TECHNICAL DATA SHEET

BRUSHES FOR SLIP RINGS AND RINGS KEY DESIGN

1. SCOPE

Slip ring machines (synchronous and asynchronous), as well as all rotating systems using slip rings, use technologies different from those used on DC motors. Technological requirements are hence different.

The judicious choice of a brush grade is consequently subject to a study principally involving the temperature rises and the available means offered by the machine design to reliably dissipate the heat generated by operation of the brushes on the slip rings.

Care shall be taken to choose grades containing a variable quantity of metal (usually copper or silver) providing a “normal“ service on slip rings, in order to carry high currents, reduce voltage drops at contact (electrical losses) and improve heat exchange. There is a very wide range of brush grades for slip rings, in which the metal content may vary from 0 to 90%.

2. SLIP RING HEATING

The first necessary step in making sure that a grade is properly adapted to its function is to consider the slip ring assembly has reached a temperature equilibrium.

When the system temperature increases abnormally, the risk of excessive wear of the slip rings and the brushes also increases. This may lead to arcing between the brushes and the ring or across rings (phase-to-phase or phase-to-ground) as a secondary effect.

The flow chart in Figure 1 below shows how the slip ring temperature rise is central in the general condition of a machine (as a result of the various parameters involved).

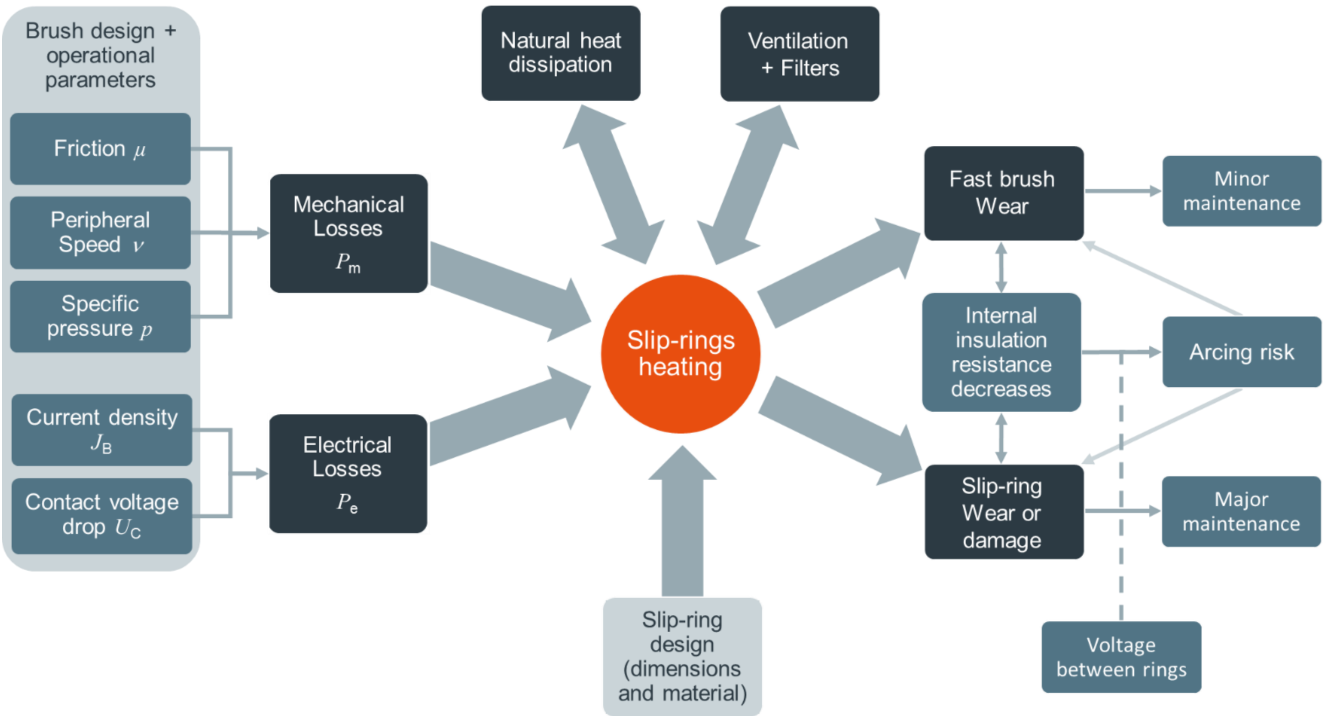


Figure 1 – Interaction between machine design and operating parameters effect on slip rings heating and the general condition of the machine

NOTE: Major maintenance may imply the replacement of the complete slip ring unit, as well as other components (brush-rocker, brush-holders…).

