DC Motor Brush Life – White Paper

Abstract

This paper looks at brush life, why brushes wear and what can be done to achieve longer brush life. It is meant to provide one with an understanding of the factors and conditions that contribute to brush wear in order that problem areas can be avoided and existing problems identified and resolved. This however, is not an instruction manual on how to fix problems. The motor manufacturer should be contacted for help in resolving brush and commutation problems. The following applies to medium and large horsepower industrial DC motors and generators.

I. Why Brushes Wear

DC brush wear is the result of mechanical friction and electrical erosion. Friction produces carbon dust; the result of electrical erosion is the vaporization of carbon with little physical residue.

A. Friction

Carbon rubbing on bare copper has a rather high coefficient of friction. A low coefficient of friction is achieved when the commutator has good film. With good film the coefficient of friction can be reduced to 10% of the original bare copper value.

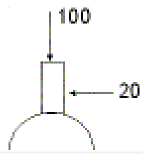
Friction changes with commutator temperature. The coefficient of friction decreases to some point, with increases in commutator temperature and then increases again as the commutator temperature increases. For example, a given brush might have a coefficient of friction of 0.15 running on a commutator with a surface temperature of 140�F, 60�C. When running on a commutator with a surface temperature of 220�F, 104�C the coefficient of friction could be 0.08. Yet higher temperatures can result in an increase in the coefficient of friction. Standard brushes on warm commutators at medium speeds will typically have a coefficient of friction of 0.13 to 0.19. This is considered to be a low coefficient of friction. The coefficient of friction, to a large degree is a result of the film produced on the commutator which is dependent on commutator surface temperature and the other factors which influence film.

Table I. Brush Coefficient of Friction

Very low	Less than 0.10
Low	0.10 to 0.19
Medium	0.20 to 0.29
High	0.30 and higher

Fig. 1. Friction

Friction is the resistance that opposes the force to slide one object over another. If the vertical brush force on the commutator is 100 and the horizontal force required for the commutator to move under the brush is 20, then the coefficient of friction is 20100 or 0.20.



Some brushes with low coefficients of friction are not as hard as brushes with higher coefficients of friction. There are however, a number of hard grades that have low coefficients of friction. A hard brush with a medium or high coefficient of friction may provide long life but could be noisy. Due to noise considerations, it sometimes becomes necessary to trade some brush life for quiet operation. A hotel elevator motor for example, would need to be quiet.

Friction can also be caused by mechanical problems such as high mica, high brush spring pressure, a feather edge on a copper bar or other imperfections on the commutator surface. Brush wear on an unpowered motor in a tandem motor-motor set or on an unloaded generator in a motor-generator set, is due to friction. Friction is a function of the atmosphere, temperature, current loading and the mechanical characteristics of the motor.

B. Erosion

Erosion can be the result of improper film on the commutator or a wear condition such as threading. Sparking and erosion can also be caused by other motor set up conditions or mechanical problems such as the brush neutral setting, interpole strength, low brush spring pressure, poor brush seating, high mica, commutator eccentricity etc. Sparking increases with current loading and motor speed. Brush life decreases with increased sparking.

The condition of the commutator film directly affects friction and erosion and thus brush life. In order to achieve good brush life, the commutator must have good film.

II. What Is Good Commutator Film

When electric current is passed between the carbon and copper in the presence of water vapor, a microscopic layer of copper carbon composite or film, is formed. Good film is chocolate brown or burnished bronze to dark brown or black and uniform in color. It is not bright copper or burnt black copper. Consult a commutator color and appearance picture chart to determine the condition of the commutator. There is a condition known as false filming in which brush graphite deposits become cooked on the commutator resulting in an appearance similar to dark film. Oil can also leave a coating which resembles film. If this film can be easily wiped away, it's not the desired good commutator film!

Commutator filming is a continuous process. That is, the film is continuously being formed and stripped away. A good film is only 200 nano inch thick (0.000,000,2 inch or 0.000,005,08 mm). Thus the conditions required to build good film must always be present. Changes in current, humidity, etc. will affect the commutator film.

