ISO 9001

The FUNCTIONS of a GOOD BRUSH

What you should know

GENERAL

Definition

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, that 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** 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 machine itself must have suitable friction properties; this is particularly true for the commutator that is in contact with the brush.

A GOOD BRUSH

Functions of a good brush

"Best match" means choosing the best possible compromise: the brush, whether we like it or not, is a part which 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 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 on the commutator;

❒ respect for the commutator: repair costs for a damaged commutator are always high, and can cause unexpected and longterm shutdowns of the machine.

Damage to the commutator

The most frequent causes of damage to commutators 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,

❒ abnormal temperature rise beyond the limits imposed by the manufacturer, and exceeding the temperature at which the commutator was stabilized,

❒ 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.

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SPARKS

Regardless of the source, a "hot" spark 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 copper.

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 reduces.

The spark is always caused by an excessive voltage difference between the brush and the commutator 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,
- ❒ ELECTRICAL with abnormal, necessary and inevitable contact breaks caused by movement of the segments under the brush.

A spark caused by electrical phenomena is called a commutation spark.

Therefore in order to attenuate or eliminate sparking, accidental contact separations must be avoided, and/or the voltage difference between the brushes and commutator segments 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;
- ❒ **commutating capacity**

  that can be defined as the capacity of the brush to cut off the current without producing any sparks dangerous for the commutator.

COMMUTATION

Commutation refers to all electrical phenomena related to reversing the current in the armature cross-section short-circuited by the brush during the transfer time for one segment gap to move across the width **t** of the brush. By definition, this transfer time is the commutation time.

The current inversion time may be greater than, equal to or less than the commutation time, depending on the reactance voltage e_r, the voltage on auxiliary poles e_s and the voltage drop at the contacts under the brushes ΔU.

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

As the difference between the inversion time and the commutation time increases, the difference in the voltage between the brush and the commutator segment increases, and commutation sparks become more dangerous.

When the inversion time is too long, a sub-commutation condition occurs and sparks appear at **the brush output**.

When the inversion time is too short, a super-commutation condition occurs and sparks appear at **the brush input**.

Commutation is said to be "linear" when the auxiliary poles, assisted by the voltage drop at the contact under the brushes, exactly compensate for the effects of the reactance voltage, and no sparks occur on the brushes.

These three commutation states are represented by the following three relations between ΔU, e_s, e_r:

$\Delta U + e_s, < e_r$	sub-commutation
$\Delta U + e_s, > e_r$	super-commutation
$\Delta U + e_s, = e_r$	linear commutation

Voltage drop at the contact under the brush

The voltage drop at the contact under the brushes ΔU_S, the value of which depends not only on the brush material but also on the current density, the temperature and applied pressure, the speed, polarity and condition of the surfaces in contact and therefore the condition of the patina, etc., form a resistance to the passage of commutation currents; it forms a damping effect, but which is always small compared with that at auxiliary poles.
In other words, **compensation by the brush is complementary to compensation by auxiliary poles, but will never replace it**.

The voltage drop at the contact of a brush that is commutating correctly must satisfy three main conditions. It must be:

- ❒ 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 patina, 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 patina.

The PATINA

The patina is what could be considered as the epidermis of the commutator (or of the rings).
Its stability depends on the balance of its component elements.

A patina is formed of three main components:

- ❒ carbon (graphite),
- ❒ water,
- ❒ metal oxides.

Purpose of constituents

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 behaviour is satisfactory.
Metal oxides (copper or ferrous) formed and regenerated from the commutator metal and the oxygen in the air are responsible for the physiochemical stability of the patina.
Satisfactory electrical and mechanical behaviour 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 patina, 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 patina 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 patina, suitable for difficult commutation with severe and frequent overloads, however this type of patina is not suitable for very low loads, or for frequent and prolonged operation.

It may be considered that a thin and light P4 type patina (note STA AE 16-31) indicates:

- ❐ moderate friction,
- ❐ good commutation,
- ❐ low temperature rise in the commutator,

this is an "ideal" patina.

A thick, dark and glossy patina type P6 indicates:

- ❐ moderate friction,
- ❐ moderate brush wear,
- ❐ very small commutator wear.

An excessively thin patina type P2 can indicate:

- ❐ high friction,
- ❐ very low brush wear,
- ❐ a tendency to develop towards a type P12 patina, with preferential transfer of current and wear of commutators.