We will develop in this document 2 aspects: **how to select the brush grade** and **the influence of the slip ring unit design** (slip ring and brush configuration).

3. CHOICE OF BRUSH GRADE

The brush grade directly affects the brush total losses ($P_m + P_e$) through its **friction coefficient** and its **voltage drop**. For more information on losses calculation, please refer to our *TDS-05*.

Under normal conditions of use, friction varies little from one grade to another (proportion about 2 to 1), whereas voltage drops may vary with ratios of 25 to 1.

The curve below shows the proportions by which the electrical losses of a motor with metal-graphite grades can theoretically be reduced.

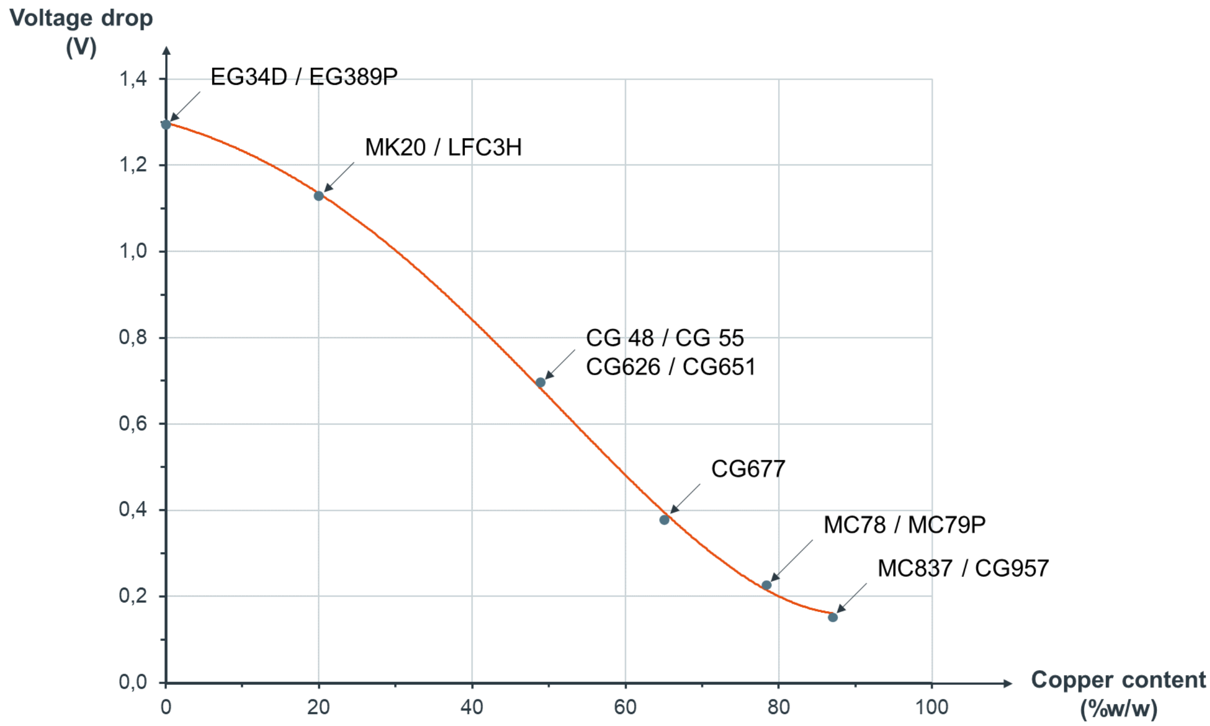


Figure 2 – Total brush voltage drop (U_B, in V) as a function of the metal content of brush grades for a current density J_B equal to 10 A/cm², peripheral speed v_p equal to 15 m/s and a specific pressure P of 18 kPa (= 180 cN/cm² = 183g/cm²).

