Technical Information

Carbon Brushes and Mathematics

You all know that carbon brushes, respectively their physical properties, are in the truest sense incalculable. Calculable however are some parameters, which are in close relation to the brush running behaviour.

Under the somewhat provocative heading **„Carbon Brushes and Mathematics“** we would like to present some important, calculable factors, which are in relation to the brush running performance. For clarity sake we combined the most important formulas with defining examples.

1. Specific Current Density

The transfer current, respectively the specific current density, is one of the determining parameters during the running behaviour of the carbon brush. Each grade group has optimal load ranges in which the carbon brush grade performs to its ultimate running performance. Under- or Over-Load conditions mostly result into a negative influence on the wear, the formation of the patina, on the condition of the commutator, etc.
Therefore it is important to be able to calculate the current density by means of the loading data.

In this presentation we do not wish to review the physical design of the DC motors, respectively the asynchronous- or synchronous-slip ring drive. Therefore, for the sake of calculating the current density, only the following general remark will be made.
As the current first flows into the commutator and then out again, one should only use half of the number of brushes employed in the formula to calculate the specific current density on a DC motor. Correspondingly, one should only consider the brushes of one pole on a DC loaded slip-ring. With AC loaded slip-rings it should only be the brush of one phase.

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Example:

Commutator Motors:

- 4 pole with 2 brushes each, i.e. 2 x 2 brushes with (+) polarity, and 2 x 2 brushes with (-) polarity. To calculate the current density only 4 brushes are considered.
- 6 pole with 5 brushes each, i.e. 3 x 5 brushes with (+) polarity, and 3 x 5 brushes with (-) polarity. The calculation is done with 15 carbon brushes.

Slip-Ring Drive :

- 3 phases, per phase one slip-ring with 5 brushes each. The calculation of the current density is carried out for 5 carbon brushes.

The current density is measured as „Current per Brush Contact Surface“, i.e. A per cm^2 (Amp/cm^2). It can then be calculated with the following explained formulas:

For the individual grade groups the following determining factors apply. Details can as well be taken out of the technical information sheet # 10.21.

Grade Group	**min. Continu-ous Current Density**	**opt. Continuous Current Density**	**max. Continu-ous Current Density**	**Short Term Overload**
Metal containing (30 – 75%)	12	15 – 20	25	40
Metal containing (above 75%)	15	25 – 30	35	50
Electrographite	4	10 – 12	16	30
Resin Bonded Graphite	1	6 – 8	10	14
Pitch Bonded Graphite	3	6 – 8	10	12

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The number of carbon brushes should, if possible, be matched in such a way that the current densities are in the range of the above mentioned optimal range. This will create optimal brush running behaviour, due to low electrical losses, low friction and low commutator temperature values.

2. Peripheral Speed

The peripheral speed of DC motors is mostly within a certain range, which is for most of the common carbon brush grades non-critical. Only on so-called „fast-drives“ as are e.g. employed on test benches for the automobile industry, and where peripheral speeds of up to 60 m/s exist, accommodation measures regarding choice of grade and design are necessary.
For slip-ring applications the speeds are a decisive aspect for the choice of grades and design. Generally for speeds above 50 m/s only „black“ grades should be used. The grade group depends on the prevailing electrical load. Slots in the contact surface to avoid aerodynamic effects, have a positive impact. This design detail is generally provided by us as well for metal containing grades and circumferential speeds above 25 m/s.

3. Electrical and Mechanical Losses

The temperature increase of electrical drives will be determined through the electrical and mechanical losses. Those relations are important e.g. with the low-voltage-motors for fork lift drives. There it matters, that the battery voltage is optimal transferred into motor power and the electrical losses are kept to a minimum. Actually those relations play an important role, e.g. with carbon/carbon slip-ring assemblies for wind-powered generators.
The mechanical losses are directly related to the contact pressure, the circumferential speed, and the friction coefficient, i.e. change of one of those factors has a direct influence on the amount of the loss.
The friction coefficient is directly dependent on the contact pressure. Generally it increases with increased pressure. Therefore doubling of the contact pressure has mostly more than double of the power loss as a consequence.

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Using the actual example of the wind-powered generator, we had great problems with excessive heat increase. Those heating problems could positively be influenced through the use of carbon grades with a low friction coefficient, and a low voltage drop.

4. S – Factor

The S-Factor gives information about the heat, which can be dissipated at the commutator or slip-ring surface. No other property of the brush is taken into account.. The factor is given in surface area per current. As smaller the S-factor, as more problems due to overheating may arise. The S-factor does not usually arise in the case of commutator machines as it is outweighed in brush grade selection by other factors – principally commutating and collecting capability.
The S factor rules are meant as to serve as a guide line to grade selection only !