III. Requirements For Good Film

Good commutator film is dependent on the fulfillment of certain requirements for each of the following items:

- Brush Current Density
- Commutator Surface Temperature
- Water Vapor
- Brush Pressure
- Commutator Surface Speed
- Brush Material or Grade
- Lack of Contamination
- Mechanical Integrity And Setup

A. Brush Current Density

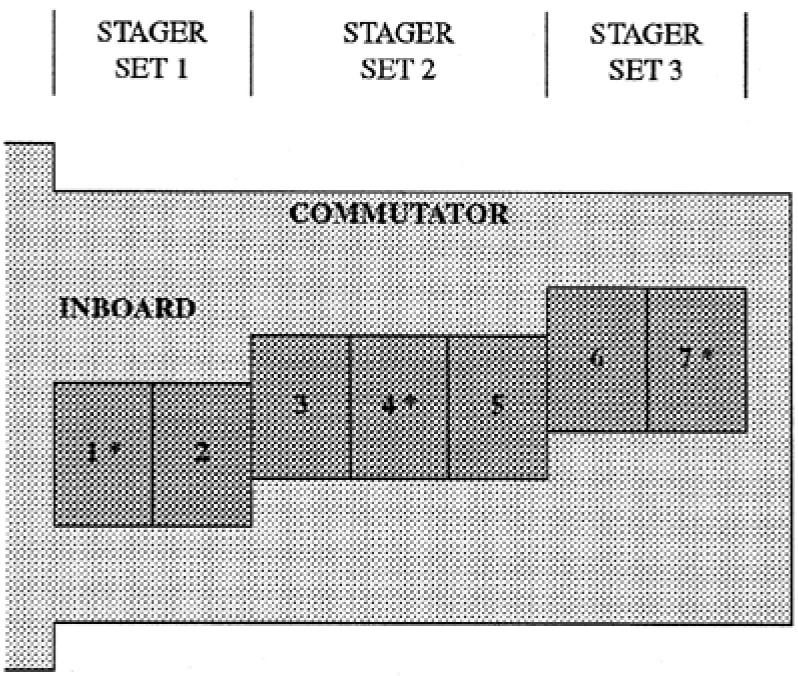
A majority of the operating time must be within the designed brush current density range. For SA45 or like grade brushes on warm commutators, this range is generally stated as 55 to 85 amps per square inch. If the current density exceeds this for long periods, the commutator will run hot, blacken and brush life will be reduced. If the current density is too low, the film will be striped from the commutator and the commutator will begin to thread. If allowed to continue, sparking and threading will increase, brushes will wear rapidly and the commutator will require resurfacing.

Often motors are run continuously at light loads where brush current density is always below the minimum. In such cases, a change in brush grade to something that will film at lower current densities, may solve the light loading problem. Many times the best solution is to remove a row or more of brushes to bring the current density back into the acceptable range. Before brushes are removed or changed, be sure that the new arrangement of brushes and brush shunts have sufficient capacity to handle the overload requirements of the motor. When removing brushes from machines with staggered brush sets, the remaining brushes on each stud must cover the same commutator surface arc as was covered prior to the removal of the brushes. This means that the brushes from the center stager set on each stud are removed first. When wear indicator brushes are used, be sure that some remain. Usually this is not a problem since the wear indicator brushes are most often the inboard and outboard brushes on the stud as well as the middle brush. The motor manufacturer can advise the order in which the brushes are to be removed. Some system must be in place to insure that the removed brushes are put back in place if the load conditions increase to near motor nameplated load.

