TECHNICAL DATA SHEET

The Functions Of A Good Brush: What You Should Know

01 – A "GOOD BRUSH"

A 'Good Brush' is one that is best matched to the machine. It is the best compromise because, whether we like it or not, it is a part that is subject to wear.

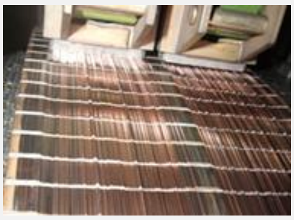
A good brush must have a set of properties, some of which are more important than others, that can be reduced to two essential qualities:

- **Moderate wear of the brush:** excessive wear would require increased monitoring of the machine, particularly due to the risk of reduced internal insulation resistance, would require high maintenance costs, and there is also a risk of malfunctions due to an abnormally low thickness of the patina (film) on the commutator / slip ring.
- **Respect for the commutator or slip ring:** repair costs for a damaged commutator or slip ring are always high, and can cause unexpected and long term shutdowns of the machine.

02 - DAMAGE TO THE COMMUTATOR OR SLIP RING

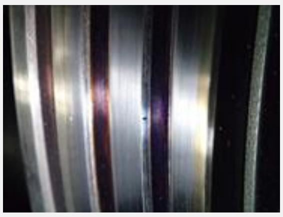
The most frequent causes are:

- **Metal wear by mechanical abrasion**, due to:
  - excessive abrasiveness of the brush material
  - a load below the minimum
  - or a temperature below the minimum
  - too low a spring pressure



P14 – Raw grooved commutator

- **Abnormal temperature rise,** beyond the limits imposed by the manufacturer, and exceeding the temperature at which the material of the commutator or the slip ring was stabilized



P42 – Oxidation of the metal

- **Metal burns** by frequent sparks or electric arcs, that can cause local or repetitive deformations, in a pattern which may or may not be related to the slot pitch or the pole pitch

B6 – Spark burn at bar edges

GENERAL

A brush is an **electrical conductor** subject to friction: therefore, it is a mechanical and electrical device that has the function of transferring a current, which may be very variable, between the rotating part of a machine and its fixed external power supply or load circuit.

The brush works correctly within a fairly wide or narrow range of speeds and electrical loads, the limits of which depend on the material (grade) and the assembly.

Choosing a brush for an application consists of best matching its mechanical and electrical properties to the conditions of the machine.

The material of the commutator or slip ring itself must have suitable friction properties, because it forms a pair together with the brush.

03 - SPARKS (electrical arcing)

Regardless of the source, sparking is always a potential problem since it is a damaging form of the electrical energy that increases the temperature far above the melting temperature of the metal of the rotating surface.

The effects of sparks increase with:
- Increasing decay energy, in other words with increasing self-inductance of the armature
- Decreasing decay time, in other words as the machine speed increases
- Decreasing surface area available to the spark, in other words as the number of brush contact points on the commutator / slip ring decreases

Effects and notation of sparks are disclosed in our Technical Note TDS-14 "Brush sparking".

The spark is always caused by an excessive voltage difference between the brush and the commutator / slip ring, resulting from a break in the electrical contact between the friction surfaces.

Direct causes may be:

- MECHANICAL:
  with abnormal, disordered and chaotic contact breaks caused by shocks or vibrations due to unstable and insufficient dynamic balancing of the brush on the commutator / slip ring
- ELECTRICAL:
  - Insulation fault in coils
  - Bad quality of voltage / current of the power supply (electronic power converter)
  - For DC machines: with abnormal, necessary and inevitable contact breaks caused by the passage of the segments under the brush, or incorrectly adjusted commutation (neutral line setting, equidistance of brush-holder arms, tangential brush covering, brush grade…)

Therefore in order to attenuate or eliminate sparking, accidental contact separations must be avoided, and/or the voltage drop between the brushes and sliding surface has to be limited.

A good brush has the following two main properties:
- **Dynamic stability**, requiring:
  - Stable and moderate friction
  - High capacity to absorb shocks and vibrations
- Sparks resistance, and, for a DC machine, commutating **ability**, can be defined as the capability of the brush to reverse the current without producing any sparks dangerous to the commutator (see criteria defined in TDS-14).

04 - COMMUTATION (DC machine)

Commutation refers to all electrical phenomena related to reversing the current in the armature coil being short-circuited by the brush during the transfer time for one segment to move across the thickness t of the brush. By definition, this transfer time is called the **mechanical commutation time**.

