

# Carbon brushes for fractional horsepower motors

## Mechanical influences on the carbon brush run

Modern and economically optimized motors are characterized by a low weight coefficient and therefore higher speeds. This means that the mechanical influences become increasingly important. The best electrical design of the motors often causes unsatisfactory results regarding the brush lifetime, because the mechanical stress outweighs all other factors.

### Guidance of the carbon brush in the brush holder

The frictional forces cause rocking movements and shaking movements at the carbon brushes. These movements must be kept as small as possible. Therefore it is necessary that the carbon brush is guided well and/or that there is as little clearance between holder wall and carbon brush as possible. If no other requirements are made, the carbon brushes and brush holders are manufactured according to standard DIN IEC 60 136. The dimensional tolerances for the standardized brush dimensions are specified in these regulations. The same applies for the brush holders, which are also specified in these regulations.

These specifications provide a permissible clearance between brush and holder, which is usually observed in conventionally manufactured reamed tubular or flange brush holders as

well as in bent sheet metal holders, which are economically manufactured in precision tools. However, these specifications are hardly or not at all observed in the case of designs that must be classified as inferior. If these DIN IEC values are more or less adhered to, then good brush run and consequently long brush service lives are ensured. Particularly synthetic resin-bonded carbon brush materials exhibit higher thermal coefficients of expansion. This must be considered during the design of the holder clearance. It is especially important for motors with reversible direction of rotation to particularly pay attention that there is only small clearance in the tangential dimensions between the carbon brushes and the holders.

The distance from the commutator to the bottom edge with motor shaft of the brush holder should be in a range of 1.2 mm up to max. 2 mm, so that the freedom of movement of the carbon brushes regarding the rocking motions is not exceeded even after reaching the wear limit.

A holder distance of 0.8 mm and smaller is to be avoided, because deposited brush abrasion dust or sufficiently high electrical field strengths can cause arcing. That does not apply to voltages smaller than 36 V where a 0.8 mm distance is here possible.

### Carbon brush contact pressure

The brush contact pressure is of great importance, because it has to ensure contact between the carbon brush and the rotating commutator. The optimal value is obtained when both the electrical wear portion and mechanical wear portion are kept to a minimum. If the brush contact pressure is incorrect, one of these two wear portions is higher than the other.

If the brush contact pressure is too small, then oscillations and out-of-round commutators can cause a loss of contact of the carbon brush, so that arcing mainly transmits the current, which leads to an erosion of the commutator copper.

In this case the electrical wear portion is higher than the mechanical wear portion. Additionally, if flush mica insulation is used, the mica does not wear off evenly anymore which can lead to a premature breakdown of the motor.

If the brush contact pressure is above the optimum value, the mechanical friction losses and therefore the mechanical wear portion will increase. The consequence is that the temperature of the commutator rises unnecessarily, and the result will be a decrease of the electrical resistance of the patina and thus a possible deterioration of the commutation.



Group

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For universal motors with a terminal voltage of 110/220 volts and with normal load conditions, a value of approximately 300 - 400 cN/cm<sup>2</sup> can be selected as initial pressure, with the final pressure being as high as possible. For motors, whose speed is reduced by a short-circuit brake when switched off, an initial pressure of 700 - 800 cN/cm<sup>2</sup> is recommended. A contact pressure of up to 600 cN/cm<sup>2</sup> applies to electric power tools that have a higher mechanical load. Such a high initial pressure is not possible for battery powered motors and motors for toys, because their motor performances are too small. A value of between 200 and 250 cN/cm<sup>2</sup>, at least however an absolute force of 15 cN, should be aimed at. Ideally the correct initial brush pressure should be determined experimentally.

A contact pressure of up to 750 cN/cm<sup>2</sup> can be recommended for machine tools with rechargeable battery.

## Use of helical compression springs for the current transmission to the carbon brushes

The majority of fractional horsepower motors are equipped with tubular brush holders made from metal. For economic reasons even tubular brush holders made purely of plastic are used in machines with less power. The plastic holders have disadvantages because of their inferior heat dissipation and their obligatory larger tolerance levels. They can only be used in motors with small power and/or with brushes with a low load factor.

Most types of holders require helical compression springs to press the carbon brushes against the commutator. For economic reasons they should possibly also be suitable for the current transmission to the carbon brushes.

