

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Rotating electrical machines – Test methods and apparatus for the measurement of the operational characteristics of brushes

Machines électriques tournantes – Méthodes d'essai et appareils pour le mesurage des caractéristiques opérationnelles des balais



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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TEST METHODS AND APPARATUS FOR THE MEASUREMENT
OF THE OPERATIONAL CHARACTERISTICS OF BRUSHES****FOREWORD**

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International standard IEC 60773 has been prepared by IEC technical committee 2: Rotating machinery.

This second edition cancels and replaces the first edition published in 1983. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- The clause structure has been modified on the view point of a laboratory testing procedure. The new sequence is as follows: test rig specification (Clause 4), general testing procedure (Clause 5), and specific procedure for each operational characteristic (Clauses 6 to 8).
- A new Clause 9 has been added to introduce the black-band test for the characterisation of the brush grades for DC machines.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
2/2045/FDIS	2/2050/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

ROTATING ELECTRICAL MACHINES – TEST METHODS AND APPARATUS FOR THE MEASUREMENT OF THE OPERATIONAL CHARACTERISTICS OF BRUSHES

1 Scope

This document applies to test methods for the measurement of the operational characteristics of brushes designed to operate on commutating and slip ring machines under specified test conditions.

By extension some tests may be relevant for other kinds of sliding electrical contacts for electrical appliances.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-19:2014, *Rotating electrical machines – Part 19: Specific test methods for d.c. machines on conventional and rectifier-fed supplies*

IEC 60136, *Dimensions of brushes and brush-holders for electrical machinery*

IEC 60276:2018, *Carbon brushes, brush holders, commutators and slip-rings – Definitions and nomenclature*

IEC 60356, *Dimensions for commutators and slip-rings*

IEC 60584-1:2013, *Thermocouples – Part 1: EMF specifications and tolerances*

IEC 60751:2008, *Industrial platinum resistance thermometers and platinum temperature sensors*

IEC TR 61015, *Brush-holders for electrical machines. Guide to the measurement of the static thrust applied to brushes*

ISO 1190-1:1982, *Copper and copper alloys – code of designation – Part 1: Designation of materials*

ISO 3274:1996, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

ISO 15510:2014, *Stainless steels – Chemical composition*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1 Terms and definitions

3.1.1

run-out

runout

inaccuracy of the rotating system, measured on the surface of the ring while turning

Note 1 to entry: This includes out-of-round (that is, lacking sufficient roundness); eccentricity (that is, lacking sufficient concentricity); or axial bending (regardless of whether the surfaces are perfectly round and concentric at every cross-sectional point).

3.1.2

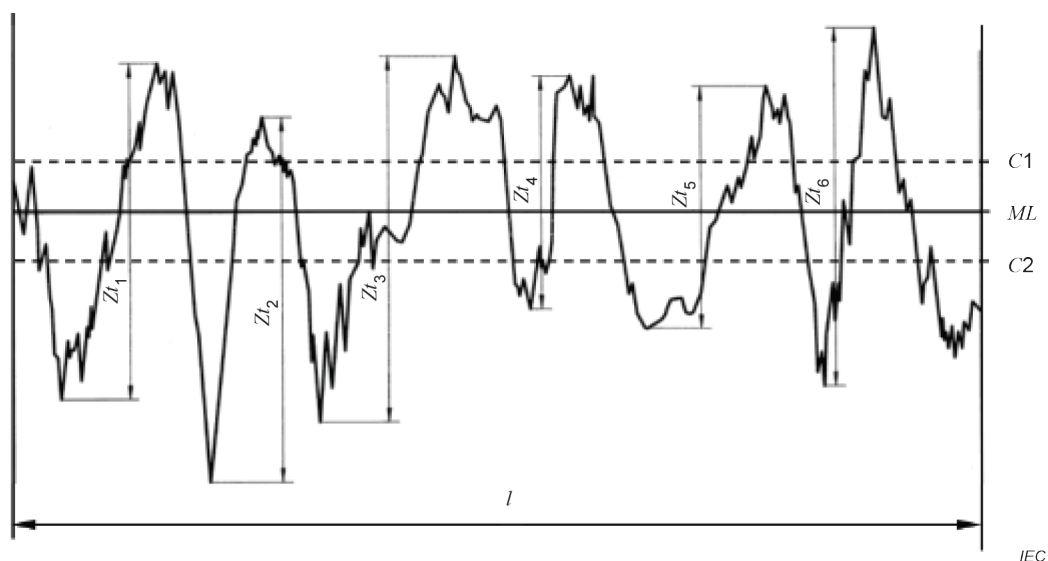
roughness

R_a

arithmetic mean of the absolute ordinate value $Z(x)$ of a profile within a sampling length l

$$R_a = \frac{1}{l} \times \int_0^l |Z(x)| \cdot dx$$

Example: Figure 1 shows an example of profile.



Key

Z_{t_i}	height of profile element i
l	sampling length
ML	mean line
$C1$ and $C2$	upper and lower intersection lines (respectively)

Figure 1 – Profile and determination of height of profile elements

[SOURCE: ISO 4287:1997, Figure 9]

3.1.3

peak count

RP_c

number of profile elements per centimeter of sampling length which exceed the upper intersection line $C1$ and fall short of the lower intersection line $C2$

Note 1 to entry: Both intersection lines are parallel to the diagram mean line (see Figure 1).

[SOURCE: ISO 4287/A1:2009, 4.3.2]

3.1.4

abrasive stone

material used to grind a surface

Note 1 to entry: The quality of the material and the method of appliance depend on its use. Therefore, for the purpose of this document, definitions 3.1.5, 3.1.7 and 3.1.8 are used.

3.1.5

grinding stone

abrasive stone used to grind the test ring

Note 1 to entry: It is generally made of hard abrasive grains.

3.1.6

brush fitting

operation at the end of which the brush contact surface is matching the ring profile

3.1.7

fitting stone

abrasive stone used for fitting the brush to the commutator/ring

3.1.8

roughness stone

abrasive stone used to obtain the proper range of roughness to the test ring, generally made of soft abrasive grain

3.1.9

brush contact area

S

area of the brush in contact with the ring surface

Note 1 to entry: When radial brush is used the brush contact surface area S_r is the cross-section of the brush:

$$S = t \times a \quad (1)$$

where t and a are respectively the tangential and axial dimensions of the brush.

When inclined brush is used the bottom angle is part of the formula giving the brush contact surface area S_α :

$$S_\alpha = \frac{t \times a}{\cos \alpha} \quad (2)$$

where α is the contact angle (or bottom angle).

3.1.10

brush specific pressure

p

force per contact area of the brush, given by formula (3):

$$p = \frac{F_p}{S} \quad (3)$$

where F_p is the force applied by the pressure system;

and S is the brush contact surface area

Note 1 to entry: When F_p is expressed in grams force (gf) and brush contact surface in cm^2 the calculated specific pressure is in gf/cm^2 . To convert into SI units: the result in gf/cm^2 multiplied by 98,07 gives p in N/m^2 (98,07 is the gravitational acceleration in m/s^2 multiplied by 10).

3.1.11 current ripple factor

q_i

ratio of the difference between the maximum value $I_{\max}$ and the minimum value $I_{\min}$ of an undulating current to two times the average value $\bar{I}$ (mean value integrated over one period):

$$q_i = \frac{I_{\max} - I_{\min}}{2 \times \bar{I}}$$

Note 1 to entry: For small values of current ripple, the ripple factor may be approximated by the following expression:

$$q_i = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

Note 2 to entry: The above expression may be used as an approximation if the resulting calculated value of q_i is equal to or less than 0,4.

[SOURCE: IEC 60034-1:2017, 3.29]

3.1.12 stable state

state of a physical system in which the relevant characteristics are considered to be sensibly constant with time

[SOURCE: IEC 60050-103:2009, 103-05-01]

3.1.13 sensibly constant

a measurement result is considered as sensibly constant when deviation from mean value of a minimum of 3 consecutive measurements is less than 2,5 % (except otherwise specified)

Note 1 to entry: Stability state may be determined from the time-measurement rise plot when the straight lines between points at the beginning and end of two successive intervals of half hour each have a deviation of less than the criteria of 2,5 %.

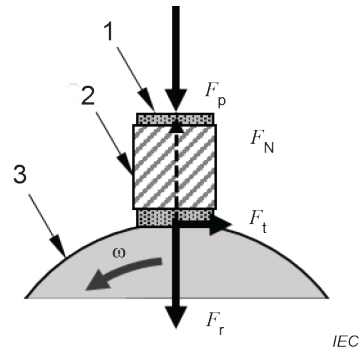
3.1.14 friction coefficient

μ

ratio of tangential force acting at the interface F_t to the radial force acting at the interface F_r :

$$\mu = \frac{F_t}{F_r} \quad (4)$$

Note 1 to entry: Figure 2 illustrates the forces acting on the brush when a radial brush-holder is applied. The numerical value of radial force F_r is equal to the numerical value of the normal reaction force F_N (of the brush contact surface on the ring) and to the numerical value of the pressure system force F_p on the brush top.



Key

- 1 Brush
- 2 Brush-holder
- 3 Test ring
- ω Angular velocity (giving the rotation direction)

Figure 2 – Forces acting on a brush

**3.1.15
brush voltage drop**

U_B

total voltage drop between the brush terminal and the slip ring or commutator

Note 1 to entry: U_B is a complex parameter which is made up from the sum of the voltage drops U_s , U_t , U_i , and U_c as illustrated in Figure 3 (which concerns a brush with a tamped flexible).

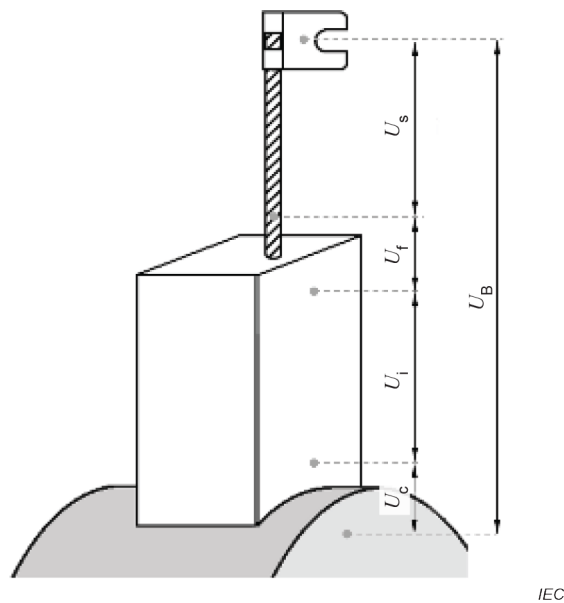


Figure 3 – Voltage drops in a brush when in operation

**3.1.16
shunt voltage drop**

U_s

voltage drop in the shunt (flexible) and in the shunt connection to the brush terminal

3.1.17 connection drop

 U_f

voltage drop between the shunt (flexible) and the brush grade

Note 1 to entry: The connection drop U_f measurement is described in IEC 60136.