This advantage is evident for slow machines with high loads. Nevertheless, metal-graphite grades imply:

- higher friction, thus mechanical wear, so the peripheral speed of the machine has to be reduced if the metal content is to be increased,
- the wear dust contains more copper, which means that they are more conductive, so the danger of short circuit is increased. Hence these grades should not be used on high voltage and completely closed machines.

Figure 3 illustrates the **range of current density and maximum limit of speed** as a function of their metal content (this figure gives only indicative values).

In addition, the following two rules should also be taken into account wherever possible:

- For closed machines, brush total losses ($P_m + P_e$) per unit area of the slip rings surface must be less than 1 W/cm².
- For open ventilated machines, the limit naturally depends very much on the ventilation mode and its efficiency; as a first approximation, it can be fixed at 1.5 W/cm².

Especially for closed machines, the most suitable brush is the brush that produces the least amount of conducting dust (with the lowest metal content) due to wear, provided that its total losses remain less than the value stated above.

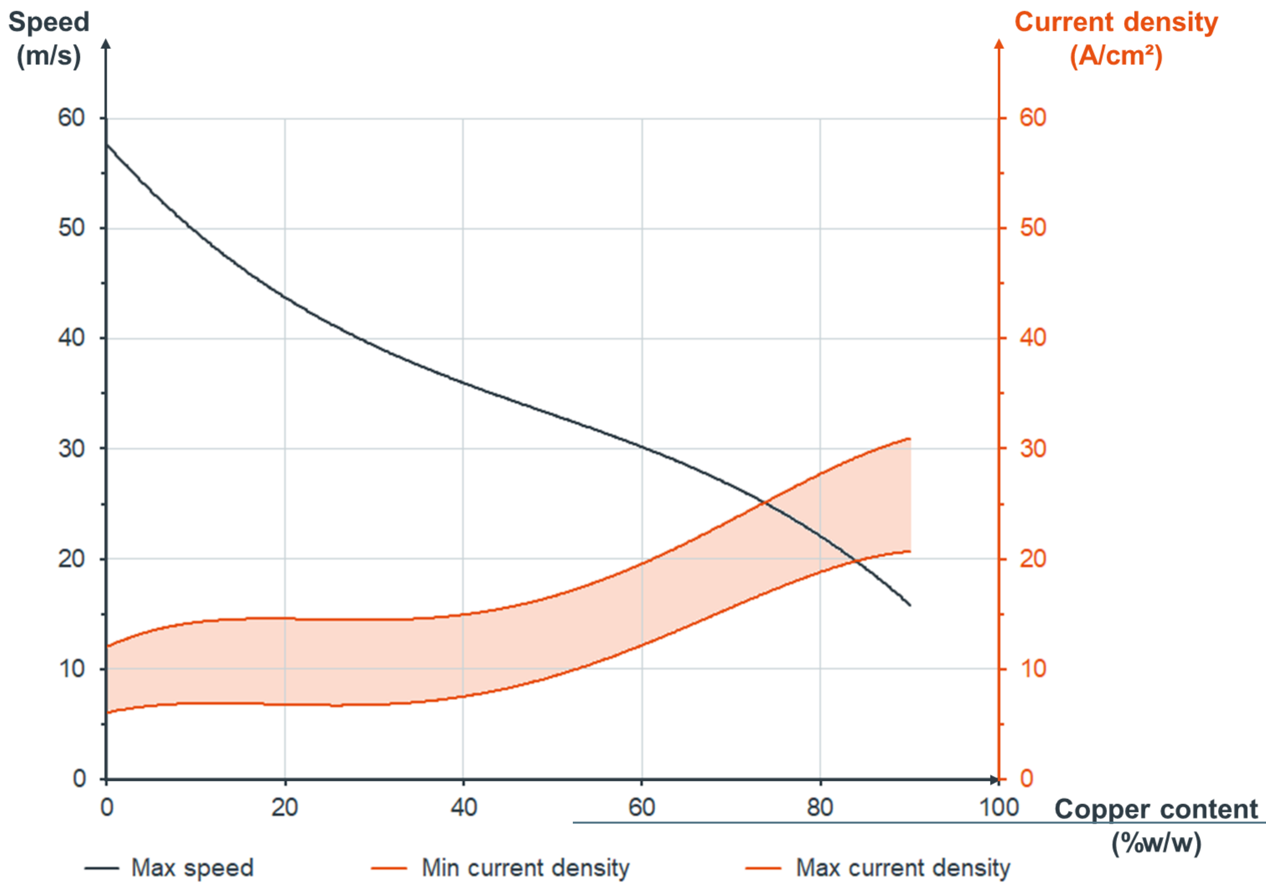


Figure 3 – Maximum allowable speed and current density recommended range according to the copper content in weight-%

4. DIMENSIONS OF THE SLIP RING UNIT

Choosing the right brush for an application is only part of the answer for the best brush and slip ring performance. The brush-holders and slip ring design dimensions, developed below, are just as critical.

S FACTOR

Based on our experience, we have defined and used a key design factor, called ***S*-factor** (S for surface), which can be considered as the **heat dissipation index** of a machine.

This S-factor is useful to **quickly evaluate the degree of difficulty** of a slip ring machine and to guide the selection of a brush grade for the application considered.

