

Short-circuit currents — Calculation of effects —

Part 1: Definitions and calculation methods

The European Standard EN 60865-1:1993 has the status of a
British Standard

UDC 621.3.014.3:621.3.064.1.001.24

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Power Electrical Engineering Standards Policy Committee (PEL/-) to Technical Committee PEL/104 upon which the following bodies were represented:

- British Cable Makers' Confederation
- Electrical Installation Equipment Manufacturers' Association (BEAMA Ltd.)
- Electricity Association
- Institution of Electrical Engineers

This British Standard, having been prepared under the direction of the Power Electrical Engineering Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 January 1994

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The following BSI references relate to the work on this standard:
Committee reference PEL/104
Draft for comment 92/23457 DC

ISBN 0 580 22688 3

Amendments issued since publication

Amd. No.	Date	Comments
8218	August 1994	Indicated by a sideline in the margin

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National foreword

This Part of BS 7726 has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It is identical with IEC 865-1:1993 *Short-circuit currents — Calculation of effects — Part 1: Definitions and calculation methods* published by the International Electrotechnical Commission (IEC).

In 1993 the European Committee for Electrotechnical Standardization (CENELEC) accepted IEC 865-1 as European Standard EN 60865-1:1993. As a consequence of implementing the European Standard this British Standard is renumbered as BS EN 60865-1 and any reference to BS 7726-1 should be read as a reference to BS EN 60865-1.

Cross-references

International Standard	Corresponding British Standard
IEC 909:1988	BS 7639:1993 <i>Short-circuit current calculation in three-phase a.c. systems</i> (Technically equivalent)
IEC 949:1988	BS 7454:1991 <i>Method for calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects</i> (Identical)

The Technical Committee has reviewed the provisions of IEC 986:1989, to which normative reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, the EN title page, pages 2 to 48, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

UDC 621.3.014.3:621.3.064.1.001.24

Descriptors: Short-circuit currents, electromagnetic effect, thermal effect

English version

Short-circuit currents — Calculation of effects Part 1: Definitions and calculation methods

(IEC 865-1:1993)

Courants de court-circuit
Calcul des effets
Partie 1: Définitions et méthodes de calcul
(CEI 865-1:1993)

Kurzschlußströme
Berechnung der Wirkung
Teil 1: Begriffe und Berechnungsverfahren
(IEC 865-1:1993)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Foreword

The text of document 73(CO)16, as prepared by IEC Technical Committee No. 73, Short-circuit currents, was submitted to the IEC-CENELEC parallel vote in October 1992.

The reference document was approved by CENELEC as EN 60865-1 on 22 September 1993.

The following dates were fixed:

- latest date of publication of
an identical national
standard (dop) 1994-09-01
- latest date of withdrawal
of conflicting national
standards (dow) 1994-09-01

Annexes designated “normative” are part of the body of the standard. Annexes designated “informative” are given only for information. In this standard, Annex A and Annex ZA are normative and Annex B is informative.

Section 1. General

1.1 Scope and object

This International Standard is applicable to the mechanical and thermal effects of short-circuit currents. It contains standardized procedures for the calculation of the effects of the short-circuit currents in two sections as follows:

- Section 2 — The electromagnetic effect on rigid conductors and flexible conductors.
- Section 3 — The thermal effect on bare conductors and electrical equipment.

For cables and insulated conductors reference is made, for example, to IEC 949 and IEC 986.

Only a.c. systems for rated voltages up to and including 420 kV are dealt with in this standard.

The following points should particularly be noted:

- 1) The calculation of short-circuit currents should be based on IEC 909.
- 2) Short-circuit duration used in this standard depends on the protection concept and should be considered in that sense.
- 3) These standardized procedures are adjusted to practical requirements and contain simplifications with safety margins. Testing or more detailed methods of calculation or both may be used.
- 4) In section 2 of this standard, for arrangements with rigid conductors, only the stresses caused by short-circuit currents are calculated. Furthermore, other stresses can exist, e.g. caused by dead-load, wind, ice, operating forces, earthquake. The combination of these loads with the short-circuit loading should be part of an agreement and/or be given by standards, e.g. erection-codes.

The tensile forces in arrangements with flexible conductors include the effects of dead-load. With respect to the combination of other loads the considerations given above are valid.

1.2 Normative references

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

IEC 909:1988, *Short-circuit current calculation in three-phase a.c. systems*.

IEC 949:1988, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*.