3.1.18 brush internal drop

 U_i

internal voltage drop of the brush (due to the brush grade resistance)

3.1.19 brush contact drop

 U_c

voltage contact drop between the brush grade and the ring

Note 1 to entry: The brush contact drop U_c is an operating characteristic of a brush. See Clause 7.

3.1.20 slot pitch

 τ_Q

distance between two consecutive slots of the ring, defined by the periphery of the ring $\pi \times D$ divided by the number of slots Q :

$$\tau_Q = \frac{\pi \times D}{Q} \quad (5)$$

where D is the diameter of the ring

[SOURCE: IEC 60027-4:2006,612]

3.1.21 covering ratio

coverage ratio

 τ_B

number of segments spanned by the brush along t dimension, calculated from formula (6)

$$\tau_B = \frac{t}{\tau_Q} \quad (6)$$

3.1.22 peripheral speed

 v_p

speed of movement of a point on the surface of a body rotating about its axis expressed as a distance per unit of time

It is calculated from formula (7)

$$v_p = \frac{n \times \pi \times D}{60} \quad (7)$$

where

D is the ring diameter, in metres, and n is the speed of rotation, in number of revolutions per minute (r/min).

[SOURCE: IEC 60050-811:2017, 811-13-29, modified – formula is added]

3.1.23 current density

J_B

quantity relative to one brush and equal to current I divided by the cross-section $t \times a$ of the brush, as per formula (8):

$$J_B = \frac{I}{t \times a} \quad (8)$$

Note 1 to entry: J_B is commonly expressed in A/cm² when I is in A and t, a in cm.

3.1.24 ambient air temperature

average temperature of the air surrounding the carbon brushes samples

3.1.25 ring surface temperature

average temperature at the surface of the tested slip ring

3.1.26 brush bedding

operation at the end of which the brush contact surface is completely bedded and the patina formed on the ring surface

3.1.27 patina skin

film on the commutator or slip ring, principally constituted of the carbon brush material, commutator/slip ring metal (and its oxides) and water

[SOURCE: IEC 60276:2018, 601]

3.1.28 brush wear

Δr_i

linear wear of a brush i during the test

For each brush i the brush wear is calculated from formula (9):

$$\Delta r_i = r_{0i} - r_i \quad (9)$$

where:

r_{0i} is the r dimension of each brush i (brush length) before the test;

r_i is the r dimension of each brush i (brush length) after the test

3.1.29 brush wear rate

WR_i

brush i linear wear during a period of time, which is calculated from formula (10):

$$WR_i = \frac{\Delta r_i}{t_{er}} \quad (10)$$

where t_{er} is the effective running time

Note 1 to entry: Generally it is expressed in mm/1 000 h (mm of brush wear/1 000 effective running hours) when brush wear is expressed in mm and the result of formula above is multiplied by 1 000. See 8.4.

3.1.30

black-band zone

BB zone

interval defined by the minimum and maximum sparkless commutation limits (in between which the commutation is achieved without sparks); the limits of sparkless commutation being obtained by boosting or subtracting the excitation current in commutation poles for load currents up to and including rated current

Note 1 to entry: It corresponds to a non spark zone. This test is sometimes called back boost test.

[SOURCE: IEC 60034-19:2014, 3.1.4 – modified: definition of limits is added]

3.2 Symbols

3.2.1 Symbols and units

a	brush axial dimension (mm)
b	slot or groove width (mm)
$C1$	upper intersection line (on roughness profile)
$C2$	lower intersection line (on roughness profile)
D	diameter of test ring (m)
dr	distance ratio
d_B	distance in the brush radial direction from brush contact surface to brush top (mm)
f	frequency (Hz)
F	force applied (N or gf)
h	pitch of helical groove (mm)
HA	absolute humidity (g/m ³ of air)
HR	relative humidity
I	current (A)
J_B	current density in a brush (A/cm ² or A/m ²)
k_R	number of grooves under the brush in tangential direction
l	length or distance (m)
la	lever arm length (m)
l_{er}	distance travelled by the track under the brush during the effective running time
q_i	ripple factor
m	mass (g)
n	rotational speed (revolutions per minute, r/min)
N_B	number of brushes per machine
p	specific pressure applied on the brush (kN/m ²)
P	power (W)
P_{in}	power input when the brushes are in contact with the commutator or slip ring (W)
P_{el}	power loss due to electrical losses (W)
P_f	power loss due to friction (W)
P_0	power input when the brushes are not in contact with (are not sliding on) the commutator or slip ring (W)

r	radial dimension of brush (mm)
r_i	dimension of brush number i after the test (mm)
r_{0i}	dimension of brush number i before the test (mm)
R	resistance (Ω)
Ra	roughness, arithmetic value (μm)
RPc	peak count (number of peaks per cm)
r_B	radius of brush (mm)
S	brush contact surface area (cm^2)
t	tangential dimension of brush (mm)
t_{er}	effective running time (h)
T	torque (N.m)
U	voltage (V)
$\overline{WR}$	mean brush wear rate (mm/1 000 h)
WR	brush wear rate (mm/1 000 h)
Δr_i	wear of brush number i (mm)
$\overline{\Delta r}$	mean brush wear (mm)
μ	friction coefficient
v_p	velocity or peripheral speed (m/s)
ρ	brush grade resistivity ($\mu\Omega\cdot\text{cm}$)
τ_Q	slot pitch (mm)
τ_B	covering ratio (number of segments spanned under the brush)
α	bottom angle (rad)
θ	temperature (K)
ω	angular velocity ($\text{rad}\cdot\text{s}^{-1}$)

NOTE $\overline{}$ means arithmetic average value.

3.2.2 Subscripts

0	initial condition
arm	armature
B	brush
c	contact
cp	commutation pole
er	effective running (time)
f	flexible (shunt) connection
H	brush-holder
i	internal (brush grade)
in	input (power)
lc	load cell

lin	linear
min	minimum value
max	maximum value
N	normal (direction)
p	pressure system
t	tangential
r	radial
R	ring
s	flexible (shunt)
T	tare
tol-	lower tolerance
tol+	upper tolerance
vol	volumetric
α	bottom angle
+	positive polarity (when a DC current is used)
–	negative polarity (when a DC current is used)
~	alternating voltage (when an AC current is used)

3.3 Abbreviated terms

A	Ammeter
B	Booster for adjusting current
BB	Black-band
BG	Resin-bonded grade- ¹
CG	Carbon-graphite grade- ¹
G	DC generator
HC	(Hard) carbon grade- ¹
M	DC motor
MG	Metal-graphite grade- ¹
MT	Starting motor
NG	Natural-graphite grade- ¹
TC	Thermocouple
V	Voltmeter

¹ Definitions in IEC 60276:2018.

4 Test rig specification

4.1 Common specification

4.1.1 General

It is possible that no single test rig can accommodate all the required application parameters; it therefore follows that more than one type of test rig would be required. These test rigs shall be so constructed that, relative to the quantities to be measured (see Clauses 6 to 8), the required brush operating parameters may be easily and accurately obtainable.

It should be appreciated that, because of the many variables involved and the fact that this equipment is "non-commutating", absolute values obtained from such test machines will differ from those obtainable from "real" machines. Moreover, for the above reasons and because of differing ambient conditions, identical results may not be obtainable from test rigs of similar design and construction.

4.1 specifies general requirements for test rig. Additional requirements for commutators applications are disclosed in 4.2 and for slip rings in 4.3.

4.1.2 Rings

4.1.2.1 General

For the reasons given above, it is not possible to specify a single "standard" test machine, but machines constructed within the framework given below should be capable of producing satisfactory results.

4.1.2.2 Ring material

Test ring material and its characteristics, in particular hardness, should be in accordance to the application. Composition and hardness according to ISO standard shall be specified in the test report.

4.1.2.3 Rings dimensions and geometry

The diameter of the test ring shall be not less than 200 mm.

The geometrical profile of the ring shall be measured using a suitable depth gauge when the ring mounted on its axis rotating slowly in its own bearings. The run-out shall not produce a depth gauge deflection of greater than 0,010 mm with one wave. Furthermore, at operating speed there shall be no significant vibration due to unbalance. The tests shall be carried out at a speed lower than the critical speed. Run-out shall be recorded in test report.

This order of accuracy shall be achieved if the ring is turned with a suitable tool at a speed as near as possible to the highest test velocity, the ring being mounted in its own bearings. All "burrs" and swarfs shall be removed from the slots / grooves and slot / grooves edges before the test. The minimum amount of metal only shall be removed during this turning process in order to prevent the formation of bevels on the edges.

From the measurement of the profile at two different tracks of the ring the cylindricity may be evaluated. A maximum value of 0,010 mm is recommended.

4.1.2.4 Roughness

Roughness is an index for the commutator or slip ring surface irregularity.

Roughness meter shall be in accordance with ISO 3274.

The measurement of roughness Ra and the peak rate RP_c shall be done within both tangential and axial directions, unless the tangential probe cannot be applied due to a small commutator bar width.

The degree of roughness Ra shall lie between 0,8 μm and 1,2 μm .

For the evaluation of RP_c it is recommended to define the upper intersection line and lower intersection line at a distance of respectively +1 μm and –1 μm from the intersection diagram mean line.

The peak rate RP_c shall be over 100 peaks per centimetre.

The suitable roughness may be readily obtained by a light application of a suitable medium grade stone to the ring surface (see 5.4.5).

4.1.3 Brushes

A minimum of two brushes per track shall be used. If more than this number of brushes per track is used, they shall be uniformly spaced around the ring.

Table 1 specifies the dimensions of test brushes, where preferred dimensions are marked in bold characters.

Table 1 – Dimensions of test brushes

Dimensions in millimetres

Dimension	Brush grade				
	EG	BG	CG-HC	NG	MG
t	12,5 – 16 – 20	10 – 12,5	10 – 12,5 – 16	25 – 32	12,5 – 20 – 32
a	25 – 32	25	25	20 – 25	20 – 25
r	40 to 50	40 to 50	40 to 50	50	50

It is appreciated that asynchronous and synchronous motor slip rings use a brush having the t dimension greater than the a dimension. To maintain the standardization of test apparatus, the same holders as recommended for "commutator" may be used. Those having the largest t dimension are to be preferred.

The brush manufacturing shall be within IEC 60136.

The brushes may preferably be made with a bottom bevel angle between 7,5° and 8° (trailing attitude – see Figure 4.c) to ensure the mechanical stability, as explained in 4.1.4.

4.1.4 Brush holders

Brush holders shall be substantially constructed and rigidly affixed to the machine so that they are free from vibration under the most adverse conditions, and of such design that they will not influence the stability of contact between test brush and test ring. Distance between brush-holder and commutator shall be between 2 mm and 3 mm. The bottom of the brush box shall be parallel to the test ring.