For Schunk carbon brushes it is basically possible to choose from the following materials for helical compression springs:

- a) Phosphor bronze
- b) Steel wire with corrosion protection layer thickness 1 - 2 µm
- c) Steel wire with corrosion protection layer thickness 10 - 15 µm
- d) High-grade steel wire
- e) Copper-encased steel wire  
Schunk material number KM 301

However, high-grade steel wire cannot be used for current transmission because this kind of wire would develop too high temperatures caused by current load.

The other materials listed above are basically all suitable for current transmission. The maximum load depends on the resistance of the material, the temperature stability and the cross-section of the wire. Phosphor bronze is the material with the smallest load capacity, because of the low level of stability of the wire material when it is subjected to temperature. Steel wire with corrosion protection of 1 - 2 µm layer thickness has also only a small load capacity.

Steel springs with corrosion protection of 10 - 15 µm layer thickness can already transfer a significantly higher current.

Experience has shown that, if currents larger than approximately 1.8 A are to be transmitted over the helical compression spring only, it is usually necessary to use spring material with better transmitting properties. Schunk solves this task with material number KM 301. This material has a considerably smaller electrical resistance than the materials mentioned before. The somewhat softer spring characteristic can be stated as disadvantage in comparison to uncoated spring wire. Therefore it is necessary in these cases to compromise in regards to the pressure values.

The design of such helical compression springs, which are to be installed onto the carbon brushes for current transmission, is a result of the following factors: the current which is to be transmitted, the necessary spring force in the existing space conditions and the load limits of the specified spring materials.

# Mechanical influences on the carbon brush run

The diagram to the right (Fig. 1) shows a load deformation curve of springs, which illustrates during favorable cooling conditions the load limits in relation to the diameter of the wire. However, these values should be considered only as recommended values during current load, since cooling conditions in the holder and the holder design itself have a strong influence. The temperature resistance of the wire materials increases in following order:

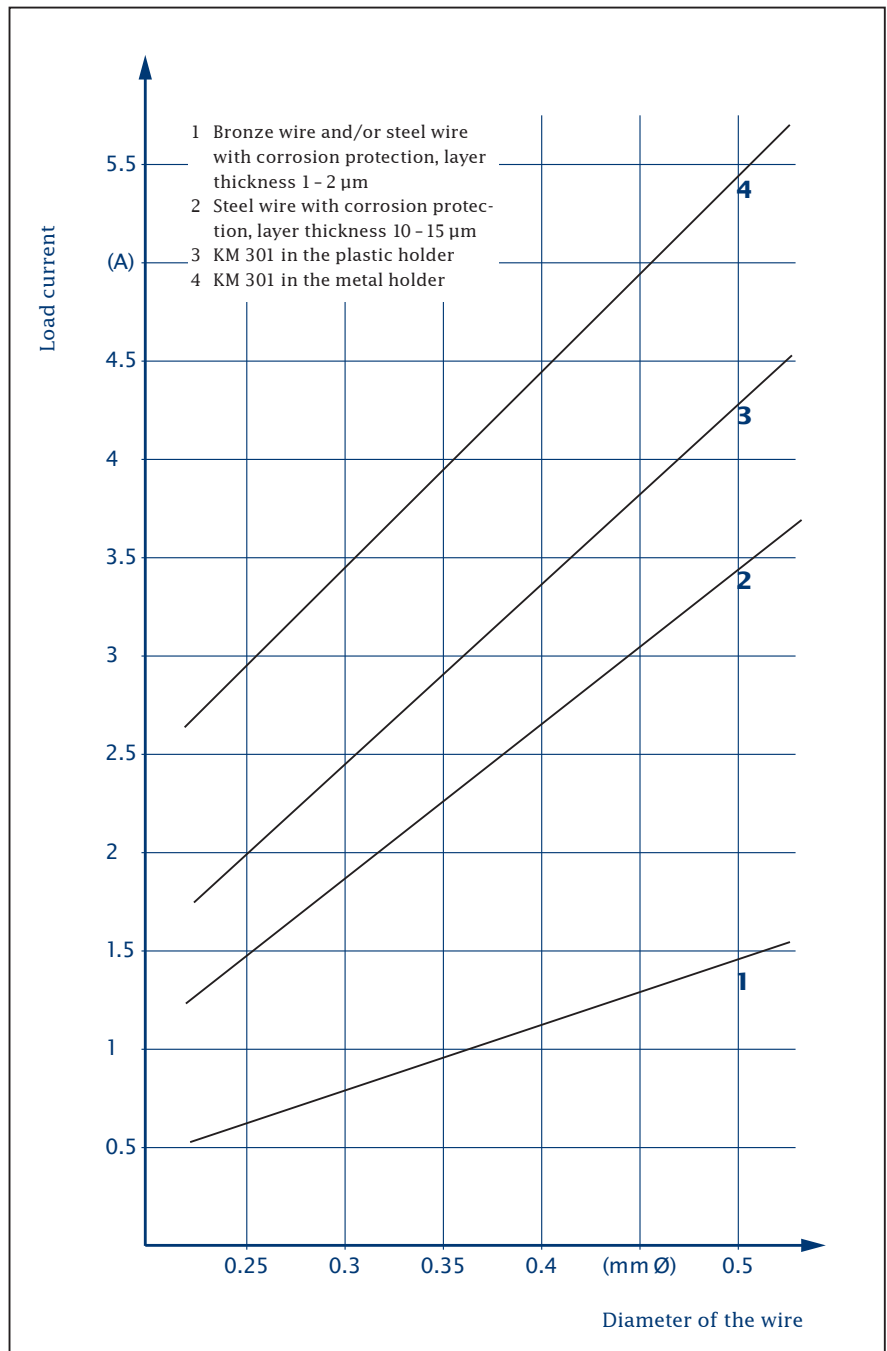
Bronze spring

Steel spring with corrosion protection

KM 301

It is usually necessary because of the current value to be transmitted to select a wire with a larger wire diameter than it would be favorable for the mechanical design regarding the pressure ratios within the existing space conditions. Therefore it is basically necessary to make a compromise.

If the spring is thermally over-loaded due to high current load, the spring starts to show symptoms of setting caused by annealing in the spring center and/or the end of the spring that is resting against the brush head. The consequence is that the spring pressure drops towards zero.



**Fig. 1**

Recommended values for the maximum load of various wire materials for helical compression springs relative to the diameter of the wire.

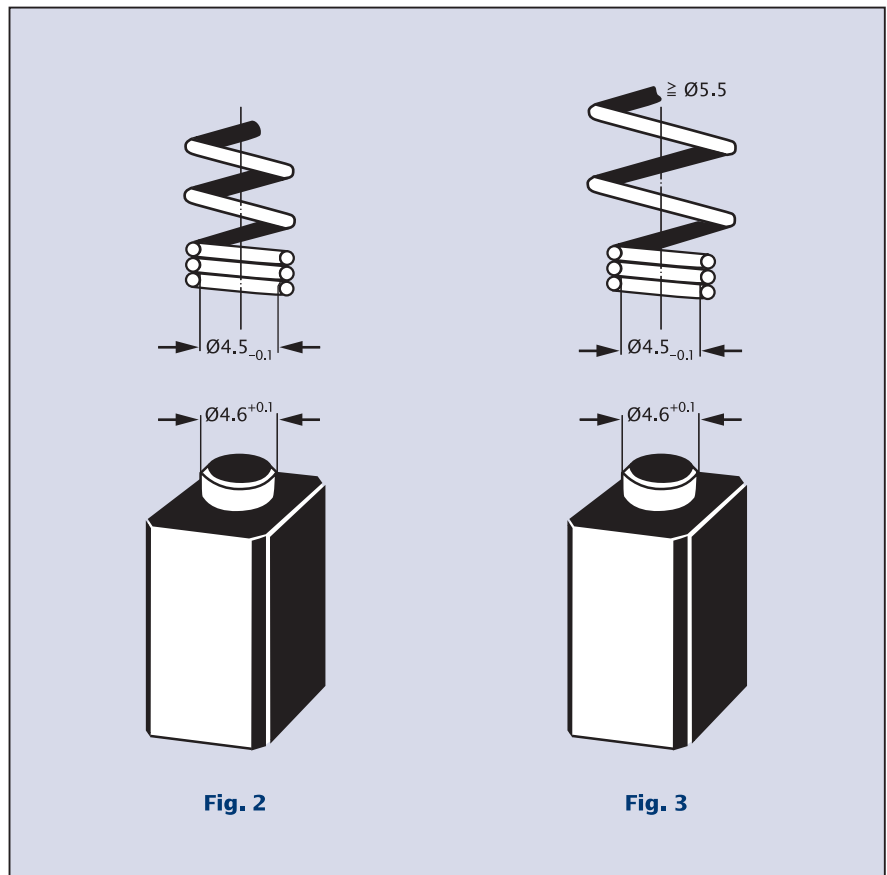
All data are typical average values and are based on measurements taken under ideal conditions. The numbers are recommended values without guarantee.