IEC 986:1989, *Guide to the short-circuit temperature limits of electric cables with a rated voltage from 1,8/3 (3,6) kV to 18/30 (36) kV*.

1.3 Equations, symbols and units

All equations used in this standard are quantity equations in which quantity symbols represent physical quantities possessing both numerical values and dimensions.

The symbols used in this standard and the SI-units concerned are given in the following lists.

1.3.1 Symbols for section 2 — Electromagnetic effects

A_s	Cross-section of one sub-conductor	m^2
a	Centre-line distance between conductors	m
a_m	Effective distance between neighbouring main conductors	m
$a_{\min}$	Minimum air clearance	m
a_s	Effective distance between sub-conductors	m
a_{1n}	Centre-line distance between sub-conductor 1 and sub-conductor n	m
a_{1s}	Centre-line distance between sub-conductors	m
a_{sw}	Effective centre-line distance between the sub-conductors in the bundle	m
b	Dimension of a sub-conductor perpendicular to the direction of the force	m
b_c	Equivalent static conductor sag at midspan	m

b_h	Maximum horizontal displacement	m
b_m	Dimension of a main conductor perpendicular to the direction of the force	m
c	Factor for the influence of connecting pieces	1
c_{th}	Material constant	$m^4/(A^2s)$
C_D	Dilatation factor	1
C_F	Form factor	1
D	Outer diameter of a tubular conductor	m
d	Dimension of a sub-conductor in the direction of the force	m
d_m	Dimension of a main conductor in the direction of the force	m
d_s	Diameter of a flexible conductor	m
E	Young's modulus	N/m^2
E_s	Actual Young's modulus	N/m^2
F	Force acting between two parallel long conductors during a short circuit	N
F_d	Force on support of rigid conductors (peak value)	N
F_f	Drop force	N
F_m	Force between main conductors during a short circuit	N
F_{m2}	Force between main conductors during a line-to-line short circuit	N
F_{m3}	Force on the central main conductor during a balanced three-phase short circuit	N
F_s	Force between sub-conductors during a short circuit	N
F_{st}	Static tensile force in flexible main conductor	N
F_t	Short-circuit tensile force	N
F_{pi}	Pinch force	N
F'	Characteristic electromagnetic force per unit length on flexible main conductors	N/m
F_v	Short-circuit current force between the sub-conductors in a bundle	N
f	System frequency	Hz
f_c	Relevant natural frequency of a main conductor	Hz
f_{cs}	Relevant natural frequency of a sub-conductor	Hz
$f\eta$	Factor characterising the contraction of the bundle	1
g_n	Conventional value of acceleration of gravity	m/s^2
I''_{k3}	Three-phase initial symmetrical short-circuit current (r.m.s.)	A
I''_{k2}	Line-to-line initial symmetrical short-circuit current (r.m.s.)	A
I''_{k1}	Line-to-earth initial short-circuit current (r.m.s.)	A
i_p	Peak short-circuit current	A
i_{p2}	Peak short-circuit current in case of a line-to-line short circuit	A
i_{p3}	Peak short-circuit current in case of a balanced three-phase short circuit	A
i_1, i_2	Instantaneous values of the currents in the conductors	A
J	Second moment of main conductor area	m^4
J_s	Second moment of sub-conductor area	m^4
j	Parameter determining the bundle configuration during short-circuit current flow	1
k	Number of sets of spacers or stiffening elements	1
k_{1n}	Factor for the effective distance between sub-conductor 1 and sub-conductor n	1
k_{1s}	Factor for effective conductor distance	1
l	Centre-line distance between supports	m
l_c	Cord length of a flexible main conductor in the span	m
l_i	Length of one insulator chain	m

