TECHNICAL REPORT

ISO/TR 22676

First edition
2006-10-01

Prosthetics — Testing of ankle-foot devices and foot units — Guidance on the application of the test loading conditions of ISO 22675 and on the design of appropriate test equipment

Prothèses — Essais de mécanismes cheville-pied et unités de pied — Directives d'application des conditions de force d'essai selon l'ISO 22675 et de la conception d'équipement d'essai approprié

Reference number
ISO/TR 22676:2006(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 22676 was prepared by Technical Committee ISO/TC 168, *Prosthetics and orthotics*.

Introduction

This Technical Report is exclusively intended for use in connection with ISO 22675.

This Technical Report offers information that is closely related to the above International Standard but is not necessarily required for its application.

In order to confine the volume of ISO 22675 to the necessary, information with guidance character has been separated from it and compiled in this Technical Report.

Prosthetics — Testing of ankle-foot devices and foot units — Guidance on the application of the test loading conditions of ISO 22675 and on the design of appropriate test equipment

1 Scope

This Technical Report offers guidance on:

a) the specification of the test loading conditions of ISO 22675;

b) the design of appropriate test equipment.

The analytical work related to these items would have expanded the length of ISO 22675 without being directly required for its application. Most of the text of this Technical Report relates to the theoretical and technical background and the design of the equipment.

2 Guidance on the specification of the test loading conditions of ISO 22675

2.1 General

Although the concept of the tests on ankle-foot devices and foot units of ISO 22675 differs from that of the corresponding tests of ISO 10328, the relevant values of loads and dimensions are adopted where possible. Nevertheless, a few adaptations are unavoidable.

In order to confine the volume of ISO 22675 to the necessary, these and other matters relevant to the specification of the test loading conditions and test loading levels of ISO 22675 are dealt with in detail in this Technical Report.

2.2 Directions of static and maximum cyclic heel and forefoot reference loading

NOTE For the meaning of “reference” see also statements under “IMPORTANT” at the end of 2.4.1 and 2.4.2.

2.2.1 Basic relationships and conditions

The specification of the directions of static and maximum cyclic heel and forefoot reference loading is based on the relationships of a) and the conditions of b) and c) below.

a) According to Figure 1, for any instant of the loading period shown in Figure 2 there is a given relationship between the test force F and the forces at the foot platform, comprising the tangential (A-P) force component F_T, the perpendicular force component F_P and their resultant F_R. This relationship is determined by the angles α, β and γ.

The following Equations apply:

$$\alpha + \beta = \gamma \quad (1)$$

$$\beta = \arctan (F_T/F_P) \quad (2)$$

b) The values of the tilting angles γ_1 and γ_2 of the foot platform for static and maximum cyclic heel and forefoot reference loading are consistent with those specified in ISO 10328 for the separate structural tests on ankle-foot devices and foot units. These values are γ_1 = – 15° for heel loading and γ_2 = 20° for forefoot loading (see Table 10, Figure 7 and 17.2 of ISO 10328:2006 and Table 8 of ISO 22675:2006).

c) The ratio F_T/F_P of the values of the tangential and perpendicular force components at the foot platform according to Figures 1 and 2 for static and maximum cyclic heel and forefoot reference loading at the tilting angles according to b) is roughly ± 0,15.

NOTE The ratio addressed in c) is based on gait analysis data representative of normal level walking.

2.2.2 Lines of action of the resultant reference forces F_{R1} and F_{R2}

The relationships of 2.2.1 a) and the conditions of 2.2.1 b) and c) allow the inclination of the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading to be specified as follows:

— from Equation (2) and the condition according to 2.2.1 c) $\beta = \arctan (F_T/F_P) = \arctan(\pm 0{,}15) = \pm 8{,}5°$;

— from Equation (1) and the conditions according to 2.2.1 b) $\alpha_1 = \gamma_1 - \beta_1 = -15° + 8{,}5° = -6{,}5°$ and $\alpha_2 = \gamma_2 - \beta_2 = 20° - 8{,}5° = 11{,}5°$.

The inclinations of the load lines of test loading conditions I and II of the principal structural tests of ISO 10328 do not correspond to these values, as the following calculation demonstrates. The inclination of their projection on the f-u-plane is defined by Equation (3).

$$\alpha_{I,\,II} = -\arctan [(f_K - f_A)/(u_K - u_A)] \tag{3}$$

The specific values of $\alpha_{I,\,II}$ calculated with the f- and u-coordinates specified for test loading level P5 (see Tables 5 and 6 of ISO 10328:2006) are α_I = – 11,31° and α_{II} = 6,52°. Together with the values β_I = – 3,69° and β_{II} = 13,48° calculated using Equation (1) and the values of γ according to 2.2.1 b) they determine the ratio of horizontal and vertical ground reaction force as

$$(F_T/F_P)_{I,\,II} = \tan \beta_{I,\,II} \tag{4}$$

giving the values $(F_T/F_P)_I$ = – 0,064 and $(F_T/F_P)_{II}$ = 0,24, which differ considerably from the ratio according to 2.2.1 c).

In order to approach the conditions illustrated in Figures 1 and 2, the inclination of the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading according to ISO 22675 need to be determined by values of the angles α_1 and α_2 close to those calculated in the above.

This has been taken into account when establishing the full set of parameters required to specify the test loading conditions of the tests on ankle-foot devices and foot units of ISO 22675.

Figure 3 illustrates the profiles (curves) of the forces F_P, F_T, F_R and F as well as the profiles (curves) of the angles α, β and γ as a function of stance phase time.

Apparently, the values of the angles α and β for static heel reference loading or maximum cyclic heel reference loading at 150 ms after heel contact (α_1 = – 6,18°; β_1 = – 8,82°) and for static forefoot reference loading or maximum cyclic forefoot reference loading at 450 ms after heel contact (α_2 = 11,14°; β_2 = 8,86°) are close to the values of the angles α_1, α_2 and β calculated in the above (α_1 = – 6,5°; α_2 = 11,5° and β = ± 8,5°).

Based on these values, the directions of static and maximum cyclic heel and forefoot reference loading according to ISO 22675 can be specified in part as follows:

— The direction of static and maximum cyclic heel reference loading is defined as a straight line inclined to the u-axis by $\alpha_1 = -6{,}18°$.

— The direction of static and maximum cyclic forefoot reference loading is defined as a straight line inclined to the u-axis by $\alpha_2 = 11{,}14°$.

NOTE The angles α_1 and α_2 only determine the inclination to the u-axis of the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading according to ISO 22675. In order to also determine their position, further parameters need to be specified, as for example the coordinates of specific reference points, through which they pass, as follows.

The different test loading conditions applicable to or particularly developed for ankle-foot devices and foot units, specified in ISO 10328 and ISO 22675, are illustrated in Figure 4 for test loading level P5. This figure illustrates:

1) the test loading conditions I and II of the principal structural tests of ISO 10328 (their projection on the f-u-plane);

2) the loading conditions of the separate structural tests on ankle-foot devices and foot units of ISO 10328;

3) the directions of static and maximum cyclic heel and forefoot reference loading of the tests on ankle-foot devices and foot units of ISO 22675.

The directions of static and maximum cyclic heel and forefoot reference loading according to ISO 22675 are specified in Cartesian coordinates as in test loading conditions I and II of the principal structural tests of ISO 10328.

For consistency at test loading level P5, the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading according to ISO 22675 have the same f_A-offsets as in test loading conditions I and II of ISO 10328 (see Figure 4).

With the values of the f_A-offsets at test loading level P5 specified in Table 7 of ISO 10328:2006 the above requirement allows the complete specification of the directions of static and maximum cyclic heel and forefoot reference loading according to ISO 22675 at test loading level P5 as follows:

— the direction of static and maximum cyclic heel reference loading at test loading level P5 is defined as a straight line which passes the ankle level at $f_{A1} = f_{AI} = -32$ mm and is inclined to the u-axis by $\alpha_1 = -6{,}18°$;

— the direction of static and maximum cyclic forefoot reference loading at test loading level P5 is defined as a straight line which passes the ankle level at $f_{A2} = f_{AII} = 120$ mm and is inclined to the u-axis by $\alpha_2 = 11{,}14°$.

2.2.3 Position of the top load application point P_T

NOTE 1 The following is in accordance with Clause 6 and Figure 1 of ISO 22675:2006.

For the tests on ankle-foot devices and foot units of ISO 22675, the top load application point P_T is the point of intersection P_i of the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading specified in 2.2.2.

The coordinates f_T and u_T of the top load application point P_T are calculated by determining at first the functions $u_1(f)$ and $u_2(f)$ of these lines of action from Equation (5)

$$u(f) = f \times \tan(90 - \alpha) + u_0 \tag{5}$$

and then determining their point of intersection P_i by putting $u_1(f) = u_2(f)$.

This method provides the following results:

— the functions of the lines of action of the resultant reference forces F_{R1} and F_{R2} are $u_1(f)_{P5} = 9{,}24 \times f + 375{,}53$ and $u_2(f)_{P5} = -5{,}08 \times f + 689{,}39$;

— their point of intersection is located at $P_{i,\ P5}$ ($f_{i,\ P5} = 22$; $u_{i,\ P5} = 578$).

The method for determining the functions $u_1(f)$ and $u_2(f)$ of the lines of action of the resultant reference forces F_{R1} and F_{R2} and their point of intersection P_i relates to test loading level P5. To apply this method to test loading levels P4 and P3, adaptations concerning the specific f_A-offsets are necessary, as described in the following.

According to 10.1.2.1 of ISO 10328:2006, "*For the principal structural tests on samples of prosthetic structures including an ankle-foot device or a foot unit […], the size of the foot selected shall allow the application of load in accordance with the combined bottom offset S_B specified for the test...*"

NOTE 2 The combined bottom offset S_{BII} determines the distance from the u-axis of the bottom load application point P_{BII} on the forefoot.

The selection of the correct size of foot providing the correct distance from the u-axis of the bottom load application point P_{BII} on the forefoot determines also the correct distance from the u-axis of the bottom load application point P_{BI} on the heel.

Assuming standard proportions for different sizes of feet, the values of S_{BII} and S_{BI} should show a similar scaling. According to the dimensions specified in Table 8 of ISO 10328:2006, this is, however, not the case. While the values of S_{BII} decrease from test loading level P5 to test loading level P3, as to be expected, the corresponding values of S_{BI} have the opposite trend. (Hence, for test loading levels P4 and P3, the bottom load application point P_{BI} of test loading condition I is likely to be located outside the heel portion of an ankle-foot device or foot unit of the size that provides the correct combined bottom offset S_{BII} of the load application point P_{BII} on the forefoot.)

The same applies, in principle, to the values of the offsets f_{BII}; f_{BI} and f_{AII}; f_{AI}.

For the determination of the reference test loading conditions for static and maximum cyclic heel and forefoot reference loading according to ISO 22675 adapted values of f_A- and f_B-offsets, identified by suffixes "1" and "2", can be established by the following conditions, which take account of the configurations described in 2.2.2 and illustrated in Figure 4.

NOTE 3 The offsets f_{AI} and f_{AII} of test loading level P5 and the offset f_{AII} of test loading levels P4/P3 of ISO 10328:2006 have been adopted as f_{A1} and f_{A2} of P5 and f_{A2} of P4/P3 without adaptation of their values.

$$(f_{A,\ P5} - f_{i,\ P5})/(u_{i,\ P5} - u_{A,\ P5}) = (f_{B,\ P5} - f_{i,\ P5})/(u_{i,\ P5} - u_{B,\ P5}) \tag{6}$$

$$f_{A1,\ P5}/f_{A2,\ P5} = f_{A1,\ P4/P3}/f_{A2,\ P4/P3} \tag{7}$$

$$f_{B1,\ P5}/f_{B2,\ P5} = f_{B1,\ P4/P3}/f_{B2,\ P4/P3} \tag{8}$$

$$(f_{B2,\ P5} - f_{B1,\ P5})/(f_{A2,\ P5} - f_{A1,\ P5}) = (f_{B2,\ P4/P3} - f_{B1,\ P4/P3})/(f_{A2,\ P4/P3} - f_{A1\ P4/P3}) \tag{9}$$

using Equation (6) $f_{B1,\ P5} = (-32 - 22)/(578 - 80) \times (578 - 0) + 22 = -41$ and

$f_{B2,\ P5} = (120 - 22)/(578 - 80) \times (578 - 0) + 22 = 136$.

using Equation (7) $f_{A1,\ P4/P3} = -32/120 \times 115 = -31$.

using Equation (8) $f_{B1,\ P4/P3}/f_{B2,\ P4/P3} = -41/136 = -0{,}3$ or

$f_{B1,\ P4/P3} = -0{,}3 \times f_{B2,\ P4/P3}$.

using Equation (9) $f_{B2,\ P4/P3} - f_{B1,\ P4/P3} = (136 + 41)/(120 + 32) \times (115 + 31) = 170$ or

$f_{B2,\ P4/P3} + 0{,}3 \times f_{B2,\ P4/P3} = 1{,}3 \times f_{B2,\ P4/P3} = 170$, giving

$f_{B2,\ P4/P3} = 170/1{,}3 = 131$ and

$f_{B1,\ P4/P3} = -0{,}3 \times f_{B2,\ P4/P3} = 39$.

Since it is desired that for static and maximum cyclic heel and forefoot reference loading the ratio F_T:F_P of the values of the tangential and perpendicular force components (see 2.2.1) is the same for all test loading levels, the inclinations of the lines of action of the resultant reference forces F_{R1} and F_{R2}, determined by the angles $\alpha_1 = -6{,}18°$ and $\alpha_2 = 11{,}14°$ (see 2.2.2) also need to be the same for all test loading levels.

The point of intersection $P_{i,\ P4/P3}$ of the lines of action of the resultant reference forces F_{R1} and F_{R2} for the specific f_A-offsets related to test loading levels P4 and P3 illustrated in Figure 5 in the style applied to Figure 4 can, therefore, be calculated in the manner described in the above for test loading level P5, using the functions determined by application of Equation (5), modified by a coordinate transformation that regards parallel shifting determined by the differences

$(f_{A1,\ P5} - f_{A1,\ P4/P3})$ for $u_1(f)$ and $(f_{A2,\ P5} - f_{A2,\ P4/P3})$ for $u_2(f)$.

The resulting coordinates of the point of intersection $P_{i,\ P4/P3}$ are

$P_{i,\ P4/P3}(f_{i,\ P4/P3} = 21;\ u_{i,\ P4/P3} = 554)$.

The different positions of the point of intersection P_i of the lines of action of the resultant reference forces F_{R1} and F_{R2} determined in the above are dependent on the size of foot determined by the foot length L rather than on the test loading level. This can be shown as follows.

Assuming again, standard proportions for different sizes of feet, the values of f_{A2}, f_{A1} or $(f_{A2} + f_{A1})$ can be expected to show a scaling that is proportional to the size of foot.

Indeed, the scaling of the f- and u-coordinates of $P_{i,\ P5}$ by the quotient $f_{A2,\ P4/P3}/f_{A2,\ P5} = 115/120$ gives exactly the same position of $P_{i,\ P4/P3}$ as calculated in the above.

For test loading level P5 test loading condition II the most appropriate size of foot meeting the condition of 10.1.2.1 of ISO 10328:2006 quoted in the above is size 26 (foot length L = 26 cm).

Consequently, the most appropriate size of foot meeting this condition for test loading levels P4 and P3 shall be size 26 scaled by either of the quotients

$(f_{A2,\ P4/P3} - f_{A1,\ P4/P3})/(f_{A2,\ P5} - f_{A1,\ P5}) = (115 + 31)/(120 + 32)$ or

$(f_{B2,\ P4/P3} - f_{B1,\ P4/P3})/(f_{B2,\ P5} - f_{B1,\ P5}) = (131 + 39)/(136 + 41)$,

which give identical values (0,96) indicating size 25 (foot length L = 25 cm).

In this relation it is important to realize that straight lines drawn from the points of intersection $P_{i,\ P5}$ or $P_{i,\ P4/P3}$ to the points on the f-axis at $f_{B1,\ P5}$ and $f_{B2,\ P5}$ or $f_{B1,\ P4/P3}$ and $f_{B2,\ P4/P3}$ determine reference triangles of identical proportions (see Figure 5).

Since the ratio of f-offsets/foot length L is identical for both sizes of foot, triangles determined by straight lines drawn from the points of intersection $P_{i,\ P5}$ or $P_{i,\ P4/P3}$ to the points on the f-axis determined by the posterior heel edge and the point of foot of the reference feet of sizes 26 (foot length L = 26 cm) and 25 (foot length L = 25 cm) will also have identical proportions (see Figure 6).

The dependence of the position of the point of intersection P_i of the lines of action of the resultant reference forces F_{R1} and F_{R2} on the foot length L described in the above has been established in the concept of the tests of ISO 22675 in the following manner.

— The point of intersection P_i of the lines of action of the resultant reference forces F_{R1} and F_{R2} of static and maximum cyclic heel and forefoot reference loading is referred to as top load application point P_T. If appropriate, the dependence of the position of the top load application point $P_T(f_T, u_T)$ on the foot length L is indicated by the additional suffix 'L' in the form $P_{T,\ L}(f_{T,\ L}, u_{T,\ L})$. If appropriate, general suffix 'L' is replaced by specific values.

— The f- and u-coordinates determining the position of the top load application point P_T are specified in Table 8 of ISO 22675:2006 for a wide range of foot lengths L. In addition, that table includes the Equations that determine these coordinates for any other foot length.

— As is illustrated in Figure 6, the proportion of the reference triangle described in the above uniformly applies to all sizes of foot, independent of the test loading level. In principle, this allows ankle-foot devices and foot units of any size of foot to be tested at any of the test loading levels specified.

For feet of different lengths L, positioned within the coordinate system as illustrated in Figure 6, the related top load application points $P_{T,\ L}$ are located on a straight line directed to the origin of the coordinate system. The distance D_{PT} between load application points $P_{T,\ L}$ relating to two successive values of foot length L has a fixed value determined by the Equation

$$D_{PT} = \frac{\sqrt{\left(f_{T,26}{}^2 + u_{T,26}{}^2\right)}}{26} \tag{10}$$

which gives a value of D_{PT} = 22,2.

2.3 Magnitudes of static and maximum cyclic heel and forefoot reference loading

The specification of the magnitudes of static and maximum cyclic heel and forefoot reference loading is based on the following general condition.

The specific values F_{R1x} and F_{R2x} of the resultant reference forces F_{R1} and F_{R2} (see Figure 1) are consistent with the corresponding values F_{1x} and F_{2x} of the test forces F_1 and F_2 specified in ISO 10328 for the separate tests on ankle-foot devices and foot units (see Tables 12 and D.3 of ISO 10328:2006). The specific values F_{R1x} and F_{R2x} of the resultant reference forces F_{R1} and F_{R2} are listed in Table 1.

The specific values F_{1x} and F_{2x} of the test forces F_1 and F_2 related to the specific values F_{R1x} and F_{R2x} of the resultant reference forces F_{R1} and F_{R2} (see Figure 1) are determined by the following Equation, derived from the relationship described in 2.2.1 a):

$$F_{1,\ 2} = F_{R1,\ R2} \times \cos \alpha_{1,\ 2} \tag{11}$$

The specific values F_{1x} and F_{2x} of the test forces F_1 and F_2 calculated using Equation (11) for α_1 = – 6,18° and α_2 = 11,14° (see 2.2.2) are listed in Tables 10 and C.2 of ISO 22675:2006.