## Mechanical influences on the carbon brush run

It is fundamental to ensure optimum contact between spring and brush head, in order to keep the contact resistance to a minimum. Otherwise this part of the spring will become thermally overloaded, thus preventing maximum electrical utilization of the spring material. The contact at the other end of the spring to the stationary connection of the coil must also be perfect. The opposite contact surface has to be corrosion resistant, in order to avoid unacceptably high contact resistances.

For a low contact resistance between the helical compression spring and the carbon brush it is advisable to fit the carbon brush with a 1.5 - 2.5 mm high cylindrical head and with a small flange at its end. The end of the spring touching the brush head should have possibly 2 - 4 turns in contact with the brush head (see Fig. 2). Springs with outside diameters larger than 5.5 mm should have additionally 2 - 4 turns in contact (see Fig. 3). This makes it possible to use as many contact points as possible for current transmission.

As far as the tolerances are concerned, the outer diameter of the carbon brush head is to be manufactured 0.1 mm larger (plus an additional 0.1 mm for the permissible maximum dimension) than the inside diameter of the spring (minus 0.1 mm for the permissible minimum dimension). See again Fig. 2 and Fig. 3.



# Mechanical influences on the carbon brush run

## Radius of the brush running surface

For a good running-in behaviour of the brushes it is basically recommended to use carbon brushes with a contact surface radius that has been matched to the radius of the commutator. However, a good brush running-in behaviour can only be guaranteed if the carbon brush starts its run from the center of the contact surface.

Since however a standardized clearance between carbon brush and holder is necessary and given, the brush may rock somehow during running. In addition, the influences of the location deviation regarding the alignment of the holders have to be taken into account. Therefore, in order to ensure that the brush is running in from the center, the specified radius of the carbon brush must be larger than the radius of the commutator. This means for practice that the brush radius for the new brush must be chosen approximately 10 – 20 %, or as a rule of thumb approximately 1 mm with an additional plus tolerance “plus 1 mm”, larger than the commutator radius. If the radius of the brush and the commutator are the same, then the brush runs in from the starting edge and in the case of undercut insulation becomes hooked into each segment groove and/or rams into each segment that protrudes only slightly.

In additional to the described design of the brush radius it is possible to accelerate the bedding in of the brush by grinding grooves into the contact surface of the brush. The contact surface of the brush is then wavy, whereby the defined grooves should run in tangential direction. This corrugated contact surface can

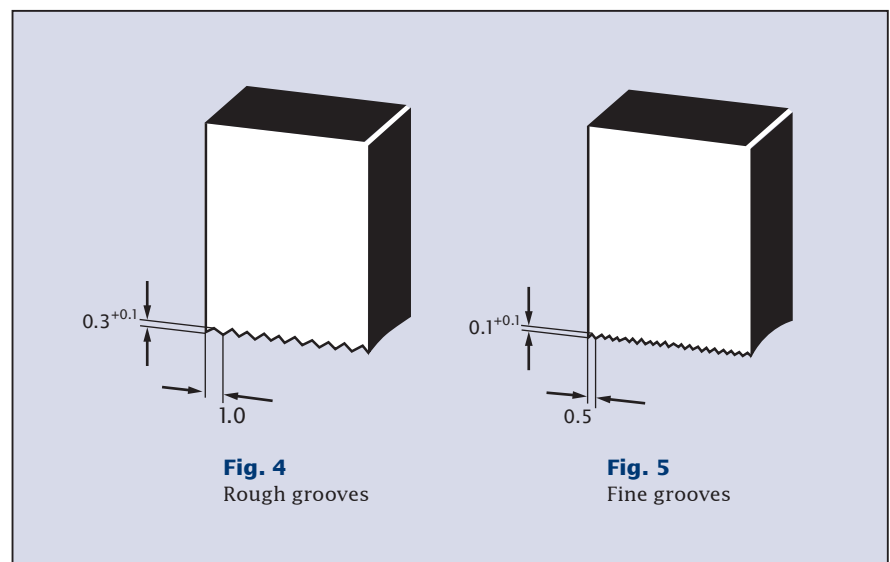
be ground both with and without a radius, thus flat. Both versions are also possible with diagonally designed contact surfaces. The result of this measure is that the specific brush contact pressure is substantially higher in the initial condition and that at the same time the smaller basic contact surface of the brush material can take a higher electrical load. Both factors cause the desired effect of a higher initial wear for a faster brush running in.

