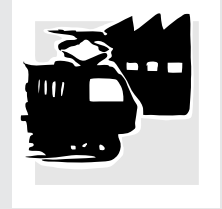


Carbon Brushes for Industrial and Railway Application



Refitting and maintenance of heavy electrical machines

Careful selection of the grade of carbon brushes and of brush design do not guarantee satisfactory operation of carbon brush equipment.

Perfect current transmission is only possible when the commutators and slip rings are in good condition and the insulation bars between segments are correctly undercut.

Besides ensuring a certain amount of care and maintenance during operation, there are several points which require particular attention, especially when making replacements, and these are dealt with in detail in the following sections.

The surface condition of commutators and slip rings

Out-of-roundness of collectors (eccentricity)

Flat spots, segments which protrude or are too low, flaws etc. – in short, all deviations from circular form, whether they occur during skimming or grinding, or during operation – are designated out-of-roundness.

They cause violent brush movement and sparking especially at high circumferential speeds. This results in increased out-of-roundness, greater wear of the carbon brushes, and, in some circumstances, severe damage to commutators, rings and carbon brushes.

With the SCHUNK Motorscope® Schunk Kohlenstofftechnik provides an instrument for the measurement of commutator and slip ring profiles. The device enables the detection of collector failures

and bar-to-bar distances even with full motor potential.

Figure 1 shows a long-wave out-of-roundness with an excessive bar-to-bar distance. It is difficult

Figure 1

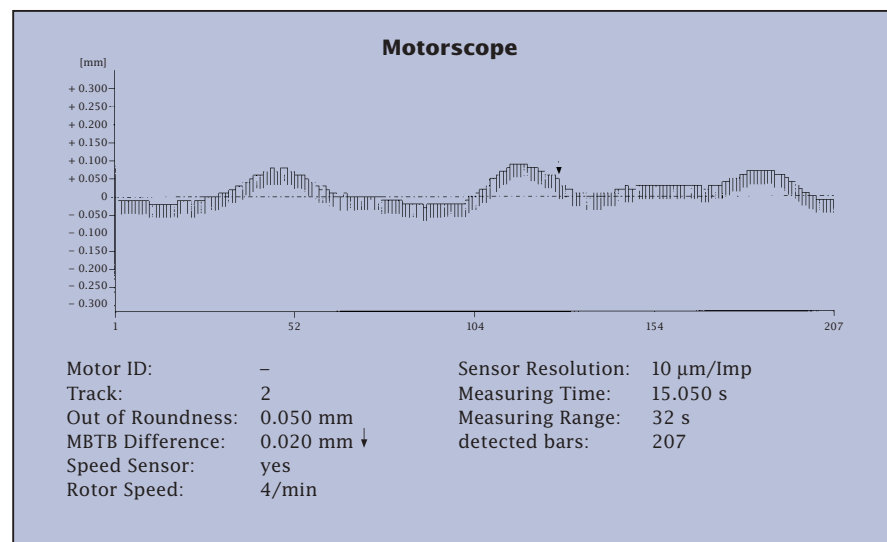
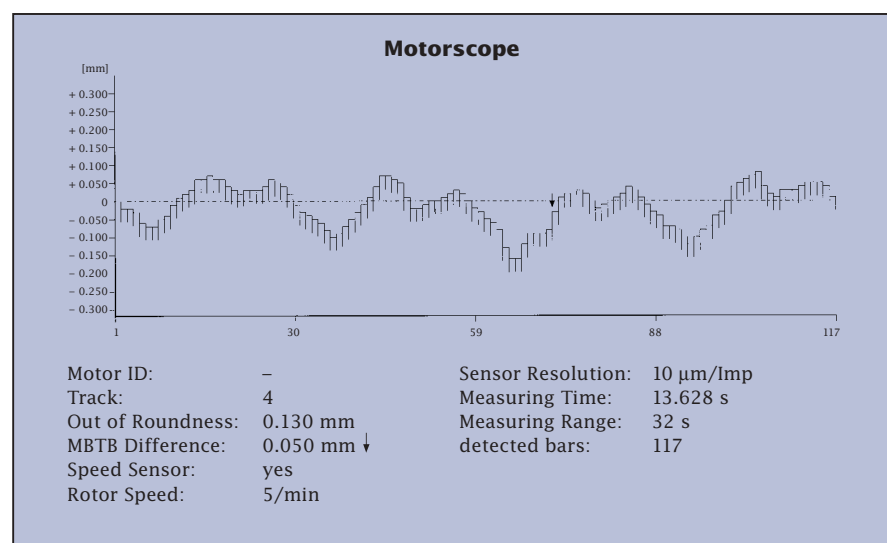
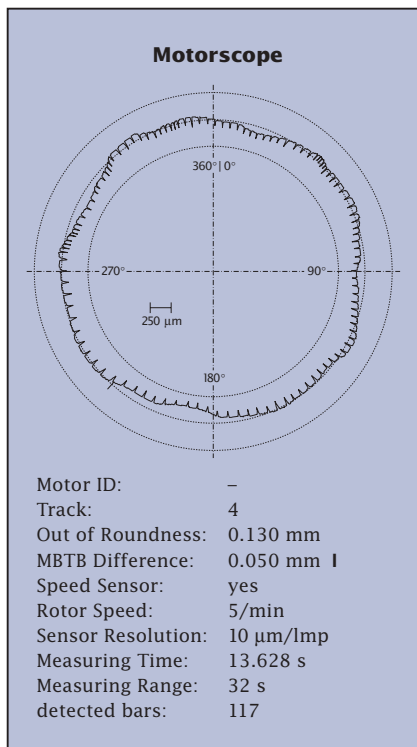