Table 1 — Magnitudes of resultant reference forces F_{R1x} and F_{R2x}

Resultant force F_{R1x}, F_{R2x}	Related test forces F_{1x} and F_{2x} of the separate tests on ankle-foot devices and foot units specified in ISO 10328 (see Tables 12 and D.3 of ISO 10328:2006)								
	Symbol	Numerical values for heel and forefoot loading F_{1x} and F_{2x} at test loading level P_y							
		P6		P5		P4		P3	
		Heel	Forefoot	Heel	Forefoot	Heel	Forefoot	Heel	Forefoot
		N							
F_{R1sp},	F_{1sp},	2 800	—	2 240	—	2 065	—	1 610	—
F_{R2sp}	F_{2sp}	—	2 800	—	2 240	—	2 065	—	1 610
$F_{R1su, lower level}$,	$F_{1su, lower level}$,	4 200	—	3 360	—	3 098	—	2 415	—
$F_{R2su, lower level}$,	$F_{2su, lower level}$	—	4 200	—	3 360	—	3 098	—	2 415
$F_{R1su, upper level}$,	$F_{1su, upper level}$,	5 600	—	4 480	—	4 130	—	3 220	—
$F_{R2su, upper level}$	$F_{2su, upper level}$	—	5 600	—	4 480	—	4 130	—	3 220
F_{R1cmax},	F_{1cr},	1 600	—	1 280	—	1 180	—	920	—
F_{R2cmax}	F_{2cr}	—	1 600	—	1 280	—	1 180	—	920
F_{R1fin},	F_{1fin},	2 800	—	2 240	—	2 065	—	1 610	—
F_{R2fin}	F_{2fin}	—	2 800	—	2 240	—	2 065	—	1 610

2.4 Reference test loading conditions of static and cyclic tests

2.4.1 Static tests

According to the statements of 2.2 and 2.3, the reference test loading conditions for static (and maximum cyclic; see NOTE) heel and forefoot loading according to ISO 22675 are determined by the parameters listed in a) to d). (For the meaning of "reference" see IMPORTANT.)

a) The position of the top load application point P_T, determined by the coordinates f_T and u_T relevant to the foot length L of the test sample (see 2.2.3); these are specified as offsets $f_{T, L}$ and $u_{T, L}$ in Table 8 of ISO 22675.

b) The direction of the lines of action of the resultant reference forces F_{R1} and F_{R2}, determined by the coordinates of the top load application point P_T [see a)] and their inclinations to the u-axis, determined by the angles $\alpha_1 = -6{,}18°$ and $\alpha_2 = 11{,}14°$ (see 2.2.2).

c) The magnitudes of the resultant reference forces F_{R1} and F_{R2}, specified in Table 1, and the related test forces F_1 and F_2 to be applied in the top load application point P_T [see a)] as illustrated in Figure 1, determined by Equation (11) for $\alpha_1 = -6{,}18°$ and $\alpha_2 = 11{,}14°$. These are specified in Table 10 of ISO 22675:2006.

d) The tilting angles $\gamma_1 = -15°$ and $\gamma_2 = 20°$ of the foot platform for static (and maximum cyclic; see NOTE) heel and forefoot loading. These are specified in Table 9 of ISO 22675:2006.

IMPORTANT — The inclinations of the lines of action of the resultant reference forces F_{R1} and F_{R2} to the u-axis addressed in b) are only relevant to the reference test loading conditions of the static (and cyclic; see NOTE) tests, since the concept of the tests of ISO 22675 allows each sample of ankle-foot device or foot unit to develop its individual performance under load corresponding to its individual design.

This will automatically determine the individual position of the bottom load application point P_{B1} on the heel or P_{B2} on the forefoot of the test sample (and with it the individual inclination of the load line) relating to the tilting position of the foot platform at γ_1 or γ_2 [see d)] and the individual magnitude of the resultant reference force F_{R1} or F_{R2}.

For this reason the configuration of the test set-up for the preparation of test loading [see 16.1.1 a) of ISO 22675:2006] is determined only by the position of the top load application point P_T relevant to the foot length L of the test sample according to a) and the tilting angles γ_1 and γ_2 of the foot platform according to d).

NOTE References (in parentheses) to the cyclic tests take into account that the linear and angular dimensions determining the reference test loading conditions for static heel and forefoot loading are identical to those for determining the reference test loading conditions for maximum cyclic heel and forefoot loading [see 2.4.2 a)].

2.4.2 Cyclic test

According to the statements of 2.2 and 2.3, the reference test loading conditions for cyclic loading according to ISO 22675 are determined by the parameters listed in a) and b). [For the meaning of "reference" in a) see IMPORTANT of 2.4.1 and for the meaning of "reference" in b) see IMPORTANT of this subclause.]

a) The reference test loading conditions for maximum cyclic heel and forefoot loading are determined by the same linear and angular dimensions as the reference test loading conditions for static heel and forefoot loading (see 2.4.1).

b) The reference test loading conditions for repeated foot loading progressing from heel contact to toe-off are determined by the parameters listed in 1) to 4).

   1) The position of the top load application point P_T [see 2.4.1 a)].

   2) The progression of the resultant force F_R, characterized by the sequence of the instantaneous directions of its line of action, which are determined by the coordinates of the top load application point P_T [see 2.4.1 a)] and the inclinations of the line of action to the u-axis at the related instantaneous values of angle α (see Figures 1 and 3).

      Figure 7 illustrates the progression of the line of action of the resultant force F_R from heel contact to toe-off in 30 ms time increments for related values of angle α shown in Figure 3.

   3) The profile (curve) of the pulsating test force F_c, to be applied in the top load application point P_T [see 2.4.1 a)] as illustrated in Figure 1 as a function of time $F_c(t)$ as illustrated in Figure 3 and in Figure 6 of ISO 22675 or as a function of tilting angle of the foot platform $F_c(\gamma)$ as illustrated in Figure 7 of ISO 22675. The instantaneous values of F_c are determined by Equation (11) for the related instantaneous values of the resultant force F_R and the angle α (see Figures 1 and 3).

      The description and specification of the profile of the test force $F_c(t)$ or $F_c(\gamma)$ is primarily based on the values F_{1cmax} (1st maximum of loading profile), F_{cmin} (intermediate minimum of loading profile) and F_{2cmax} (2nd maximum of loading profile), specified in Table 10 of ISO 22675.

      Further guidance on the description and specification of the profile of the test force F is given in Figure 3 and Tables 11 and 12 and also by Equation (2) of 13.4.2.9 of ISO 22675.

   4) The profile (curve) of the tilting angle $\gamma(t)$ of the foot platform, determining its periodical oscillation within the range of $-20° \leqslant \gamma \leqslant 40°$ specified for the period between the instants of heel contact and toe-off (see Figure 3).

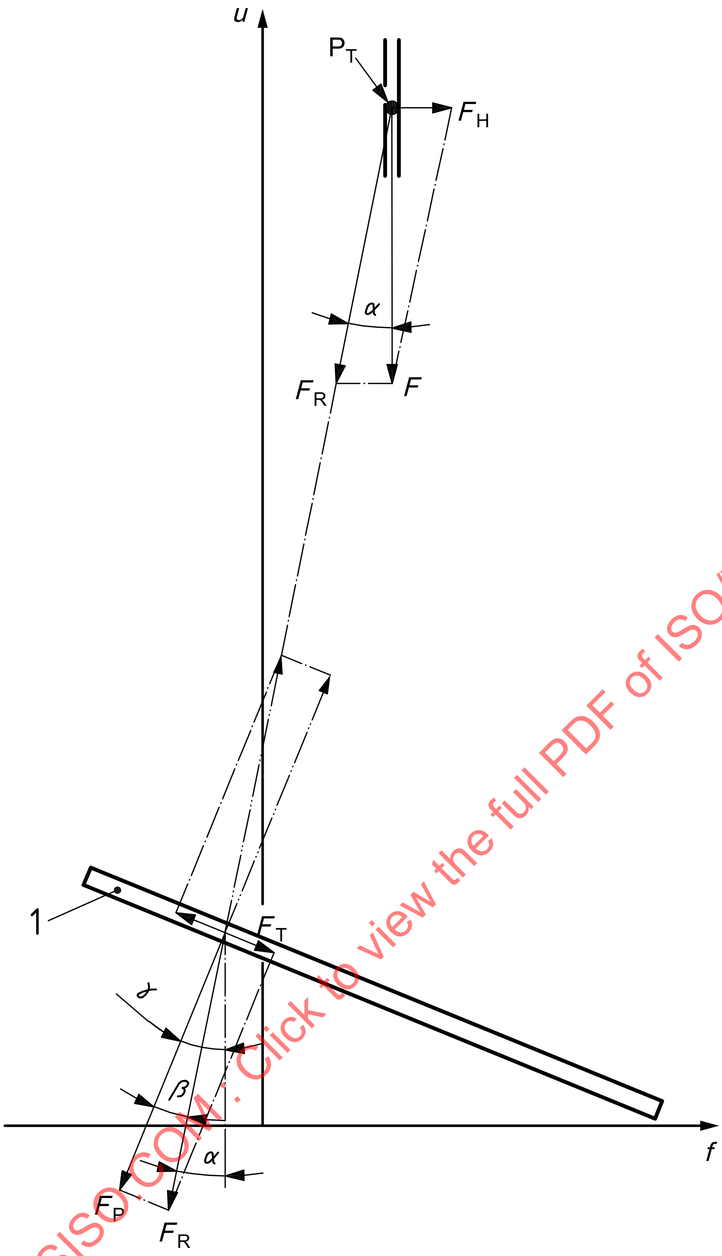
      The description and specification of the profile of the tilting angle $\gamma(t)$ of the foot platform is primarily based on the values $\gamma_1 = -15°$ (instant of 1st maximum F_{1cmax} of loading profile), $\gamma_{Fcmin} = 0°$ (instant of intermediate minimum F_{cmin} of loading profile) and $\gamma_2 = 20°$ (instant of 2nd maximum F_{2cmax} of loading profile), specified in Table 9 of ISO 22675:2006.

      Further guidance on the description and specification of the profile of the tilting angle $\gamma(t)$ is given in Table 12 and also by Equation (1) of 13.4.2.8 of ISO 22675:2006.

IMPORTANT — The progression of the lines of action of the resultant force F_R addressed in b) 2) is only relevant to the reference test loading conditions for the cyclic test, since the concept of the tests of ISO 22675 allows each sample of ankle-foot device or foot unit to develop its individual performance under load corresponding to its individual design.

This will automatically determine the individual position of the bottom load application point P_B on the foot of the test sample relating to the specific value of tilting angle $\gamma(t_x)$ of the foot platform and the individual inclination and magnitude of the resultant force F_R.

For this reason the configuration of the test set-up for the preparation of test loading [see 16.1.1 b) of ISO 22675] is determined only by the position of the top load application point P_T relevant to the foot length L of the test sample according to b) 1) and an appropriate initial tilting position of the foot platform. [According to 16.1.1 b) 3) of ISO 22675:2006 an appropriate initial tilting position of the foot platform is determined by the temporary tilting angle $\gamma = 0°$ relevant to the instant of the intermediate minimum F_{cmin} of the loading profile.]



Key

1 foot platform

P_T top load application point

F_R resultant force

F_P force component perpendicular to foot platform

F_T force component tangential to foot platform

F_H force component transverse to line of application of test force F

α angle of inclination to u-axis of line of action of resultant force F_R

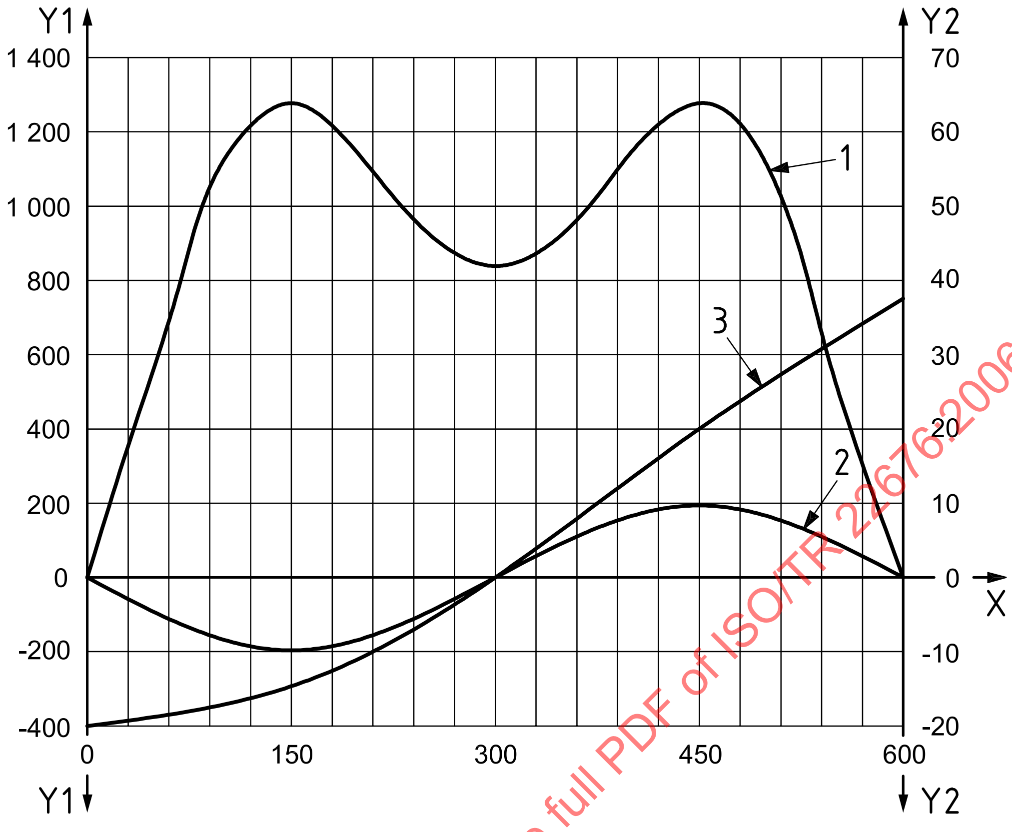
β angle between resultant force F_R and force component F_P determining ratio F_T/F_P

f, u axes of coordinate system

F test force

γ tilting angle of foot platform

Figure 1 — Illustration of different components of loading



NOTE The loading period of 600 ms corresponds to the average stance phase time of a typical walking cycle of 1 second duration. (The remaining time of 400 ms of the walking cycle corresponds to the swing phase.)

Key

1 force component F_P perpendicular to foot platform

2 force component F_T tangential to foot platform

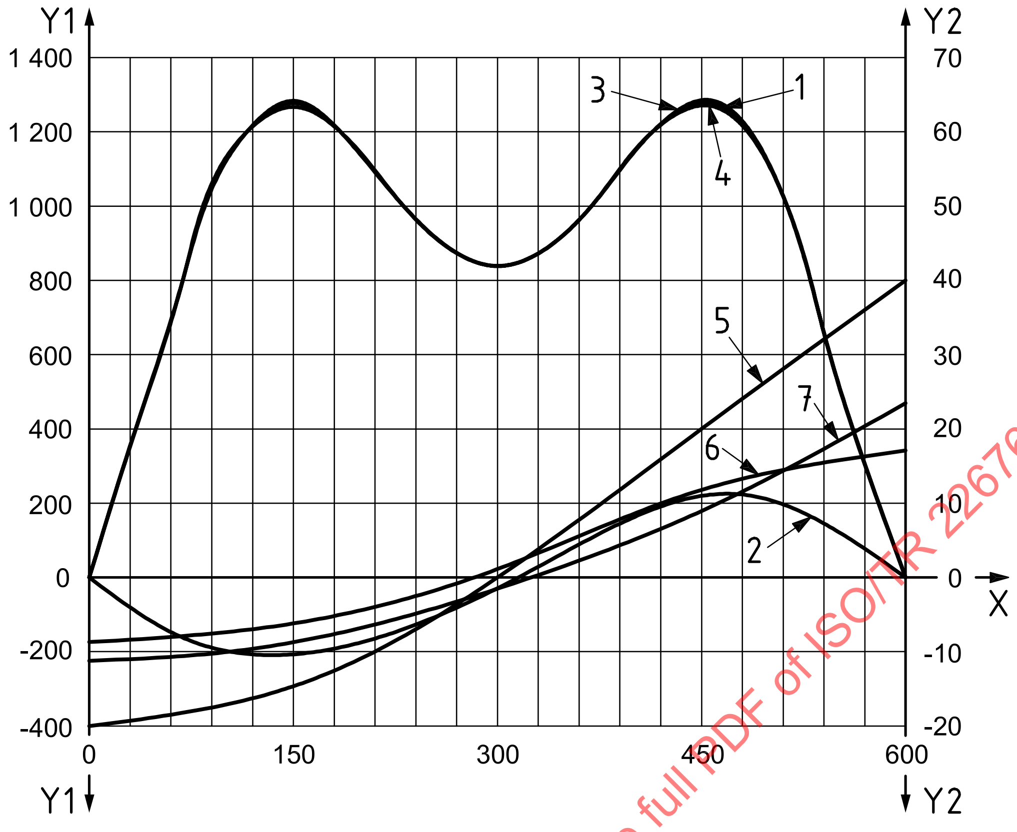
3 tilting angle γ of foot platform

X loading time in milliseconds

Y_1 forces in newtons

Y_2 angles in degrees

Figure 2 — Profiles (curves) of force components and tilting angle for test loading level P5, based on gait analysis data representative of normal level walking

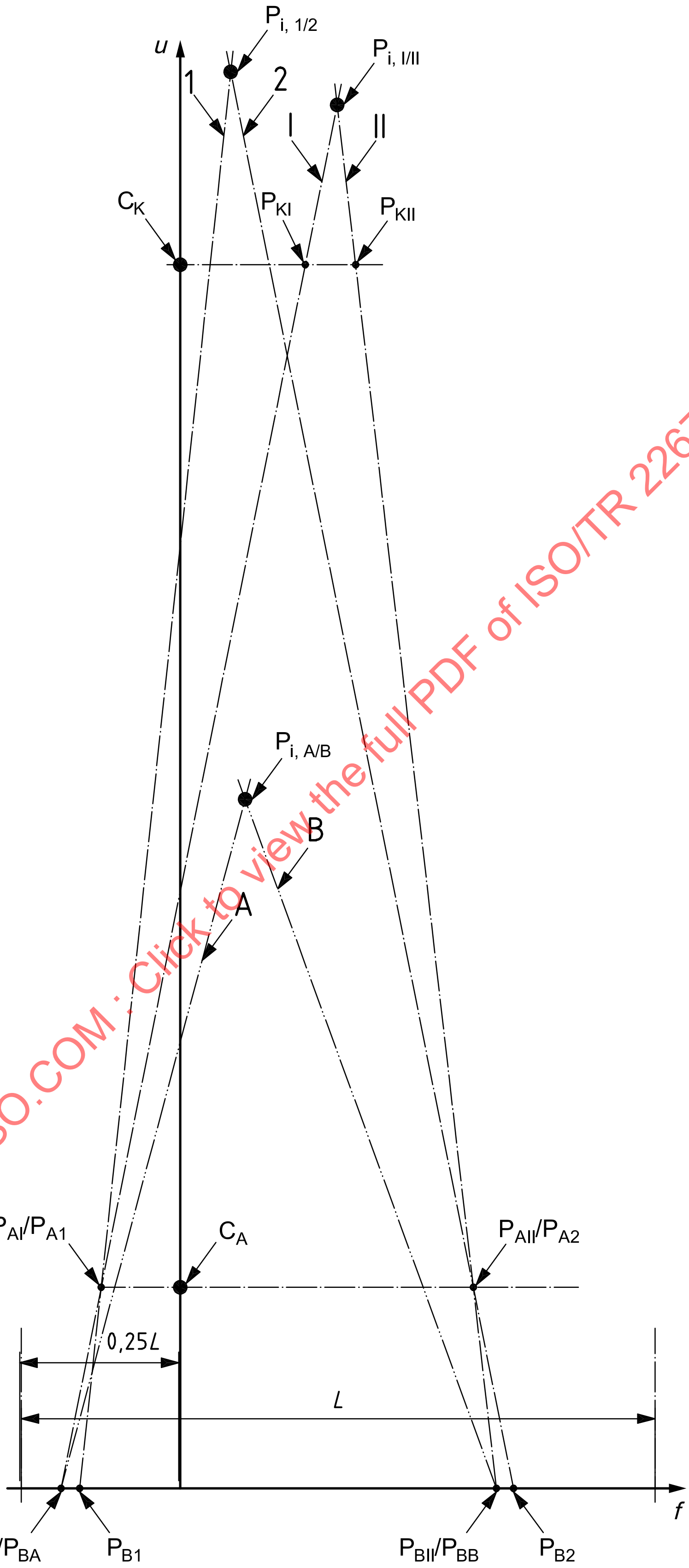


NOTE The loading period of 600 ms corresponds to the average stance phase time of a typical walking cycle of 1 second duration. (The remaining time of 400 ms of the walking cycle corresponds to the swing phase.)