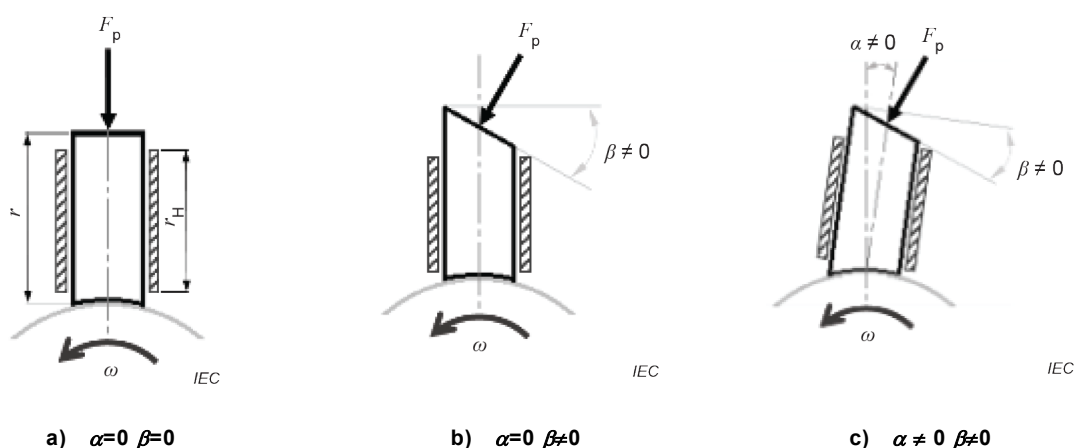
The dimensions a and t of the brush holder shall be suitable for brushes dimensions as indicated in Table 1, with respect to the clearances specified in IEC 60136.

The radial dimension of the brush holder r_H shall be not less than $\frac{3}{4}$ of the radial dimension r of a new brush.

The brush-holder shall be such that the force is applied in the radial dimension r of a brush (as shown in Figure 4) to get a good stability of the brush:

- a) when bottom bevel α is equal to zero:
 - 1) within a radial pressure system (such as compressive spring acting directly on the top): without any top bevel, as shown in Figure 4a);
 - 2) within a self-recoiling spring: with an adequate top bevel β (example $22,5^\circ$), as shown in Figure 4b);
- b) with an adequate top bevel β when the contact angle α is $7,5^\circ - 8^\circ$ (Figure 4c).

Bevel angles shall be written in the test report.



Key

- α Bottom bevel
- β Top bevel
- r_H Radial dimension of the brush-holder
- F_p Force applied by the pressure system
- ω Angular velocity (direction of rotation)

Figure 4 – Brush holder configuration

The required brush specific pressure p , as specified in 5.2, shall be to a tolerance of $\pm 5\%$ between brushes.

The pressure force F_p of the spring system shall be defined according to the brush contact surface area S and the required brush specific pressure p from formula (3) defined in 3.1.10.

It is recommended to measure the pressure force F_p according to IEC TR 61015. Other measuring instruments may be used, for example dynamometers. All instruments shall have a good accuracy (2,5 % maximum deviation).

NOTE When a commutator type test ring is applied the slots dimensions are not considered for the calculation of brush pressure.

4.1.5 Power supply

4.1.5.1 General

Whichever type of power source is chosen, it should be capable of maintaining the selected load current to within ± 5 % of the required value for the test in progress and have a quick response to changes of contact voltage.

4.1.5.2 Direct current supply

4.1.5.2.1 DC generator

To be capable of supplying the maximum likely demand when a stabilizing ballast resistance is included in the test brush circuit; alternatively, a constant-current source of short time-constant, such as a welding generator, may be used.

4.1.5.2.2 Diode rectifier

Fed from an AC source and capable of supplying the maximum likely demand.

The ripple factor q_i of the source shall not exceed 0,05 (5 %). This value should be recorded for each test.

4.1.5.2.3 Controlled rectifier

Specification for controlled rectifier is the same as for diode rectifier (4.1.5.2.2).

4.1.5.3 Alternating current supply

The alternating current supply, for example an inverter, shall be selected so that a sensibly pure sine wave output can be obtained over the required current range.

4.1.6 Instrumentation

4.1.6.1 Friction coefficient

4.1.6.1.1 General

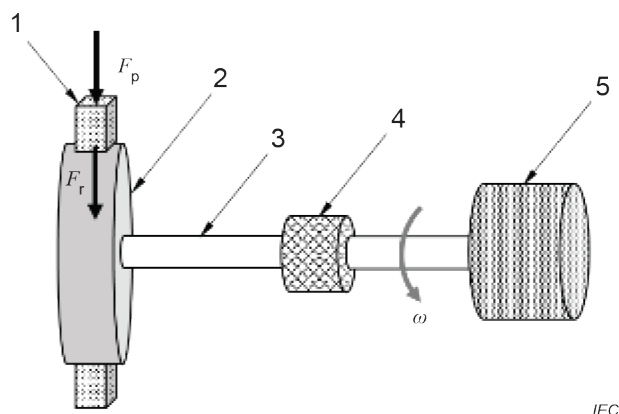
There are two main systems by which the coefficient of friction is usually measured. They are presented in 4.1.6.1.2 and 4.1.6.1.3. Whatever system is used it shall have negligible effect on the mechanical stability and electrical performance of the brush.

There are many suitable mechanical systems which may be used for making this measurement and all should be acceptable provided their accuracy is according to 4.1.6.1.6.

4.1.6.1.2 Method a): Measurement of the tangential forces acting on the rotating surface

The method consists in measuring the mechanical torque with and without the carbon brushes at the same operating condition of the drive motor and same parameters (J_B , pressure, HR , etc.) for the carbon brushes and the excitation system. Then the friction coefficient can be determined from the relation between the torque and the applied calibrated force onto the brush (should be normal and constant) according to formula (14) specified in 6.4.1.

Figure 5 is a simplified sketch which clarifies the method of measuring the coefficient of friction by using method a).



Key

- 1 Brush
- 2 Test ring
- 3 Shaft
- 4 Torque meter
- 5 Drive motor
- ω Angular velocity
- F_r Reaction force of the ring
- F_p Force applied on the brush by the pressure system

Figure 5 – Measurement of the mechanical torque by Method a)

NOTE With the test rig arrangement of Figure 5 the brush-holder is radial to the ring. Therefore numerical value of F_r is equal to the numerical value of F_p (directions are opposite but absolute values are equal).

Vibrations on the test bench are recommended to be as low as possible. An accelerometer may be used to control the vibration along the test duration.

4.1.6.1.3 Method b): Measurement of the tangential forces acting on the brush

4.1.6.1.3.1 General principle

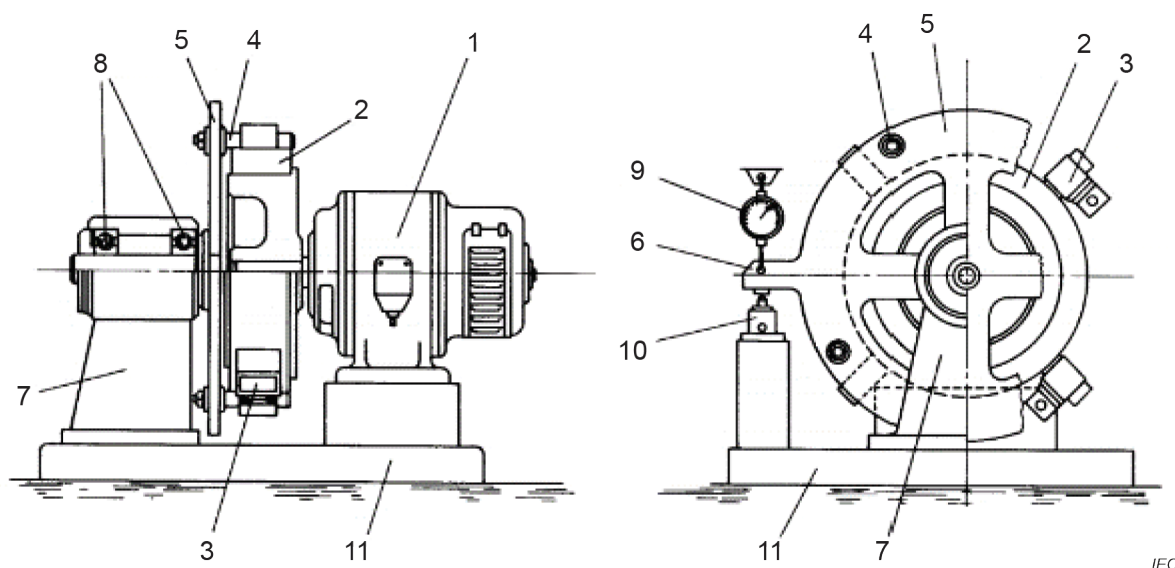
Figure 6 shows the fundamental design of a test rig arrangement. The test rig shall fulfill the following requirements:

- The axes of the rotating slip ring and the brush holder support ring shall be made as concentric as possible.
- The dynamometer assembly shall be mechanically stiff (i.e. rigid) and have the maximum possible mass in order to provide adequate damping of the high frequency vibrations generated by the brushes under test.
- Great care shall be taken to ensure that the friction of the brush holder support ring bearings is minimal in order that the measured brush friction force is not adversely affected. The angular movement of the brush holder support ring shall be restricted so that the relative tangential movement of the brush to cage should not exceed 0,5 mm. A means for blocking the rocker movement within the ring rotation direction shall be added. For this purpose a cable may be fixed on the lever arm.
- There are, nowadays, many acceptable systems, both mechanical and electrical available for measuring the brush friction force; one suitable for the design of the dynamometer should be selected from the following list:
 - a) strain gauge;
 - b) load cell;
 - c) displacement transducer;

- d) differential transformer;
- e) lever and mass;
- f) spring balance.

Instruments a) to d) allow use of recording instruments for continuous measurements.

Preferred method is using a load cell (item b) above and 10 in Figure 6) equipped with a connection for recording output voltage.