Figure 2



to give general guide-line values for the out-of-roundness. They depend on the frame size, the peripheral speed, the electrical loading and the number of brushes connected in parallel.

Figure 3



As a guide in the case of mean circumferential speeds, a total out-of-roundness of 0.1 mm should not be exceeded and a difference in height of 0.01–0.03 mm between adjacent segments should be regarded as the limit.

The value for the maximal permitted bar-to-bar distance depends on the frame size and the peripheral speed. Misinterpretations due to mechanical shocks, pollution of the collector surface, and tolerances of the bearing are not possible at measurements with the SCHUNK Motorscope®.

An increase in wear rate of the carbon brushes and damage on

the commutator or slip ring surface are most likely if the roundness goes like figure 2.

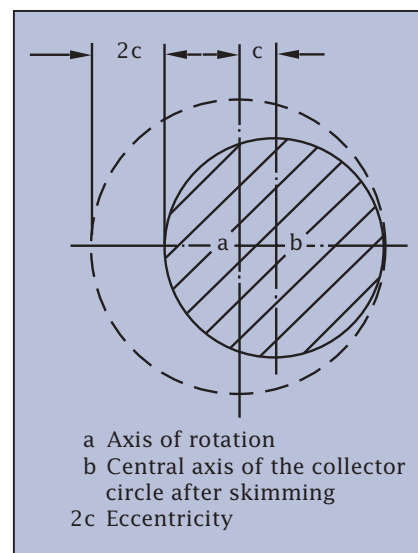
Figure 3 shows an alternative graph which enables the fast detection of ovality and other surface failures like flat spots etc.

It is important if possible to carry out measurement of out-of-roundness when the commutator is warm after operation and also when it is cold since thermal deformations such as may exist especially in the case of smaller highly-stressed commutators are then also detected. If thermal deformation is found, it must be removed first before skimming or grinding, i.e., the commutator must be stabilised thermally.

Collector runout

Collector runout is referred to when, in the case of circular surfaces or even non-circular collectors, the axis of rotation is not identical to the central axis of the collector circle as shown on sketch.

Exaggerated representation of collector runout



The collector surface then runs eccentrically, the greatest variation in a radial direction being equal to twice the axial displacement.

Collector runout occurs virtually only as the result of incorrect skimming when for example the rotor is not held in its own bearings or when centre displacement occurs in this position. At the comparatively low speeds of heavy machines, commutator runout is generally not as critical as for example in the case of small machines running at several thousand revolutions per minute when the carbon brushes can only follow the radial movement of the collector imperfectly due to their inertia.

In this event, a flaw is soon formed which then superimposes out-of-roundness on the runout, bringing all its negative consequences with it.

The maximum collector runout should not greatly exceed the limiting value for out-of-roundness of about 50 µm in the case of machines running at high speeds, while for heavy slow running machines, greater values depending on the speed and in extreme cases even going as high as about 0.4 mm may be allowed.

Machining processes

Grinding the rotor surface

A small degree of out-of-roundness can generally be eliminated by grinding the commutator or ring surface with a silicon-carbide grindstone which is applied manually to the collector surface.

When using this method it may of course be necessary first of all to

carry out a preliminary grinding operation with a coarser stone and then to carry out the final operation with a stone of finer grain.

With the machine running at rated speed where this is possible, the grindstone should be guided to and fro with uniform light pressure and an oscillatory motion over the whole contact surface to ensure uniform grinding. In order to avoid increasing the out-of-roundness when grinding, the tangential dimension of the stone should be at least 2 x as large as the defective place to be removed on the rotor. It is expedient to move the stone along a guiding aid which for example can take the form of a rigid straight sheet metal strip fixed to a bar or straight edge. Tangential movements or oscillations of the manually guided stone can thus be avoided.

If the defective places are very wide or if the commutator is severely out-of-round, grinding must be carried out with a stone having a fixed means of guidance. For this purpose it is best to use suitable equipment which can also be fitted with rotating grinding wheels. A rotating grinding wheel must turn in the opposite direction to the rotation of the rotor.