Because the brush achieves very quickly an optimum level of contact,

the characteristics of the motor are reached faster. The stationary condition in the form of stable speed, steady performance and more uniform radio interference is achieved faster by the motors, although the contact surface of the brush has not yet reached its full carrying capacity.

We can recommend two different types of grooving:

For brushes with larger dimensions rough grooving, as shown in Fig. 4, or however fine grooving for all smaller brushes, as shown in Fig. 5.



# Mechanical influences on the carbon brush run

## Commutator surface finish

In order to obtain a good lifetime for the carbon brush assembly, particular attention should be paid during the manufacturing process of the commutators to the following conditions:

- Correct surface roughness
- Minimum out-of-roundness of the commutator
- Lowest possible commutator eccentricity
- Lowest possible slip bar to bar

Commutator eccentricity is present if the mechanical axis deviates from the rotation axis. An out-of-roundness is present if the commutator surface exhibits deviations from a circular shape.

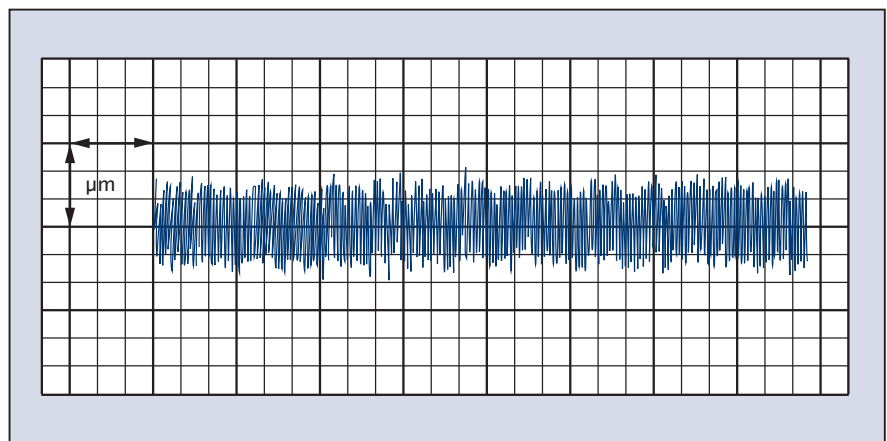
## Surface roughness

The commutator surface must exhibit a certain surface roughness for a fast and smooth brush running-in. Experience has shown that a surface roughness in axial direction measured according to  $R_z$  of 8–12  $\mu\text{m}$ , is necessary, in order to avoid increased values of the coefficient of friction. This surface roughness should be caused by having as many grooves as possible and should spread uniform across the segment length in axial direction. If a commutator is too smooth, then the coefficient of friction of the carbon brushes increases. In extreme cases this can result in slip stick effect. In this case contact is predominantly made only by arcing, because of the mechanical contact separation. The resulting commu-

tator sparking causes uneven staining of the commutator over its circumference, which in turn causes excessive brush wear. In the most favorable case the commutator will roughen up with increasing running time in such a way that the brush will later end up running smoothly. Usually however the staining causes the commutator to be out-of-round and the motor fails prematurely due to worn out carbon brushes.