IEC

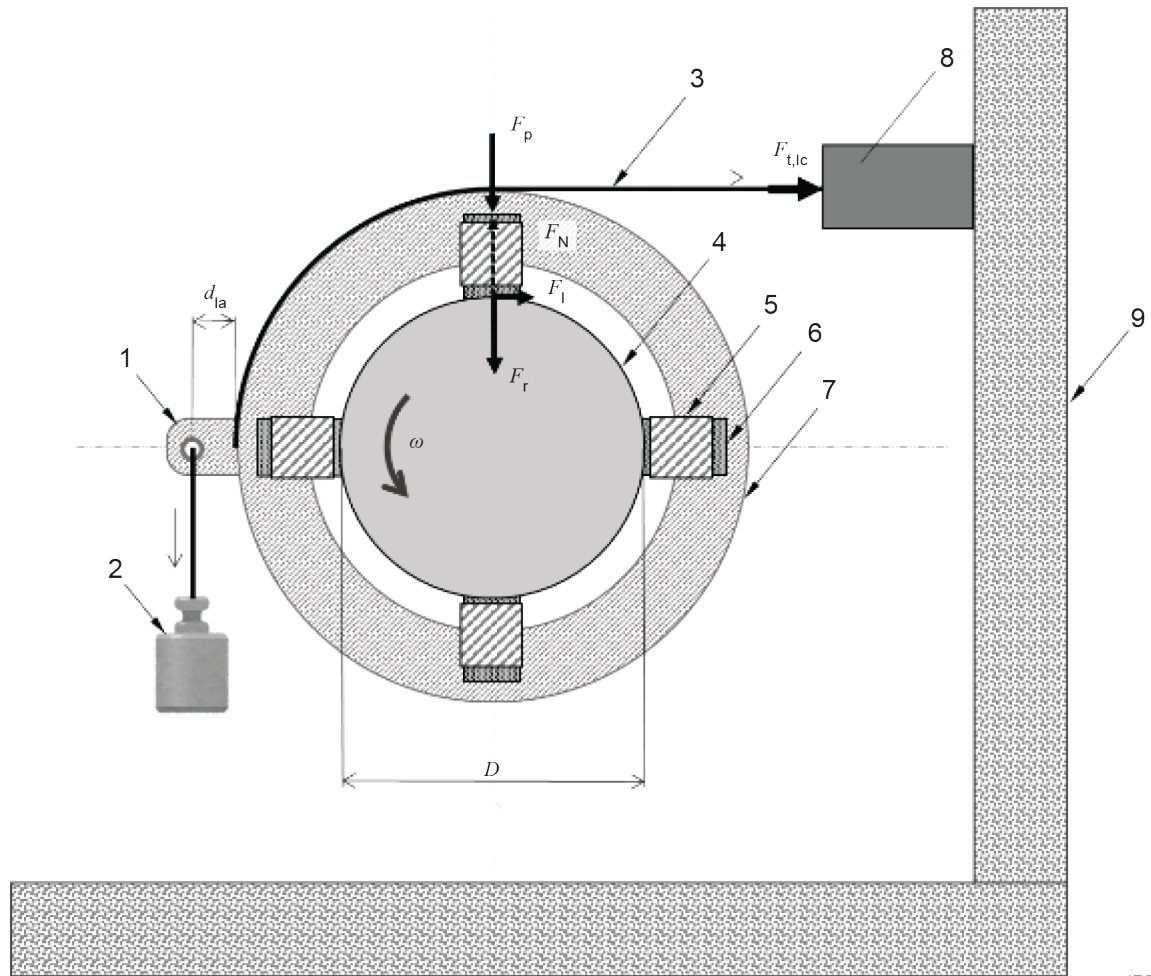
Key

- 1 DC motor or variable speed drive
- 2 Test ring
- 3 Brush holder and brush
- 4 Brush holder support spindle
- 5 Brush holder support ring
- 6 Dynamometer lever
- 7 Dynamometer bearing housing and pedestal
- 8 Dynamometer bearings
- 9 Force measuring device (spring balance)
- 10 Electric load cell
- 11 Base plate

Figure 6 – Brush test machine for Method b)

4.1.6.1.3.2 Principle for the method with the load cell

Figure 7 illustrates the principle. The brush rocker is mobile on its rotation axis. The strain gauge is connected to the brush rocker with a cable. The cable is fixed on a lever arm which is part of the rocker. As the rocker ring will move when the ring is rotating, a tare (known mass) is hung to the lever arm.



IEC

Key

- 1 Lever arm
- 2 Tare
- 3 Cable
- 4 Test ring
- 5 Brush holder
- 6 Brush
- 7 Free rocker ring
- 8 Strain sensor
- 9 Support of the test rig
- ω Angular velocity (direction of rotation)
- F_r Force in the radial direction
- F_t Force in the tangential direction
- F_p Force of the spring applied on the brush
- $F_{t,lc}$ Tangential force measured by the load cell
- F_N Normal force

Figure 7 – Test rig arrangement with a load cell

The mass of the tare m_T is chosen to block the displacement of the rocker along the rotating direction of the ring and to ensure a proper tension of the cable. As the tare will be part of the forces acting on the rocker, its mass value shall necessary be taken into account in calculations.

The tangential force is directly measured by the load cell when properly adjusted.

The load cell adjustment could be done by different methods. One method is described in Clause A.2.

NOTE The test rig described in Figure 7 uses a radial brush-holder.

4.1.6.1.4 Calibration

In order to get accurate values sensors (load cell, torque meter, etc.) shall be calibrated regularly. A period of 3 months is recommended in order to ensure there is no deviation.

NOTE Calibration concerns the test instrument itself, whereas adjustment is relative to the calculation of a physical quantity from output values of the test instrument.

For more accuracy the friction of air could be taken into account. As it is speed dependent a measurement of the residual friction has to be done at different values of speed.

4.1.6.1.5 Adjustment

When using Method b) with a load cell, the tangential force is directly measured by the load cell by an adjustment. The load cell adjustment could be done by different methods. One method is described in Clause A.2.

4.1.6.1.6 Accuracy

Instruments of accuracy up to 5 % will be adequate.

4.1.6.1.7 Stable state

Friction coefficient is considered as sensibly stable when deviation from mean value of a minimum of 3 consecutive measurements is less than 5 %.

4.1.6.2 Voltage drop

4.1.6.2.1 General

Voltage drop is determined by using an instrument for measuring voltage between 2 contact points, one on the brush and the other one on the ring.

4.1.6.2.2 specifies the instruments for measuring voltage.

Ring contact probe is specified in 4.1.6.2.3.

The contact point location on the brush depends on the type of voltage drop intended to be determined (contact or total voltage drop – see Clause 7) and brush contact probes are described in 4.1.6.2.4.

4.1.6.2.2 Measurement instruments for voltage

4.1.6.2.2.1 Voltage measurement instruments for DC

Any DC voltmeter having an internal resistance of not less than 1 000 Ω/V is suitable. If a pointer type instrument is used, then the minimum indication shall be not less than 20 % of full scale deflection.

4.1.6.2.2.2 Voltage measurement instruments for AC

AC contact drop voltage should be measured with an instrument capable of measuring true r.m.s. Such instruments are:

- a) thermocouple instruments,
- b) ironless electrodynamic instruments,
- c) any electronic instrument capable of measuring true r.m.s.

The internal impedance shall be as specified in 4.1.6.2.2.1.

Rectifier type multimeters are not recommended.

It is highly recommended to select an instrument compatible with data acquisition system, so that voltage could be measured and recorded continuously during a test.

4.1.6.2.2.3 Accuracy

Instruments of accuracy up to 2,5 % will be adequate.

4.1.6.2.2.4 Stable state for voltage

Voltage drop is considered as sensibly stable when deviation from mean value of a minimum of 3 consecutive measurements is less than 5 %.

4.1.6.2.3 Rotating part probe

The contact probe to be applied to the rotating part shall be so constructed that it will have negligible influence on the value of the measured voltage. Various acceptable methods of making this probe are available, for example:

- a) a small metal-graphite brush running on the rotating part but clear of the test brush track (generally made of silver-graphite),
- b) a "brush" made from fine copper wires (brush flexible) applied in the same way as the metal-graphite brush (see item a) above),
- c) an additional measuring ring electrically connected to the test ring and equipped with measuring brushes,
- d) a mercury transmitting system.

Contact probe type will depend on the instrument used for measuring voltage.

Whichever type of probe a) or b) is used, it is essential that the point of application to the rotating part shall be clear of the test brush track(s). It is recommended to apply the contact probe on the disk part of the ring.

4.1.6.2.4 Brush contact probe

4.1.6.2.4.1 General

The brush contact probe shall be applied to the brush so that no disturbance of the brush operation is caused. It may be permanently attached to the brush or to the brush-holder, or may be applied by hand.

4.1.6.2.4.2 Brush probe type 1 for total brush voltage U_B

The probe shall be applied to the brush terminal.

When hand recording instruments are used, it is recommended to use a pointed stainless steel probe.

4.1.6.2.4.3 Brush probe type 2 for brush contact voltage U_c

The location of the contact probe on or in the brush shall be at a point not more than 5 mm from the sliding contact surface and at a distance of 5 mm from the centre line of the brush as illustrated by Figure 8.

Dimensions in millimetres

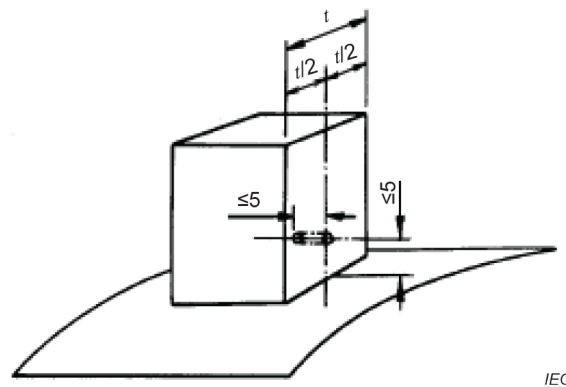


Figure 8 – Brush contact probe application point for U_c

4.1.6.3 Temperature instrumentation

4.1.6.3.1 General

Instruments for the measurement of temperature will depend on the location of the temperature to be measured and on the range of temperature. Therefore instruments to be applied on brushes and rings may be different.

IEC 60751 and 60584-1 describe some measuring instruments.

4.1.6.3.2 Temperature of brushes

For brush temperature measurement, following sensors shall be used:

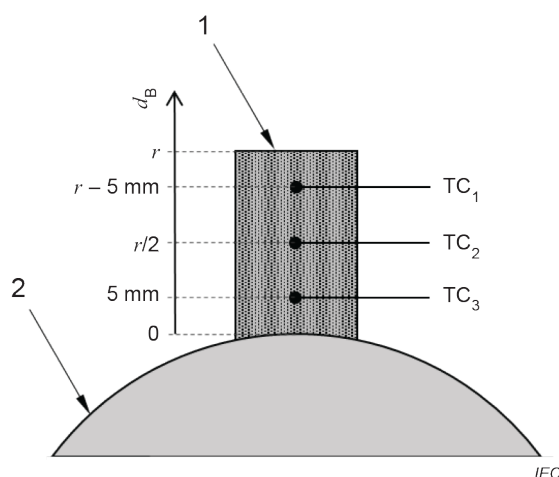
- platinum applied resistance temperature sensor, as specified in IEC 60751,
- thermocouples, as specified in IEC 60584-1.

The advantage of the first one is the linearity between temperature and its output resistance value. A typical example is Pt100 where the typical resistance value is 100 Ω at 0 °C.

However, thermocouples are easy to apply, due to their smaller sizes, but need to be carefully chosen and well calibrated.

For the distribution temperature measurement inside the brushes thermocouples TC shall be inserted along the center line of the brush at three location points as illustrated in Figure 9:

- TC₁ at 5 mm from the brush top (distance d_B is therefore equal to $r-5$ mm),
- TC₂ in the center of the brush (distance d_B is therefore equal to $r/2$) and
- TC₃ at 5 mm from the contact surface (distance d_B is therefore equal to 5 mm).