An excessively thick, very dark and matt patina type P7 or P8 indicates:

- ❐ high commutator temperature rises,
- ❐ bad commutation (sparking),
- ❐ possible burn marks on segments or rings,
- ❐ high brush wear.

The graphite content of a patina is therefore a very important factor in correct operation of a brush. It depends on the roughness of the commutator which depends on the brush material, and also partly depends on the product manufacturing method.

MANUFACTURE of BRUSHES (ELECTROGRAPHITIC)

The brush manufacturer has three independent variables (constituents, agglomeration and treatments) that he can adjust when he wants to create a brush for a given application.

Constituents

"Amorphous" carbon appears in a wide variety of forms distinguished from each other by their behaviour and the relative ease or difficulty with which they are transformed into well-crystallized graphite by heat treatment at high temperature.

Varieties of amorphous carbon can be grouped into two distinct groups:

- ❐ "oil coke" type graphitable carbons which are easily transformed into artificial graphite, and in high proportions. They deposit relatively large quantities of graphite by friction and are consequently suitable as basic constituents for brushes which are to form rich patinas to be used on machines with low loads;
- ❐ only slightly graphitable carbons such as "smoke black" transform into artificial graphite with difficulty, and in low proportions. They deposit little graphite by friction and are consequently suitable as basic constituents of brushes with a weak patina intended to be used on machines with difficult commutation.

Combinations of the constituents of these two groups in variable proportions give "intermediate" brushes, which are capable of adapting to no load operations and to overloads.

Agglomeration of constituents

Constituents are agglomerated with carbonated binders which, after distillation and cokefaction, leave a solid residue of carbonated 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 slow 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 graphitation. They consist of inserting dissolved or melted foreign elements into the brush porosity, in order to correct 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 three sets:

- ❒ **fatty bodies** including mineral oils, waxes, paraffins, etc., in order to momentarily reduce the friction of a brush and to protect the patina against the aggressive action of chemical pollutants in suspension in the ambient air;
- ❒ **polymerizable resins or varnishes** used to strengthen the polishing power of a brush, to control the patina or provide the moisture necessary to lubricate friction surfaces when the ambient air is relatively dry; these resins or varnishes always harden the brush material and frequently require higher pressures;
- ❒ **metals** may also be added into the brush in the form of metal salts, or in the molten or pressurized 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 that all treatments that tend to increase the patina thickness also reduce the brush commutation capacity. Therefore these treatments should be used with caution.

BRUSH SHAPES and MOUNTINGS

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 and provided that commutator cylindricity defects, segment deformations, shocks and vibrations and brush holder imperfections remain within allowable limits;
- ❒ the good quality of electrical links 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 dynamic balancing conditions, a good mounting must:

- ❒ guarantee good contact between the brush and the commutator through many stable and uniformly distributed support points across the entire bearing surface,
- ❒ provide uniform distribution of the bearing force transmitted by the brush holder push rod, to ensure that the pressure remains constant on the friction face,
- ❒ guarantee fast and efficient damping of shocks and vibrations.

Three principles are used to achieve these three results:

Symmetrical shapes

The only rational shape for a fast motor rotating in two directions is the straight brush (radial type) because it is symmetrical; an inclined asymmetrical shaped brush is more stable for one direction of rotation than for the other, and is usually only used on machines with only one direction of rotation.

Correct operation of the radial brush in both directions obviously assumes low clearance between the brush and the brush holder, 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 twin brushes (2 or 3 strips) for the same reasons.

Division of the brush

On a fast machine, the single piece brush has to be replaced by a hinged assembly consisting of two, three (or even four) equal, parallel and mutually independent strips, where each strip is electrically independent and has its own current input cables in order to improve mechanical and electrical contact on the commutator.

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

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

❒ the strength, and consequently whether or not cables can be fixed in the strip,

❒ the minimum "coverage" condition on the commutator which corresponds to approximately two segment widths for one strip,

❒ the machining complication which affects the price of the brush.

Damping

On a fast and badly 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 sensitive to aging under the effect of temperature or time) shock absorbing elements are adapted to the brush.

These damping systems are fixed to the top of the brush, most frequently by gluing. Elastomers are used.

Furthermore, it is a good idea to fit a hard insulating plate on the damper, which will prevent the push rod from perforating the elastomer and especially will uniformly distribute the thrust of the brush support spring on the brush head.

Finally and if necessary, the plate must maintain the push rod in a fixed position, due to an appropriate recess machined in the middle of the plate.

Note that 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.

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