It is calculated as the ratio between the slip ring surface over the nominal current:

$$S = \frac{\pi \times D \times L}{I}$$

Where:
S is expressed in cm²/A,
D is the slip ring diameter in cm,
L is the slip ring width in cm, and
I is the nominal current intensity per slip ring (I rotor) in A.

As S decreases and the risks of overheating become more severe, total losses should be reduced by a judicious choice of the brush grade, as well as a suitable ventilation (see *TDS-12*).

The following table 1 gives **indicative minimum values of the *S*-factor** corresponding to Mersen main grades for slip rings for closed and ventilated machines. It has been determined from observations and practical tests on bronze slip rings.

S-factor per housing type		Grade	Metal content
Ventilated	Closed		
> 1	> 1,2	EG34D EG389P	0%
> 0,8	> 1	M9426 MK20 LFC3H CG48 CG626 CG55 CG651	5%-50%
> 0,6	> 0,9	CG677	55-80%
> 0,5	> 0,7	MC79P MC78 CG957 MC837	≥ 80%

Table 1 – Main grades for S-factors depending of ventilation or closed housing for bronze rings

Losses on ordinary steel or stainless steel slip rings are always higher than on bronze slip rings. Thus, minimum values of S in the above table should be increased by 10 to 20%.

NOTE: When the ***S***-factor is too small, in other words < 0.5, a specific combination of the slip ring unit design, especially brush rocker and ventilation, and brush grade will have to be carefully chosen. We highly recommend to test the configuration for validation.

COVERAGE RATE

One can see from the above discussion that the main concern with slip ring machines is heat exchange or dissipation of heat due to losses. The result is that we need to consider two other parameters to give a fairly precise idea of the capacity of the machine design to dissipate losses from brushes operation.

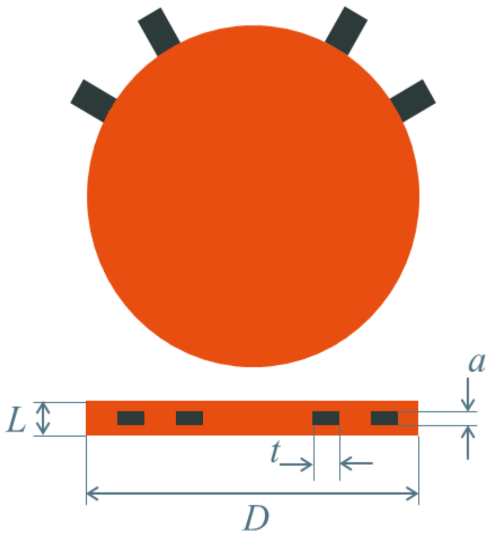
The coverage rate concept is complementary and inseparably linked to the S-factor concept.