l_s	Centre-line distance between connecting pieces or between one connecting piece and the adjacent support	m
m'	Mass per unit length of main conductor	kg/m
m'_s	Mass per unit length of one sub-conductor	kg/m
m_z	Total mass of one set of connecting pieces	kg
N	Stiffness norm of an installation with flexible conductors	1/N
n	Number of sub-conductors of a main conductor	1
q	Factor of plasticity	1
$R_{p0,2}$	Stress corresponding to the yield point	N/m ²
r	The ratio of electromechanical force on a conductor under short-circuit conditions to gravity	1
S	Resultant spring constant of both supports of one span	N/m
s	Wall thickness of tubes	m
T	Period of conductor oscillation	s
T_k	Duration of short-circuit current	s
T_{k1}	Duration of the first short-circuit current flow	s
T_{pi}	Time from short-circuit initiation until reaching F_{pi}	s
T_{res}	Resulting period of the conductor oscillation during the short-circuit current flow	s
V_F	Ratio of dynamic and static force on supports	1
V_r	Ratio of stress for a main conductor with and without three-phase automatic reclosing	1
V_{rs}	Ratio of stress for a sub-conductor with and without three-phase automatic reclosing	1
V_σ	Ratio of dynamic and static main conductor stress	1
$V_{\sigma s}$	Ratio of dynamic and static sub-conductor stress	1
y_a	Centre-line distance between non-clashing sub-conductors during short-circuit current flow	m
Z	Section modulus of main conductor	m ³
Z_s	Section modulus of sub-conductor	m ³
α	Factor for force on support	1
β	Factor for main conductor stress	1
γ	Factor for relevant natural frequency estimation	1
δ_1	Angular direction of the force	degrees
δ_k	Swing-out angle at the end of the short-circuit current flow	degrees
δ_m	Maximum swing-out angle	degrees
ε_{ela}	Elastic expansion	1
ε_{th}	Thermal expansion	1
$\varepsilon_{st}, \varepsilon_{pi}$	Strain factor of the bundle contraction	1
ζ	Stress factor of the flexible main conductor	1
η	Factor for calculating F_{pi} in the case of non-clashing sub-conductors	1
κ	Factor for the calculation of the peak short-circuit current	1
μ_0	Magnetic constant, permeability of vacuum	H/m
v_1, v_2, v_3, v_4, v_e	Factors for calculating F_{pi}	1
ξ	Factor for calculating F_{pi} in the case of clashing sub-conductors	1
σ_m	Bending stress caused by the forces between main conductors	N/m ²
σ_s	Bending, stress caused by the forces between sub-conductors	N/m ²
σ_{tot}	Resulting conductor stress	N/m ²

σ_{fin}	Lowest value of σ when Young's modulus becomes constant	N/m ²
χ	Quantity for the maximum swing-out angle	1
φ, Ψ	Factors for the tensile force in a flexible conductor	1

1.3.2 Symbols for section 3 — Thermal effects

A	Main conductor cross-section	m ²
I_k	Steady-state short-circuit current (r.m.s.)	A
I'_k	Initial symmetrical short-circuit current (r.m.s.)	A
I_{th}	Thermal equivalent short-time current (r.m.s.)	A
I_{thi}	Individual thermal equivalent short-time current at repeated short-circuits (r.m.s.)	A
I_{thr}	Rated short-time withstand current (r.m.s.)	A
K	Factor for calculating S_{thr}	As ^{0.5} /m ²
m	Factor for the heat effect of the d.c. component	1
n	Factor for the heat effect of the a.c. component	1
S_{th}	Thermal equivalent short-time current density (r.m.s.)	A/m ²
S_{thr}	Rated short-time withstand current density (r.m.s) for 1 s	A/m ²
T_k	Duration of short-circuit current	s
T_{ki}	Duration of individual short-circuit current flow at repeated short circuits	s
T_{kr}	Rated short-time	s
θ_b	Conductor temperature at the beginning of a short circuit	°C
θ_e	Conductor temperature at the end of a short circuit	°C

1.4 Definitions

For the purpose of this standard the following definitions apply. Reference is made to IEV (IEC 50) when applicable.

1.4.1 Definitions for section 2 — Electromagnetic effects

1.4.1.1

main conductor

a conductor or an arrangement composed of a number of conductors which carries the total current in one phase

1.4.1.2 sub-conductor

a single conductor which carries a certain part of the total current in one phase and is a part of the main conductor

1.4.1.3

fixed support

a support of a rigid conductor which does not permit the conductor to move angularly at the point of the support

1.4.1.4

simple support

a support of a rigid conductor which permits angular movement at the point of support

1.4.1.5 Connecting piece

Any additional mass within a span which does not belong to the uniform conductor material. This includes among others: Spacers, stiffening elements, bar overlappings, branchings, etc.

1.4.1.5.1

spacer

a mechanical element between sub-conductors, rigid or flexible, which, at the point of installation, maintains the clearance between sub-conductors

1.4.1.5.2**stiffening element**

a special spacer intended to reduce the mechanical stress of rigid conductors

1.4.1.6**short-circuit tensile force, F_t**

maximum tensile force in a flexible main conductor due to swing out reached during the short circuit

NOTE Peak forces can occur in the conductor anchors and connector bolts, which can be greater than the short-circuit tensile forces. See clause 2.4.