Key

1 force component F_P perpendicular to foot platform
2 force component F_T tangential to foot platform
3 resultant force F_R
4 test force F
5 tilting angle γ of foot platform
6 angle α between resultant force F_R and u-axis
7 angle β between resultant force F_R and force component F_P
X loading time in milliseconds
Y1 forces in newtons
Y2 angles in degrees

Figure 3 — Profiles (curves) of force components and angles for test loading level P5, establishing the basis from which to specify the test loading conditions of ISO 22675

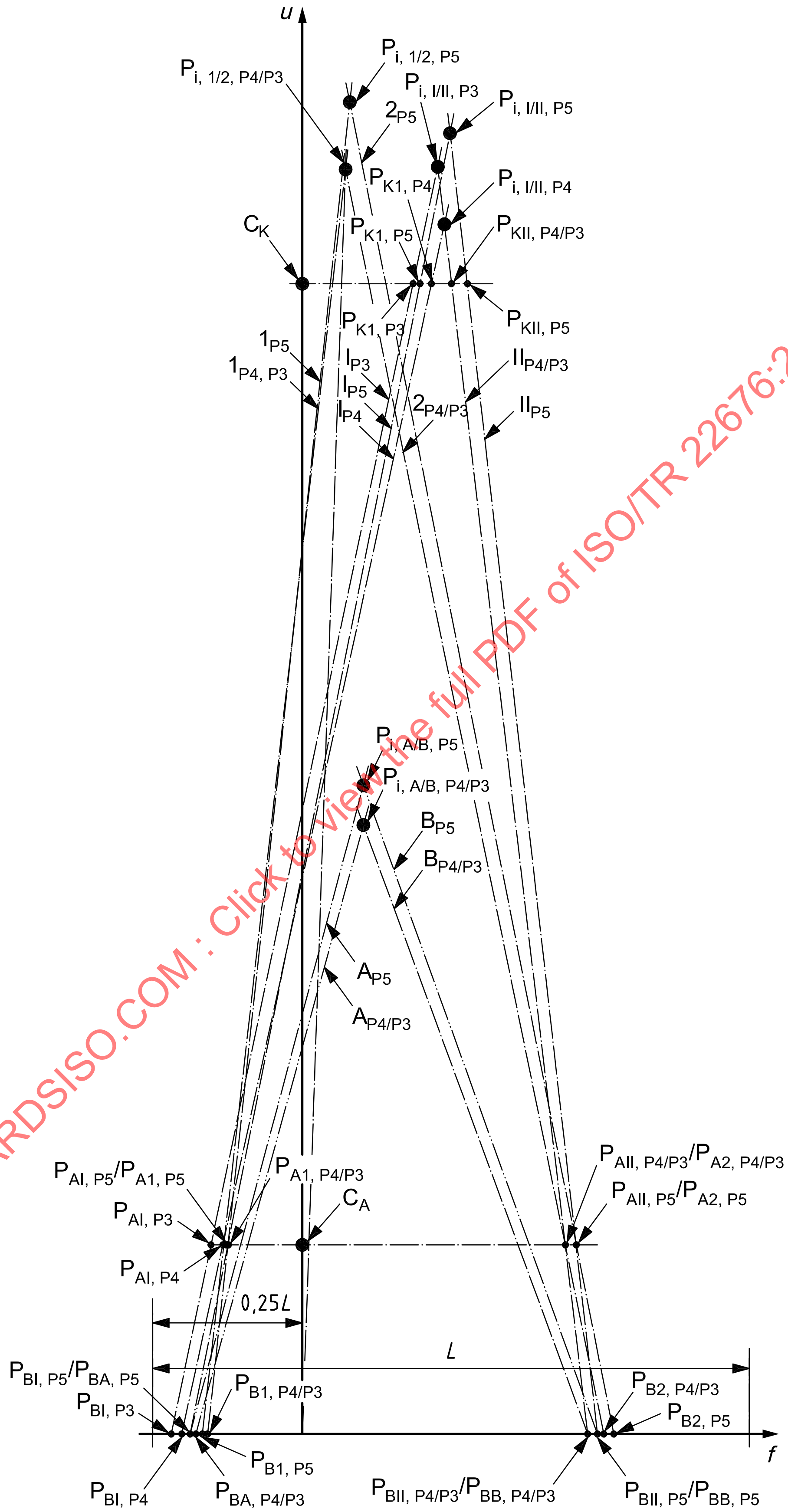


See page 14 for the key to this figure.

Figure 4 — Illustration of different test loading conditions for test loading level P5

Key to Figure 4

f, u	axes of coordinate system
C_K	effective knee joint centre
C_A	effective ankle joint centre
L	foot length
I, II	directions of test loading conditions I (heel loading) and II (forefoot loading) of principal tests of ISO 10328
A, B	directions of heel (A) and forefoot (B) loading of separate tests on ankle-foot devices and foot units of ISO 10328
1, 2	directions of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006
$P_{i, I/II}$	point of intersection of lines of application of test loading conditions I and II of principal tests of ISO 10328
$P_{i, A/B}$	point of intersection of lines of application of heel (A) and forefoot (B) loading of separate tests on ankle-foot devices and foot units of ISO 10328:2006
$P_{i, 1/2}$	point of intersection of lines of action of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006
$P_{KI/KII}$	knee load reference points of test loading conditions I and II of principal tests of ISO 10328
$P_{AI/AII}$	ankle load reference points of test loading conditions I and II of principal tests of ISO 10328
$P_{A1/A2}$	ankle load reference points of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006
$P_{BI/BII}$	bottom load application points of test loading conditions I and II of principal tests of ISO 10328
$P_{BA/BB}$	bottom load application points of heel (A) and forefoot (B) loading of separate tests on ankle-foot devices and foot units of ISO 10328:2006
$P_{B1/B2}$	bottom load application points of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006



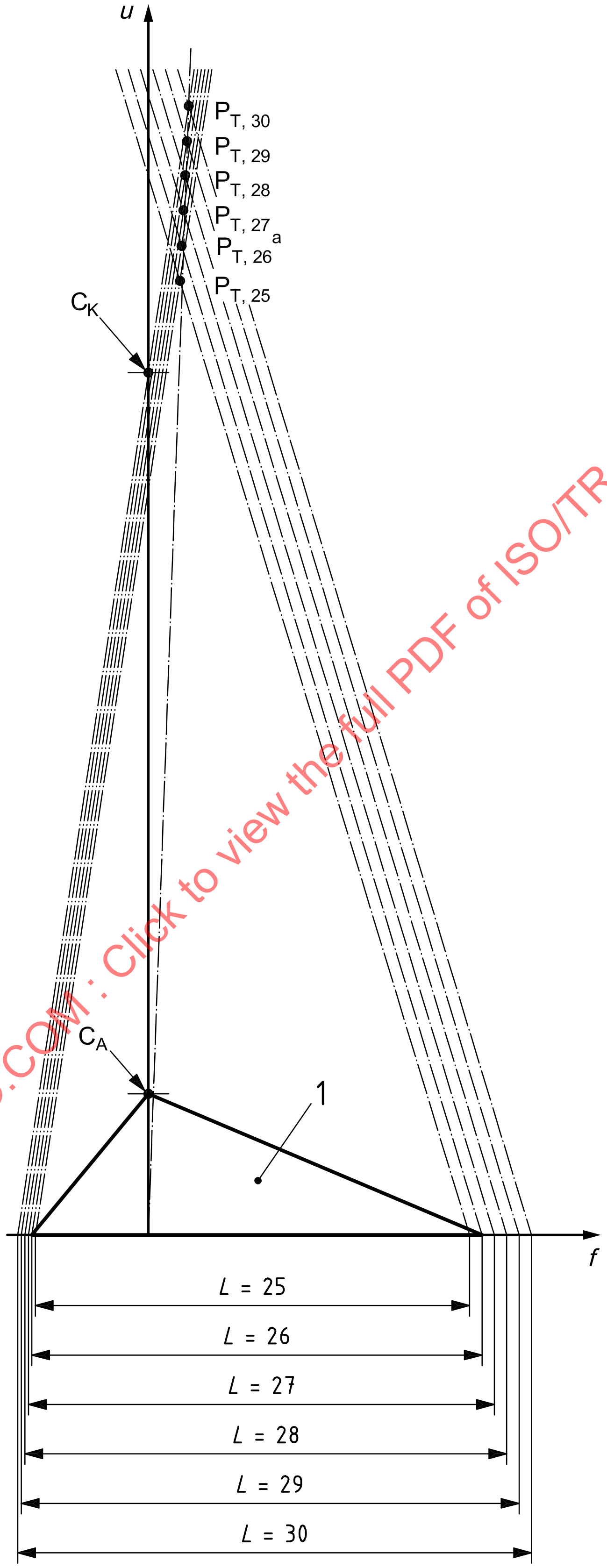
See page 16 for the key to this figure.

Figure 5 — Illustration of different test loading conditions for test loading levels P5, P4 and P3

Key to Figure 5

f, u	axes of coordinate system
C_K	effective knee joint centre
C_A	effective ankle joint centre
L	foot length
$I_{P5, P4, P3}$	directions of test loading condition I (heel loading) of principal tests of ISO 10328 for test loading levels P5, P4 and P3 according to suffix
$II_{P5, P4/P3}$	directions of test loading condition II (forefoot loading) of principal tests of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$A_{P5, P4/P3}$	directions of heel loading (A) of separate tests on ankle-foot devices and foot units of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$B_{P5, P4/P3}$	directions of forefoot loading (B) of separate tests on ankle-foot devices and foot units of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$1_{P5, P4/P3}$	directions of static and maximum cyclic heel loading (1) of ISO 22675 for test loading levels P5 and P4/P3 according to suffix
$2_{P5, P4/P3}$	directions of static and maximum cyclic forefoot loading (2) of ISO 22675 for test loading levels P5 and P4/P3 according to suffix
$P_{i, I/II, P5, P4, P3}$	points of intersection of lines of application of test loading conditions I and II of principal tests of ISO 10328 for test loading levels P5, P4 and P3 according to suffix
$P_{i, A/B, P5, P4/P3}$	points of intersection of lines of application of heel (A) and forefoot (B) loading of separate tests on ankle-foot devices and foot units of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{i, 1/2, P5, P4/P3}$	points of intersection of lines of action of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006 for test loading levels P5 and P4/P3 according to suffix
$P_{KI, P5, P4, P3}$	knee load reference points of test loading condition I of principal tests of ISO 10328 for test loading levels P5, P4 and P3 according to suffix
$P_{KII, P5, P4/P3}$	knee load reference points of test loading condition II of principal tests of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{AI, P5, P4, P3}$	ankle load reference points of test loading condition I of principal tests of ISO 10328 for test loading levels P5, P4 and P3 according to suffix
$P_{AII, P5, P4/P3}$	ankle load reference points of test loading condition II of principal tests of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{A1, P5, P4/P3}$	ankle load reference points of static and maximum cyclic heel loading (1) of ISO 22675 for test loading levels P5 and P4/P3 according to suffix
$P_{A2, P5, P4/P3}$	ankle load reference points of static and maximum cyclic forefoot loading (2) of ISO 22675 for test loading levels P5 and P4/P3 according to suffix
$P_{BI, P5, P4, P3}$	bottom load application points of test loading condition I of principal tests of ISO 10328 for test loading levels P5, P4 and P3 according to suffix
$P_{BII, P5, P4/P3}$	bottom load application points of test loading condition II of principal tests of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{BA, P5, P4/P3}$	bottom load application points of heel loading (A) of separate tests on ankle-foot devices and foot units of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{BB, P5, P4/P3}$	bottom load application points of forefoot loading (B) of separate tests on ankle-foot devices and foot units of ISO 10328 for test loading levels P5 and P4/P3 according to suffix
$P_{B1, P5, P4/P3}$	bottom load application points of static and maximum cyclic heel loading (1) of ISO 22675:2006 for test loading levels P5 and P4/P3 according to suffix
$P_{B2, P5, P4/P3}$	bottom load application points of static and maximum cyclic forefoot loading (2) of ISO 22675:2006 for test loading levels P5 and P4/P3 according to suffix

Dimensions in centimetres



See page 18 for the key to this figure.

Figure 6 — Illustration of the dependence of the position of the top load application point P_T **on the foot length** L (see 2.2.3)

Key to Figure 6

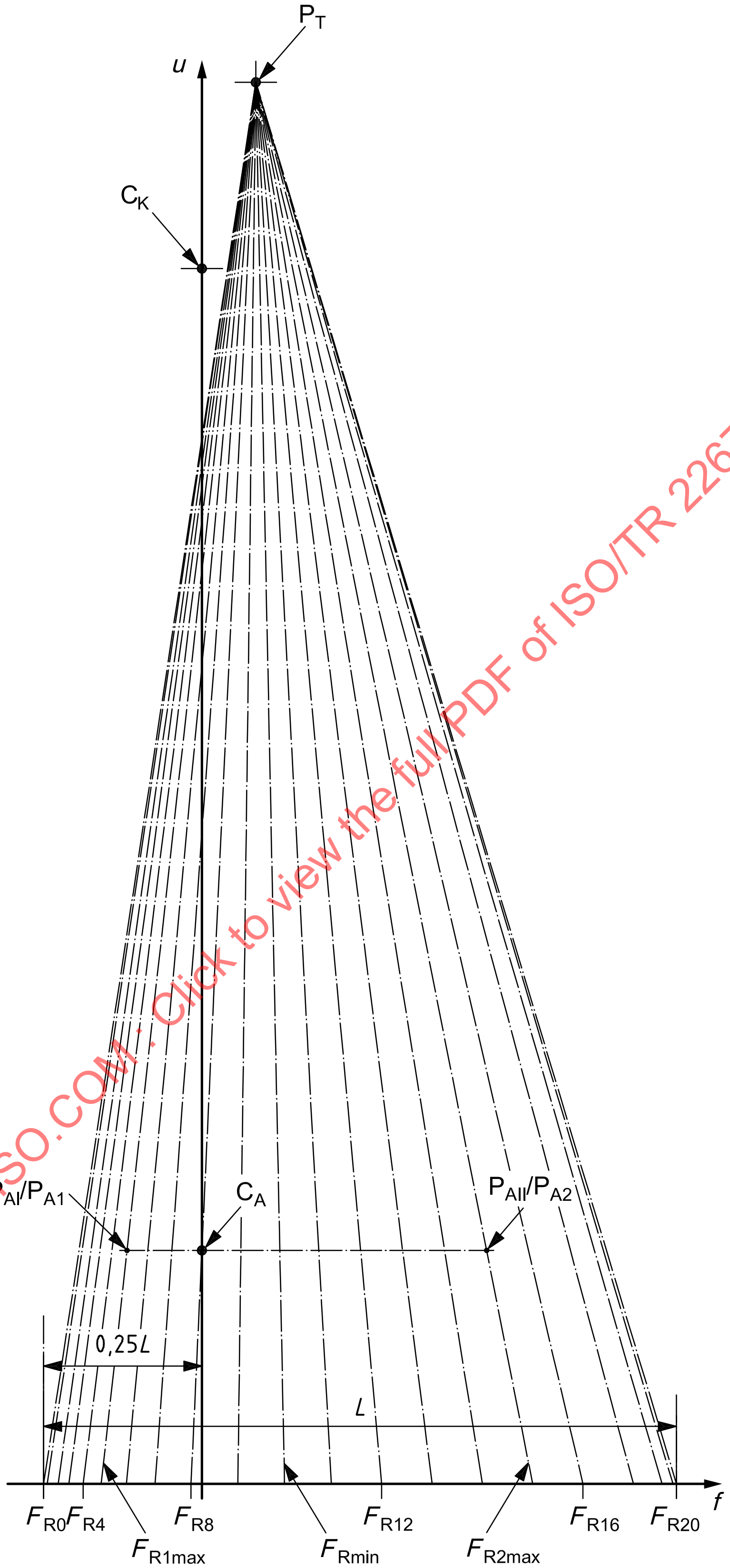
1 symbolic view of foot

f, *u* axes of coordinate system

C_K effective knee-joint centre

C_A effective ankle-joint centre

[a] Top load application points relevant to indicated foot length *L* (reference: $P_{T, 26}$ for *L* = 26 cm).



See page 20 for the key to this figure.

Figure 7 — Illustration of the progression of the line of action of the resultant force F_R from heel contact to toe-off in 30 ms time increments for related values of angle α shown in Figure 3

Key to Figure 7

f, u	axes of coordinate system
P_T	top load application point
C_K	effective knee joint centre
C_A	effective ankle joint centre
L	foot length
$P_{AI/AII}$	ankle load reference points of test loading conditions I and II of principal tests of ISO 10328
$P_{A1/A2}$	ankle load reference points of static and maximum cyclic heel (1) and forefoot (2) loading of ISO 22675:2006
F_{R1max}	1st maximum of resultant force F_R, referred to as *resultant reference force* F_{R1}
F_{Rmin}	intermediate minimum of resultant force F_R
F_{R2max}	2nd maximum of resultant reference force F_R, referred to as *resultant reference force* F_{R2}
$F_{R0...20}$	instantaneous lines of action of resultant force F_R in 30 ms time increments

3 Guidance on the design of appropriate test equipment for the application of ISO 22675

3.1 Background statement

The guidance on the design of test equipment offered in this Technical Report is based on the mathematical and graphical analysis of various situations of interest. As far as physical characteristics of ankle-foot devices or foot units are concerned, the analytical work is based on simplified foot models. This does, however, not impair the power of statement of the related findings, since all of them are also applicable, in principle, to relevant arrangements with real ankle-foot devices and foot units.

The guidance offered establishes a basis that can also be used for deliberations and decisions on a uniform design concept for the test equipment required, in order to optimize the conditions of comparability of test results achieved at different places.