Peripheral coverage ratio τ_p

This value defines the **ratio of the slip ring perimeter covered by the brushes** and is expressed in %:

$$\tau_p = \frac{N \times t}{\pi \times D} \times 100$$

where:
t is the tangential dimension of the brush, in mm
D is the slip ring diameter in mm
N is the number of brushes per track



Global coverage ratio τ_g

It defines **the ratio of the slip ring area covered by the brushes**, as a proportion of the total surface area of the slip ring, and is expressed in %:

$$\tau_g = \frac{N \times t \times a}{\pi \times D \times L} \times 100$$

where:
t is the tangential dimension of the brush, in mm
a is the axial dimension of the brush, in mm
D is the slip ring diameter in mm
L is the slip ring width in mm
N is the number of brushes per track

Our experience has shown that:

When τ_p < 15 %, it is optimum.

If **15 % < τ_p < 20 %** there is a **risk of abnormal temperature rise**.

If τ_p **> 20 %** there will be problems with **difficult operation of the slip rings, brushes and the entire assembly**.

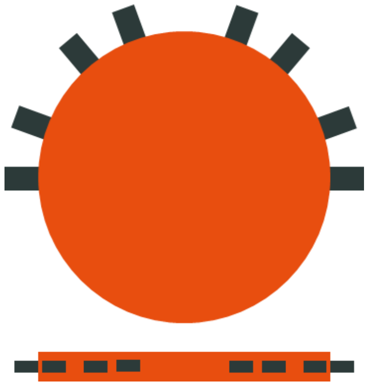
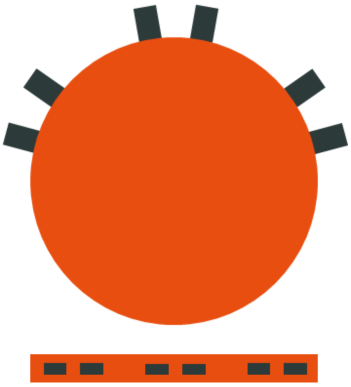
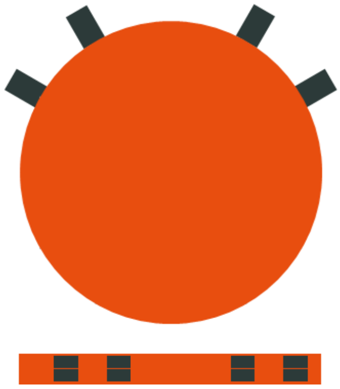
The same kind of issue will occur when τ_g > 15 %.

One can understand from the formula above that the adaptation of brushes dimensions and number may be done to reduce the temperature rise risk (for given slip ring dimensions).

NOTE: Special attention shall be paid when changing either the number of brushes or their dimensions. Since the current density in brushes would change, the choice of the grade shall be confirmed or changed.

Example of calculation:

Dimensions of brushes: t x a = 40 x 20 (mm)
Dimensions of slip ring: D = 500mm and L = 50mm

Initial configuration: 8 brushes on 1 track.	Configuration 1: Decrease the number of brushes to 6.	Configuration 2: Arrange 8 brushes on 2 tracks.
		
τ_p = 20.4% and τ_g = 8.2% ⇨ Over heating issues for the whole system.	τ_p = 15.3% and τ_g = 6.1% ⇨ τ_p is at the first limit, but the system may operate well. ⇨ Check the brush grade (the current density increases of 33%).	τ_p = 10.2% and τ_g = 8.1% ⇨ No problem expected (providing S-factor is within the ranges of table 1).

NOTE: In addition, even if the S-factor is within the values given in the table 1 above and the coverage ratio lower than 15%, the positions of the brushes and the ventilation design still need to be determined such that the brushes operate smoothly.

In practice, the **choice of a grade of brushes** for slip rings must take account of:

- the **recommended limits of the operational parameters** as indicated in Mersen Technical Guide *Brushes for Motors and Generators* (pages 14 & 15),

- the **total losses** at the contact between ring and brushes for the nominal load and speed of the motor,

- the **type** (open or closed) and **the ventilation** (design, speed, air flow…) of the machine,

- the capacity of the slip ring unit to dissipate heat from losses, by a calculation of **the S-factor and the coverage ratios.**

HELICAL GROOVES

Helical grooves are used on slip rings **to improve the current distribution between brushes**. It has been explained by the fact that during each revolution parts of the brush contact surface is inoperative during a certain (small) lapse of time, forcing the current to pass through a smaller surface. Another induced effect is the cooling enhancement due to the air circulation inside grooves. In addition, it permits to reduce the air layer trapped at contact between the brush and the ring.