In order to ensure the desired surface roughness, a sufficiently high feed rate must be selected for the final turning process of the commutators after the

assembly of the complete rotor. We recommend a distance of 60–120  $\mu\text{m}$  between the turning grooves. A forward feed of 100–150  $\mu\text{m}/\text{revolution}$  is recommended. The cutting speed must not be too large, in order to ensure an uniform cutting of the turning tool. In critical cases a final yet gentle grinding step (e.g. with a pumice stone or a commutator stone) can additionally improve the surface, whereby the grinding should be done axially. If a pumice stone is used, the brand SB70 is recommended. This will create the desired irregular surface of the commutator. Fig. 6 shows a good commutator surface.



**Fig. 6**

Diagram of the surface roughness of a final turned commutator surface, measured in axial direction

$R_z = 8-12 \mu\text{m}$        $R_a = 0.8-1.6 \mu\text{m}$

## Commutator out-of-roundness

The term out-of-roundness describes all deviations of the commutator circumference from its circular shape, no matter if they are of periodic or arbitrary sequence. Examples of out of roundness can be: flat spots at the commutator; form fluctuations caused by insufficient firmness during the run or temperature influences; segments protruding in groups or individually from the structure; irregularities of the surface, which were caused by oscillations during the final turning process.

Commutators with eccentricity stimulate the carbon brushes running on them to periodic oscillations. This in turn causes a periodic contact separation between commutator and carbon brush with defined staining as a consequence. After some running time basically an additional out-of-roundness develops to the eccentricity with progressively rising brush wear and strongly decreased brush service life as result.

The concentricity diagrams shown on the next page (Fig. 7-9) show developed views of defective commutators with such defects.

Out-of-roundness often develops during the final turning process of the commutators after the rotor has been assembled; if it is not the result of the use of a wrong material, coil damage or commutator eccentricity.

There are various reasons why out-of-roundness can be caused during the final turning process: oscillations of the entire lathe or its support, the freely clamped turning tool is too

long, a dull turning tool, the cutting speed may be too high, the turning tool might be fitted with the wrong bevel or the cutting plane of the turning tool might deviate from the rotation axis.

For the final turning of commutators with flush mica insulation it is recommended to use widia-tipped turning tools. Diamond-tipped turning tools can also be used for undercut insulation.

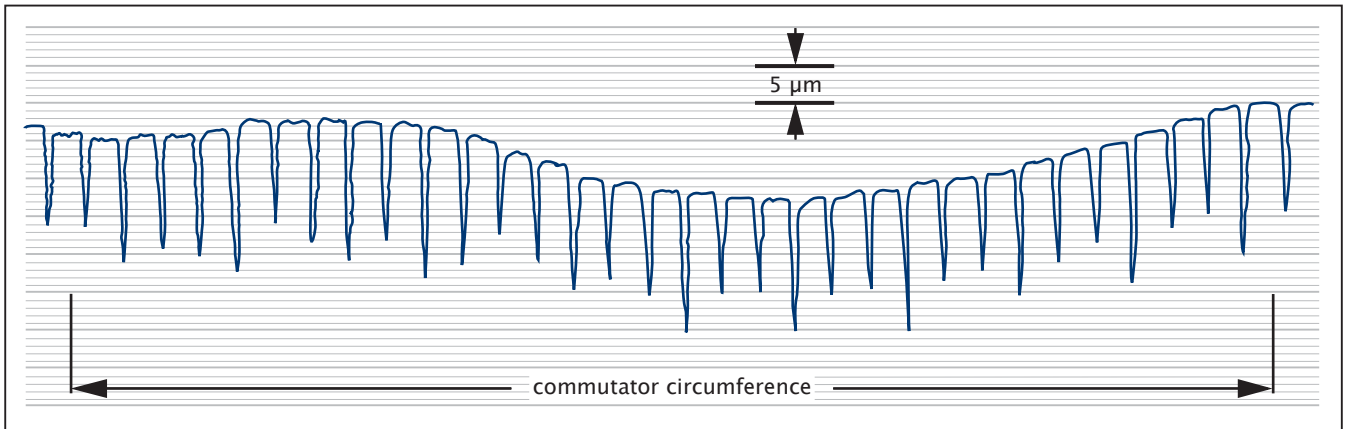
The indicated cutting speeds for widia-tipped turning tools are 160 up to max. 200 m/min and for diamond-tipped turning tools 300 up to max. 350 m/min. The forward feed should be set at 100 - 150  $\mu\text{m}/\text{revolution}$  and the cutting depth for the final cut should be 0.08 mm.