3.2 Basic design for test equipment

Figure 8 illustrates the basic design concept of test equipment capable of performing cyclic loading in accordance with the requirements of 13.4.2 of ISO 22675:2006, characterized by the following features.

a) An actuator applies the test force $F_c(t)$ or $F_c(\gamma)$ to the top side of the test sample. The application of force can be carried out directly or indirectly, depending on whether additional components are arranged between the actuator and the test sample e.g.:

— a device of axial guiding, used to protect the actuator against forces or moments transverse to the direction of actuating or against torque about the axis of actuating;

— a load cell, required for the control of the actuator.

b) The test sample is set up in the test equipment in a manner that does not allow it to perform angular movement typical of the progression during the stance phase of walking from heel contact to toe-off.

c) Instead, this angular movement is simulated by a foot platform capable of active tilting about an axis transverse to the direction of progression of the test sample. As illustrated in principle in Figure 9, one way to actuate the tilting of the foot platform is by means of a crank gear. The particular profile (curve) of tilting angle $\gamma(t)$ required (see Table 11, 13.4.2.4 and Figure 6 of ISO 22675:2006) can be achieved by appropriate dimensioning of

— the length of the cantilever fixed to the foot platform;

— the position of the crank shaft relative to the tilting axis TA of the foot platform;

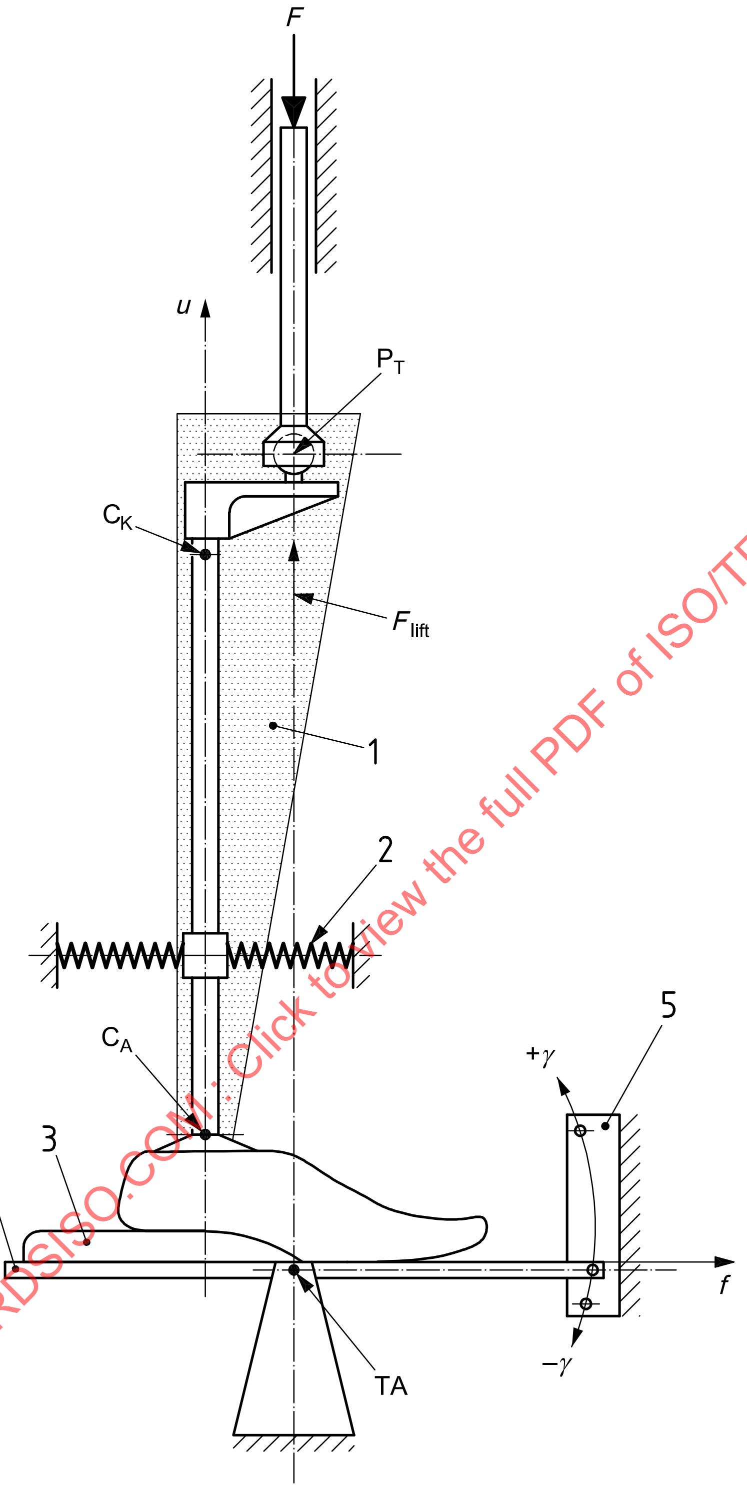
— the length of the crank arm;

— the length of the driving rod.

Test equipment capable of performing cyclic loading in accordance with the requirements of 13.4.2 of ISO 22675:2006 may also be capable of performing static heel and forefoot loading in accordance with the requirements of 13.4.1 of ISO 22675:2006, depending on its design.

This capability is, for example, of particular interest if the final static tests at proof load level following each successfully completed cyclic test (see 16.4 of ISO 22675:2006) are intended to be conducted on the same test equipment, on which the cyclic test has been conducted.

In this case it is recommended that means be provided to lock the foot platform in the positions of static heel and forefoot loading at the tilting angles γ_1 and γ_2 (see Table 8 of ISO 22675:2006) to facilitate its adjustment and to avoid overloading of the tilting drive mechanism (see Figure 8).



See page 23 for the key to this figure.

Figure 8 — Diagrammatic view of test equipment with test sample

Key to Figure 8

1 reasonable area for the arrangement of alternative end attachments in consideration of the current spectrum of foot designs

2 example of appropriate means to flexibly resist dislocation of the foot in the f-u-plane during the lift-off phase of the test sample to ensure contact of the foot on the foot platform in correct position for the next loading cycle (corresponding means to resist dislocation in the plane transverse to the f-u-plane and about the long axis of the test sample not shown)

3 block of recommended heel height h_r with specific shape of top surface to provide a smooth transition towards the forefoot

4 tiltable foot platform,

— either fixed at the values of tilting angle γ_1 and γ_2 specified for static heel and forefoot loading

or

— periodically oscillating with $\gamma(t)$ within the range specified for progressive heel and forefoot loading from heel contact to toe-off

5 means of locking the foot platform at the values of tilting angle γ_1 and γ_2 specified for static heel and forefoot loading (option)

F test force $F_c(t)$ or $F_c(\gamma)$, F_{sp} or F_{fin}, F_{su}

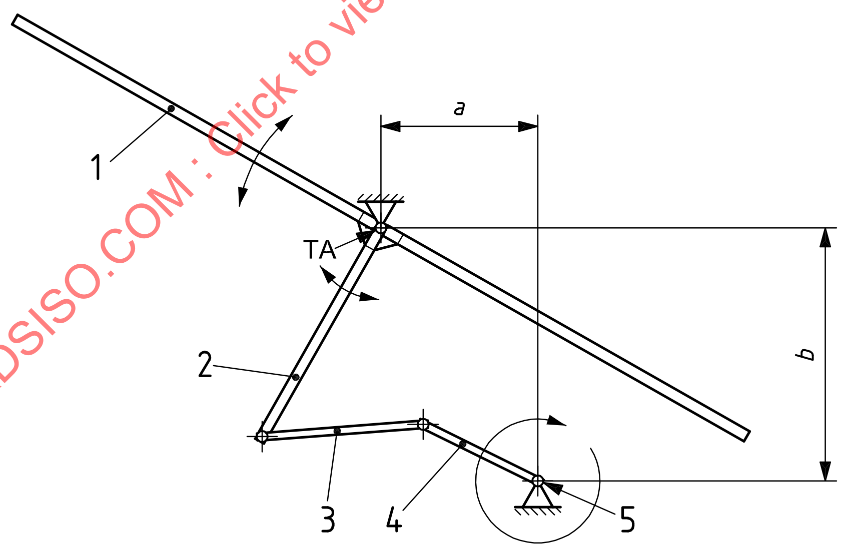
F_{lift} lifting force to lift the test sample off the foot platform during the period corresponding to the swing phase of walking

P_T top load application point, preferably allowing rotation of the test sample about each of the 3 spatial axes

C_K effective knee-joint centre

C_A effective ankle-joint centre

TA tilting axis of foot platform



Key

1 foot platform

2 cantilever

3 driving rod

4 crank arm

5 crank shaft

TA tilting axis of foot platform

[a] Horizontal distance between tilting axis of foot platform TA and crank shaft (5).

[b] Vertical distance between tilting axis of foot platform TA and crank shaft (5).

Figure 9 — Parameters of a crank gear capable of driving the foot platform of the test equipment to generate the profile (curve) $\gamma(t)$

3.3 Design variants for load application

3.3.1 General

Two different designs for load application have been discussed. They are briefly described in 3.3.2 and 3.3.3 as design variants A and B.

In this Technical Report preference has been given to design variant A, carefully balancing its advantages and disadvantages against those of design variant B, outlined in 3.3.4, 3.4 to 3.7 and 3.9.

3.3.2 Design variant A

The test force F is applied in a direction parallel to the u-axis by an actuator fixed to the base frame of the test equipment.

The top load application point P_T of the test sample is directly or indirectly (see NOTE) attached to the driving part of the actuator (e.g. the piston rod of a fluid system) by a connecting device providing at least one degree of freedom in order to allow free angular movement of the test sample in the f-u-plane, caused by the superimposed effects of tilting of the foot platform and loading by the test force F (see statements below), and to exclude the transmission of A-P bending moments.

A second degree of freedom may allow free angular movement of the test sample perpendicular to the f-u-plane and exclude the transmission of M-L bending moments, and a third degree of freedom may allow free rotation about the axis of actuating and exclude the transmission of torque.

NOTE For actuators sensitive to forces or moments transverse to the direction of actuating or to torque about the axis of actuating, a guiding device to prevent transmission of these load actions may be required, to be arranged between the actuator and the test sample. In addition, a load cell, required for the control of the actuator, is likely to be arranged between the actuator and the guiding device.

3.3.3 Design variant B

The test force F is applied by an actuator capable of tilting relative to the base frame of the test equipment about an axis parallel to the tilting axis TA of the foot platform, located in a position P_{TE} corresponding to that of the top load application point P_T of the test sample in its neutral position, i.e. with the tilting angle γ of the foot platform set at zero.

The test sample is directly or indirectly (see NOTE of 3.3.2) attached rigidly to the driving part of the actuator (e.g. the piston rod of a fluid system), the driving part thus representing a particular piece of end attachment of variable length relative to the top load application point P_{TE}.

The axis of tilting of the actuator allows free angular movement of the test sample in the f-u-plane and excludes the transmission of A-P bending moments [except those generated by effects addressed in 3.3.4 b) 2) and NOTE].

A second and a third degree of freedom may be provided at any appropriate position for the purposes described in 3.3.2 for design variant A.

3.3.4 Main differences between design variants A and B

The main differences between design variants A and B briefly described in 3.3.2 and 3.3.3 are addressed below (see also 3.7 and Figures 20 and 21).

a) For the distance u_T of the top load application point P_T (P_{TE}) from the f-axis, which is decisive for the test sample set-up, the following applies:

   1) for design variant A, this distance does not change during a loading cycle from heel contact to toe-off;

   2) for design variant B, this distance varies with the amount of elevation of the test sample caused by the superimposed effects of the related values of tilting angle of the foot platform and test force F applied.

b) For the orientation of the actuator the following applies:

   1) for design variant A, the orientation of the actuator parallel to the u-axis does not change during a loading cycle from heel contact to toe-off;

   2) for design variant B, the actuator is tilted by the angle $\Delta\varphi$, which will cause additional deviations from the specified test loading conditions (see 3.7) and which may cause mass effects, depending on the magnitude of the angular accelerations, the magnitude of the total mass of all components tilted and the position of its centre of gravity relative to the position of the top load application point P_{TE} (see also NOTE).

NOTE If the centre of gravity of the total mass of the arrangement of actuator and adjacent components gets into a position above the tilting axis with which they are linked to the base frame of the test equipment, this arrangement will become top-heavy and tend to exert unintended A-P bending moments on the test sample during the loading cycle from heel contact to toe-off and eventually to topple or capsize during the lift-off phase of the test sample, if special suspensions do not prevent this.

3.4 Examples of crank gear designs

3.4.1 General

In principle, two different types of crank gear design can be used. Examples of each type are briefly described in 3.4.2 and 3.4.3.

3.4.2 Asymmetrical (60:40) crank gear

The crank gear according to Figure 10 has asymmetric positions of the dead centres determining the maximum angular positions of the foot platform. The larger rotation of the crank arm (upper right portion) exceeds its smaller rotation (lower left portion) by 36°.

The resulting ratio is (180° + 36°):(180° – 36°) = 60:40; i.e. it takes 60 % of the time of one revolution to pass through the upper right portion used to tilt the foot platform during the period of loading from its position specified for heel contact ($\gamma = -20°$) to its position specified for toe-off ($\gamma = +40°$) and 40 % to pass through the lower left portion used to return the foot platform to the angular position specified for heel contact.

Hence, the ratio of 60:40 corresponds exactly to the average ratio of stance phase time and swing phase time of a typical walking cycle, intended to be simulated by the test cycle; i.e. within a test cycle simulating a typical walking cycle of 1 s duration the loading period simulating the stance phase will be 600 ms (but see NOTE).

NOTE This statement is only correct if the rotational speed of the crank is constant. This may require particular technical measures, taking into account that the load on the mechanism varies over a wide range and reverses in direction.

However, the asymmetrical crank gear according to Figure 10 has two disadvantages, one regarding the deviations of the profile of tilting angle $\gamma(t)$ created from the profile (curve) of tilting angle specified (see Table 11, 13.4.2.4 and Figure 6 of ISO 22675:2006) and the other regarding the critical dimensions of the components of the crank gear specified.

a) The profile of tilting angle $\gamma(t)$ created by the upper right portion of this crank gear design is shown in Figure 12. It deviates from the profile of tilting angle specified (see Figure 6 of ISO 22675:2006) by slightly less than ± 5°.

b) The boundary conditions for the design of a crank gear with an asymmetry of 60:40 of the positions of the dead centres determining the maximum angular positions of the foot platform and a range of tilting angle of $-20° \leqslant \gamma \leqslant +40°$ are very limiting. This leads to the following conditions:

   1) the angle of the driving rod to the cantilever, occurring in the position of the dead centre determining the position of the foot platform specified for heel contact ($\gamma = -20°$), is 15°; as a consequence, the sum of the lengths of the driving rod and the cantilever is only about 1,5 mm longer than the distance between the centres of the crank shaft and the tilting axis TA of the foot platform;

   2) when the crank arm passes through the upper right portion used to tilt the foot platform during the period of loading, the angles between the driving rod and the crank arm and between the driving rod and the cantilever reach low values, resulting in the force in the driving rod being considerably higher than it would be if the rod were at right angles to the crank arm.

The conditions addressed in 1) and 2) need to be carefully considered in the design, manufacturing and assembling of the system. The condition listed in 1) may require technical means such as a buffer, preventing the tilting of the foot platform in the wrong direction when passing the dead centre.

Further details are given in 3.5 to 3.7 and 3.9.

3.4.3 Symmetrical (50:50) crank gear

The crank gear according to Figure 11 has symmetrical positions of the dead centres determining the maximum angular positions of the foot platform, i.e. the ratio of the angles of the upper right and lower left portions is 180°:180° = 50:50; i.e. it takes 50 % of the time of one revolution to pass through each of the upper right and lower left portion (but see NOTE of 3.4.2).

The crank gear is designed to tilt the foot platform within an angular range of $-20° \leqslant \gamma \leqslant +50°$ (toe-off position + 10°). This measure allows a better approach of the linear course of the final part of the specified profile (curve) of tilting angle $\gamma(t)$ of the foot platform up to the maximum value of + 40° at toe-off (see Table 11, 13.4.2.4 and Figure 6 of ISO 22675:2006), since the diminishing of the slope of the final part of the profile of tilting angle produced by the crank gear drive is mainly progressing within the range of + 40° to + 50° early in the lift-off phase of the test sample.

The profile of tilting angle $\gamma(t)$ created by the lower left portion of this crank gear design up to the value of $\gamma = +40°$ at toe-off is shown in Figure 12. It is much closer to the profile of tilting angle specified than the profile of the crank gear design according to 3.4.2, deviating from the profile of tilting angle specified (see Figure 6 of ISO 22675:2006) by at most + 1° or – 0,6°.

However, the symmetrical crank gear according to Figure 11 has also two disadvantages, one regarding the timing and the other regarding the elevation and A-P displacement of the test sample caused by the tilting of the foot platform.

a) The angular position of the crank arm corresponding to the angular position of the foot platform specified for toe-off ($\gamma = +40°$) is reached at 143° from the dead centre (0°) determining the angular position of the foot platform specified for heel contact ($\gamma = -20°$) and 37° to the dead centre (180°) determining the maximum angular position of the foot platform (after toe-off) of $\gamma = +50°$.

   The resulting ratio of angle and/or time is (180° – 37°):(180° + 37°) = 39,7:60,3; i.e. it takes 39,7 % of the time of one revolution to pass through the lower left portion used to tilt the foot platform during the period of loading up to the value specified for toe-off ($\gamma = + 40°$) and 60,3 % to pass through the upper right portion used to reach the maximum angular position of the foot platform (after toe-off) of $\gamma = + 50°$ and then to return the foot platform to the angular position specified for heel contact ($\gamma = - 20°$) (but see NOTE of 3.4.2).

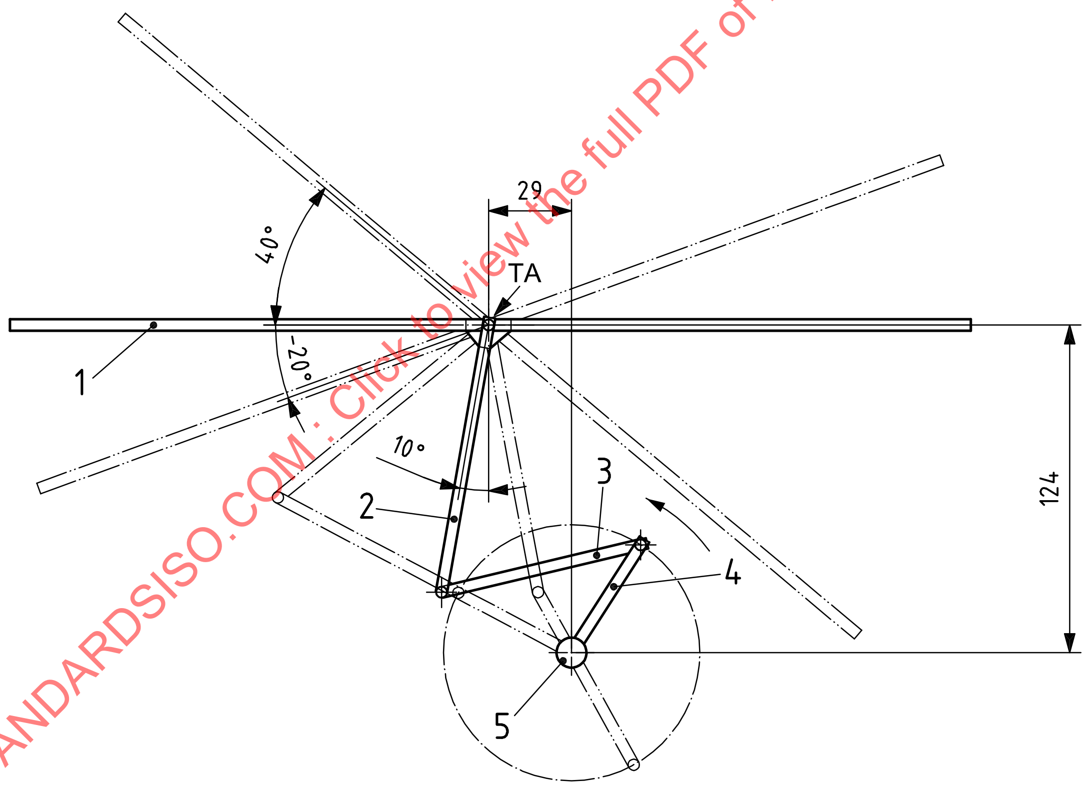
Hence, if 39,7 % of the time of one revolution is 600 ms, one full revolution takes 1,5 s, which is 50 % longer than the time of one full revolution of the crank gear design according to 3.4.2.

b) The tilting of the foot platform elevates and horizontally displaces the test sample at the foot. Apparently, the value of elevation and A-P displacement is higher for a tilting angle of $\gamma = + 50°$ than for a tilting angle of $\gamma = + 40°$.