For the machining of steel rings coarser stones should be used than for copper or non-ferrous metals.

In our experience when machining copper and non-ferrous metal, an SC 80 K4 BA stone is very suitable for the preliminary grinding and an SC 220 K3 BA (DIN 69 100 designation) for finish grinding. If steel rings have to be machined,

an SC 46 K5 BA stone should be used for preliminary grinding and an SC 80 K4 BA stone for the final machining. When the latter grindstones in each case are correctly applied to the ground surface, they will produce a surface structure with peak-to-valley heights of the order of $R_z = 5 - 8 \mu\text{m}$ which is favourable for the running-in of carbon brushes (see also in this connection instructions in the section on surface roughness).

Subsequent polishing (smoothing) of the ground rotors should be omitted. For the same reason, the use of emery paper should also be dispensed with since in our experience this can easily produce a surface which is too smooth. In addition, emery grains which find their way under the carbon brushes may cause grooves.

If emery paper is used it must only be in conjunction with a block of wood which is shaped to suit the diameter of the collector. There must be no resilient intermediate backing between the emery cloth and the wooden block.

It is expedient to extract immediately any dust which accumulates during grinding. After completion of the grinding operation all contaminated parts of the machine must be thoroughly cleaned.

Skimming of the rotor surface

If the out-of-roundness or collector runout is very great, it is recommended on account of the higher metal removal rate, that the commutators or rings should be skimmed. Furthermore, skimming produces less contamination (no grinding dust).

Skimming can either be carried out in situ (mainly in the case of medium size or large machines) or by turning the dismantled rotor in a lathe. If the rotor is not skimmed while on its own bearings, but is held for example between centres, a check must first be made after setting up in the lathe to ensure true running in the bearings. If this shows up deviations greater than 0.01 mm, recentering is required. If skimming is carried out in situ, any axial play in the bearings must be removed.

If there is a risk that the insulation bars between the segments are no longer sufficiently undercut after turning or are even flush, they must be recut (see "Undercutting of segment insulation bars").

Both diamond and carbide tipped cutting tools can be used for turning the machines in question when they have undercut segment insulation bars. When the insulation bars are flush only carbide should be used. Diamond is used in metal cutting predominantly to give a superfinish, i.e. it has advantages when surface with minimum peak-to-valley heights have to be produced at high speeds. Since we are not aiming here for any mirror smooth surface finish, carbide may be preferred unless the greater service life of diamond is the decisive factor.

In addition to ensuring true running, skimming is intended to achieve a surface peak-to-valley height which will produce a good contact between carbon brush and collector as quickly as possible. As already mentioned under the heading "Grinding the rotor

surface” this peak-to-valley height is of the order of $R_z = 5 - 8 \mu\text{m}$.

The peak-to-valley height resulting from the machining is influenced by the cutting angles of the tool, the hardness of the material being machined, the cutting rate and the feed. It is therefore difficult to make general statements which are valid for all cases. The data in the literature are also to be regarded only as a guide with reference to our own peak-to-valley height requirements and deviations have to be made from these as necessary to fit the case in question.

Our experience shows that cutting speeds of the order of 160–200 m/min are advisable with carbide tools and 300–350 m/min with diamond tools. The feed should be about 30 μm at a cutting depth of 0.05–0.1 mm.

When turning copper it should be noted that, depending on the hardness, build-up can occur on the cutting edge of the tool causing tearing of the chips. As a result, the metal is no longer cut cleanly but is torn from the surface due to the wedge effect. The torn surface is a disadvantage for running carbon brushes since light copper particles may be released from the torn structure becoming embedded in the material of the carbon brushes.

The build-up of material on the cutting tool can be counteracted by increased cutting speeds and feed.

Rake angles of 13°–25° have proved to be effective when skimming copper. In this connection it must be noted, however, that as the rake angle is increased there is a greater risk of the turning tool snagging on the oncoming seg-

ments. If the turning tool is overhung to a great extent, vibrations can easily be set up causing an unsatisfactory turned finish. The turning tool should therefore be clamped with the smallest possible overhang which also has a positive effect on the service life of the tool.

If there is uncertainty whether the collector has the correct peak-to-valley height after turning – at the least, it must not have a very mirror-like appearance – the surface may again be lightly ground as described under “Grinding the rotor surface”. At the same time this has the advantage that any copper particles or very fine chips adhering to the surface of the collector which could otherwise become embedded in the brushes are removed.

When the turning operation has been completed the collector must be thoroughly cleaned. If necessary the edges of the segments must be chamfered (see under “Undercutting the segment insulation bars”).