Key

- 1 Brush
- 2 Test ring
- TC_i Thermocouple position number i
- r Radial dimension of the brush
- d_B Distance in the brush along r direction from the contact surface

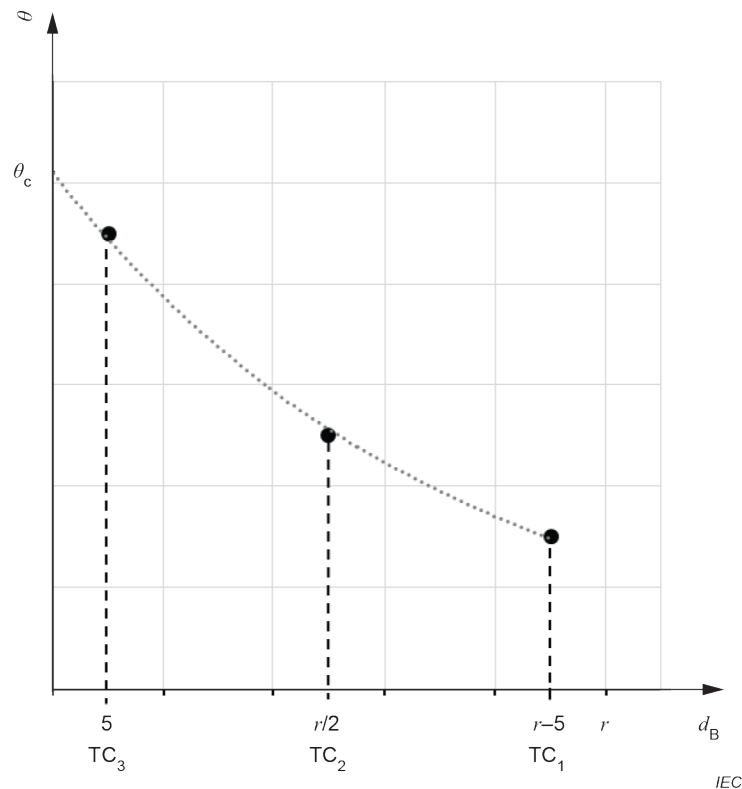
Figure 9 – Thermocouples insertion position

Thermal conductivity of the brush grade is recommended to be included in the test report.

The temperature at the brush/ring interface θ_c shall be measured either by:

- embedded temperature sensors in the ring (see 4.1.6.3.3), or
- extrapolation from the readings of the three embedded thermocouples TC1, TC2 and TC3, as illustrated by Figure 10, by using a linear regression with an exponential function.

NOTE For a higher degree of accuracy evaluation may be based on thermal conductivities and temperature measured by the couples TC1, TC2 and TC3 in the centre line of the brush.



Key

- d_B Distance from the contact surface to the top of the brush in radial direction
 r Radial dimension of the brush
 TC_i Thermocouple position number i
 θ Temperature
 θ_c Contact temperature

Figure 10 – Evaluation of contact temperature θ_c by interpolation

4.1.6.3.3 Rings temperature

Two main methods of measuring the temperature of rings are recommended:

- a thermocouple (according to IEC 60584-1) or any kind of fingertip using a thermocouple (for example a surface pyrometer including thermocouples);
- a resistant thermometer (according to IEC 60751).

Alternatively, another method is possible, in which a thermocouple may be embedded into the ring during its construction, and the wires brought out to two auxiliary measuring slip rings or a telemetry mounted coaxially to the test ring. If this method of measurement is adopted, the auxiliary slip rings shall be made of copper, silver-plated copper or silver and made to the smallest practical diameter. The output voltage of the thermocouple shall be collected by not less than two silver-graphite brushes per ring. These auxiliary slip rings shall be protected from external thermal effects. For applications where steel slip rings with grooves are common these slip rings can be also used for the tests. Additionally, the thermal conductivity of the steel and the exact position of the thermocouples have to be considered to extrapolate to the ring surface temperatures on the bases with a reasonable degree of accuracy.

Methods a) and b) will give an average temperature of the ring, whereas the method within the thermocouple embedded into the ring will provide a distribution of temperature of the ring. Any attention shall be paid during interpretation when using the last method.

When possible, a cooling curve of temperature versus time should be made for each test machine, in particular when a new test is planned.

A bulb-thermometer is not recommended.

An infrared camera should not be used to measure the slip ring surface temperature because of its low accuracy and poor precision. Anyway it could be helpful for interpretation to get the temperature distribution around the brush/slip ring environment.

4.1.6.3.4 Accuracy

The instrument used shall enable the temperature to be measured within a precision of $\pm 0,5$ K or better.

4.1.6.3.5 Calibration

The temperature sensors such as thermocouples shall be periodically calibrated. A period of 3 months is recommended to ensure that the relationship between the voltage and the temperature has not deviated.

4.1.6.3.6 Stable state for temperature

Temperature characteristic is considered as sensibly stable when deviation from mean value of a minimum of 3 consecutive measurements is less than 1 K.

4.1.6.4 Brush dimension measuring instruments

4.1.6.4.1 Measuring instrument

The choice of instrument, micrometer, vernier calliper or depth gauge, used to make the measurement will largely depend on the amount of wear which has occurred.

To measure brushes of difficult shape, a suitable jig to fit in the micrometer could be constructed to ensure positive location of the brush to be measured. Furthermore, the choice of micrometer anvil shape depends on the profile of the shape to be measured.

4.1.6.4.2 Accuracy

The instrument used shall enable the wear to be measured within a precision of $\pm 2,5$ % or better.

4.1.6.4.3 Calibration

Measurement instruments for dimension shall be periodically calibrated. A period of 1 year is recommended.

4.1.6.5 Current measuring instruments

4.1.6.5.1 Measuring instrument

Any suitable test measuring device can be used. One simple method is using a clamp ammeter to measure the current passing through the cables of each brush. Hall effect sensors or an oscilloscope may also be used.

Attention shall be paid while selecting the test device according to the nature of the current to be measured (some of them do not allow measurement of AC current) and to the sensitivity (for AC and DC).

4.1.6.5.2 Accuracy

The instrument used shall enable the current to be measured within a precision of $\pm 0,5$ % or better.

4.1.6.5.3 Calibration

Measurement instruments for current shall be periodically calibrated. A period of 1 year is recommended.

4.1.6.5.4 Stable state

Current measurement is considered as stable when deviation in percent from mean value of a minimum of 3 consecutive measurements is less than 5 %.

4.1.6.6 Peripheral speed

4.1.6.6.1 General

Peripheral speed v_p characteristic is calculated from the rotational speed of the ring measurement and ring diameter by formula (7) defined in 3.1.22.

4.1.6.6.2 Rotational speed instrument

Any suitable test measuring device can be used. One simple method is using a stroboscope. For more accuracy and automatic measurement a tachometer may be installed on the test rig.

4.1.6.6.3 Accuracy

The instrument used shall enable the speed to be measured within a precision of ± 50 r/min or better.

4.1.6.6.4 Stable state

Speed characteristics is considered as stable when deviation from mean value of a minimum of 3 consecutive measurements is less than 2,5 %.

4.2 Test rig specification for commutators

4.2.1 General

For DC operation the test rig is not exactly a real commutator, that is to say the test ring design simulates the mechanical behaviour by using slots machined along the axial direction, but does not introduce commutation.

4.2.2 Test rings

4.2.2.1 Material

Test ring material should be in accordance to the application of DC machine. The test ring shall be constructed of copper as specified in IEC 60356.

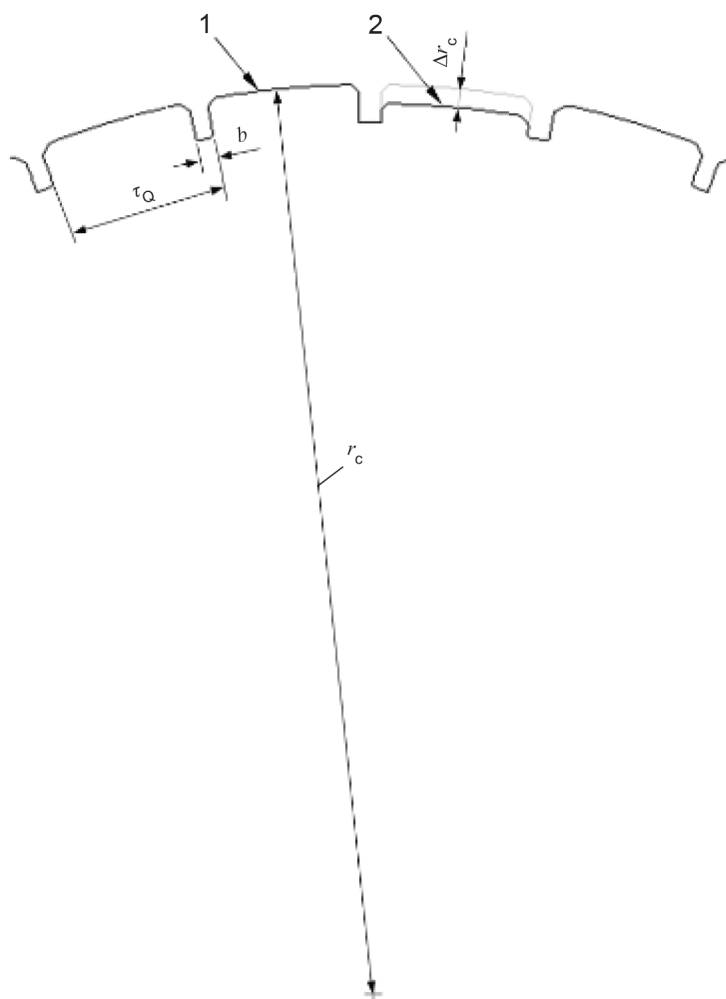
4.2.2.2 Dimensions of test rings

The diameter D of the test ring shall be not less than 200 mm and not more than 300 mm. Preferred dimension is 220 mm.

The axial length of the slotted ring shall be equal to the a dimension of the test brush, plus at least 6 mm.

Axial slots, evenly spaced on the surface of the ring shall be cut to give a slot pitch τ_Q in the range of 5,0 mm to 7,5 mm. The width b of the slots shall be between 0,8 mm and 1 mm and their depth between 1 mm and 3 mm. Each segment shall have the same radius as that of the whole ring.

During preparation the use of abrasive paper or cloth to remove tool marks and/or a very high surface polish shall be limited in order to avoid "doming" the bar section. See Figure 11.



IEC

Key

- r_C Radius of the test ring
- Δr_C Difference between the radius of the test ring and the radius of a doming bar section
- b Slot width
- τ_Q Slot pitch
- 1 Standard bar section (with a radius r_C)
- 2 "Doming" bar section (with a radius $r_C - \Delta r_C$)

Figure 11 – Illustration of bar grooves dimensions and preparation

The dimensions τ_Q and b shall be carefully chosen to eliminate the risk of mechanical resonance by considering the number of segments spanned by the brush (also named covering ratio τ_B). Formulas (11) and (12) give the relationship between τ_Q , t and b :

$$k \times \tau_Q \neq q \quad (11)$$

and

$$t - b < q < t + b \quad (12)$$

where

- k is a whole number selected from the values 2, 3 or 4;
- q is a variable number;
- t is the brush tangential dimension;
- b is the slot width;
- τ_Q is the slot pitch.