NOTE In contrast to the crank gear design according to 3.4.2, the crank gear design according to 3.4.3 does not suffer from limiting boundary conditions. For example, it is possible to increase only the length of the driving rod, in order to reduce the load level at which the transmission of the driving forces is performed. Of course, the profile of tilting angle will change, accordingly, and may deviate from the profile of tilting angle at a greater extent than is the case for the crank gear design specified in 3.4.3 and Figure 11.

Further details are given in 3.5 to 3.7 and 3.9.

Dimensions in millimetres



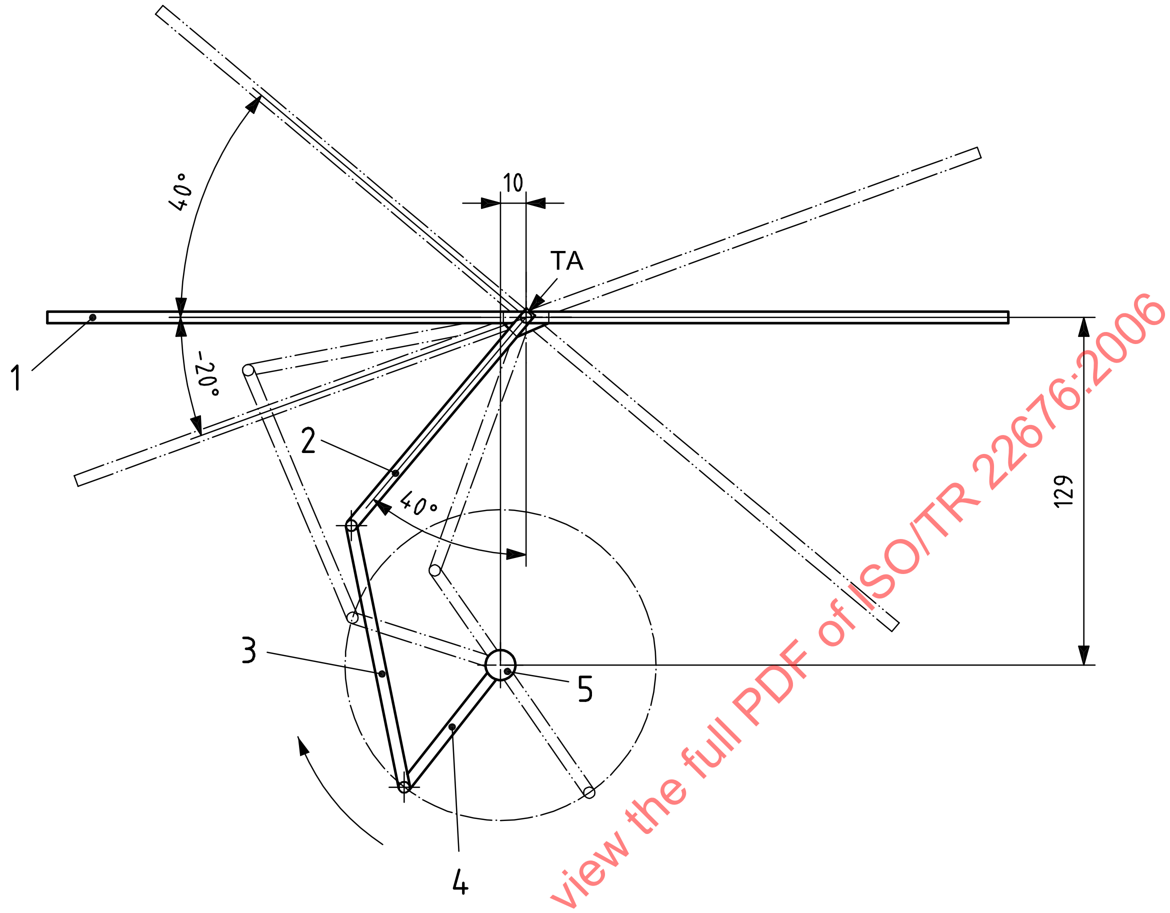
NOTE The crank gear characteristic does not change, if the given values of lengths (except the minimum length of the foot platform) are proportionally scaled.

Key

1 foot platform of length ⩾ 350 mm
2 cantilever of specific length 100 mm
3 driving rod of specific length 75 mm
4 crank arm of specific length 47 mm
5 crankshaft
TA tilting axis of foot platform

Figure 10 — Asymmetrical (60:40) crank gear according to 3.4.2 — Tilting range – 20° (heel contact) to + 40° (toe-off)

Dimensions in millimetres



NOTE The crank gear characteristic does not change, if the given values of lengths (except the minimum length of the foot platform) are proportionally scaled.

Key

1 foot platform of length ⩾ 350 mm

2 cantilever of specific length 100 mm

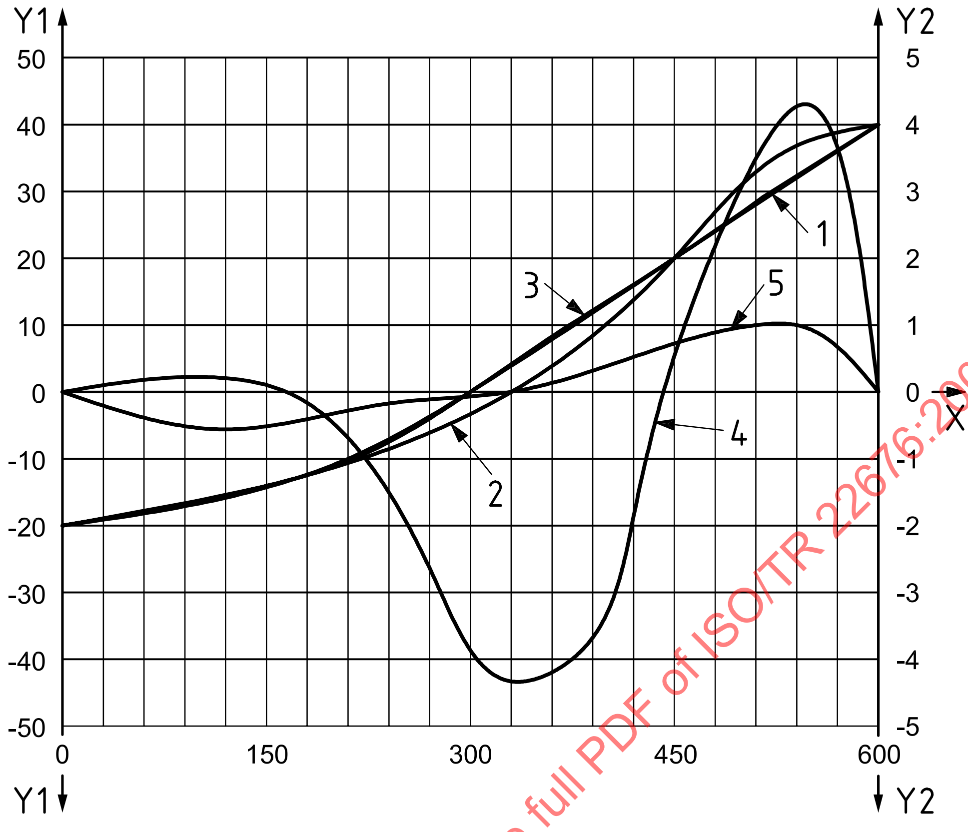
3 driving rod of specific length 100 mm

4 crank arm of specific length 57 mm

5 crankshaft

TA tilting axis of foot platform

Figure 11 — Symmetrical (50:50) crank gear according to 3.4.3 — Tilting range — 20° (heel contact) via + 40° (toe-off) to + 50°



Key

X loading time in milliseconds

Y1 angles in degrees

Y2 deviation of angles in degrees

1 specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

2 tilting angle $\gamma(t)$ produced by crank gear 60:40 upper right portion of rotation

3 tilting angle $\gamma(t)$ produced by crank gear 50:50 lower left portion of rotation

4 deviation of tilting angle produced by crank gear 60:40 from specified profile

5 deviation of tilting angle produced by crank gear 50:50 from specified profile

Figure 12 — Tilting characteristics of asymmetrical (60:40) crank gear according to 3.4.2 and Figure 10 and symmetrical (50:50) crank gear according to 3.4.3 and Figure 11

3.5 Effect of deviations of the tilting angle $\gamma(t)$ from the specified profile (curve), addressed in 3.4, on the test loading conditions of ISO 22675

Apparently, the deviations of the tilting angle $\gamma(t)$ of the foot platform, which occur if this is driven by the crank gear described in 3.4.2 and illustrated in Figure 10, will affect the related angles α and β and, consequently, the ratio of the force components F_P and F_T, acting perpendicular and tangential to the foot platform [see Figure 1 and Equations (1) and (2) of 2.2.1].

There are two possibilities of evaluating this effect, as described in a) and b).

a) The instantaneous values of the tilting angle $\gamma(t)$ of the foot platform driven by the crank gear according to 3.4.2, which occur in 30 ms time increments from the instant of heel contact to the instant of toe-off, will also occur in the course of the prescribed profile of tilting angle $\gamma(t)$, however, at different instants wherever the two profiles deviate from each other. The different instants determine the distortion of the time base of the prescribed profile of tilting angle $\gamma(t)$ necessary to adapt it to that produced by the crank gear according to 3.4.2. A graph of the angles α and β as a function of the distorted time base facilitates the determination of their values at the regular 30 ms time increments. With these values the force components F_P and F_T, acting respectively perpendicular and tangential to the foot platform, can be calculated. The results of this measure are shown in Figures 13 to 16.

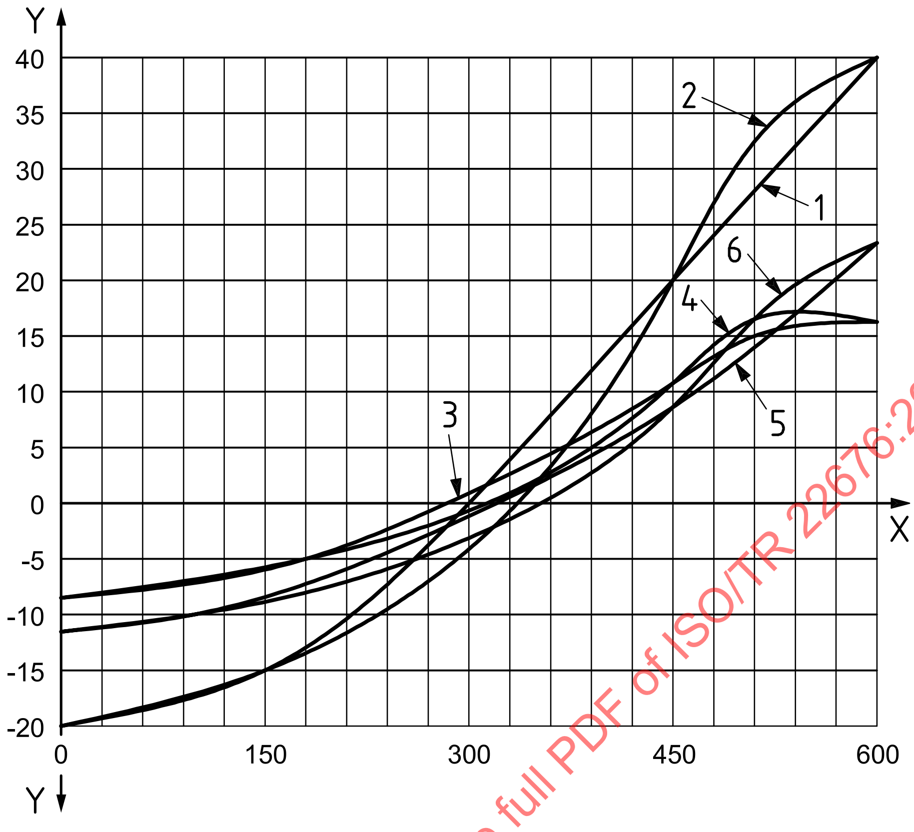
   The most noticeable effects are that on the force component F_T tangential to the foot platform. The first occurs at the instant of 360 ms after heel contact. According to Figure 16, the deviation from the prescribed value at this instant is – 36 N, which is about – 80 %. The second occurs at the 2nd maximum. According to Figure 16, the deviation from the prescribed value at this instant is 48 N, which is about 20 %. These deviations are considered to exceed the tolerable range.

   The effect on the force component F_P perpendicular to the foot platform can be neglected. The same applies to the resultant force F_R, composed of F_P and F_T, and the test force F (Figure 1).

b) The situation described in a) is based on the condition that the profiles of tilting angle and test force are applied as synchronized functions of time $\gamma(t)$ and $F(t)$.

   This need not necessarily be the case. As already addressed in 13.4.2 of ISO 22675:2006, an appropriate alternative is the application of the profile of tilting angle as a function of time $\gamma(t)$ and the profile of test force as a function of tilting angle $F(\gamma)$. In this case the deviations referred to in a) are irrelevant, since the test force follows the tilting angle as specified by the profile $F(\gamma)$, independent of the time base of the tilting angle.

   However, any distortion of the time base of the tilting angle [see a)] will also apply to the test force. Hence, the only noticeable effect is that on the test force $F(\gamma)$ when plotted against the distorted time base, as Figure 17 illustrates. The influence of this effect on test results is not yet known.



Key

X loading time in milliseconds

Y angles in degrees

1 specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

2 tilting angle $\gamma(t)$ produced by crank gear 60:40 upper right portion of rotation

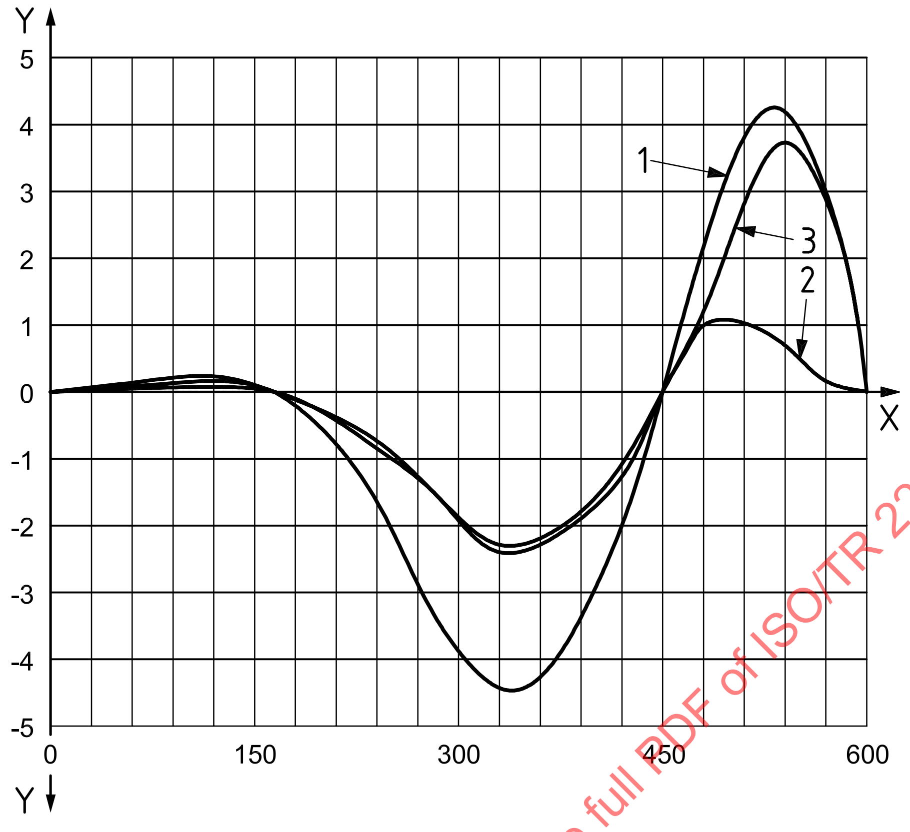
3 angle α between resultant force F_R and u-axis of coordinate system related to specified profile of tilting angle

4 angle α related to tilting angle produced by crank gear 60:40

5 angle β between resultant force F_R and force component F_P perpendicular to foot platform related to specified profile of tilting angle

6 angle β related to tilting angle produced by crank gear 60:40

Figure 13 — Profiles (curves) of angles α, β and γ as specified and as produced by crank gear 60:40



Key

X loading time in milliseconds

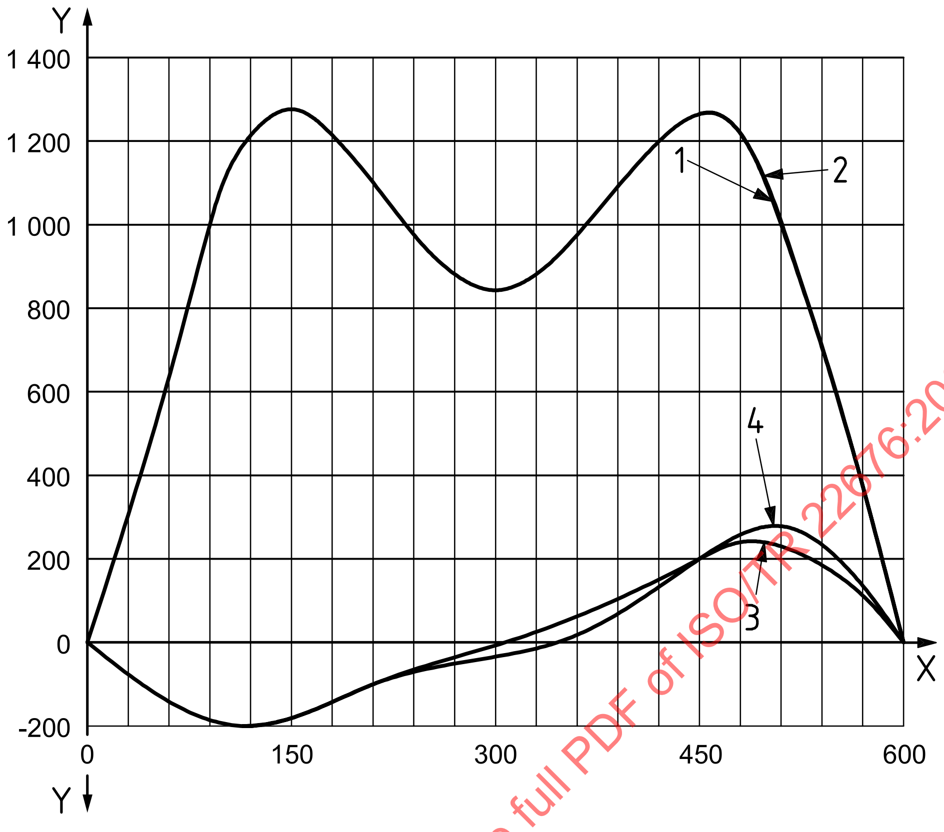
Y angles in degrees

1 deviation of tilting angle of foot platform produced by crank gear 60:40 from specified profile (curve) $\gamma(t)$ of foot platform

