to resist the change of posture by the lumbar bending moment around the y-axis. This tension of the muscles is known as a source of compressive force on lumbar disks. On the other hand, the trunk of the test apparatus does not have muscles and its mechanical structure does not allow any change of posture unlike the spine. To compensate for this difference, the equation for LCR uses the corrected lumbar compressive force $F(t)$ and $F^{ref}(t)$ under the assumption that $M_y(t)$ and $M_y^{ref}(t)$ are all supported by virtual erector spinae muscles and virtual abdominal rectus muscles. This document adopts a 0,05 m moment arm from the L5/S1 lumbar disk to the virtual erector spinae muscles and a 0,1 m moment arm to the virtual abdominal rectus muscles[4][5].

NOTE 3 During the reference movement, the weight of the upper body of the test apparatus is expected to always compress the fixed lumbar joint and $\psi(\alpha,\beta)=\alpha-\beta$ always applies. However, this document defines ψ in a more general form to be applicable to tensile forces and to be consistent with the formula for ATI.

NOTE 4 When ψ is positive, the lumbar stress of the user is expected to be reduced during the reference movement. When ψ is negative, the lumbar stress of the user is expected to be increased during the reference movement.

Table 1 — Time range to calculate ATI and LCR

ATI [b]	LCR [b]	Reference movements	t_1 [a]	t_2 [a]
$ATI_{1\,000}^{Lower}$	$LCR_{1\,000}^{Lower}$	Lowering	$t_d - 1$ [s] [c]	t_d [s] [c]
ATI_{200}^{Lower}	LCR_{200}^{Lower}	Lowering	$t_d - 0{,}2$ [s] [c]	t_d [s] [c]
$ATI_{1\,000}^{Hold}$	$LCR_{1\,000}^{Hold}$	Holding	$\frac{t_d}{2} - 0{,}5$ [s]	$\frac{t_d}{2} + 0{,}5$ [s]

[a] t_1 and t_2 define a time range when the necessary torque of the user and the lumbar stress are the largest assuming the beginning time of each reference movement is 0 (see Annex A). Because the angle trajectories of the reference movement are increasing or decreasing monotonically, ATI and LCR can be considered as an average within a specific angle range. However, because 1) assistive torque can generate varying angle trajectories; 2) it is difficult to define the relevant angle ranges of the trunk, the hip joint and the knee joint simultaneously; and 3) the amount of data points for calculating the average can vary, this document adopts a time average to define ATI and LCR.

[b] ATI and LCR with a 1 s average ($ATI_{1\,000}^{Lower}$, $ATI_{1\,000}^{Hold}$, $ATI_{1\,000}^{Raise}$, $LCR_{1\,000}^{Lower}$, $LCR_{1\,000}^{Hold}$ and $LCR_{1\,000}^{Raise}$) can also be considered as an indication whether the robot can output assistive torque and reduce the lumbar stress continuously. On the other hand, ATI and LCR with a 0,2 s average (ATI_{200}^{Lower}, ATI_{200}^{Raise}, LCR_{200}^{Lower} and LCR_{200}^{Raise}) can be an indication of how much the robot can reduce the peak of necessary torque and the compressive force on the lumbar disks responsively (see Annex A). This is due to the fact that they only focus on a short time range. This document adopts a 0,2 s response time for humans to reflect the reaction to sudden load on lumbar spinal cord[3][9].

[c] t_d is the actual duration of the reference movement.