Reversal time

The current reversal time may be greater than, equal to or less than the mechanical commutation time, depending on the reactance voltage e_r, the voltage on auxiliary poles e_S and the voltage drop at the contact surface under the brushes ΔUc.

The reactance voltage reduces the reversal speed; on the other hand, the compensation voltage induced by the auxiliary poles increases the reversal speed.

As the difference between the reversal time and the commutation time increases,

- the difference in the voltage between the brush and the commutator / slip ring segment increases,
- and commutation sparks become more dangerous.

When the **reversal time is too long**, an under-commutation condition occurs and sparks appear at the **brush output**.

When the **reversal time is too short**, an over-commutation condition occurs and sparks appear at the **brush input**.

Under-commutation: $\Delta U_c + e_s < e_r$
Over-commutation: $\Delta U_c + e_s > e_r$
Linear commutation: $\Delta U_c + e_s < e_r$

Voltage drop at the contact under the brush

The voltage drop at the contact under the brushes ΔUc, forms a resistance to the passage of commutation currents; it has a damping effect that is small compared to that provided by the auxiliary poles. In other words, **compensation by the brush is complementary to the compensation provided by the auxiliary poles**.

The value of voltage drop depends not only on the brush material but also on the current density, the temperature and the applied pressure, the peripheral speed, the polarity and the condition of the surfaces in contact (skin and brush contact surface), the material of the commutator or slip ring, etc.,

The contact voltage drop of a brush that is commutating correctly shall be moderate to avoid any abnormal temperature rise and any degradation of the sliding contact performance due to the electrical losses (for calculation of losses, see TDS-05).
Moreover it has an influence on the commutation and current balance between brushes. It must satisfy three main conditions:

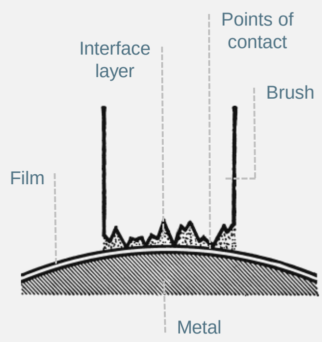
- relatively high
- gradually increasing as a function of the current in the brush
- stable with time and not very dependent on temperature.

These three conditions actually express that the distribution of points through which the current passes, should be uniform and stable over the entire friction surface of the brush; this is a fundamental theoretical condition for good commutation. It is also confirmed by the appearance of the film (regular and uniform), which always faithfully reflects operating conditions and the commutation quality; the first thing to do when searching for brush problems is always to inspect the film.

05 - FILM

Inspection of the film is necessary for the diagnostic of the “state of health“ of your rotating electrical machine. You can refer to our Technical note TDS-13 “Film aspects" which sets out various common and typical aspects of film conditions and commutator / slip ring faults, and their signification.

The film is a complex mixture which is deposited on the commutator / slip ring. Its stability depends on the balance of its components.



Its three main components are:

- **carbon** (mainly graphite)
- **water** (from humidity of the air)
- **metal oxides**.

PURPOSE OF THE CONSTITUENTS OF THE SKIN

The moisture in the environment, and the carbon (graphite) deposited by the brush maintain friction within allowable limits, and consequently ensure that the brush mechanical behavior is satisfactory.

Metal oxides (copper or ferrous) formed and regenerated from the sliding surface and the oxygen in the air are responsible for the physiochemical stability of the film. Satisfactory electrical and mechanical behavior of the brush depend on this compound formed by metal oxides and deposited graphite.

Thus **the importance of the graphite deposit** controls the appearance of the film, and also defines the **limits of the electrical load and the speeds between which the brush works correctly**.

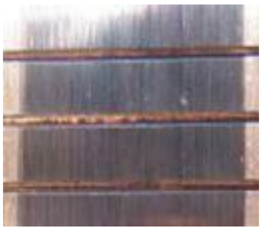
An **abundant** graphite deposit gives a dark, shiny film suitable for operation at no load during long periods, but which is not appropriate for machines with difficult commutation, or which are highly loaded.

A **small** deposit of graphite gives a light, thin, slightly satin and relatively fragile film, suitable for difficult commutation with severe and frequent overloads. However this type of film is not suitable for very low loads, or no load operation, when frequent and/or prolonged.

FIRST ASSESSMENT FROM THE FILM

It may be considered that a thin and light **P4** type film (note TDS-13) indicates:
- moderate friction
- good commutation
- low temperature rise in the commutator / slip ring

This is an "ideal" film.