In other words the covering ratio of the brush τ_B shall not be a whole number. Preferred values of τ_B , are to be selected between 3 and 6, with a first decimal number as closed as possible to 5.

Example: 3,5 or 4,5.

Figure 12 shows an example of correct or wrong brush covering.

NOTE To be more comprehensive, one practical method for determining proper dimensions step by step is proposed below:

- a) Dimension t shall be chosen from preferred values in Table 1.
- b) Choose a value of τ_Q between 5,0 mm and 7,5 mm.
- c) Check if τ_Q is suitable:
 - 1) Calculate the number of slots Q by applying formula (5). It shall be a whole number. If not go back to b),
 - 2) Calculate the covering ratio τ_B (number of segments spanned by the brush) by formula (6).
- d) If τ_B is an integer, chose another value of τ_Q :
 - 1) Calculate new τ_Q from a value of τ_B closed to the previous one with a first decimal equal to 5 (see example below),
 - 2) Calculate new Q by using formula (5). If not a whole number, round off to the nearest and calculate again τ_Q and τ_B (see example below).
- e) Choose a value of b between 0,8 mm and 1,0 mm.
- f) Check if b is suitable according to formulas (11) and (12).

Example: ring diameter D : 220 mm.

- a) Select a tangential dimension of brush t : 25 mm.
- b) Select the width τ_Q : 5 mm.
- c) Then calculate Q and τ_B :

Formula (5) $Q = D / \tau$ numerical value is 44: whole number – valid.

Formula (6) $\tau_B = t / \tau_Q$ numerical value is 5: whole number – invalid. Therefore the value of τ_Q shall be changed.

- d) Choose a new value of τ_B with a first decimal of 5: 4,5.

Then calculate the numerical value of τ_Q : 5,55 mm and of Q : 39,6

Q is invalid because it is not a whole number. It shall be rounded off to the nearest whole number: 40.

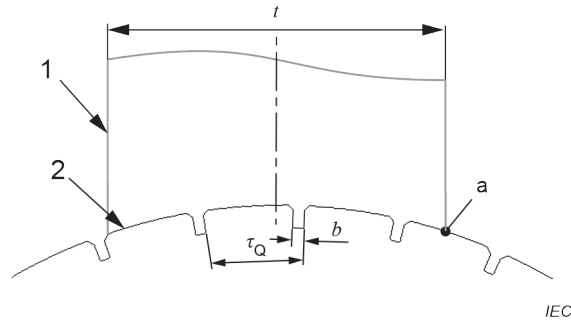
Then calculate again the numerical value of τ_Q : 5,5 mm and of τ_B : 4,54. All criteria are satisfied.

- e) Choose a slot width b : 0,8 mm. Then calculate:
 f) $t - b$ numerical value is 24,2 mm and $t + b$ numerical value is 25,8 mm

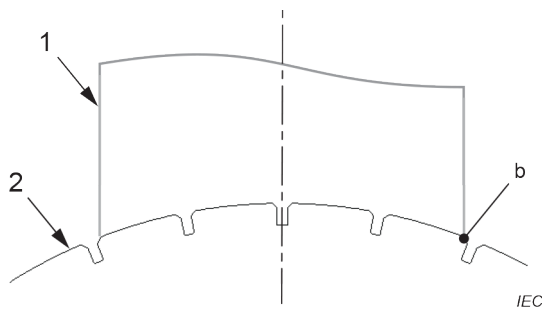
Calculation of $k \times \tau_Q$ for different values of k :

k	2	3	4
$k \times \tau_Q$ (mm)	11	16,5	22

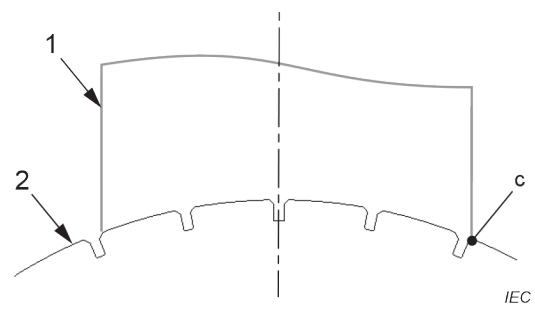
All values of $k \times \tau_Q$ are below 24,2 mm. It means that the numerical value for b 0,8 mm is correct.



a) Correct



b) Wrong



c) Wrong

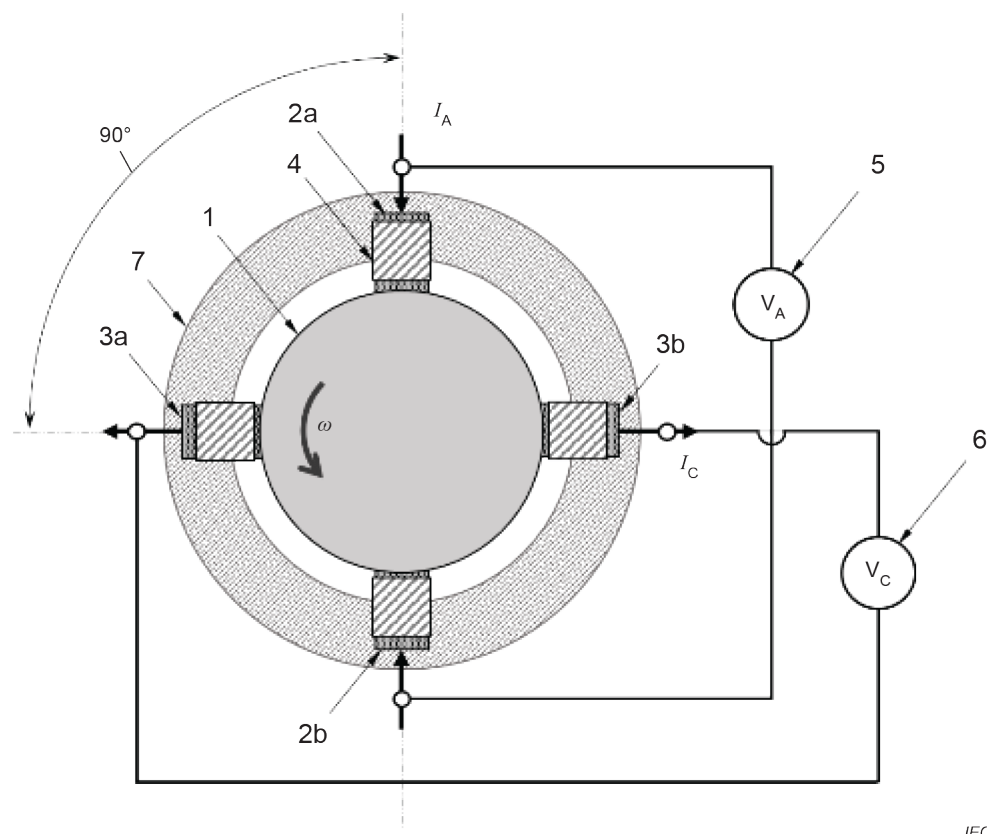
Key

- 1 Brush
- 2 Brush-holder
- a Correct brush covering: 3,5 (3 segments + 3 slots + ½ segment)
- b Wrong brush covering: 3,9 (4 segments + 3 slots)
- c Wrong brush covering: 4 (4 segments + 4 slots)

Figure 12 – Brush covering

4.2.3 Brushes arrangement

Preferably, four brushes equally spaced around the test ring shall be used, as indicated in Figure 13. The brushes shall be of alternate polarity.



IEC

Key

- 1 Slip ring
- 2 Positive brush (anode brush) a and b
- 3 Negative brush (cathode brush) a and b
- 4 Brush-holder
- 5 Voltmeter V_A for positive brush total contact drop
- 6 Voltmeter V_C for negative brush total contact drop
- 7 Brush-rocker
- I_A Anode brush current
- I_C Cathode brush current

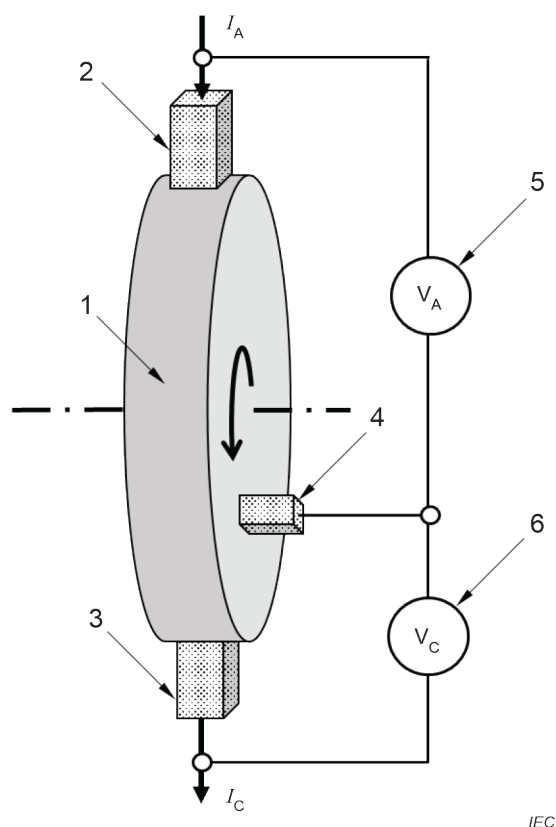
Figure 13 – Brushes configuration

If, for any reason, it is necessary to operate with two brushes only, then the angular spacing between them should be between 90° and 180° .

4.2.4 Special brush for voltage drop measurement

Brushes are arranged by pair: one positive for current entry and one negative for current exit. A control brush is added on the side of the ring. It shall have a negligible voltage drop. Generally it is made of silver graphite grade.

Figure 14 describes a brush arrangement (with 2 brushes) for the measurement of brush total contact drop U_B . In this configuration the voltage drop U_B is the average of the voltage drop of each polarity.



Key

- 1 Slip ring
- 2 Positive brush (anode brush)
- 3 Negative brush (cathode brush)
- 4 Control brush
- 5 Voltmeter V_A for positive brush total contact drop
- 6 Voltmeter V_B for negative brush total contact drop
- I_A Anode brush current
- I_C Cathode brush current

Figure 14 – Control brush arrangement

4.3 Test rig specification for slip rings

4.3.1 General

Except dimensions the test ring and brush arrangement shall be as close as possible to the real application. Especially the material selection is important in the view point of friction coefficient and voltage drop evaluation.

4.3.2 Ring

4.3.2.1 Materials

Based on the application, these rings may be manufactured of non-ferrous materials (bronze, copper) or ferrous material (steel, stainless steel).

The use of copper alloys containing zinc, silicon, lead, aluminium, chromium shall be avoided. They may affect brush operation by causing mechanical instability (brush wear, high friction, etc.).