It can be summarized that out-of-roundness at the commutator can in any case shorten the lifetime of the brush assembly significantly and/or can cause short-range defects. Individually protruding segments are most critical. Then the contact is almost exclusively made with arcing. Thus the copper of the segments is burned off and roughened up. If there are individually protruding segments, these will hit against the leading edge of the carbon brushes when the rotor is rotating and cause usually the mechanical destruction of the carbon brushes. Protruding segments can be a result of the copper being too soft, more often however a too high welding pressure causes them when the coil windings are being connected to the segments and/or thermal overloading of the molding compound.

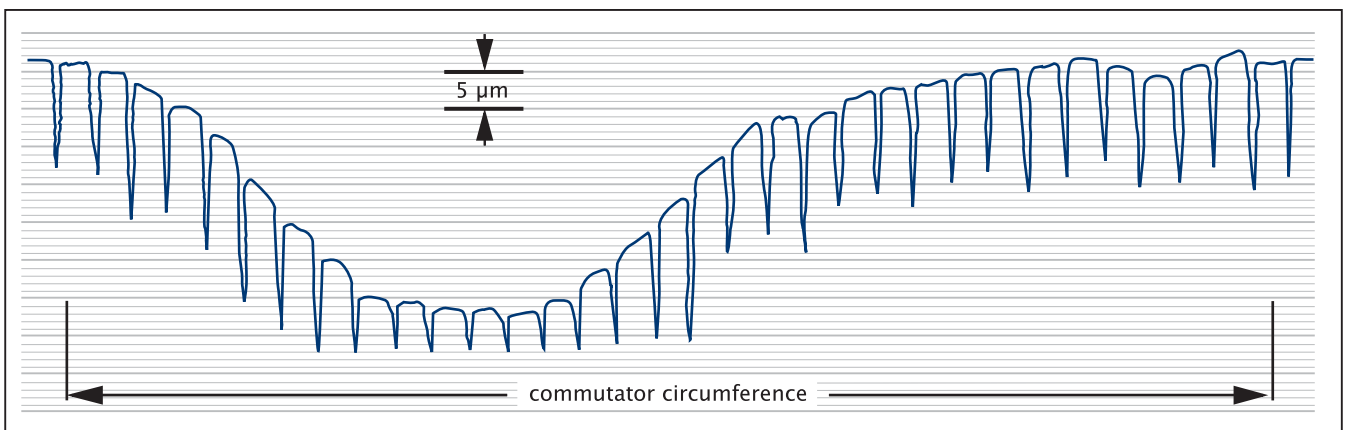
The concentricity diagrams of such cases show segments measured at the flange slightly undercut, measured in the center flush and measured at the shaft end of the commutator protruding from the structure.

Form fluctuations of the commutator caused by inadequate stability during the run of the motor lead to progressive brush wear with increased commutator friction. The out-of-roundness limit for larger areas of the commutator circumference, in relation to the diameter, is a maximum of 8  $\mu\text{m}$  for low-speed motors and a maximum of 4  $\mu\text{m}$  for high-speed motors. A value of 1  $\mu\text{m}$ , in few cases of a maximum of 2  $\mu\text{m}$ , applies to individually protruding segments, depending on the diameter of the commutator and the motor speed.