P4

An excessively **thin film** type **P2** can indicate:
- high friction
- very low brush wear

This film tends to develop towards a **P12** type film, with preferential transfer of current and wear of commutators / slip rings.


P2

A thick, dark and glossy film type **P6** suggests:
- moderate friction
- moderate brush wear
- very small commutator / slip ring wear

If the film evolves to an excessively thick, very dark and matt film, it will be a symptom of:
- high commutator / slip ring temperature rises
- poor commutation (sparking)
- possible burn marks on segments or rings
- high brush wear


P6

Note: The graphite content of a film is therefore a very important factor in correct operation of a brush.
It depends particularly on:
- the brush grade (constituents, process),
- the roughness of the commuator / slip ring (see TDS-02),
both conditionning the development and maintenance of the skin.

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Expertise, our source of energy

06 - BRUSH GRADE MANUFACTURING

THE BRUSH MANUFACTURER HAS THREE INDEPENDENT VARIABLES (CONSTITUENTS, AGGLOMERATION AND TREATMENTS) THAT CAN BE ADJUSTED WHEN SELECTING OR CREATING A BRUSH GRADE FOR A GIVEN APPLICATION.

CONSTITUENTS

Graphite is the common constituent of all our brush grades. It is a crystalline compound of carbon layers. Each layer is composed of sheets of carbon atoms assembled in a hexagonal pattern (also called graphene layers). These layers can slide between each other conferring solid lubricant property to graphite.

You can refer to our Carbon Brush Technical Guide which defines and explains the main constituents and their origin for each grade family.

AGGLOMERATION OF CONSTITUENTS

Constituents are agglomerated with carbonated binders which, after baking, leave a solid residue of carbon bonds between the grains of the basic constituents.

As the quantity of the binder added into the mixture increases, the bonds become more numerous and the brush becomes “harder”. Conversely, if the amount of this binder is reduced, the number of bonds is reduced and the product becomes “softer”.

“Hard” brushes have low internal damping capacity (high Shore), they generally produce low wear but do not adapt satisfactorily to fast machines.

On the other hand, “soft” brushes have high internal damping (low Shore) and adapt well to fast machines, but normally at the price of higher wear.

TREATMENTS

Treatments are impregnations which take place after thermal treatment. They consist of inserting dissolved or molten foreign elements into the brush porosity, in order to correct at least one of the basic characteristics of the material.

There is a very wide variety of impregnation products, but very few are used frequently, and they can be grouped into two sets:

- Polymerizable resins used to control the patina ("polishing power") or provide the moisture necessary to lubricate friction surfaces when the ambient air is relatively dry; these resins always increase the mechanical characteristics of the brush material and are adapted to higher pressures
- Metals may also be added into the brush in the form of metal salts, or in the molten state in order to reduce the voltage drop at the contact and to increase the allowable specific load, while maintaining the advantages of the basic material’s resistance to wear.

> **Note:** All treatments that tend to increase the patina thickness also reduce the brush commutation ability. Therefore these treatments should be used with caution.

Mersen has developed a wide range of brush grades to meet even the most demanding applications. We recommend you to contact the Customer Technical Assistance Service to correctly select the most suitable grade for your specific application. To help us please fill the description form page 32 of our “Carbon brushes for motors and generators” technical guide.

07 - BRUSH SHAPES AND MOUNTING

Shapes and mountings, in other words special brush machining features and the various methods of fixing accessories such as cables, rivets, plates, limit stops, etc. have been designed and made so as to guarantee:

- High brush stability even at maximum speeds, provided that commutator cylindrical defects, segment deformations, shocks and vibrations and brush-holder imperfections remain within allowable limits
- Good contact with the external circuit during the entire life of the brush, without a risk of slow deterioration (aging) or fast deterioration (ruptures) under the effect of heating and vibrations.

In order to satisfy the changing dynamic conditions a stable brush-holder mounting must:

- Guarantee good contact between the brush and the commutator through many stable and uniformly distributed support points across the entire contact surface
- Provide uniform distribution of the bearing force provided by the brush-holder pressure system, to ensure that the pressure remains constant on the friction face (see TDS-11)
- Guarantee fast and efficient damping of shocks and vibrations

MAKE PERIODIC CARBON BRUSH PRESSURE MEASUREMENTS

THREE PRINCIPLES ARE USED TO ACHIEVE THESE THREE RESULTS:

Symmetrical shapes

The most rational shape for a motor rotating in two directions is the **straight brush (radial type)** because it is symmetrical.