For general purpose the use of bronze type CuSn12 or CuSn8Ni3P according to ISO 1190-1 or stainless steel type X10Cr13, which corresponds to 4006-410-00-I according to ISO 15510, is recommended.

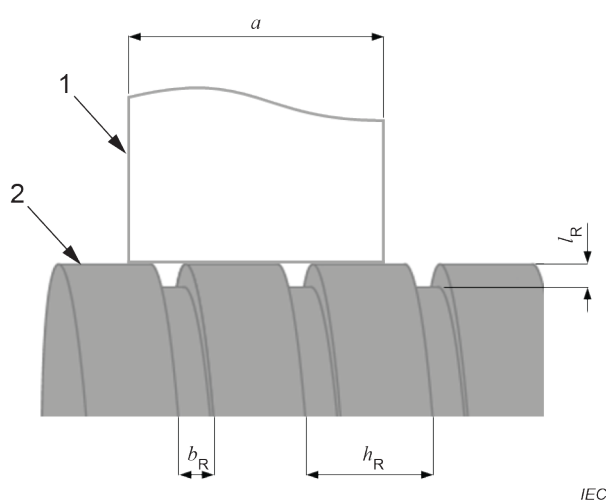
Together with the test results, the composition and mechanical characteristics or the reference of the ISO standard material of the ring should be stated.

4.3.2.2 Dimensions

- a) These rings shall be not less than 200 mm diameter and may be plain or helically grooved. Preferred diameter D is 220 mm.

The selection of the diameter shall take into account the peripheral speed. In case of large dimensions stability may decrease due to vibrations. It is recommended a maximum of 250 mm.

- b) If helically grooved, the following configuration of Figure 15 shall be used:



Key

- 1 Brush
- 2 Helically grooved slip-ring
- a Axial dimension of the brush
- b_R Groove width
- h_R Groove pitch
- l_R Groove depth

Figure 15 – Characteristics of grooves

The groove shall be "single-start". The depth of the slot l_R is generally between 4 mm and 5 mm and shall not be below 3 mm.

Groove pitch h_R shall be a submultiple of a (axial dimension of the brush) in order to avoid pulsations of brush pressure. In other words the the number of grooves under the brush k_R shall be an integer.

Example: For a brush with a dimension of 25 mm, pitch h_R numerical value is 12,5 mm.

The groove width b_R should lie between $h_R/3$ and $h_R/4$. A numerical value of 3 mm is recommended.

The instrument used for profile measurement shall be adapted to this configuration.

- c) The calculation of brush pressure (formula (3) defined in 3.1.10) and current density J_B (formula (8) defined in 3.1.23) shall be the same as for plain rings, that is, the effect of a helical groove on these quantities shall be ignored.

NOTE In case of helical groove with a large groove width b_R the current density at contact J_{Bc} may be an important information for interpretation. It is calculated from formula (8) by replacing the brush section $t \times a$ by the real contact surface of the brush:

$$J_{Bc} = \frac{I}{t \times a - b_R \times k_R}$$

where k_R is the number of grooves under the brush (integer).

4.3.3 Brushes

A minimum of two brushes per ring shall be used. If more than this number of brushes per ring is used, they shall be uniformly spaced around the slip ring and in no case shall the total brush surface area exceed 15 % of the surface area of the ring.

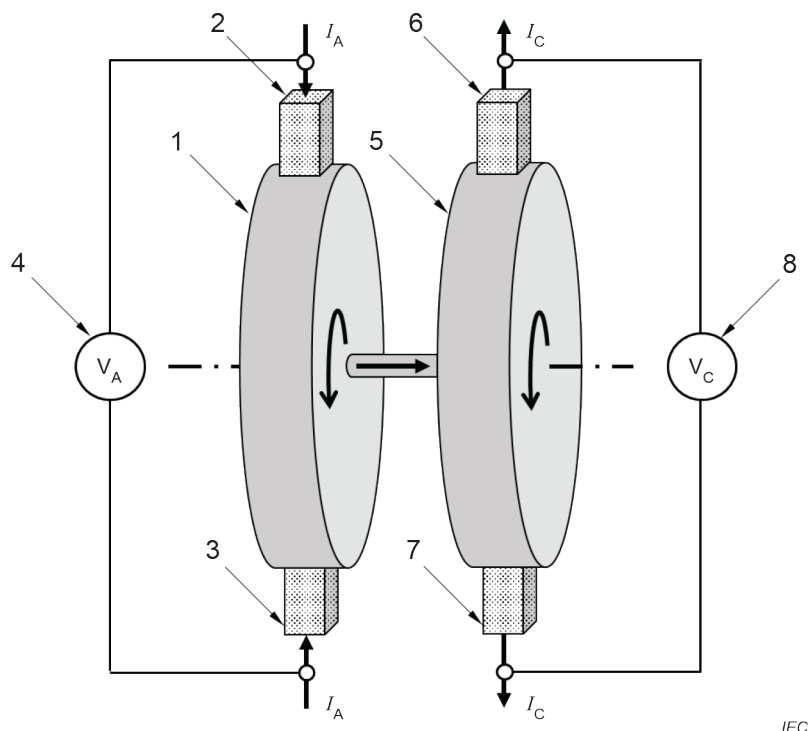
NOTE In purely comparative testing it is considered that the use of "trailing" aspect brush holders would not be deleterious and would reduce the number of brush holder types required.

4.3.4 Configuration for DC and AC operation

4.3.4.1 For DC operation

Each polarity (anode and cathode) shall be tested separately. Two methods can be employed:

- a) 2 different rings on the same test rig: one running as anode, the other one as cathode. In that case, on each ring, brushes are at the same polarity, as illustrated by Figure 16.



IEC

Key

- 1 Anode slip ring
- 2 Positive brush 1 (anode brush)
- 3 Positive brush 2 (anode brush)
- 4 Voltmeter 1 for anode brush total contact drop
- I_A Anode brush current
- 5 Cathode slip ring
- 6 Negative brush 1 (cathode brush)
- 7 Negative brush 2 (cathode brush)
- 8 Voltmeter 2 for cathode brush total contact drop
- I_C Cathode brush current

Figure 16 – Test rig arrangement for DC operation with 2 brushes per polarity

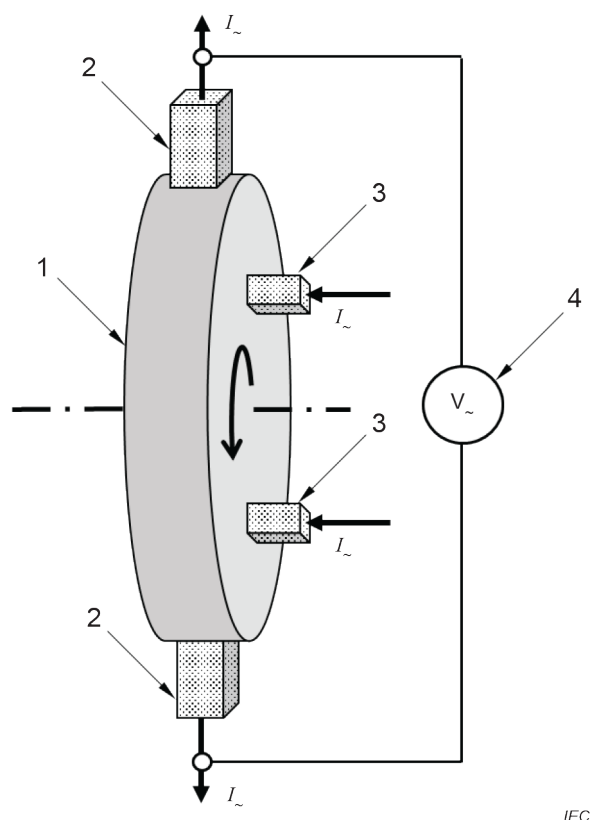
- b) One ring: test firstly anode condition then cathode conditions. In that configuration an additional brush is added on the flat part of the tested ring to close the circuit.

4.3.4.2 For AC operation

Only one phase is tested. AC power supply is connected on one hand to the test ring, by applying one or two additional brushes on the flat part of the test ring, and on the other hand to the brushes, as illustrated in Figure 17.

As for the special brush for voltage measurement specified in 4.2.4, the additional brushes for connecting the current to the test ring shall be of a suitable material such as the contact voltage to the ring is negligible. For example suitable grade is selected in the silver-graphite family.

At high rotating speed the grade of the additional brush may be chosen from natural graphite family. The use of a composite brush made with one layer of natural graphite grade and one layer of silver graphite grade may be also a good compromise to reduce both the contact voltage drop and the wear.



Key

- 1 Slip ring
- 2 Test brushes
- 3 Additional brushes
- 4 Voltmeter $V_{\sim}$ for measurement of brush total contact drop of 2 brushes
- $I_{\sim}$ AC current

Figure 17 – Test rig arrangement for AC operation with 2 brushes

5 Test schedule and operating conditions

5.1 General

This clause is relative to the general test procedure to achieve measurements of friction coefficient, voltage drop and wear.

Operating condition includes (but not limited to): the material and surface condition of the slip ring or commutator, humidity, temperature, brush pressure, current density, peripheral speed, etc.

In view of the nature of the brush material, changes within the recommended ranges of ambient conditions, etc., absolute repeatability of test results is not to be expected. If all controllable parameters are accurately maintained, repeat tests carried out on the same machine with the same brush sets shall give accuracy versus repeatability of coefficient of friction, contact drop voltage and brush wear within, say, $\pm 10\%$ for each measurement compared with the average results found on previous tests. The above remarks assume that the same test procedure has been strictly followed.

It is also suggested that sets of test brushes in various materials are reserved for machine calibration tests. Before each test, it is recommended that the connection millivolt drop be monitored and that the connections be re-made if significant changes in connection millivolt drops are found.

5.2 Environmental conditions

5.2.1 Laboratory environment

The test shall be made indoors in an environment substantially free from air currents, except those generated by heat from the sample being tested. In practice, this condition is reached when the air velocity does not exceed 0,5 m/s.

All the tests should be carried out in an atmosphere substantially free from dust, chemical vapour, etc.

5.2.2 Ambient air temperature and ring surface temperature

The ambient air temperature shall be settled to achieve the suitable ring surface temperature for a good operation of the carbon brush system.

The recommended average ring surface temperature range is from 60 °C to 80 °C. Therefore it may be necessary to run several tests to define the suitable ambient air temperature inside the room (or chamber) where the test rig is installed to achieve the ring surface temperature range specified above.

Nevertheless, for drawing comparison between brushes of the same grade family on the same test rig (slip ring dimensions and material, current configuration, etc.), the ambient temperature may not be adjusted, provided the ring surface temperature does not exceed a difference of 10 °C from the limits specified above (in other words it shall lay between 50 °C and 90 °C).

To ensure an homogenous temperature around the ring a ventilation system (or other means) may be fitted.