Surface roughness

Newly bedded-in carbon brushes and, in the case of large machines, those with a large amount of overlap, should have the best possible electrical contact from the outset and run trouble-free. An important contributory factor is the surface roughness of the collectors. If the surface is too smooth, the coefficient of friction may periodically become excessive at fairly low speeds since the carbon brushes are almost subject to static friction, while at higher sliding speeds there is a risk of aerodynamic effects occurring. Both lead to poor contact over the

circumference of the collector. In addition, the carbon or graphite particles which are abraded from the running surfaces of the carbon brushes do not adhere sufficiently to smooth surfaces, so that a patina only forms very slowly and incompletely.

This then quickly causes damage to the surface of the segments in the form of flaws especially in the case of highly stressed commutator machines, resulting in sparking at the brushes.

If the surface of the collectors is rough, high initial wear, which it should be possible to avoid, soon occurs, although on the whole a somewhat rougher surface is considerably less critical for running-in than one which is too smooth.

For optimum operation of the brushes, the surface roughness of the collectors must therefore lie within the limits of being not too smooth and not too rough.

Trials and experience have shown that a peak-to-valley height R_z of the order of 5–8 μm should be aimed at. In this connection it should be noted that this peak-to-valley height must be produced by turning of grinding tool marks which are of uniform depth and distributed evenly in the axial direction.

If measurements of the peak-to-valley height is not possible, it will of course be difficult to assess the condition of the surface. As a rough approximation for grinding it can be said that the desired peak-to-valley height can be achieved by a machining operation which lies somewhere between normal grinding and precision grinding. With turning, the desired peak-to-valley height is

Refitting and maintenance of heavy electrical machines

achieved by machining with carbide – a process known as precision turning.

After machining, the collector surface must not have a very mirror-like appearance. Such a surface is a certain sign of too small a peak-to-valley height. It should rather have a tendency towards a mat finish.

If slip rings or commutators are found to be in satisfactory condition before making a replacement and if a good patina has formed on the surface it may be possible to leave them as they are. If, however, they are very smooth and have a mirror finish, it is advisable as already mentioned above to roughen this patina slightly

with a grindstone so as to avoid problems in operation.

This may be done, although the conditions on a smooth patina are not quite so critical, due to the embedded graphite, as for example on a smooth copper surface. If the peak-to-valley height is to be measured, it is important to

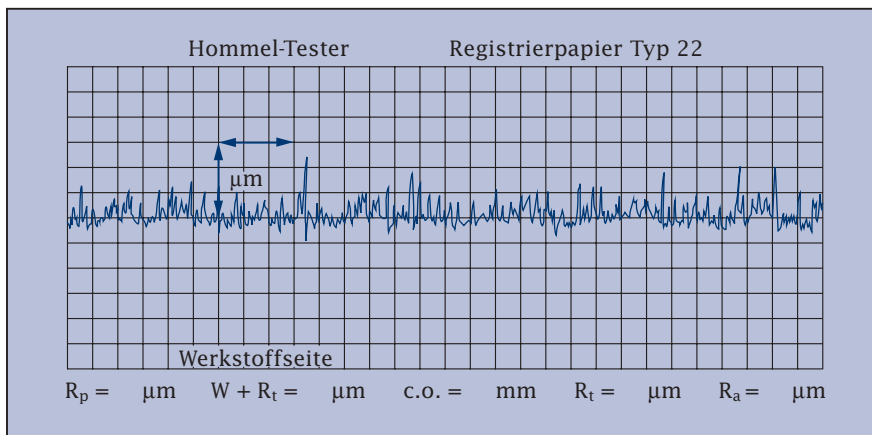
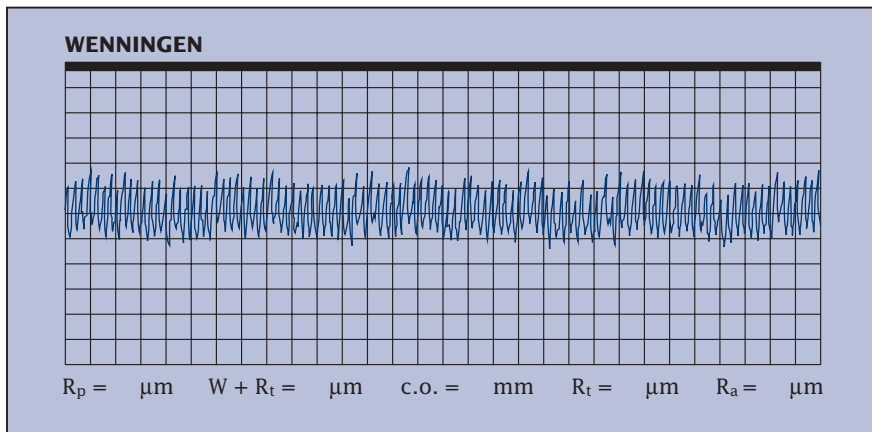