Correct operation of the radial brush in both directions obviously assumes low clearance between the brush and the brush-holder (specified in our TDS-04), in order to limit the effect of the brush tipping inside its holder whenever the direction of operation is reversed. It is preferable to use multiple wafers, generally 2 or 3 depending on the commutator geometry.

An asymmetrical inclined brush will be more stable for one rotating direction ("trailing" position) than for the other; therefore such a brush shape shall be used for a machine operating with only one rotating direction.

American manufacturers tend to favor **inclined brushes**, typically inclined at 14 degrees for a unidirectional machine (trailing) and 25-30 degrees for a bi-directional machine.

Inclined brush

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Division of the brush

Split brush

On a high speed DC machine, the single wafer brush has to be replaced by assembly consisting of two or three equal, parallel and mutually independent wafe where each wafer is electrically independent and has its own cables in order to impro mechanical and electrical contact on the commutator / slip ring.

This increased mounting complexity is compensated by improved commutation a lower brush wear.

Subdivision of the brush is limited only by the minimum allowable thickness, whi controls:

- The strength, and consequently whether or not cables can be fixed in the wafer
- The machining complication which affects the price of the brush

Particular attention shall be paid when mounting a split brush. It is important that:

- Wafers shall be pressed down to the commutator / slip ring by the means of a resilient pad which uniformly distributes the force of the pressure system (threaded on the flexibles or glued, design depending on the pressure system)
- The resilient pad shall allow a slight movement of the brush wafers relative to each other so that some wafers always remain in contact with the commutator / slip ring regardless of its out of round (within reasonable limits).

> **Note:** In addition, for a DC machine, one shall consider the coverage rate, which is the number of bars spanned by the burh in tangential direction (calculated from the bar pitch and number of bars per slot). This number shall not be an integer, to limit any mechanical resonance.

Damping

On a high speed and poorly balanced machine, shocks and vibrations transmitted to the brush by moving masses must be efficiently dampened.

This is why high impedance and stable (in other words not sensitive to aging under the effect of temperature and/or time) **shock absorbing elements** are adapted to the brush.

Brush with shock absorber plate

These damping systems are elastomers and fixed to the top of the brush, most frequently by gluing (see picture). Threading on two (or more) flexible is also possible.

Furthermore, it is a good idea to fit a hard insulating plate on the damper, which will:

- prevent the pressure system from damaging the elastomer
- and uniformly distribute the thrust of the brush pressure system spring on the top of the brush

Finally and if necessary, the plate could maintain the pressure system in a fixed position, due to an appropriate design of the pad (for instance: hole - see picture).

Note: Vibrations transmitted to the brush and which need to be damped, lie within a wide range of frequencies and amplitudes. In principle, high frequency and low amplitude vibrations are damped using the same material as the brush, due to its elastic or plasto-elastic deformation capabilities.
However, **low frequency and high amplitude vibrations are absorbed in the brush shock absorbers**.

MERSEN SERVICES

Benefit from the knowledge and experience of Mersen's experts for any motor inspection, maintenance or training requirement:

- Measurements and diagnostics
- In-situ machining and refurbishment of your slip ring assemblies and commutators
- Technical advice to help you maximize the efficiency of your equipment and minimize your operating and maintenance costs
- Retrofit solutions

FOR ADDITIONAL INFORMATION PLEASE REFER TO OUR "CARBON BRUSHES FOR MOTORS AND GENERATORS" TECHNICAL GUIDE, AVAILABLE FROM OUR WEBSITE WWW.MERSEN.COM.

Mersen supplies maintenance tools and devices. Read our brochure « *Tools & devices for the maintenance of electric machines* ».

These documents are available on our internet web site **WWW.MERSEN.COM**.

Our Customer Technical Assistance Service is at your disposal for any question:

E-mail: info.ptt@mersen.com

List of citations:
IEC 61015/TR: "Brush-holders for electrical machines – Guide to the measurement of static thrust applied to brushes"
Mersen Maintenance Guide : "How to maintain carbon brushes, brush-holders, commutators and slip rings"
TDS-02: Condition of the surface of commutators and slip rings - Roughnesss
TDS-04: Dimensions of carbon brushes and brush-holders
TDS-11: Pressure on carbon brushes
TDS-13: Aspects of commutator skins
TDS-14: Brush sparking