1.4.1.7**drop force, F_f**

maximum tensile force in a flexible main conductor which occurs when the span drops down after swing out

1.4.1.8**pinch force, F_{pi}**

maximum tensile force in a bundled flexible conductor due to the attraction of the sub-conductors in the bundle

1.4.1.9**duration of the first short-circuit current flow, T_{k1}**

the time interval between the initiation of the short circuit and the first breaking of the current

1.4.2 Definitions for section 3 — Thermal effects**1.4.2.1****thermal equivalent short-time current, I_{th}**

the r.m.s. value of current having the same thermal effect and the same duration as the actual short-circuit current, which may contain d.c. component and may subside in time

NOTE If repeated short circuits occur (resulting from repeated reclosures) a resulting thermal equivalent short-time current is evaluated (see 3.2.2).

1.4.2.2**rated short-time withstand current, I_{thr}**

the r.m.s. value of current that the electrical equipment can carry during a rated short time under prescribed conditions of use and behaviour

NOTE 1 It is possible to state several pairs of values of rated short-time withstand current and rated short time; for thermal effect 1 s is used in most IEC specifications.

NOTE 2 The rated short-time withstand current as well as the corresponding rated short time are stated by the manufacturer of the equipment.

1.4.2.3**thermal equivalent short-time current density, S_{th}**

the ratio of the thermal equivalent short-time current and the cross-section area of the conductor

1.4.2.4**rated short-time withstand current density, S_{thr} , for conductors**

the r.m.s. value of the current density which a conductor is able to withstand for the rated short time

NOTE The rated short-time withstand current density is determined according to 3.2.

1.4.2.5**duration of short-circuit current, T_k**

the sum of the time durations of the short-circuit current flow from the initiation of the first short circuit to the final breaking of the current in all phases

1.4.2.6**rated short time, T_{kr}**

the time duration for which:

- an electrical equipment can withstand a current equal to its rated short-time withstand current;
- a conductor can withstand a current density equal to its rated short-time withstand current density.

Section 2. The electromagnetic effect on rigid conductors and flexible conductors

2.1 General

With the calculation methods presented in this section, stresses in rigid conductors, tensile forces in flexible conductors, forces on insulators and substructures, which might expose them to bending, tension and/or compression, and span displacements of flexible conductors can be estimated.

Electromagnetic forces are induced in conductors by the currents flowing through them. Where such electromagnetic forces interact on parallel conductors, they cause stresses that have to be taken into account at the substations. For this reason:

- the forces between parallel conductors are set forth in the following clauses;
- the electromagnetic force components set up in conductors with bends and/or crossovers may normally be disregarded.

In the case of metal-clad systems, the change of the electromagnetic forces between the conductors due to magnetic shielding can be taken into account. In addition, however, the forces acting between each conductor and its enclosure and between the enclosures shall be considered.

When parallel conductors are long compared to the distance between them, the forces will be evenly distributed along the conductors and are given by the equation

$$F = \frac{\mu_0}{2\pi} i_1 i_2 \frac{l}{a} \quad (1)$$

where

- i_1 and i_2 are the instantaneous values of the currents in the conductors;
- l is the centre-line distance between the supports;
- a is the centre-line distance between the conductors.

When the currents in the two conductors have the same direction, the forces are attractive. When the directions of the currents are opposite, the forces are repulsive.

NOTE For additional information see: CIGRÉ: The mechanical effects of short-circuit currents in open air substations. Paris: CIGRÉ SC 23, WG 02, 1987.

2.1.1 Influences on stress reduction

When calculating the maximum possible short-circuit current, additional details of other IEC standards may be considered if this results in stress reduction.

2.1.2 Consideration of automatic reclosing

Automatic reclosing shall be taken into account for rigid conductors only if three-phase automatic reclosing is used.

2.2 Rigid conductor arrangements

2.2.1 Calculation of electromagnetic forces

2.2.1.1 Calculation of peak force between the main conductors during a three-phase short circuit

In a three-phase system with the main conductors arranged with the same centre-line distances on the same plane, the maximum force acts on the central main conductor during a three-phase short circuit and is given by:

$$F_{m3} = \frac{\mu_0}{2\pi} \frac{\sqrt{3}}{2} i_{p3}^2 \frac{l}{a_m} \quad (2)$$

where

- i_{p3} is the peak value of the short-circuit current in the case of a balanced three-phase short circuit. For calculation, see IEC 909;
- l is the maximum centre-line distance between supports;
- a_m is the effective distance between main conductors in 2.2.1.4.