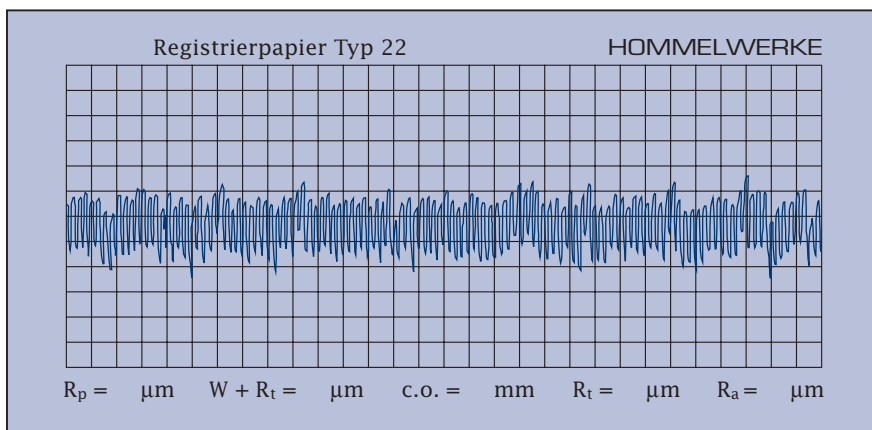
Figure 4

Diagrams of the peak-to-valley height of machined collector surfaces

Ground copper surface
 $R_z = 6.4 \mu\text{m}$



Turned copper surface
 $R_z = 5.8 \mu\text{m}$



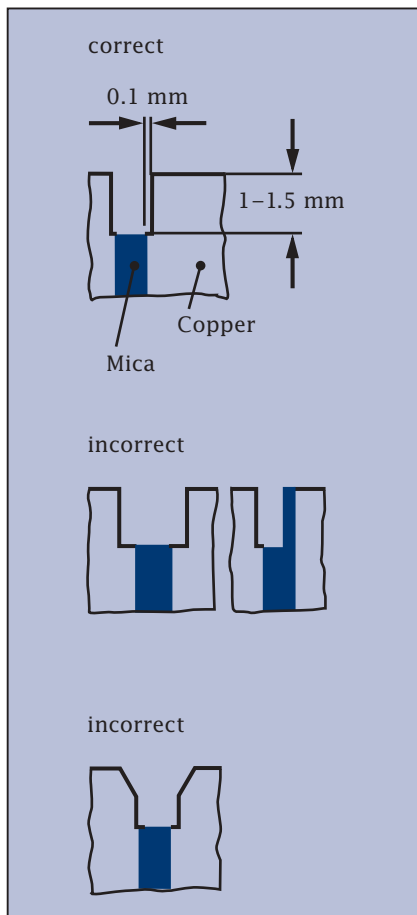
Gz Sn Bz5-turned surface
 $R_z = 6.7 \mu\text{m}$

note that the datum R_z is only valid in conjunction with electrical stylus instruments in accordance with DIN 4768. In this way the effective profile is converted to a roughness profile by means of filtering with a wave filter (cut-off).

R_z is the arithmetic mean value of the individual peak-to-valley heights of 5 adjacent sampling lengths. In this way, R_z is evaluated automatically after travelling over the measured length and is shown up on the indicator. For small commutators the measured length is 5 mm and for large ones 15 mm. Scanning takes place at right angles to the machining grooves.

Figure 5

The correct undercutting of the segment insulation of a commutator



Depending on the method of machining and the resulting effective peak-to-valley profile measurement is carried out with a cut-off of 0.8 mm.

The following illustrations (figure 4) show the traces of the peak-to-valley profiles of ground and turned surfaces.

Undercutting the segment insulation bars

On machines used today in industry and on the railways, practically the only carbons used are of a quality which is not capable of wearing down the insulation bars between the commutator segments. The insulation bars must therefore be neatly undercut. Imperfectly undercut insulation or even mica which remains standing proud leads to contact problems creating collector flaws and high brush wear.

There are not fast rules to be observed for the form of the segment grooves, the sawing, scraping or milling out of the mica, or for the most favourable depth of the insulation groove, or for the edge chamfer. It has generally been found that a milled-out depth equal to the width of the insulation is sufficient.

It is important to ensure that no mica or insulation residue remains at the edges. The milling out should therefore be wider by about $\frac{1}{10}$ mm than the insulation bar which also takes account of possible dividing errors; see the illustration (figure 5) at the left side.

After undercutting the insulation bars and also after heavier grinding or skimming it is usually nec-

essary to chamfer the sharp edges of the segments. A scraper or similar tool may be used for this.

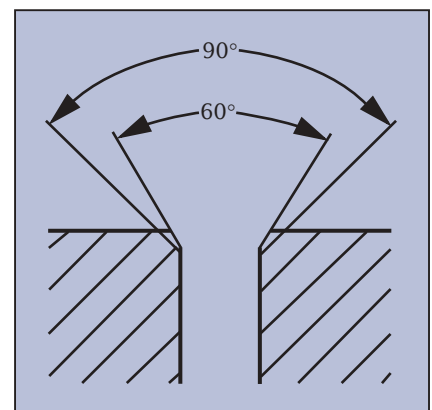
The most usual angles for the edge chamfer lie between 60° and 90° . See the following sketch (figure 6).