Ambient air temperature and average ring surface temperature shall be recorded daily during the tests and the average reported in the test report.

5.2.3 Ambient humidity

The absolute humidity HA of the test room atmosphere (or climatic enclosure) shall be between 8 g/m³ and 12 g/m³ all along the test. It shall be recorded daily and the average reported in the test report.

NOTE When an instrument for measuring relative humidity is used the absolute humidity is calculated from relative humidity HR and ambient temperature.

5.3 Operating conditions

The test conditions range listed in Table 2 are "medium" conditions likely to be met on non-specialized machines.

Table 2 – Test conditions

Symbol	Name	Unit	EG	BG	HC-CG	NG	MG ^a
v_p	Peripheral speed	m/s	25 to 55	25 to 35	10 to 30	50 to 100	10 to 40
J_B	Current density	A/cm ²	10 to 12,5	5 to 10	6 to 10	8 to 12,5	10 to 35
p	Brush pressure	kN/m ² ^b	18 to 22	18 to 22	18 to 22	13 to 18	18 to 25
^a Test conditions depend on the type of metal-graphite grade (sintered or metal impregnated) and the metal content. Generally the higher is the metal content, the lower speed and higher current density shall be used. ^b An equivalent unit is kPa. NOTE It is suggested to apply the medium current density recommended by the brush manufacturer.							

5.4 Test preparation and inspection

5.4.1 General

The following sequence shall be applied prior to the tests.

NOTE Subclause 5.6 specifies the measurements and observations to be recorded before starting the test.

5.4.2 Test rig

Prepare the test rig as indicated in Clause 4.

Instruments (and their means of recording) shall be installed in the test rig and be calibrated and/or adjusted when necessary.

5.4.3 Brush-holders

Set the specified pressures according to Table 2 in 5.3.

5.4.4 Test brushes

- The test brushes prepared according to 4.1.3 shall all be of the same grade and of the same batch number. The connection drop U_f of the test brushes shall be measured prior to testing, and brushes of similar connection drop values should be selected for test with a tolerance of not more than ± 20 %.
- Fit the test brushes to the ring. Check if the brush contact surface is matching the ring profile. Different methods exist for this operation:
 - Preferential method is the use of a non-conducting abrasive cloth.
 - Use of a separate tool where a rotating ring made of an abrasive material within the same diameter as the test ring is used to machine the brush contact surface.
 - Applying a medium silicon-oxide or aluminium-oxide stone (fitting stone) on the ring when brushes are in their boxes. In that case check if no oxide remains at the contact surface of the brush and use a grinding stone on the test ring to obtain the suitable roughness.
- Thoroughly clean the test ring, brushes and brush boxes after these operations. It is recommended to use a vacuum cleaner with a sufficient suction power. After the use of a fitting stone, attention shall be paid to the cleaning and to the brush contact surface aspect.

5.4.5 Ring roughness

The roughness Ra and peak count Rpc should be measured after brushes fitting and before any test. If it differs from the range defined in 4.1.2.4, a new preparation of ring surface shall be done.

5.4.6 Brush bedding

Brush bedding shall then be commenced at the specified conditions of speed and current density for the test according to Table 2 and ambient air temperature and humidity as specified in 5.2.2 and 5.2.3.

Bedding shall be continued for 24 h minimum. During this period, visual inspection and measurements shall be made as required in 5.6.4.

When the film (patina) is formed the surface temperature of the ring shall be checked. If it is out of the range disclosed in 5.2.2., then the ambient temperature shall be corrected (increased or decreased) and bedding shall be continued. This operation shall be repeated until the ring surface temperature reaches the recommended range in 5.2.2. When it is not achieved check the test rig and parameters, in particular the ventilation system.

Bedding is considered as satisfactorily concluded when:

- all brushes are fully bedded, that is, the brush surfaces are uniformly well polished, and a substantially uniform patina (skin) has been developed, and
- stable measurements have been stated according to stability criteria for each parameter (refer to each corresponding subclause).

When bedding is not completed running shall continue for 24 h. When bedding is still not satisfactory, stop and check the test rig and instruments.

5.4.7 Brushes measurement

All the brushes shall be numbered and their radial dimension r_0 measured. Check if tolerances between brush and brush-holders has not been changed during bedding operation.

It is most important that each brush be then replaced in exactly the same manner and in the same brush box it occupied in "bedding" and that the brush pressure system be replaced on the top of the brush in exactly its previous position.

5.5 Test sequence

5.5.1 Test starting

The test can start when test rig preparation is concluded as indicated in 5.4.

Testing parameters shall be settled according to Table 2 and ambient air temperature and humidity set up as specified in 5.2.2 and 5.2.3. The load current, and rotational speed shall be applied within ± 5 % of the specified values.

5.5.2 Test duration

If brush wear measurements are not required, the test shall run until stable values of ring surface temperature, friction coefficient and voltage drop are obtained.

If, however, brush wear measurement is required, this period shall be extended to 150 h at least, to determine the average brush wear with a good accuracy.

5.6 Measurements and observations

5.6.1 General

Observations and measurements in the following subclauses shall be made before and/or along the test duration and/or after the test. They shall be reported in a test report. An example is given in Annex C.

If any anomaly occurs it shall be then reported in the test report.

The test report shall not be confused with a data sheet. The test report is an internal document issued by the laboratory that have proceeded to the tests. The data sheet is an external document in which some average values or graphs are provided for a customer (machine user or manufacturer). However, it shall contain essential data (parameters and average values of measurements) to ensure a good understanding.

5.6.2 Interval between measurements

Interval between measurements shall be less than 2 h, except for brush wear measurement for which the interval shall be 50 h.

5.6.3 Before starting a test sequence

5.6.3.1 Ring

- a) run-out (specification according to 4.1.2.3);
- b) eccentricity;
- c) flat spots;
- d) ring surface film finish and patterns (according to IEC 60276:2018);
- e) roughness (specification according to 4.1.2.4);

For commutator test rings only (Figure 9):

- f) check bar section elevations: too high / too low;
- g) check bevelled edges of each bar section; confirm appropriate chamfer and no copper drag;
- h) bar section surfaces and bar-to-bar grooves shall be clean and free from any dirt (oil or dust).

NOTE Ring profile measurement (preferably on each brush track if more than one track is applied) provides a), b), c) and f).

5.6.3.2 Brush-holders

- a) brush pressure, which is determined by spring force and brush area S , shall be confirmed according to the specifications in Table 2 for the brush type and adjusted if required;
- b) brush-holder position relative to the ring should be checked as specified in 4.1.4 (radial and axial position within the ring and distance between ring and brush-holder);
- c) brush holders should be clean and free from any dirt (dust or oil);
- d) clearance between brush and holder should be checked and correct to the specifications in IEC 60136.

5.6.3.3 Brushes

- a) r_i dimension of each brush i shall be measured and reported according to their position; short brushes should be identified and changed to a new one if necessary;
- b) brush dimensions should be measured and their tolerances shall be in accordance with IEC 60136;
- c) brush axial side a shall not be skewed but shall be parallel to the slot;
- d) the brush grade shall be checked and batch number reported;
- e) all moveable parts should be free (for instance springs).

It is most important that if any brush have been removed, they should be then replaced in exactly the same brush box and in the same orientation and also that the brush pressure system shall contact the head of the brush in exactly its previous position.

5.6.4 Measurements during a test sequence

The following items shall be measured, checked and recorded periodically (for intervals see 5.6.2):

- a) ring speed (4.1.6.6),
- b) ring and brushes temperature (4.1.6.3),
- c) brushes current (4.1.6.5),
- d) friction coefficient (according to Clause 6 and 4.1.6.1),
- e) voltage drop (according to Clause 7 and 4.1.6.2),
- f) brush length, when required (see 4.1.6.4 and Clause 8).

The load current and rotational speed shall be maintained within ± 5 % of the specified values. Parameters shall be re-adjusted periodically if necessary.

If an operation is performed on the ring surface then the brush seating / bedding should be checked and corrected if necessary.

During the test sequence close observation shall be made to ascertain that no abnormal brush performance occurs (chattering, ring grooving, sparking, ring blackening, excessive ring surface temperature, abnormal current distribution between brushes, etc.). These phenomena can adversely affect the test. If any of the parameters show an instability, stop the test and check again the test rig and operating parameters. This inspection shall be done almost once a day.

5.6.5 Measurements after a test sequence

At the end of the test, when the machine has stopped, the following items shall be inspected and recorded:

- a) brush aspect (in particular contact surface): the description shall be according to 5.7 of IEC 60276:2018 and a picture shall be taken,
- b) ring surface aspect: the description shall be in accordance with 5.6 of IEC 60276:2018 and a picture shall be taken,
- c) ring roughness (Ra and RPc),
- d) when brush wear measurement is required: measurement of the dimension r_i of each brush i .

6 Determination of friction coefficient

6.1 General

Friction coefficient μ is involved in mechanical losses of brushes, which may be calculated from formula (13):

$$P_m = 10 \times \mu \times v_p \times F_p \quad (13)$$

where:

- P_m is the mechanical losses;
- μ is the friction coefficient;
- v_p is the peripheral speed;
- F_p is the force applied by the pressure system.

In formula (13) the term "10" is from the constant of gravity. For precise calculation it may be replaced by its exact value: 9,807.

Friction coefficient is affected principally by the speed, the specific pressure, the current density and the brush grade.

There are two main methods by which the coefficient of friction is usually measured:

- Method a): measurement of the tangential forces acting on the rotating surface (see 4.1.6.1.2);
- Method b): measurement of the tangential forces acting on the brush (see 4.1.6.1.3).

NOTE Although there may be differences in the coefficient of friction due to the anodic and cathodic brushes, these are generally added together and only the average friction due to both brushes is calculated.

6.2 Test conditions

The test shall be carried out according to operating condition specified in 5.2 and 5.3.

As friction coefficient is speed dependant, test shall be repeated with 5 different speeds within the range specified in Table 2. The interval between two adjacent speed shall give an accurate plotted curve of friction coefficient versus speed (see example in Figure 18).

When a dependence to the current density is expected the whole test sequence may be repeated at different current density within the range of Table 2.

6.3 Measurements

6.3.1 General

Test conditions parameters shall be controlled during the test and reported together with the other measurements and observations according to 5.6.

The measurement of friction coefficient shall be recorded at stationary operating conditions during the test duration according to 5.5.2.

6.3.2 Test rig arrangement of Method a)

When using the instrumentation according to Method a) two measurements are necessary:

- Measurement of T_0 : remove carbon brushes and measure the torque at specified peripheral speed.
- Measurement of T_m : set the brushes on the test rig and record the values of torque along the test duration.

6.3.3 Test rig arrangement of Method b)

When using the instrumentation according to Method a) the force measured by the sensor $F_{t,lc}$ (see Figure 7) shall be recorded along the test duration.

6.4 Calculation of friction coefficient

6.4.1 Test rig arrangement of Method a)

When using the instrumentation according to Method a), the the friction coefficient is calculated from the measured torques by using formula (14):