Brush Current Density, amps/in^2 = Motor Current, amps divided by Total No. Brushes x .5 x Brush Surface Area, in^2

Fig 2. Brush Removal

Brush removal for light load example

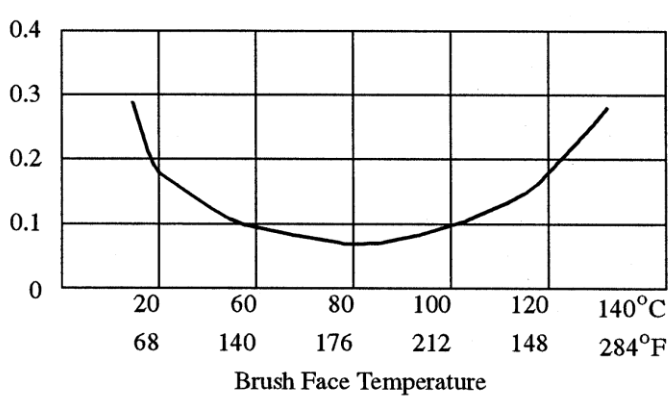


Pictured is one stud with 3 stager brush sets, 7 brushes per stud. When removing brushes due to a light load, remove the same brushes from each stud as follows:

No. Per Stud Removed	Brush No.
1	4
2	3,5
3	3,4,5

* Wear indicator brushes are numbers 1, 4 and 7.

Fig. 3. Coefficient of Friction and Temperature



B. Commutator Surface Temperature

It is generally accepted that the commutator temperature at the face of the brush should not be less than 60�C, 140�F. A sufficient layer of copper oxide will not form if the commutator runs cold. The commutator surface temperature should be between 60�C, 140�F and 115�C, 239�F for the majority of the running time with 100�C, 212�F about right for the best film building with standard brush grades. The graph in Fig. 3 is an example of how the coefficient of friction changes with brush face temperature. This is an example only, values change with brush grade, commutator film, brush pressure etc.

Hot commutators due to high ambient temperatures, overloads, or loss of coolant not only result in increased brush wear but reduced insulation life as well. The motor thermal protection is designed to help guard against this condition.

C. Water Vapor

An Absolute Humidity of 2 to 7 grains of water per cubic foot of air is required to build good film with SA45 or like grade brushes. When the Absolute Humidity is less than 2 grains (about 0.004,57 oz.) of water per cubic foot (about 20% Relative Humidity at 75�F, 24�C or 40% Relative Humidity at 55�F, 13�C), brushes will wear rapidly. High humidity can cause over filming or even more of a problem, low insulation megohm readings or ground faults.

There are several digital meters on the market that can be used to quickly measure Temperature and Relative Humidity. Measurements should be taken where the air enters the motor and at several points around the motor. The readings should be in the same range. Motors some distance away may be in ambients that give different results. Expect summer readings to differ from winter readings. On the enclosed Humidity Chart, read the Absolute Humidity on the horizontal line at the point of intersection of the diagonal Temperature line and the vertical Relative Humidity line.

D. Brush Pressure

It is running brush pressure, not spring pressure, that concerns us. Brush pressure is dependent on spring pressure and the position of the brush. It is also affected by the friction between the brush and holder. The coefficient of friction of the brush and holder is affected by commutator speed, brush grade, brush holder finish and brush clearance in the holder. It thus becomes difficult to measure brush pressure in the field, so spring pressure is measured. If the springs are weak, spring pressure being light, the brush will spark. If the pressure is too great, friction and wear increase. Good brush life and performance is usually achieved with brush spring pressures of 2 to 8 lbs per square inch (1.38 to 5.52 Newtons per square centimeter or 0.14 to 0.56 kilogram per square centimeter). This number varies with manufacturer, motor size and motor application. Spring pressure should be as recommended by the motor manufacturer.

lb/in^2 = N/cm^2 x 1.45

lb/in^2 = kg/cm^2 x 14.21

The best laboratory brush life is achieved with brush pressures of 2 to 4 lbs per square inch with filmed commutators running at speeds below 8,000 fpm. Typical brush pressures for integral horsepower industrial motors is in the range of 3 to 6 lbs per square inch. When a brush is at some angle to the commutator, as opposed to radial, there is a loss in the spring's force due to the brush angle. This loss is about 6.0% with a 20�angle and 9.4% with a 25�angle. Today most manufacturers supply brush springs that provide constant pressure throughout the life of the brush.