Undercutting the segment insulation bars of small machines can be done manually. It is however advisable where a higher quantity of pieces is involved, to use special machines which are offered by the industry for this purpose.

If the edges of the segments have to be chamfered, this should be done before the last turning or grinding operation so that any flash which may stand proud can be removed. The grooves must be thoroughly cleaned after machining.

Figure 6

Limiting values for the angle of edge chamfer



Arrangement and mounting of brush holders

The tangential dimension of the brushes of commutator machines depends on the overlap or the width of the reversal zone. Care must be taken to ensure that this tangential dimension of the brushes or the partial dimension in the case of twin or triple carbons is

Refitting and maintenance of heavy electrical machines

not equal to the width of a segment since experience shows that if they are equal uneven mechanical operation of the brushes is caused.

When fitting the holder, the pole pitch of the machine must be transferred as accurately as possible to the commutator. Deviations of $\pm \frac{1}{2}$ insulation bar should not be exceeded if possible. This applies on condition that the machine is electrically and magnetically symmetrical, i. e. that the geometrical pole pitch on the stator is equal to the electrical pitch on the commutator. Fitting the brush holder is facilitated by laying a paper strip round the commutator which has previously been accurately marked with the pitch.

Furthermore, the leading and trailing edges of the brushes must be exactly parallel to the edges of the segments.

If the commutation conditions require it and the width of the neutral zone allows, the brushes may also be staggered in a tangential direction. In addition to

improving the electrical condition, such staggering also has the advantage that if out-of-roundness exists, not all the brushes on one bar are affected at the same time.

Apart from the pole pitch, the axial displacement of the brushes on the commutator is also important to ensure that no untravelled tracks appear on it (figure 7).

Since the patination depends on the polarity of the brushes, the number of plus and minus brushes must be as nearly equal as possible in all tracks. In many cases of course there has to be a compromise on this (e. g. 6 pole machines).

In order to weaken polarity effects, care must be taken to ensure when a compromise solution has been reached that, in particular, no tracks occur which have only cathodic loading. Cathodic brushes (generator + and motor -) alone in one track lead relatively easily to commutator attack.

When fitting synchronously rotating rings under alternating cur-

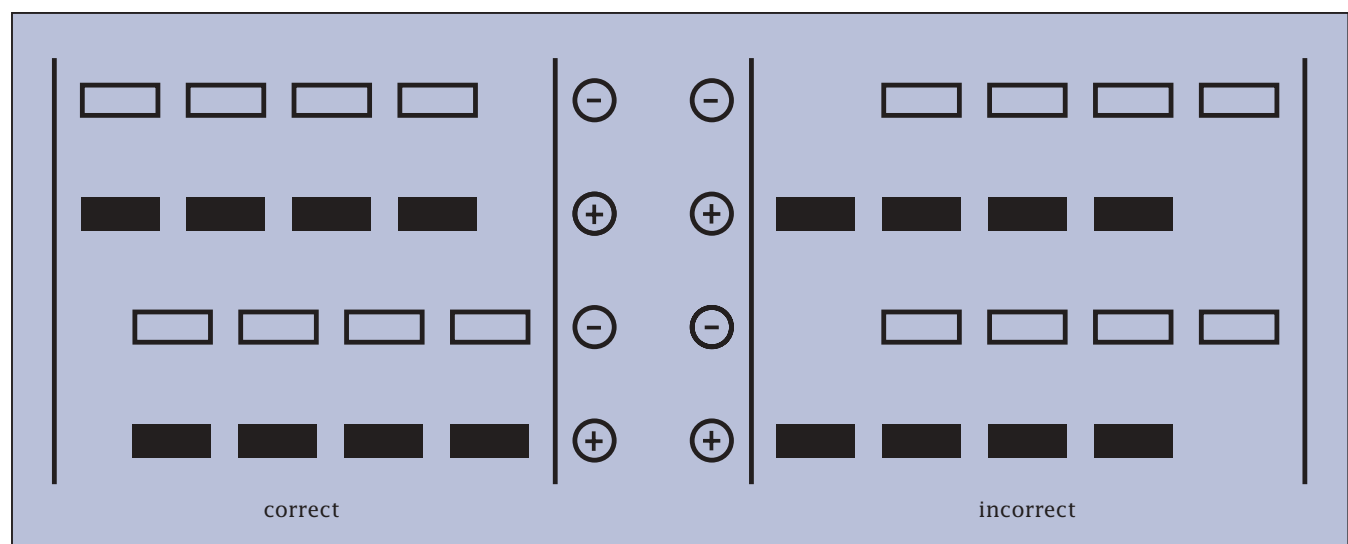
rent loading, specific sections of the rings must be prevented from always being loaded with the negative or positive halfwave. If this occurs, the patina on the circumference of the ring becomes uneven causing flaws and sparking at the brushes. The distribution of the brushes around the circumference must be arranged so as to avoid unipolar loading of any particular section of the circumference.