2 deviation of angle α between resultant force F_R and u-axis of coordinate system related to tilting angle produced by crank gear 60:40 from angle α related to specified profile of tilting angle

3 deviation of angle β between resultant force F_R and force component F_P perpendicular to foot platform related to tilting angle produced by crank gear 60:40 from angle β related to specified profile of tilting angle

Figure 14 — Illustration of angular deviations produced by crank gear 60:40



Key

X loading time in milliseconds

Y force in newtons

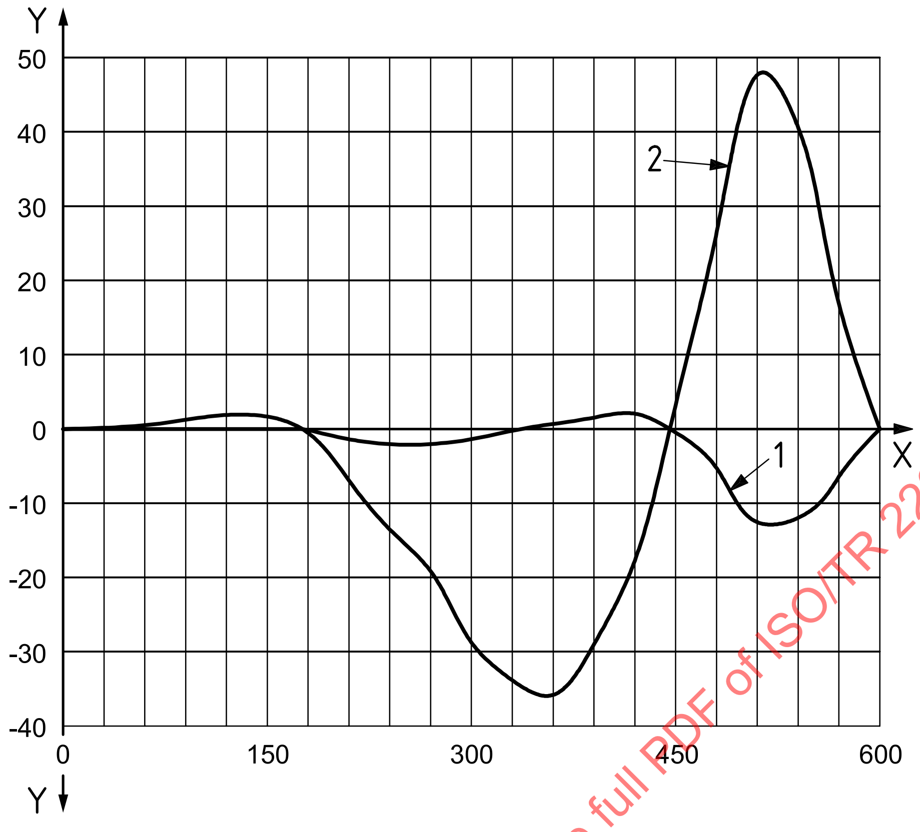
1 force component F_P perpendicular to foot platform related to specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

2 force component F_P related to tilting angle produced by crank gear 60:40

3 force component F_T tangential to foot platform related to specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

4 force component F_T related to tilting angle produced by crank gear 60:40

Figure 15 — Profiles (curves) of force components F_P and F_T, as specified and as produced by crank gear 60:40



Key

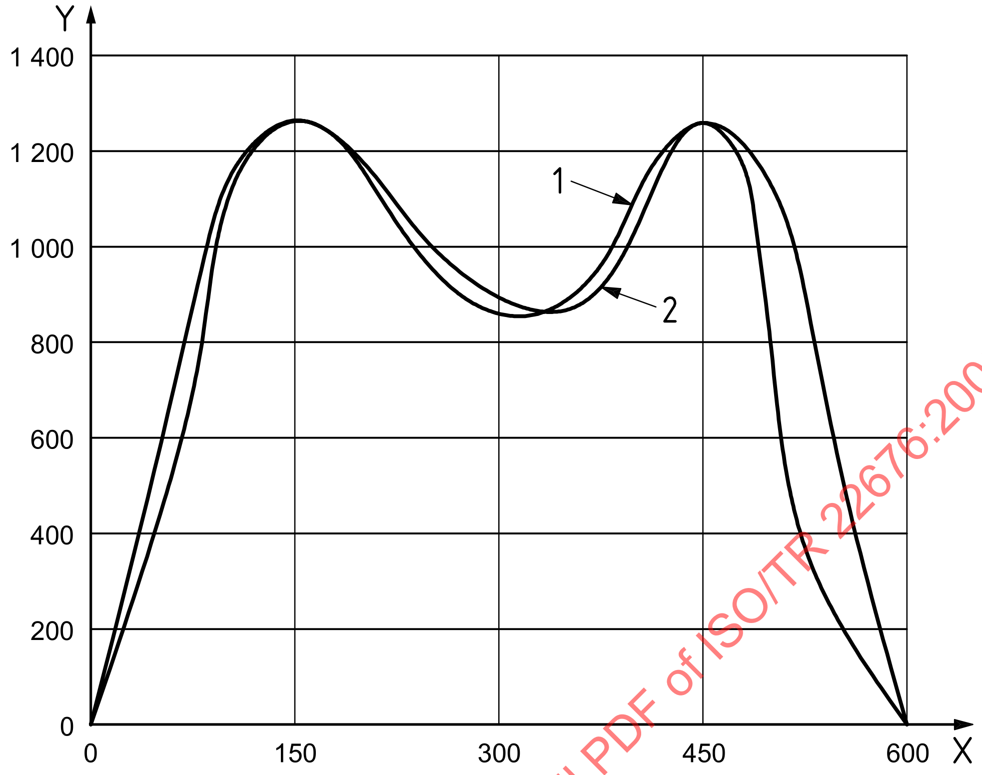
X loading time in milliseconds

Y force in newtons

1 deviation of force component F_P perpendicular to foot platform related to tilting angle produced by crank gear 60:40 from force component F_P related to specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

2 deviation of force component F_T tangential to foot platform related to tilting angle produced by crank gear 60:40 from force component F_T related to specified profile (curve) of tilting angle $\gamma(t)$ of foot platform

Figure 16 — Illustration of force deviations produced by crank gear 60:40



Key

X loading time in milliseconds

Y force in newtons

1 specified profile (curve) of test force as function of time $F(t)$

2 test force F related to tilting angle produced by crank gear 60:40 as function of distorted time

Figure 17 — Illustration of distortion of time base of test force F produced by crank gear 60:40

3.6 Effect of the position of the tilting axis TA of the foot platform on the elevation E and the A-P displacement Δf of the test sample at the foot

3.6.1 General

As is outlined in 3.6.3 and 3.6.4, the tilting of the foot platform during the cyclic test up to the values occurring at the instant of heel contact ($\gamma_{HC} = -20°$) and at the instant of toe-off ($\gamma_{TO} = 40°$), specified in Table 12 of ISO 22675:2006, can move the ankle-foot device or foot unit by considerable amounts of both elevation E, illustrated in Figure 18, and A-P displacement Δf, illustrated in Figure 19.

For the reasons given in a) and b), this is not desirable.

a) The higher the maximum value of elevation E is, the longer the travel of the actuator needs to be. If, for example, a fluid cylinder is used, the travel required may well result in a length of the piston rod that makes the system sensitive to transverse forces, thus requiring additional means of axial guidance.

   There is also a direct relationship between the travel of the piston (rod) and the volume of the fluid needed for its operating. This affects the capacity of the pump and the flow control required and, consequently, the cost-price and the operating expenses of the system.

b) As is outlined in 3.7, any A-P displacement Δf of a test sample at the foot will result in an angular movement $\Delta\varphi$ of the test sample about the top load application point P_T (P_{TE}). The higher the maximum value of A-P displacement Δf is, the greater will be the angular movement $\Delta\varphi$ and, hence, the deviations from the specified test loading conditions.

As a general rule, the maximum value of angular movement $\Delta\varphi$ about the top load application point P_T (P_{TE}) at the instants of F_{1cmax} (1st maximum of the loading profile) and F_{2cmax} (2nd maximum of the loading profile) should not exceed 1°. The statements in 3.6.3 to 3.6.5 and 3.7 demonstrate that this can be achieved by an appropriate positioning of the tilting axis TA of the foot platform.

3.6.2 Position of the tilting axis TA of the foot platform

According to Figures 18 and 19 the position of the tilting axis TA of the foot platform within the f-u plane of the coordinate system is determined by the coordinates f_{TA} and u_{TA}.

Together with the dimensions determining the position of the foot of an ankle-foot device or foot unit within the f-u plane of the coordinate system the offset u_{TA} can be calculated as

$$u_{TA} = -(0{,}25\,L + f_{TA}) \times \tan(x \times \gamma_{HC}) \quad (12)$$

$$u_{TA} = (0{,}75\,L - f_{TA}) \times \tan(y \times \gamma_{TO}) \quad (13)$$

with y_1 = 0,25, y_2 = 0,5 and y_3 = 0,41 for the illustrated situations at heel contact and toe-off (see also NOTE).

The value of f_{TA} = 25 mm, applied to Figures 18 and 19, corresponds to the value of $f_{T,\,30}$ of the top load application point $P_{T,\,30}$, specified in Table 8 of ISO 22675:2006 for foot length L = 30 cm, i.e. for the situation illustrated, the centre of the tilting axis TA is located on a parallel to the u-axis passing through the top load application point $P_{T,\,30}$.

NOTE The value of y_3 = 0,41 results from the condition applying to that elevated position of the tilting axis TA of the foot platform, at which the maximum value of anterior displacement $\Delta f_{max,\,ant.}$ occurring during elevation of the forefoot is the same as the value of posterior displacement Δf_{TO} at the instant of toe-off (see 3.6.3). This condition can be calculated determining at first the dimensions $\Delta f_{max,\,ant.}$ and Δf_{TO} and then putting $\Delta f_{max,\,ant.} = \Delta f_{TO}$.

The Equations determining the dimensions $\Delta f_{max,\,ant.}$ and Δf_{TO} can be derived from the following geometric and trigonometric relationships (see Figure 19):

$\Delta f_{max,\,ant.} = D_{TA\text{-}TO} - (0{,}75\,L - f_{TA})$ and $\cos(y \times \gamma_{TO}) = (0{,}75\,L - f_{TA})/D_{TA\text{-}TO}$ for the maximum anterior displacement or

$\cos[(1-y) \times \gamma_{TO}] = [(0{,}75\,L - f_{TA}) - \Delta f_{TO}]/D_{TA\text{-}TO}$ and $\cos(y \times \gamma_{TO}) = (0{,}75\,L - f_{TA})/D_{TA\text{-}TO}$ for the posterior displacement at toe-off, respectively,

where $D_{TA\text{-}TO}$ is the distance of the point of the foot from the tilting axis TA of the foot platform.

Putting $\Delta f_{max,\,ant.} = \Delta f_{TO}$ gives the condition $\cos[\gamma_{TO} \times (1-y)] = 2 \times \cos(y \times \gamma_{TO}) - 1$, from which the value of y_3 = 0,41 results.

3.6.3 Values of elevation E

NOTE 1 All values calculated in 3.6.3 are also listed in Table 2.

NOTE 2 The values of elevation E in parentheses apply, if the foot platform is driven by a crank gear of a design according to 3.4.3 and Figure 11.

The values of elevation E at the instants of heel contact and toe-off are determined by the following Equations (for their derivation see NOTE 3):

$$E_{heel\ contact} = E_{HC} = u_{TA} - (0{,}25\,L + f_{TA}) \times \sin[(1-x) \times \gamma_{HC}]/\cos(x \times \gamma_{HC}) \quad (14)$$

$$E_{toe\text{-}off} = E_{TO} = u_{TA} + (0{,}75\,L - f_{TA}) \times \sin[(1-y) \times \gamma_{TO}]/\cos(y \times \gamma_{TO}) \quad (15)$$

or, with Equations (12) and (13)

$$E_{HC} = - (0{,}25\ L + f_{TA}) \times \{\sin (x \times \gamma_{HC}) + \sin [(1 - x) \times \gamma_{HC}]\}/\cos (x \times \gamma_{HC}) \quad (14a)$$

$$E_{TO} = (0{,}75\ L - f_{TA}) \times \{\sin (y \times \gamma_{TO}) + \sin [(1 - y) \times \gamma_{TO}]\}/\cos (y \times \gamma_{TO}) \quad (15a)$$

with y_1 = 0,25, y_2 = 0,5 and y_3 = 0,41 for the illustrated situations at heel contact and toe-off (see also NOTE of 3.6.2).

NOTE 3 Equations 14 and 15 are derived from two trigonometric relationships each (see Figure 19), reading

$\sin [(1 - x) \times \gamma_{HC}] = - (E_{HC} - u_{TA})/D_{TA\text{-}HC}$ and $\cos (x \times \gamma_{HC}) = (0{,}25\ L + f_{TA})/D_{TA\text{-}HC}$ for the situation at heel contact or

$\sin [(1 - y) \times \gamma_{TO}] = (E_{TO} - u_{TA})/D_{TA\text{-}TO}$ and $\cos (y \times \gamma_{TO}) = (0{,}75\ L - f_{TA})/D_{TA\text{-}TO}$ for the situation at toe-off, respectively, where $D_{TA\text{-}HC}$ and $D_{TA\text{-}TO}$ are the distances from the tilting axis TA of the foot platform to the posterior heel edge or the point of the foot, respectively.

For the position of the tilting axis TA at platform level, the factors x and y become zero. This simplifies Equations (14a) and (15a) to

$$E_{HC} = - (0{,}25\ L + f_{TA}) \times \sin \gamma_{HC} \quad (14b)$$

$$E_{TO} = (0{,}75\ L - f_{TA}) \times \sin \gamma_{TO} \quad (15b)$$

For the position of the tilting axis TA at platform level, the values of elevation of an ankle-foot device or foot unit of foot length L = 30 cm at the instants of heel contact and toe-off are $E_{HC,\ 0}$ = 34 mm and $E_{TO,\ 0}$ = 129 mm; (154 mm, see NOTE 2).

The position of the tilting axis TA at platform level required to achieve a balanced proportion of elevation at the instants of heel contact and toe-off can be calculated by the condition

$$E_{HC} = E_{TO} \quad (16)$$

resulting in a value of f_{TA} determined by

$$f_{TA} = L \times (0{,}75 \times \sin \gamma_{TO} + 0{,}25 \times \sin \gamma_{HC})/(\sin \gamma_{TO} - \sin \gamma_{HC}) = 0{,}40 \times L;\ (0{,}44 \times L, \text{ see NOTE 2}) \quad (17)$$

For an ankle-foot device or foot unit of foot length L = 30 cm, the value of elevation at heel contact and toe-off is $E_{HC,\ 0} = E_{TO,\ 0}$ = 67 mm; (71 mm, see NOTE 2).

3.6.4 Values of A-P displacement Δf

NOTE 1 All values calculated in 3.6.4 are also listed in Table 2.

NOTE 2 The values of A-P displacement Δf in parentheses apply, if the foot platform is driven by a crank gear of a design according to 3.4.3 and Figure 11.

The values of A-P displacement Δf at the instants of heel contact and toe-off are determined by the following Equations:

$$\Delta f_{\text{heel contact}} = \Delta f_{HC} = (0{,}25\ L + f_{TA}) \times \{1 - \cos [(1 - x) \times \gamma_{HC}]/\cos (x \times \gamma_{HC})\} \quad (18)$$

$$\Delta f_{\text{toe-off}} = \Delta f_{TO} = (0{,}75\ L - f_{TA}) \times \{1 - \cos [(1 - y) \times \gamma_{TO}]/\cos (y \times \gamma_{TO})\} \quad (19)$$

with y_1 = 0,25, y_2 = 0,5 and y_3 = 0,41 for the illustrated situations at heel contact and toe-off (see also NOTE of 3.6.2).

For the position of the tilting axis TA at platform level, the factors x and y become zero. This simplifies the Equations (18) and (19) to

$$\Delta f_{HC} = (0{,}25\ L + f_{TA}) \times (1 - \cos \gamma_{HC}) \quad (19a)$$

$$\Delta f_{TO} = (0{,}75\ L - f_{TA}) \times (1 - \cos \gamma_{TO}) \quad (20a)$$

For the position of the tilting axis TA at platform level, the values of A-P displacement Δf of an ankle-foot device or foot unit of foot length L = 30 cm at the instants of heel contact and toe-off are $\Delta f_{HC,\,0}$ = 6 mm and $\Delta f_{TO,\,0}$ = 47 mm (72 mm, see NOTE 2).

At the position of the tilting axis TA at platform level required to achieve a balanced proportion of elevation at the instants of heel contact and toe-off (see 3.6.3), the values of A-P displacement Δf are $\Delta f_{HC,\,0}$ = 12 mm (12 mm, see NOTE 2) and $\Delta f_{TO,\,0}$ = 25 mm (33 mm, see NOTE 2).

Apparently, a position of the tilting axis TA at platform level at f_{TA} = 0,4 L (0,44 × L, see NOTE 2) also diminishes the A-P displacement $\Delta f_{TO,\,0}$ at the instant of toe-off to a considerable extent. Nevertheless, the A-P displacement during elevation of the forefoot remains more critical than that during the elevation of the heel, due to the higher value of maximum tilting angle.

The values of A-P displacement Δf can be diminished further by elevating the position of tilting axis TA at u_{TA}, the values of u_{TA} being determined by the Equations (12) and (13). In Figure 19 three different elevated positions are shown, determined by the values of $u_{TA,\,1}$, $u_{TA,\,2}$ and $u_{TA,\,3}$ (see Table 2).

The corresponding values of A-P displacement $\Delta f_{TO,\,1}$, $\Delta f_{TO,\,2}$ and $\Delta f_{TO,\,3}$ shown in Figure 19 can be calculated using Equation (19) (see Table 2).

The findings described in the foregoing paragraphs suggest that two specific positions of the tilting axis TA of the foot platform exist, at which

a) at the instants of heel contact and toe-off the values of elevation E_{HC} and E_{TO} are the same, and the values of A-P displacement Δf_{HC} and Δf_{TO} are zero and

b) at the instants of the first and second maximum of the test force $F_c(t)$, F_{1cmax} and F_{2cmax}, at which the lines of action of the corresponding resultant reference forces F_{R1} and F_{R2} are passing through the bottom load application points P_{B1} (heel) or P_{B2} (forefoot), respectively (see Figure 1 of ISO 22675:2006), the values of elevation E_{PB1} and E_{PB2} are the same, and the values of A-P displacement Δf_{B1} and Δf_{B2} are zero.

All values can be calculated, using the Equations (14a)/(15a) and (18)/(19) with the following modifications for the calculation of the values of elevation and A-P displacement at the bottom load application points P_{B1} and P_{B2} at the instants of F_{1cmax} and F_{2cmax}. All values calculated are listed in Table 2.

$$E_{PB,\,heel} = E_{PB1} = -(f_{B1} + f_{TA}) \times \{\sin (x \times \gamma_1) + \sin [(1 - x) \times \gamma_1]\}/\cos (x \times \gamma_1) \quad (20)$$

$$E_{PB,\,forefoot} = E_{PB2} = (f_{B2} - f_{TA}) \times \{\sin (y \times \gamma_2) + \sin [(1 - y) \times \gamma_2]\}/\cos (y \times \gamma_2) \quad (21)$$

$$\Delta f_{PB,\,heel} = \Delta_{fB1} = (f_{B1} + f_{TA}) \times \{1 - \cos [(1 - x) \times \gamma_1]/\cos (x \times \gamma_1)\} \quad (22)$$

$$\Delta f_{PB,\,forefoot} = \Delta f_{B2} = (f_{B2} - f_{TA}) \times \{1 - \cos [(1 - y) \times \gamma_2]/\cos (y \times \gamma_2)\} \quad (23)$$

with $x = \{\arctan [u_{TA}/(f_{B1} + f_{TA})]\}/\gamma_1$ and $y = \{\arctan [u_{TA}/(f_{B2} - f_{TA})]\}/\gamma_2$ and with $\gamma_1 = -15°$ and $\gamma_2 = 20°$ (see Table 8 of ISO 22675:2006).