NOTE Equation (2) can also be used for calculating the resulting peak force when conductors with circular cross-sections are in the corners of an equilateral triangle and where a_m is the length of the side of the triangle.

2.2.1.2 Calculation of peak force between the main conductors during a line-to-line short circuit

The maximum force acting between the conductors carrying the short-circuit current during a line-to-line short circuit in a three-phase system or in a two-line single-phase-system is given by:

$$F_{m2} = \frac{\mu_0}{2\pi} i_{p2}^2 \cdot \frac{l}{a_m} \quad (3)$$

where

i_{p2} is the peak short-circuit current in the case of a line-to-line short circuit;

l is the maximum centre-line distance between supports;

a_m is the effective distance between main conductors in 2.2.1.4

2.2.1.3 Calculation of peak value of forces between coplanar sub-conductors

The maximum force acts on the outer sub-conductors and is between two adjacent connecting pieces given by:

$$F_s = \frac{\mu_0}{2\pi} \left(\frac{i_p}{n} \right)^2 \cdot \frac{l_s}{a_s} \quad (4)$$

where

n is the number of sub-conductors;

l_s is the maximum existing centre-line distance between two adjacent connecting pieces;

a_s is the effective distance between sub-conductors;

i_p is equal to i_{p3} for a three-phase system or to i_{p2} for a two-line single-phase system.

2.2.1.4 Effective distance between main conductors and between sub-conductors

The forces between conductors carrying short-circuit currents depend on the geometrical configuration and the profile of the conductors. For this reason the effective distance a_m between main conductors has been introduced in 2.2.1.1 and 2.2.1.2 and the effective distance a_s between sub-conductors in 2.2.1.3. They shall be taken as follows:

Effective distance a_m between coplanar main conductors with the centre-line distance a :

— Main conductors consisting of single circular cross-sections:

$$a_m = a \quad (5)$$

— Main conductors consisting of single rectangular cross-sections and main conductors composed of sub-conductors with rectangular cross-sections

$$a_m = \frac{a}{k_{12}} \quad (6)$$

k_{12} shall be taken from Figure 1, with $a_{1s} = a$, $b = b_m$ and $d = d_m$.

Effective distance a_s between the n coplanar sub-conductors of a main conductor:

— Sub-conductors with circular cross-sections:

$$\frac{1}{a_s} = \frac{1}{a_{12}} + \frac{1}{a_{13}} + \frac{1}{a_{14}} + \dots + \frac{1}{a_{1s}} + \dots + \frac{1}{a_{1n}} \quad (7)$$

— Sub-conductors with rectangular cross-sections:

Some values for a_s are given in Table 1. For other distances and sub-conductor dimensions the equation

$$\frac{1}{a_s} = \frac{k_{12}}{a_{12}} + \frac{k_{13}}{a_{13}} + \frac{k_{14}}{a_{14}} + \dots + \frac{k_{1s}}{a_{1s}} + \dots + \frac{k_{1n}}{a_{1n}} \quad (8)$$

can be used. The values for $k_{12}, \dots, k_{1n}$ shall be taken from Figure 1.

2.2.2 Calculation of stresses in rigid conductors and forces on supports

2.2.2.1 General

The conductors may be supported in different manners, either fixed or simple or in a combination of both. Depending on the type of support and the number of supports, the stresses in the conductors and the forces on the supports will be different for the same short-circuit current. The equations given also include the elasticity of the supports.

The stresses in the conductors and the forces on the supports also depend on the ratio between the relevant natural frequency of the mechanical system and the electrical system frequency. For example in the case of resonance or near to resonance, the stresses and forces in the system may be amplified. If $f_c/f < 0,5$ the response of the system decreases and the maximum stresses are in the outer phases.

2.2.2.2 Calculation of stresses in rigid conductors

The assumption that the conductor is rigid means that the axial forces are disregarded. Under this assumption the forces acting are bending forces and the general equation for the bending stress caused by the forces between main conductors is given by:

$$\sigma_m = V_\sigma \cdot V_r \cdot \beta \cdot \frac{F_m l}{8 Z} \quad (9)$$

where F_m is either the value F_{m3} of three-phase systems according to equation (2) or F_{m2} of two-line single-phase systems according to equation (3).

Z is the section modulus of the main conductor and shall be calculated with respect to the direction of forces between main conductors.