However, the presence of a helical groove may affect the air circulation around the brush-slip ring system, in particular when enclosed.

Pitch

The groove dimension (width and depth) **and the pitch shall be carefully chosen** for the optimization of the heating losses.

Although there is no unanimity about the groove sizing, we could indicate a range of size in use:

- the pitch may vary from 8 to 25 mm,
- the groove width ranges from 2 to 5 mm,
- the depth is generally between 3 and 4 mm (more or less equal to the groove width).

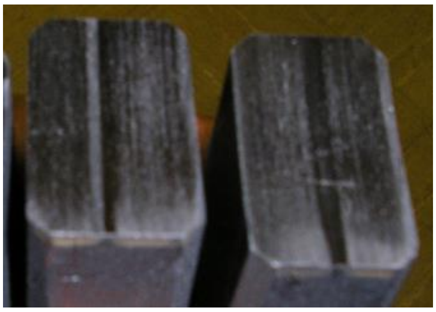
To ensure a good operation of the brush **two important conditions** shall be met:

- the **brush axial dimension shall be a multiple of the groove pitch**.

- **the real surface area** covered by the brush with a grooved ring shall **not be lower than 60%** of the surface area covered with a plain ring.

Example: A brush with *a* = 25 mm will fit a grooved ring with a pitch *h* = 12,5 mm. In that case two grooves will always be present under the brush contact surface.

When the first rule is not respected the real contact surface of each brush with the ring, as well as the specific pressure at contact, will oscillate between two limits. Therefore, the current of each brush will also vary periodically. The brush contact surface may be grooved, as shown on the picture beside.



In addition, below a contact ratio of 60%, an assessment of the brush stability and operational parameters shall be studied. In particular, one shall notice that the real contact pressure may be over the recommended range for the considered grade.

Influence of helical groove on brush operational parameters

Despite the helical groove helps to dissipate heat thanks to the circulation of air, it shall be noticed that it may affect the brush operation. As the contact surface is reduced, the specific pressure increases, thus increasing the stress on the material, and increasing the brush wear.

This is the reason why it is highly recommended to **take into account the helical groove dimension** when calculating the mechanical losses from brushes.

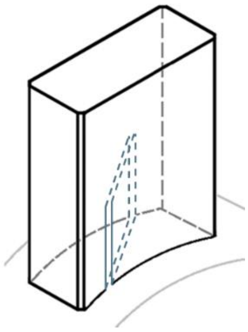
It has to be noted that the current density at contact increases but not the current density inside the brush section. As the electrical losses are calculated through the contact voltage drop and the global current, it is generally admitted that electrical losses are not modified by the existence of helical groove.

NOTE: Great care shall be made when machining helical grooves. A chamfer of 45° is recommended.
See Mersen PTT Technical Data Sheet TDS-03.

Slotted brushes

In the **absence of a helical groove** (i.e. plain ring), **a slotted brush** is recommended to remove the air layer. It is made by cutting one or two slots across the brush section from its contact surface (along its height with a specific angle).

NOTE: a slotted brush is not recommended in case of a grooved slip ring.



GENERAL NOTICE:

This approach is not new, anyway we still encounter abnormal heating issues due to an improper slip ring design, because this outline is too often forgotten or unknown by the slip ring unit designer. Once the machine is built it is generally impossible to solve these problems since no brushes can resist the resulting conditions.

Therefore, the simple and fast to calculate parameters exposed above should be taken into account when designing slip ring units to make sure that the dimensions enable satisfactory operation.

Mersen highly suggests to proceed to a numerical simulation and/or to laboratory tests before validating a slip ring unit design.

Cited documents:
Technical Guide: Brushes for motors and generators.
Mersen PTT Technical data sheets:
TDS-03: Edge chamfering
TDS-05: Losses in brushes
TDS-12: Ventilation

PTT-TDS20-EN-2202