The two specific positions according to a) and b) are illustrated in Figure 20 and specified in Table 2. As to be expected, they deviate considerably from each other:

— the condition of a) is met at f_{TA} = 0,423 L and u_{TA} = 0,120 L, resulting in an elevation $E_{HC} = E_{TO}$ = 71 mm and an A-P displacement $\Delta f_{HC} = \Delta f_{TO}$ = 0 for a foot length L = 30 cm;

— the condition of b) is met at f_{TA} = 0,222 L and u_{TA} = 0,053 L, resulting in an elevation $E_{PB1} = E_{PB2}$ = 30 mm and an A-P displacement $\Delta f_{B1} = \Delta f_{B2}$ = 0 for a foot length L = 30 cm.

Hence, the final step of optimizing is the specification of a compromise position of the tilting axis TA of the foot platform, at which

c) the elevation E_{HC} occurring at the instant of heel contact and the elevation E_{TO} occurring at the instant of toe-off deviate from that according to a) by approximately equal values of opposite sign;

d) the A-P displacement Δf_{HC} occurring at the instant of heel contact and the A-P displacement Δf_{B1} occurring at the instant of the first maximum of the test force $F_c(t)$, F_{1cmax}, deviate from zero by approximately equal values of opposite direction;

e) the A-P displacement Δf_{B2} occurring at the instant of the second maximum of the test force $F_c(t)$, F_{2cmax}, and the A-P displacement Δf_{TO} occurring at the instant of toe-off deviate from zero by approximately equal values of opposite direction.

As illustrated in Figure 20 and specified in Table 2, the conditions of c), d) and e) are satisfactorily met by a compromise position of the tilting axis TA of the foot platform at f_{TA} = 0,365 L and u_{TA} = 0,1 L (the values below are related to a foot length L = 30 cm):

— The values of elevation according to condition c) are E_{HC} = 65 mm $\leqslant$ 71 mm $\leqslant$ E_{TO} = 81 mm.

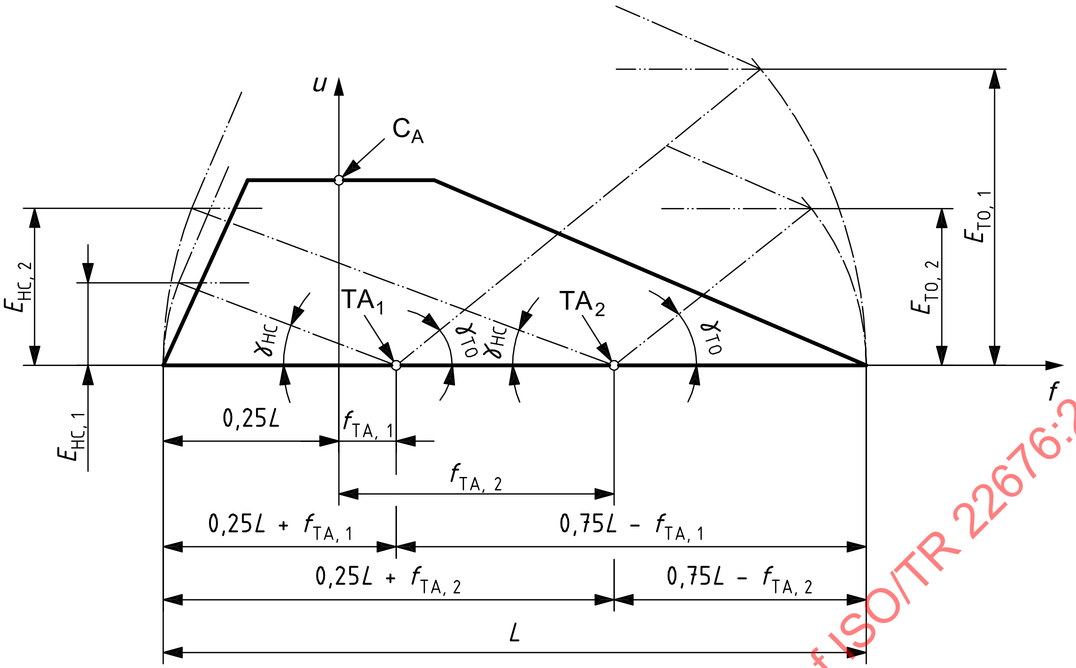
— The values of A-P displacement according to conditions d) and e) are Δf_{HC} = 1 mm anterior versus Δf_{B1} = 2 mm posterior or Δf_{B2} = 8 mm anterior versus Δf_{TO} = 8 mm posterior, respectively.

3.6.5 Conclusions

The foregoing analysis indicates the position of the tilting axis TA of the foot platform, which minimizes the values of the elevation E and the A-P displacement Δf, at

f_{TA} = 0,365 L and u_{TA} = 0,1 L, where L is the foot length in centimetres.

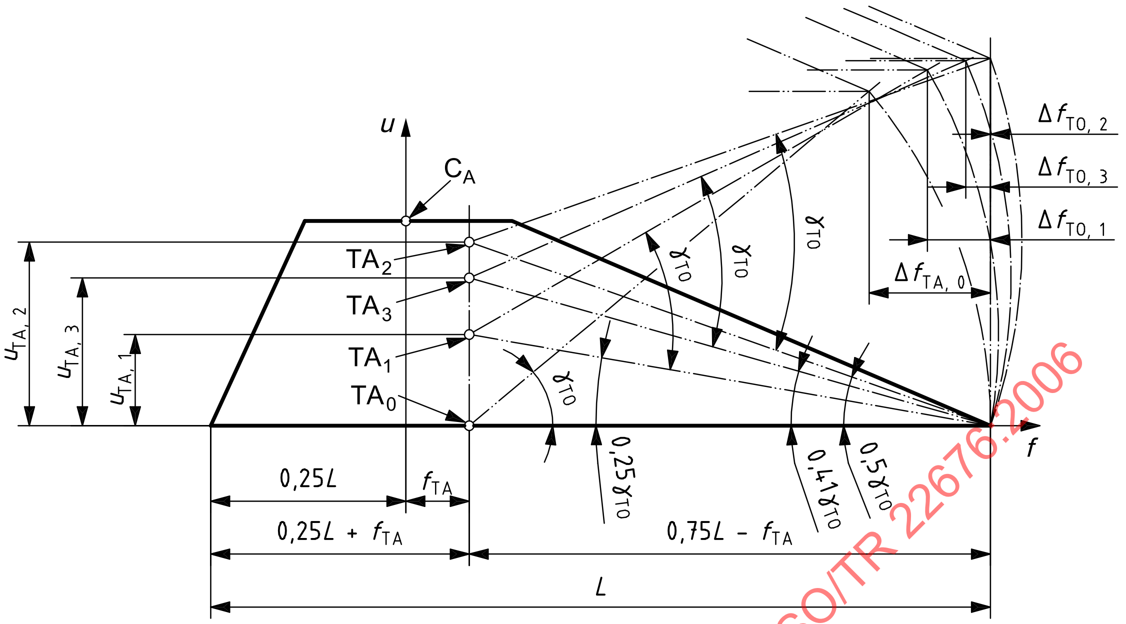
In order to limit the complexity of the design of the foot platform, it is possible to regard the dependence of the position of its tilting axis TA on the foot length L by a corresponding transposition of the related top load application point P_T, which needs to be adjusted anyway, since it is also dependent on the foot length L. This can be carried out in several ways, described in 3.8.



Key

f, *u*	axes of coordinate system
C_A	effective ankle-joint centre
$TA_{1, 2}$	specific positions of tilting axis of foot platform on *f*-axis
L	foot length
γ_{HC}	tilting angle of foot platform at instant of heel contact (γ_{HC} = – 20°)
γ_{TO}	tilting angle of foot platform at instant of toe-off (γ_{TO} = 40°)
$E_{HC, 1, 2}$	specific values of elevation at instant of heel contact, related to specific positions of tilting axis TA of foot platform
$E_{TO, 1, 2}$	specific values of elevation at instant of toe-off, related to specific positions of tilting axis TA of foot platform

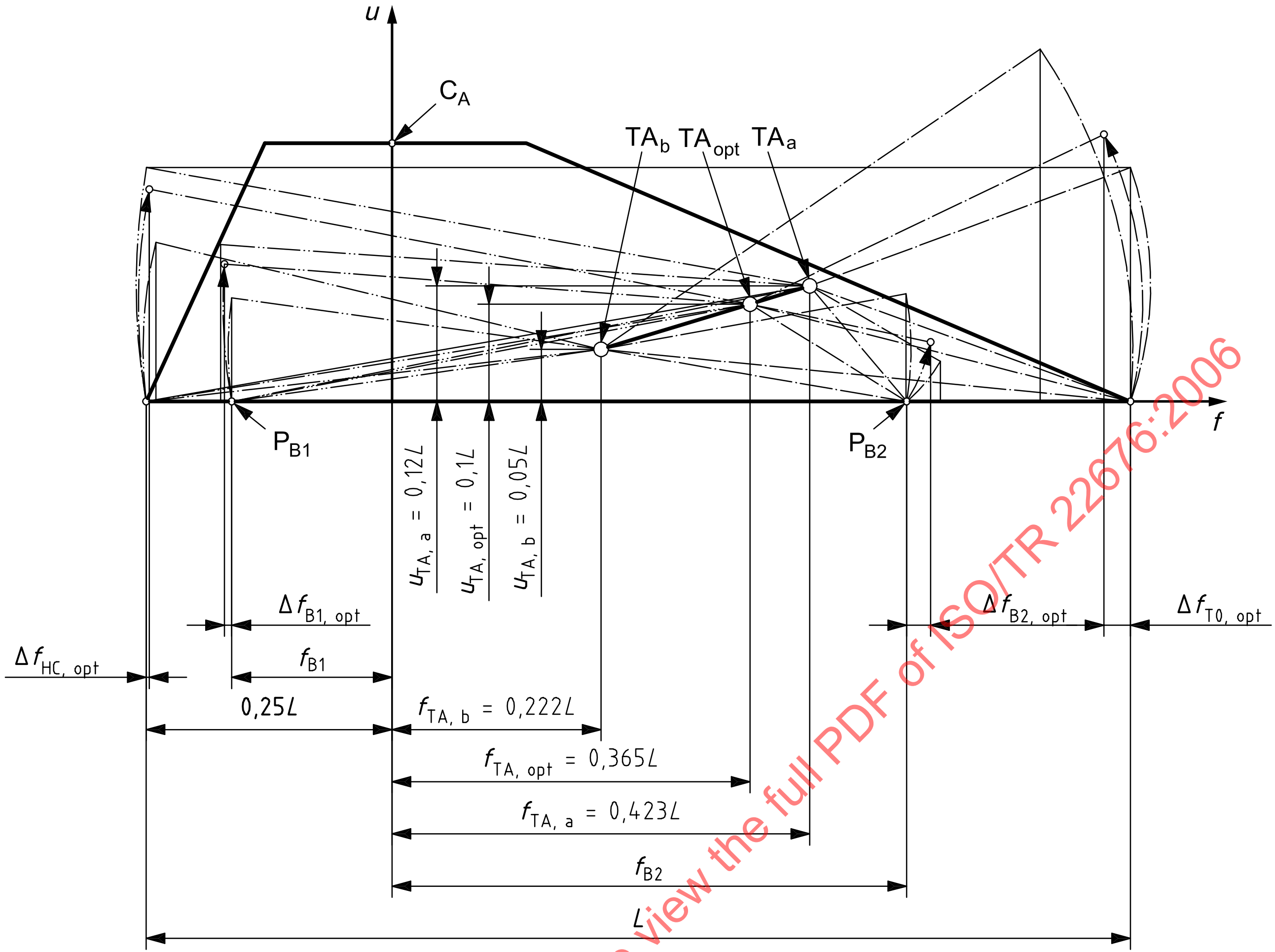
Figure 18 — Effect of *f*-position of tilting axis TA of foot platform on the elevation *E* of the foot at the instants of heel contact and toe-off



Key

f, u	axes of coordinate system
C_A	effective ankle-joint centre
$TA_{0...3}$	specific positions of tilting axis of foot platform on straight line parallel to u-axis
L	foot length
γ_{TO}	tilting angle of foot platform at instant of toe-off (γ_{TO} = 40°)
$\Delta f_{TO,\ 0...3}$	specific values of A-P displacement at instant of toe-off, related to specific positions of tilting axis TA of foot platform

Figure 19 — Effect of u-position of tilting axis TA of foot platform on the A/P displacement Δf of the foot at the instant of toe-off



Key

f, u	axes of coordinate system
C_A	effective ankle-joint centre
$TA_{a, b, opt.}$	specific positions of tilting axis TA of foot platform
$f_{TA, a, b, opt.}$	f-coordinates of specific positions of tilting axis TA of foot platform
$u_{TA, a, b, opt.}$	u-coordinates of specific positions of tilting axis TA of foot platform
P_{B1}	position of bottom load application point on heel
P_{B2}	position of bottom load application point on forefoot
$\Delta f_{HC, opt.}$	anterior displacement at heel of foot at instant of heel contact (test force F = 0) for optimum position of tilting axis $TA_{opt.}$ of foot platform
$\Delta f_{B1, opt.}$	posterior displacement at P_{B1} on heel of foot at instant of maximum heel reference loading (test force $F = F_{1cmax}$) for optimum position of tilting axis $TA_{opt.}$ of foot platform
$\Delta f_{B2, opt.}$	anterior displacement at P_{B2} on forefoot at instant of maximum forefoot reference loading (test force $F = F_{2cmax}$) for optimum position of tilting axis $TA_{opt.}$ of foot platform
$\Delta f_{TO, opt.}$	posterior displacement at point of foot at instant of toe-off (test force F = 0) for optimum position of tilting axis $TA_{opt.}$ of foot platform
L	foot length

Figure 20 — Values of elevation E and A-P displacement Δf at specific positions of tilting axis TA

Table 2 — Coordinates f_{TA} and u_{TA} of the tilting axis TA of the foot platform and related values of elevation E and A-P displacement Δf for foot length L = 30 cm

Figure	Position of tilting axis TA mm		Elevation E mm		A-P displacement Δf mm			
					Heel		Forefoot	
	f_{TA}	u_{TA}	Heel	Forefoot	Posterior	Anterior	Posterior	Anterior
18	$f_{TA,1}$ = 25	0	34	129 (154)		6	47 (72) at TO	
19	f_{TA} = 25	$u_{TA,1}$ = 35		137 (170)			24 (38) at TO	
19	f_{TA} = 25	$u_{TA,2}$ = 73		146 (187)			0 (0) at TO	
19	f_{TA} = 25	$u_{TA,3}$ = 59		143 (181)			9 (14) at TO	
18	$f_{TA,2}$ = 0,4 L	0	67	67 (71)		12 at HC	25 (33) at TO	
20	f_{TA} = 0,222 L	u_{TA} = 0,053 L	49 at HC 30 at F_{1cmax}	105 at TO 30 at F_{2cmax}	0 at F_{1cmax}	3 at HC	28 at TO	0 at F_{2cmax}
20	f_{TA} = 0,423 L	u_{TA} = 0,120 L	71 at HC 46 at F_{1cmax}	71 at TO 10 at F_{2cmax}	3 at F_{1cmax}	0 at HC	0 at TO	11 at F_{2cmax}
20	f_{TA} = 0,365 L	u_{TA} = 0,100 L	65 at HC 41 at F_{1cmax}	81 at TO 16 at F_{2cmax}	2 at F_{1cmax}	1 at HC	8 at TO	8 at F_{2cmax}

NOTE The values of elevation E and A-P displacement Δf in parentheses (see 3.6.2 and 3.6.3) apply, if the foot platform is driven by a crank gear of a design according to 3.4.3 and Figure 11.

3.7 Effect of the elevation E and A-P displacement Δf of the test sample, caused by the tilting of the foot platform, on the test loading conditions of ISO 22675

The elevation E and the A-P displacement Δf of the test sample at the foot, caused by the tilting of the foot platform during the cyclic test up to the values of γ_{HC} and γ_{TO} occurring at the instants of heel contact and toe-off at magnitudes depending on the position of the tilting axis TA of the foot platform, is described in detail in 3.6 and illustrated in Figures 18 to 20. Specific values are listed in Table 2.

One example of the effect of elevation E and A-P displacement Δf of the test sample at the foot on the test loading conditions of ISO 22675 is illustrated in Figures 21 and 22 for the two different designs of test equipment, briefly described in 3.3.2 and 3.3.3.

The situation illustrated in Figures 21 and 22 is determined by:

— a specific position of the top load application point P_T at $f_{T,L}$ and $u_{T,L}$ relevant to a specific foot length L;

— a position of the tilting axis TA of the foot platform on a straight line passing through the top load application point P_T parallel to the u-axis;

— a (fictitious) design of ankle-foot device or foot unit with a plane foot sole, illustrated by a symbolic view of foot;

— the instant of toe-off at a tilting angle of the foot platform of γ_{TO} = 40°, specified in Table 11 of ISO 22675:2006.

From Figures 21 to 22 the following can be concluded.

a) The elevation E_{TO} and the A-P displacement Δf_{TO} of the test sample at the point of the foot, caused by the tilting of the foot platform at an angle of γ_{TO}, results in an angular movement of the test sample about the top load application point P_T by $\Delta\varphi_{TO}$.

The value of angular movement $\Delta\varphi_{TO}$ reached in test equipment according to 3.3.2 and Figure 21 is lower than that reached in test equipment according to 3.3.3 and Figure 22, due to the circumstance that the "internal" top load application point P_T has a fixed position on the test sample and, hence, a fixed distance to the point of the foot, while the "external" top load application point P_{TE} has a fixed position on the base frame of the test equipment and, hence, a distance to the point of the foot of the test sample that shortens approximately by the amount of its elevation.

b) The angular movement of the test sample about the top load application point P_T (P_{TE}) increases the angle between the foot (sole) and (the contact surface of) the foot platform at a total of $\gamma_{TO,\ total} = \gamma_{TO} + \Delta\varphi_{TO}$.

c) Apparently, a deviation of the tilting angle γ of the foot platform from the specified profile (curve) will affect the values of the angles α and β, related to the tilting angle γ by the Equation $\alpha + \beta = \gamma$ [see Equation (1) and Figure 1].

d) In addition to the effect on the values of the angles α and β addressed in c), the arrangement according to 3.3.3 and Figure 22 provides an increased value of the angle $\alpha_{TO,\ PTE}$, enclosed by the parallel to the u-axis passing through the top load application point P_{TE} and the straight line connecting this point with the point of the foot. This increase is likely to diminish the value of the ratio F_T/F_P of the tangential and the perpendicular force components at the foot platform (see Figure 1).

e) Finally, attention has to be paid to an earlier statement [see 3.3.4 b) 2)], according to which the actuating system in the arrangement according to 3.3.3 and Figure 22 is tilted by $\Delta\varphi_{TO}$. The possible effects resulting from this angular movement are already addressed in 3.3.4 b) 2).