The bending stress caused by the forces between sub-conductors is given by:

$$\sigma_s = V_\sigma \cdot V_r \cdot \frac{F_s l_s}{16 Z_s} \quad (10)$$

where F_s according to equation (4) shall be used.

Z_s is the section modulus of the sub-conductor and shall be calculated with respect to the direction of forces between sub-conductors.

V_σ , $V_{\sigma s}$, V_r and V_{rs} are factors which take into account the dynamic phenomena, and β is a factor depending on the type and the number of supports. The maximum possible values of V_σ , V_r and $V_{\sigma s}$, V_{rs} shall be taken from Table 2 and the factor β shall be taken from Table 3.

NOTE For the beams in Table 3 (except the single span beam with simple supports) the realistic ultimate loads are calculated with the factors β given in Table 3 and q given in Table 4.

Non-uniform spans in continuous beams may be treated, with sufficient degree of accuracy by assuming the maximum span applied throughout. This means that:

- the end supports are not subjected to greater stress than the inner ones,
- span lengths less than 20 % of the adjacent ones shall be avoided. If that does not prove to be possible, the conductors shall be decoupled using flexible joints at the supports. If there is a flexible joint within a span, the length of this span should be less than 70 % of the lengths of the adjacent spans.

If it is not evident whether a beam is supported or fixed, the worst case shall be taken into account.

For further consideration, see 2.2.2.6.

2.2.2.3 Section modulus and factor q of main conductors composed of sub-conductors

The bending stress and consequently the mechanical withstand of the conductor depend on the section modulus.

If the stress occurs in accordance with Figure 2 a), the section modulus Z is independent of the number of connecting pieces and is equal to the sum of the section moduli Z_s of the sub-conductors (Z_s with respect to the axis x-x). The factor q has then the value 1,5 for rectangular cross-sections and 1,19 for U and I sections.

If the stress occurs in accordance with Figure 2 b) and in the case there is only one or no stiffening element within a supported distance, the section modulus Z is equal to the sum of the section moduli Z_s of the sub-conductors (Z_s with respect to the axis y-y). The factor q has then the value 1,5 for rectangular cross-sections and 1,83 for U and I sections.

When within a supported distance there are two or more stiffening elements, higher values of section moduli may be used:

- For main conductors composed of sub-conductors of rectangular cross-sections with a space between the bars equal to the bar thickness, the section moduli are given in Table 5.
- For conductor groups having U and I cross-sections, 50 % of the section moduli with respect to the axis 0-0 should be used.

The factor q then has a value of 1,5 for rectangular cross-section and 1,83 for U and I sections.

2.2.2.4 Permitted conductor stress

A single conductor is assumed to withstand the short-circuit forces when:

$$\sigma_m \leq q R_{p0,2} \quad (11)$$

where $R_{p0,2}$ is the stress corresponding to the yield point.

The factor q shall be taken from Table 4, see also 2.2.2.3.

When a main conductor consists of two or more sub-conductors the total stress in the conductor is given by:

$$\sigma_{tot} = \sigma_m + \sigma_s \quad (12)$$

NOTE For rectangular cross-sections σ_{tot} is the algebraic sum of σ_m and σ_s independent of the loading directions (see Figure 2).

The conductor is assumed to withstand the short-circuit forces when:

$$\sigma_{tot} \leq q R_{p0,2} \quad (13)$$

It is necessary to verify that the short circuit does not affect the distance between sub-conductors too much, therefore a value

$$\sigma_s \leq R_{p0,2} \quad (14)$$

is recommended.

In Table 4 the highest acceptable values for q for different cross-sections are given. For $\sigma_m = q R_{p0,2}$ respectively $\sigma_{tot} = q R_{p0,2}$ small permanent deformations may occur, approximately 1 % of the distance between supports for q -values according to Table 4, which do not jeopardize the safety of operation as long as by this the minimum clearances between main conductors or between a main conductor and the earthed structure are not violated.

NOTE For the yield point of conductor materials, $R_{p0,2}$, the standards often state ranges with minimum and maximum values. If only such limit values rather than actual readings are available, the minimum value should be used in 2.2.2.4 and the maximum value in Table 2.

2.2.2.5 Calculation of forces on supports of rigid conductors

The dynamic force F_d shall be calculated from:

$$F_d = V_F V_r \alpha F_m \quad (15)$$

where F_m is either the value F_{m3} of three-phase systems according to equation (2) or F_{m2} of two-line single-phase systems according to equation (3) shall be used.

The maximum possible values of $V_F V_r$ shall be taken from Table 2.