A few examples are given below (figure 8) of correct and incorrect arrangement of the carbon brushes.

When fitting radial holders, it should be noted that, unless they are fitted accurately radially, a slight reaction setting results for the carbon brushes in association with a corresponding direction of rotation of the collector. Experience has shown that this can easily cause uneven running of the brushes at high coefficients of friction. Particular care must be taken therefore when using radial holders on reversing motors to ensure correct fitting. On

Figure 7

Axial displacement of the carbon brushes of a 4 pole machine



machines which only rotate in one direction, we recommend that the brush holders should be fitted so as to be quite weakly trailed (of the order of 1°) in order to avoid accidentally causing a slight reaction setting.

The foregoing statements do not however apply to reaction holders since these are specifically designed to meet the requirements of reaction operation.

In addition, it should be noted in connection with the fitting of holders that the space between the lower edge of the holder box and the collector surface is about 2 mm. Having regard to this, the space between the lower 4 corner pockets and the collector surface must be equal.

If the adjustment of the brush rocker has become displaced dur-

ing fitting, it must be correctly repositioned.

Bedding-in the carbon brushes

From the outset, the carbon brushes must be as fully as possible in contact with the commutator or ring surface both over their whole tangential width and their axial length. In most cases it will therefore be necessary to bed-in new carbon brushes, and in any case when a complete set is changed. However, if the diameter of the commutator or ring is very large in comparison with the size of the brushes, bedding-in may be omitted in certain circumstances. This also applies when only individual items of larger set have to be changed.

Various methods of bedding-in are used in practice. One very

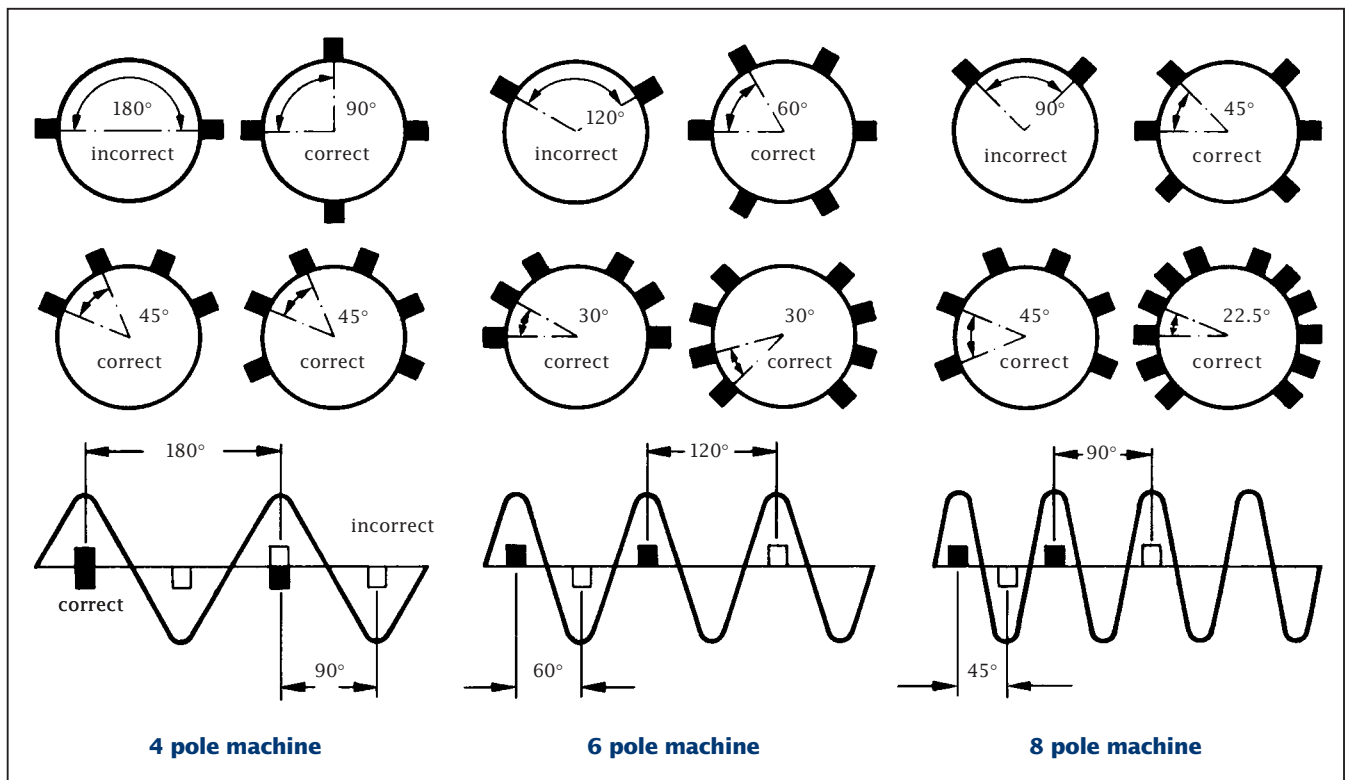
attractive method for large machines is to fix the emery cloth used for grinding to the commutator or ring with adhesive film. By slowly turning the rotor in the normal direction the carbon brushes are then bedded-in. After removing the emery cloth, the commutator or ring surface must be carefully cleaned of any remaining adhesive.