Kind of motor	**Ventilated**	**Closed**
DC Motors		
Large DC motors > 250kW	3,5 – 5	5 - 7
Small DC motors 1 – 250kW	6 – 10	9 – 12
Slip rings		
Bronze rings	0,5 – 2	1 – 3
Steel rings	1 – 3	2 - 4

The next table shows guide line values of the S-factor for some brush grades for slip rings.

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Kind of motor	**Ventilated**	**Closed**
Electro Graphite	>1	>1,2
Metal Graphite (40-50%)	0,9	1,1
Metal Graphite (60-70%)	0,5 – 0,8	0,7 -1
Metal Graphite (>85%)	0,4	0,6

5. Especially for slip rings

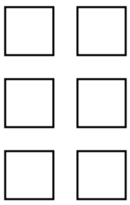
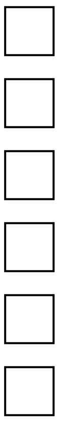
An important determining factor for slip rings is the heat dissipation of the electrical and mechanical losses. .

Two more parameters must be taken into consideration, in order to get a precise idea of the capacity how to dissipate heat with a given brush arrangement.

The concept of the coverage rate is complementary to the S Factor. Both values are intrinsically tied to each other. If the S-factor is within the given tolerance, the brush arrangement has still to be defined, to get an optimal film formation and brush performance.

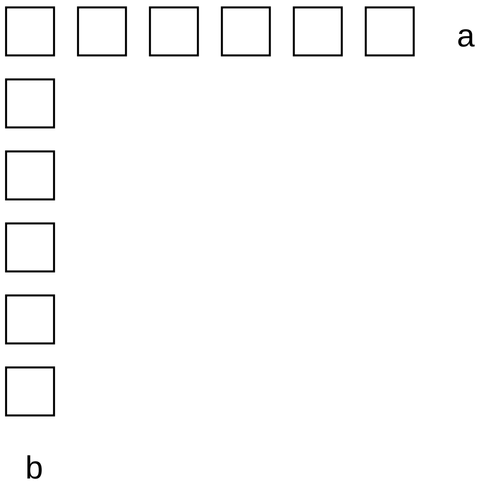
5.1. Peripheral coverage ratio Fp

That ist he ratio of slip ring covered by the brushes along the tangential direction and the total slip ring periphery.

		*Example: 6 brushes / Ring* *t-dimension = 40mm* *diameter 300mm* It would be optimal to arrange brushes in two tracks with 3 brushes each. This will increase the S factor and improve the peripheral coverage ratio.
$Fp = \frac{3 * 40}{\pi * 300}$ = 12,7%	$Fp = \frac{6 * 40}{\pi * 300}$ = 25,7%	

5.2 Total coverage ratio Ft

That ist the ratio of slip ring covered by brushes and total slip ring surface area.



Example

Number of brushes q = 6
Diameter D: 300mm
Slip ring Width 100mm
t-dimension 40mm
a-dimension 20mm

$$Ft = \frac{6 * 40 * 20}{\pi * 300 \, x 100} = 4{,}2\%$$

Guide line values:

- Ft < 15% is optimal
- If Ft between 15% und 20% higher surface temperature may arise.
- If Ft > 20% heavy brush problems can be expected.
- The same is for Fg > 15%

These guide line data have a special importance for the design of slip ring drives. Later in the field design changes are impossible.

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Formula	Example
Spec. Current Density DC Motors	
$$S = \frac{I}{(N/2) \times t \times a}$$ I = Current [A] N = Number of Carbon Brushes t = Tangential Dimension [cm] a = Axial Dimension [cm}	1000 A – 6 pole 5 cb's each, i.e. 30 brushes, i.e. calculation with 15 brushes 20 x 32 x 50 mm³ $$\frac{1000A}{15 \times 2cm \times 3.2cm} = 10.4A/cm^2$$ 1000A - 4 pole 5 ea. **Tandem Brushes** , i.e. 20 brushes, calculation with 10 brushes 12,5 x 32 x 50mm³ Tandem Brushes i.e. total dimension - t – is 25mm $$\frac{1000A}{10 \times 2{,}5cm \times 3{,}2cm} = 12.5A/cm^2$$

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Formula	Example
Spec. Current Density Slip-Rings	
$$S = \frac{I}{N \times t \times a}$$ I = Current [A] N = Number of Carbon Brushes t = Tangential Dimension [cm] a = Axial Dimension [cm}	Turbogenerator 1000A - 2 rings with 10 cb's each , i.e. calcu-lation with 10 brushes – 32 x32 x64mm³ $$\frac{1000A}{10 \times 3.2cm \times 3.2cm} = 9.7A/cm^2$$ Asynchronous-Slip-Ring Drive 500A - 3 rings 5 cb's, i.e. calculation with 5 brushes – 40 x 20 x 40 mm³ $$\frac{500A}{5 \times 4cm \times 2cm} = 12.5A/cm^2$$