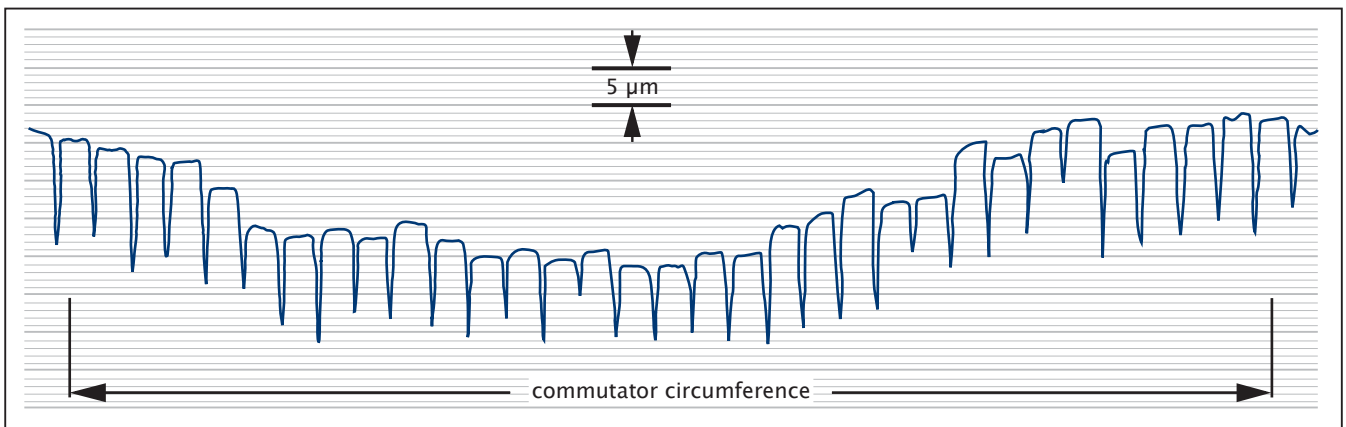
# Mechanical influences on the carbon brush run



**Fig. 7**  
Example of a commutator with eccentricity



**Fig. 8**  
Example of a commutator with out-of-roundness



**Fig. 9**  
Example of a commutator with protruding segments

# Mechanical influences on the carbon brush run

## Commutator copper

For good mechanical processing and a sufficient strength of the commutator, the copper has to have a minimum hardness. Values of HB 80 to HB 120 must be observed, whereby the middle range values of HB 95 to HB 105 are recommended. Electrolytic copper with a small percentage value of silver content is used as standard material, in order to guarantee sufficient hardness even under temperature influences. During the process of soldering on and/or welding the coil windings to the segments, high temperatures occur short-term, which reduce the hardness of pure copper content to a value below the permissible minimum.

The silver content allows the electrolytic copper to recrystallize at a temperature above 350 °C. Experience shows that silver content values of 0.03 % to 0.1 % can be recommended.

If particularly high thermal loads are expected, maximum silver content of 0.2 % is recommended.

## Mica insulation of the commutator

There are basically two types of commutator insulation: the sawn out, i. e. undercut and the not sawn out, so-called flush mica insulation. The tendency today is clearly towards the undercut insulation, whose use has become absolutely necessary because of the use of electronic speed regulations and/or the number of revolutions being constant independent of

the load as well as higher peripheral speeds of the commutator. Flush mica insulation is nowadays used only for economic reasons in household appliances with small power, as far as no electronic components are used in the appliance.

The use of undercut insulation has advantages for the carbon brush. Carbon or resin-bonded graphite materials must be used with flush commutator insulation, in order to mechanically remove the mica, which inevitably develops through the copper erosion of the segments caused by commutator sparking.

This is not necessary with undercut mica insulation. Here it is possible to use materials with a small coefficient of friction and without abrasive components. Such a composition guarantees that the commutator is preserved and that the result is good running behaviour and good commutation. Furthermore, the light flashing over caused by burning the conducting bridges above the mica causes increased radio interference in flush mica insulation.

A slot width of 0.7 mm should not be exceeded with undercut insulation, to ensure that the brush runs quietly. If the commutator has a large diameter, e. g. with machine tools of highest power, a maximum of 1 mm can be allowed.

For motors with difficulties during commutation it is important to observe a sufficient slot depth.

# Mechanical influences on the carbon brush run

## Improvement of the mechanical running behaviour of the carbon brushes through impregnations

It is today basically possible to improve the mechanical running behaviour of carbon brush materials through impregnations. This is particularly the case for the carbon-graphite materials of our L-series, which contain, due to their raw materials and

their production method, slightly abrasive components, which prevent staining on the commutators, however increase at the same time the coefficient of friction. By impregnation these carbon brushes with impregnating agents, e.g. with F7, F10, F12, F13, F20, F25, F101 and F131, the coefficient of friction can be reduced.

Our impregnations should not only be seen as a means of assisting with running in, but as an improvement of

the carbon brush during its entire lifetime.

The mentioned reduction of the coefficient of friction results in a smoother brush run, which means that per time unit more contact points are available for the current transmission and/or commutation. This in turn generally causes a reduction of the commutator temperature, less commutator sparking and a decrease in radio interference.

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