Another possibility is to draw a strip of emery cloth to and fro beneath the carbon brushes. In the case of non-reversing machines it is essential however that the last grinding operation should be carried out so that the emery cloth is only drawn beneath the brushes in the direction of rotation of the machine. When the cloth is drawn back, the brushes should be lifted.

Bedding-in with emery cloth generally provides a sufficient de-

Figure 8

Examples of the correct and incorrect arrangement of carbon brushes on synchronously running rings



Refitting and maintenance of heavy electrical machines

gree of conformity between commutator – or ring – and the brush radius created (the latter is insignificantly larger).

If, on switching on the machine, the carbon brushes are to be in effective contact over their whole surface, this can be achieved by using a soft pumice stone which is held against the ring or commutator in front of the brushes

brushes on the rotating collector (contact pressure in cN/cm^2). Contact pressure should therefore be regarded as an important factor together with the requirements for trouble-free current transference and low carbon brush wear.

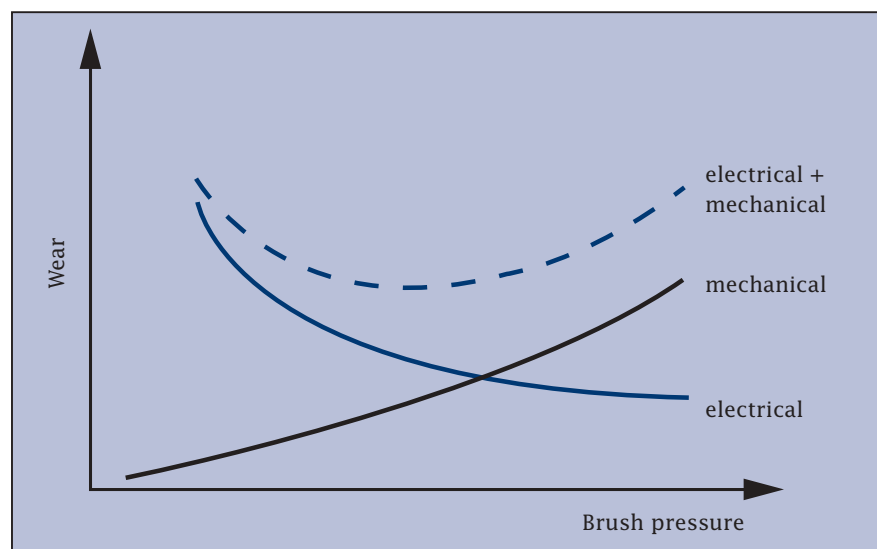
If the contact pressure is too low, it may, in combination with out-of-round collectors and vibration, cause contact separation, result-

Depending on the smoothness of running of the machine it may possibly be necessary to increase the recommended brush pressure.

In the case of stationary machines however it is not advisable to exceed $250 \text{ cN}/\text{cm}^2$. In the case of highly metalliferous carbons, their own increased weight must be taken into account by adding or subtracting it according to the position of the holder.

Figure 9

Fundamental trend of brush wear as a function of the contact pressure



while the rotor rotates. The pumice powder thus produced finds its way under the brushes and beds them in.

The disadvantage of this method is the relatively large accumulation of dust which makes a subsequent thorough cleaning essential. It has the advantage that any patina which exists becomes roughened making for an improvement of the running conditions.

The contact pressure for carbon brushes

Electrical contact is made by means of pressing the carbon

ing in current transference by sparking and arcing. This causes increased brush wear. If the pressure is too high, mechanical wear predominates. Figure 9 shows the fundamental trend of the curves of wear.

The values of pressure recommended in leaflet 10.21e are the result of many years experience of normal operating conditions. Using these values for the pressure, contact can be expected to be sufficiently good and the wear on carbon brushes and collectors sufficiently low under varying conditions of operation, provided of course that they are not too extreme.

It is important to ensure that the pressure is equal on all the carbon brushes with a tolerance of about $\pm 5\%$. Greater deviations lead to uneven current distribution with all its disadvantages.

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