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Formula	Example
Circumferential Speed	
$$v = \frac{\pi \times d}{1000} \times \frac{n}{60}$$ d = Diameter [mm] n = Revolutions [rpm] π = Circular Number = 3.14	350mm Diameter – 1500 Revolutions/min $$\frac{3.14 \times 350mm}{1000} \times \frac{1500 \min^{-1}}{60} = 27.5m/\sec$$
Mechanical Losses	
$$Vm = \frac{\mu \times N \times t \times a \times p}{10000} \times v$$ μ = Friction Coefficient N = Number of Brushes t = Tangential Dimension [mm] a = Axial Dimension [mm] p = Specific Pressure [cN/cm²] v = Circumferential Speed [m/sec]	E101 – Friction Coefficient 0,11 – 4 pole with 3 cb's 16 x 25 x 50 mm each – 180cN/cm² - 350mm Diameter - 1500 Upm $$\frac{0{,}11 \times 12 \times 16mm \times 25mm \times 180vN/cm^2}{10000}$$ $$x27{,}5m/s = 26\frac{Nm}{s} = 260W$$

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Formula	Example
Electrical Losses **DC Motors**	
$Ve = 2 \times I \times U_{ü}$ I = Current [A] $U_{ü}$ = Voltage Drop per Brush [V]	Current 230A - E101 Voltage Drop per Brush 1.25V Ve = 2 x 230A x 1.25V = 535W
Electrical Losses **Slip-Ring Drives**	
$Ve = I \times U_{ü}$	Current 230A A12S – Voltage Drop per Brush 0,6V Ve = 230A x* 0.6V = 138W
Total Losses	
Vt = Vm + Ve	Above Examples for DC Motors Vt = 261W + 535W ≈ 800W

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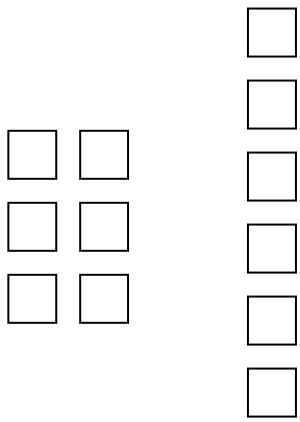
S-Factor	
$$S = \frac{\pi * D * W}{I}$$ D = Slip ring/commutator diameter [cm] W = Width of the ring [cm] I = Current per ring [A]	Diameter : 150mm Width: 50mm Current 1000A $$S = \frac{3.14 * 15 * 5}{1000}$$ $= \frac{235,5}{1000}$ = 0,23
Peripheral coverage ratio Fp	
$$Fp = \frac{c * t}{\pi * D}$$ C = Number of brushes behind each other along the periphery t = t-dimension D = Diameter	 C = 3 c = 6 Diameter : 300mm t-dimesnsion 40mm $Fp = \frac{3 * 40}{\pi * 300}$ $Fp = \frac{6 * 40}{\pi * 300}$ = 12,7% = 25,7%

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<tr><th>Total coverage ratio Ft</th><th></th></tr>
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$$Ft = \frac{q * t * a}{\pi * D * W}$$

q = Number of brushes
t,a = brush dimensions
D = Slip ring diameter
W = Width of slip ring

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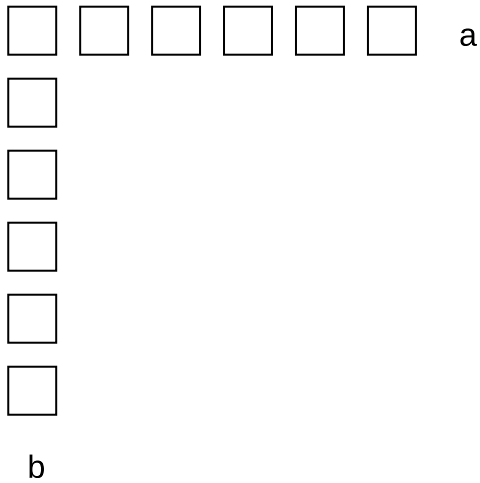

Number of brushes q = 6
Diameter D: 300mm
Width W: 100mm
t-dimension 40mm
a-dimension 20mm

a) $Ft = \frac{6 * 40 * 20}{\pi * 300 x 100}$ = 5,1%

Fp = 4,2%

b) Ft = 5,1 %

Fp = 25,5%

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