The value of $\Delta\varphi_{TO}$ can be calculated by adopting the general Equation below, which provides sufficient accuracy within the range of angular movement occurring,

$$\Delta\varphi = \arctan\ (\Delta f / u_T) \qquad (24)$$

in the form

$$\Delta\varphi_{TO} = \arctan\ (\Delta f_{TO}/u_T) \text{ for a test sample set-up in a test equipment according to 3.3.2 or} \qquad (24a)$$

$$\Delta\varphi_{TO} = \arctan\ (\Delta f_{TO}/u_{TE}) \text{ for a test sample set-up in a test equipment according to 3.3.3.} \qquad (24b)$$

The value of u_{TE} can be calculated from the condition $(0{,}75\ L - f_T)^2 + u_{TE}^2 = (0{,}75\ L - f_T - \Delta f_{TO})^2 + (u_T - E_{TO})^2$.

The value of α_{TO} can be calculated by adopting the general Equation

$$\alpha_x = \arctan\ [(f_x - f_T)/u_T] \qquad (25)$$

in the form

$$\alpha_{TO,\ PT} = \arctan\ [(0{,}75\ L - f_T)/u_T] \qquad (25a)$$

$$\alpha_{TO,\ PTE} = \arctan\ [(0{,}75\ L - f_T)/u_{TE}] \qquad (25b)$$

For the arrangements according to Figures 21 and 22 and a foot length L = 30 cm, the following values apply (see also Table 3).

— Arrangement according to Figure 21: $\Delta\varphi_{TO}$ = 4,03°; $\alpha_{TO, PT}$ = 16,69°

with u_T = 667 mm (see Table 7 of ISO 22675:2006).

— Arrangement according to Figure 22: $\Delta\varphi_{TO}$ = 5,14°; $\alpha_{TO, PTE}$ = 20,96°

with u_{TE} = 522 mm [see condition following Equation (24b)].

Corresponding adoptions of Equation (24) permit the calculation of the angular movement $\Delta\varphi$ of the test sample about the top load application point P_T (P_{TE}), caused by the tilting of the foot platform, at any other value Δf occurring at the discrete instants of the loading cycle specified.

For specific values of Δf see 3.6.4, Figures 18 to 20 and Table 2.

In order to demonstrate once more the influence of the position of the tilting axis TA of the foot platform, a series of informative values has been calculated or determined by graphical analysis for the specific positions of the tilting axis TA at $f_{TA, 1}$ = 25 mm; $u_{TA, 1}$ = 0 mm and $f_{TA, 2}$ = 0,365 L; $u_{TA, 2}$ = 0,10 L according to 3.6.5, all related to a foot length L = 30 cm.

The results are listed in Table 3, comprising

— values of A-P displacement Δf and angular movement $\Delta\varphi$ for specified instants of the loading cycle;

— values of the deviation $\Delta\gamma_{total}$ of the total angle $\gamma_{total} = \gamma + \Delta\varphi$ between the foot (sole) and (the contact surface of) the foot platform for the period between the instants of 210 ms and 420 ms and the period between the instants of 480 ms and 570 ms after heel contact, at which the tilting angle $\gamma(t)$ of the foot platform produced by the crank gear 60:40 (see Figure 10) deviates from the specified value by $-4,5 \leqslant \Delta\gamma \leqslant +4,4°$.

The latter list of values is interesting for the following reason.

As demonstrated in 3.5 and illustrated in Figures 14 and 15, the deviation of $-4,5° \leqslant \Delta\gamma \leqslant +4,4°$ alone results in deviations of the force component F_T from the specified profile of -36 N $\leqslant F_T \leqslant +48$ N.

This deviation can be diminished or enlarged by the angular movement $\Delta\varphi$ of the test sample about the top load application point P_T (P_{TE}) addressed in the above, depending on the position of the tilting axis TA of the foot platform, the resulting magnitudes and directions of A-P displacement Δf of the test sample at the foot and the arrangement according to either of the Figures 21 and 22.

For example, a position of the tilting axis TA at $f_{TA, 1}$ = 25 mm and $u_{TA, 1}$ = 0 mm in the arrangement according to Figure 21 will increase the positive deviation of $\Delta\gamma$ = 4,4°, produced by the crank gear 60:40 at the instant of 540 ms after heel contact, by another 3,3° (see Table 3). Apparently, this will increase the related positive deviation of F_T considerably.

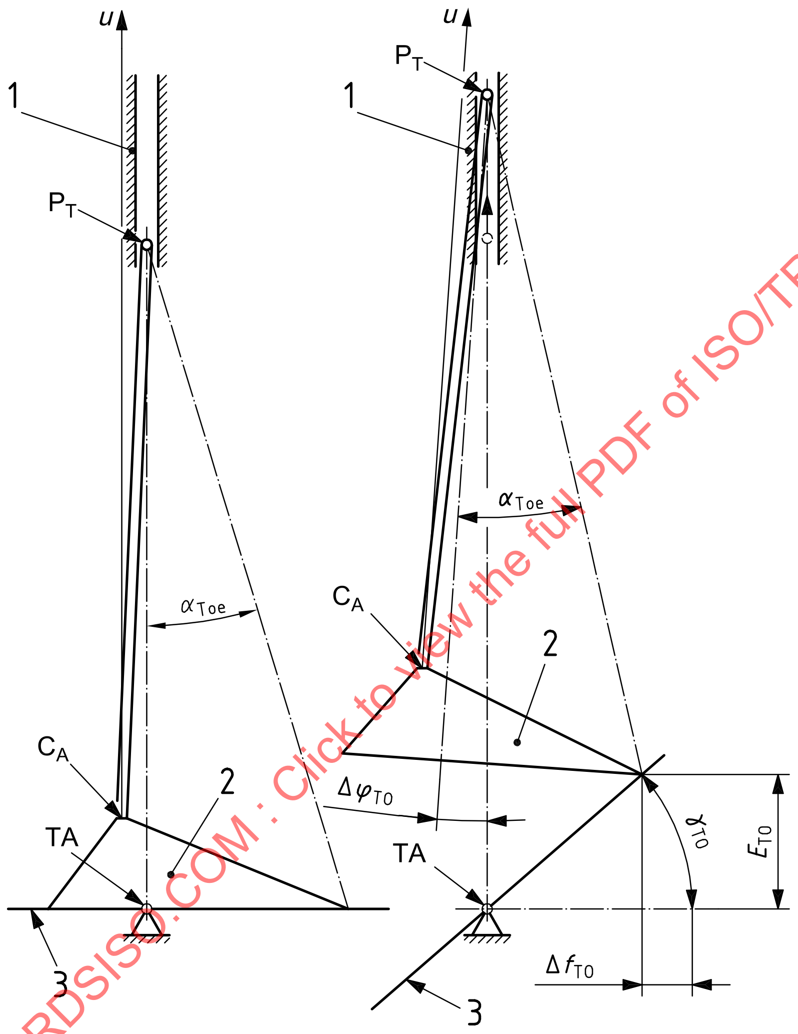
The relevant values listed in Table 3 disclose the following.

The ranges of angular movement $\Delta\varphi$, caused by the tilting of the foot platform with its tilting axis TA positioned at $f_{TA, 1}$ = 25 mm and $u_{TA, 1}$ = 0 mm, are considerably diminished by a position of the tilting axis TA positioned at $f_{TA, 2}$ = 0,365 L and $u_{TA, 2}$ = 0,10 L according to 3.6.5:

a) for a position of the tilting axis TA of the foot platform at $f_{TA, 1}$ = 25 mm and $u_{TA, 1}$ = 0 mm the range of angular movement $\Delta\varphi$ is 0,5° anterior $\leqslant \Delta\varphi \leqslant$ 4° posterior;

b) for a position of the tilting axis TA of the foot platform at $f_{TA,\,2}$ = 0,365 L and $u_{TA,\,2}$ = 0,10 L according to 3.6.5 relating to a foot length L = 30 cm, i.e. for a position at $f_{TA,\,2}$ = 0,365 × 30 cm = 110 mm and $u_{TA,\,2}$ = 0,10 × 30 cm = 30 mm the range of angular movement $\Delta\varphi$ is 0,7° anterior $\leqslant \Delta\varphi \leqslant$ 0,7° posterior;

c) one particular effect of the diminished ranges of angular movement $\Delta\varphi$ is the reduction of the considerable deviation $\Delta\gamma_{total}$ of the total angle $\gamma_{total} = \gamma + \Delta\varphi$ between the foot (sole) and (the contact surface of) the foot platform during the period between the instants of 480 ms and 570 ms after heel contact.



Key

1 axial guidance fixed to base frame of equipment with its axis parallel to u-axis of coordinate system

2 symbolic view of foot

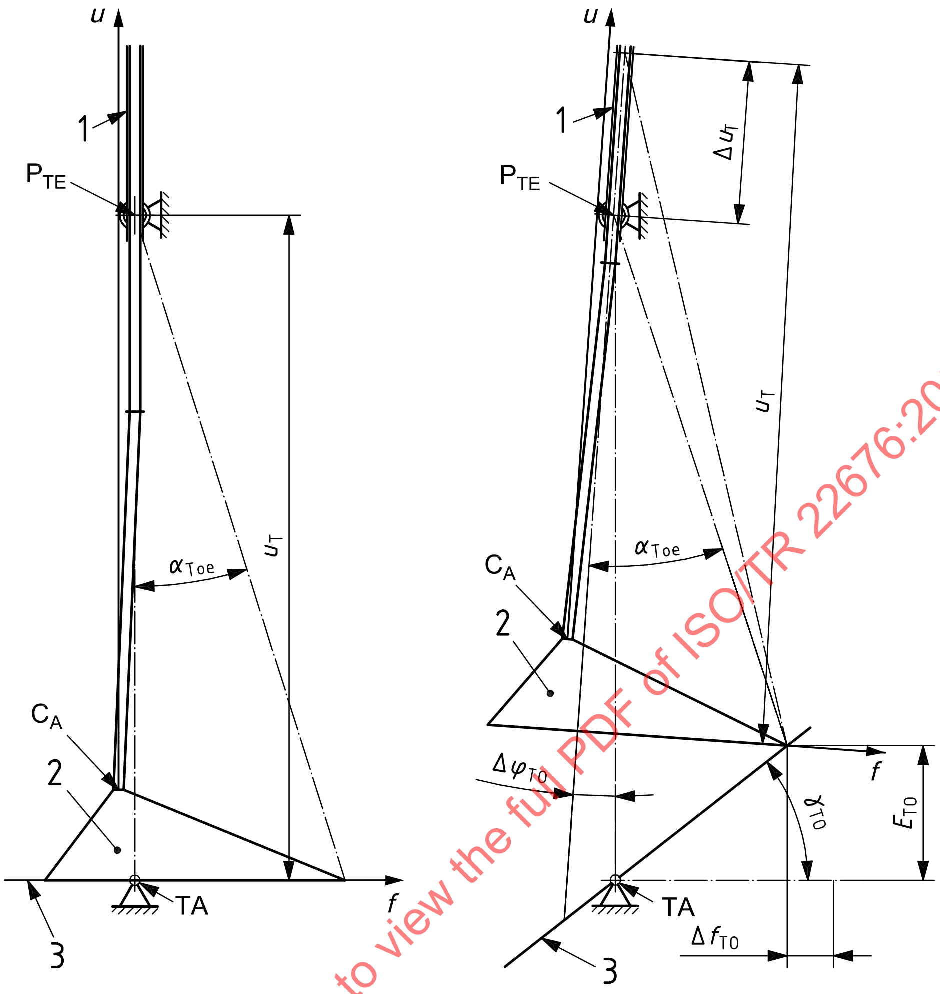
3 foot platform

C_A effective ankle-joint centre

P_T “internal” top load application point with fixed position on test sample

TA tilting axis of foot platform

Figure 21 — Illustration of the effect of A-P displacement Δf on the angular movement $\Delta\varphi$ of the test sample about the "internal" top load application point P_T in an arrangement according to 3.3.2



Key

1 axial guidance tiltable about axis passing through P_{TE} and fixed to base frame of equipment parallel to tilting axis TA of foot platform

2 symbolic view of foot

3 foot platform

C_A effective ankle-joint centre

P_{TE} "external" top load application point on axis fixed to base frame of equipment parallel to tilting axis TA of foot platform (see 1)

TA tilting axis of foot platform

Figure 22 — Illustration of the effect of A-P displacement Δf on the angular movement $\Delta\varphi$ of the test sample about the "external" top load application point P_{TE} in an arrangement according to 3.3.3

Table 3 — Specific values demonstrating the effect of A-P displacement Δf on the angular movement $\Delta \varphi$ of the test sample about the top load application point P_T for foot length L = 30 cm

Instant ms	Event	Position of tilting axis TA f_{TA} mm	 u_{TA} mm	A-P displacement Δf Numerical value mm	 Direction	Tilting angle γ specified °	Tilting angle γ produced by crank gear 60:40 °	Angular movement $\Delta\varphi$ °	Total deviation of angle between foot and platform °
0	Heel contact	25	0	6	anterior	– 20	– 20	0,5	0,5
150	F_{1cmax} at P_{B1}	25	0	3	anterior	– 15	– 15	0,3	0,3
210	Deviation of tilting angle γ produced by crank gear 60:40	25	0	$\leqslant$ 1	anterior	– 10,5	– 11,3	$\leqslant$ 0,1	– 0,8
240				$\leqslant$ 1	anterior	– 7,5	– 9,2	$\leqslant$ 0,1	– 1,7
270				$\leqslant$ 1	anterior	– 4	– 6,6	$\leqslant$ 0,1	– 2,6
300				$\leqslant$ 1	anterior	0	– 3,9	$\leqslant$ 0,1	– 3,9
330				0		4	– 0,5	0	– 4,5
360				$\leqslant$ 1	posterior	8	3,7	$\leqslant$ 0,1	– 4,3
390				1,5	posterior	12	8,6	0,1	– 3,3
420				4	posterior	16	14	0,3	– 1,7
450	F_{2cmax} at P_{B2}	25	0	9	posterior	20	20	0,8	0,8
480	Deviation of tilting angle γ produced by crank gear 60:40	25	0	13	posterior	24	26,4	1,1	3,5
510				27	posterior	28	32,1	2,3	6,4
540				38	posterior	32	36,4	3,3	7,7
570				46	posterior	36	39	3,9	6,9
600	Toe-off	25	0	47	posterior	40	40	4,0	4,0
0	Heel contact	0,365 L	0,10 L	1	posterior	– 20	– 20	0,1	– 0,1
150	F_{1cmax} at P_{B1}	0,365 L	0,10 L	2	posterior	– 15	– 15	0,2	– 0,2
210	Deviation of tilting angle γ produced by crank gear 60:40	0,365 L	0,10 L	3	posterior	– 10,5	– 11,3	0,3	– 0,5
240				4	posterior	– 7,5	– 9,2	0,3	– 1,4
270				3	posterior	– 4	– 6,6	0,3	– 2,3
300				2	posterior	0	– 3,9	0,2	– 3,7
330				0		4	– 0,5	0	– 4,5
360				2	anterior	8	3,7	0,2	– 4,5
390				5	anterior	12	8,6	0,4	– 3,7
420				6	anterior	16	14	0,5	– 2,5
450	F_{2cmax} at P_{B2}	0,365 L	0,10 L	8	anterior	20	20	0,7	– 0,7
480	Deviation of tilting angle γ produced by crank gear 60:40	0,365 L	0,10 L	7	anterior	24	26,4	0,6	1,8
510				2	anterior	28	32,1	0,2	3,9
540				2	posterior	32	36,4	0,2	4,6
570				5	posterior	36	39	0,4	3,4
600	Toe-off	0,365 L	0,10 L	8	posterior	40	40	0,7	0,7

3.8 Transposition of the top load application point P_T for compensation of the dependence of the position of the tilting axis TA of the foot platform on the foot length L

3.8.1 General

As already indicated in 3.6.5, it is possible to take account of the dependence of the position of the tilting axis TA of the foot platform on the foot length L by a corresponding transposition of the related top load application point P_T, which needs to be adjusted anyway, since it is also dependent on the foot length L.

This procedure has two advantages:

— it simplifies the setting-up of the test sample in the test equipment, since it reduces the amount of adjustment work;

— it does not necessarily require a design of the foot platform that allows the position of its tilting axis TA to be adjusted (but see NOTES of 3.8.2).

3.8.2 Possibilities of transposing the top load application point P_T

According to the illustrations in Figure 23, the procedure addressed in 3.8.1 can be carried out in principle by

a) specifying a fixed standard or compromise position of the tilting axis TA of the foot platform, determined by the offsets $f_{TA, 20}$ and $u_{TA, 32}$ (see NOTE 1) or $u_{TA, C}$, respectively (see NOTE 2);

b) transposing the top load application point $P_{T, L}$ relevant to a specific foot length L of the test sample parallel to the f-axis by $\Delta f_{TA, L}$, the value of $\Delta f_{TA, L} = (f_{TA, 20} - f_{TA, L})$ representing the difference between the offset $f_{TA, 20}$ of the fixed position of the tilting axis TA [see a)] and its offset $f_{TA, L}$ relevant to a specific foot length L (see Table 4);

c) transposing the top load application point $P_{T, L}$ relevant to a specific foot length L of the test sample parallel to the u-axis by $\Delta u_{TA, L}$ [see 1)] or $\Delta u_{TA, C}$ [see 2)], where

   1) the value of $\Delta u_{TA, L} = (u_{TA, 32} - u_{TA, L})$ represents the difference between the offset $u_{TA, 32}$ of the fixed position of the tilting axis TA [see a)] and its offset $u_{TA, L}$ relevant to a specific foot length L, and

   2) the value of $\Delta u_{TA, C} = (u_{TA, 32} - u_{TA, C})$ represents the difference between the offset $u_{TA, 32}$ of the fixed position of the tilting axis TA [see a)] and a specified compromise offset $u_{TA, C}$ of the tilting axis TA of the foot platform, uniformly applied to test samples of any foot length L,

   the values of $\Delta u_{TA, L}$ and $\Delta u_{TA, C}$ corresponding to the thickness of the compensation plates used for the elevation of the contact surface of the foot platform required to adapt it to the value of $u_{TA, L}$ or $u_{TA, C}$, respectively (but see NOTE 3).

   The results of c) 1) and c) 2) are also listed in Table 4.

NOTE 1 The possibilities of transposing the top load application point P_T shown in this subclause, Figure 23 and Table 4 require the fixed standard position of the tilting axis TA to be determined by a value of $f_{TA, L}$ relevant to the smallest size and a value of $u_{TA, L}$ relevant to the largest size of foot covered by the range 20 cm $\leqslant L \leqslant$ 32 cm, which is considered to cover the vast majority of sizes expected to be submitted for test. If appropriate, this range can easily be extended to smaller or larger sizes with subsequent changes of the values of $\Delta f_{TA, L}$, $\Delta u_{TA, L}$ and $\Delta u_{TA, C}$.

NOTE 2 The most appropriate uniform compromise offset $u_{TA, C}$ of the tilting axis TA of the foot platform addressed in c) 2) is that providing values of A-P displacement Δf, which will cause the lowest possible deviations from the specified test loading conditions [see 3.6.1 b) and 3.7] at <u>both</u> the instant of F_{2cmax} for a test sample of an ankle-foot device or foot unit of a low value of foot length as for example L = 20 cm <u>and</u> the instant of toe-off for a test sample of an ankle-foot device or foot unit of a high value of foot length as for example L = 32 cm.