E. Commutator Surface Speed

The coefficient of friction between the brush and commutator increases approximately as the speed. Brush wear is proportional to the coefficient of friction. At higher speeds, above 5,000 or 6,000 fpm, greater brush pressure may be required, resulting in decreased brush life. At high field weakened speeds, commutation deteriorates, that is sparking increases. At higher speeds the film can be stripped from the commutators faster than it is being formed. If the motor runs at high speeds for only short periods of time, film can still be maintained.

For a given motor rpm, the smaller the commutator diameter, the lower the surface speed and the greater the brush life. In general, the commutator surface speed of industrial motors limited to 8,000 fpm.

Commutator Surface Speed, fpm = Commutator Diameter, in divided by 12 x 3.1416 x Motor Speed, rpm

F. Brush Material or Grade

With the above conditions met, SA45 or like grade brushes produce good commutator film on most integral horsepower DC motors. Special brush grades are available that will help compensate for certain undesirable conditions. Keep in mind that every brush fix is a compromise. That is, the fix is to compensate for something that in field operation, differs from the primary motor design mission. Thus new problems can sometimes be introduced as a result of the fix.

There is no magic brush that will give good life with a variety of loads, humidity, commutator conditions, etc. The magic is in controlling the conditions so that they all work together to provide the best brush life.

G. Lack of Contamination

Other chemical ingredients present in the air will become part of, or influence the composite that is film. So we can say that an absence of foreign chemicals is required to produce good film. Silicone vapors, chlorine, sulfur, PVCs, dirt such as carbon black, and oil are some of the industrial contaminants that are particularly harmful to commutator film.

Silicone based sealants must not be used in sealing motor air duct work, hand hole covers or any mating surfaces on or near the motor. Acetic acid vapors from silicone sealants will destroy commutator film. Other types of sealants also give off vapors when curing, that can be harmful to commutator film. Non-silicone Permatex sealants can be used without harm.

H. Mechanical Integrity And Setup

The commutator must be concentric and the surface free of imperfections. The brush rigging needs to be sound and properly aligned. Springs must be checked for proper tension. Brush holders and brushes must be checked to assure that brush side to side movement in the holder is not excessive. Brushes must be free to travel in their holders and seated to the commutator.

Brush shunts or pig tails, must be tight in the brush and of sufficient size to handle overload current requirements when they are in excess of the standard 150%. The brushes must be on electrical neutral. Interpoles need to be properly adjusted, shimmed and secure.

Replace springs that measure outside of the recommended range. If the brush is sloppy in the holder, compare the manufacturer's dimensions to the measured brush and holder dimensions to determine if the problem is with the brush or the holder. Replace worn parts as required. Failure to seat brushes results in sparking and can cause brushes to chip. Seat brushes with sandpaper; never use emery cloth since the grit is conductive and can lodge between commutator bars. Rough seating can be done with 60 or 100 grit sandpaper. Final seating should be done with fine sandpaper.

The surface finish of new or turned commutators should be in the range of 40 to 70 micro inches (0.000,040 to 0.000,070 inch). On new commutators, the mica is undercut approximately 1/16 inch, 1.59 mm. Brush holders should be adjusted for approximately 3/32 inch, 2.38 mm commutator clearance.

IV. Commutation And Brush Life

The above paragraph lists the mechanical and setup considerations necessary to achieve good commutation. But what is commutation and how does it affect brush life?

In a DC motor, commutation is the process of periodically reversing the current flowing in individual armature coils in order to maintain unidirectional torque as the armature coils move under alternate field poles. The commutator must reverse current through armature coils which left the influence of one field pole and are approaching the influence of an alternate field pole. The motor brush then contacts more than one commutator segment and an armature loop is momentarily shorted. If the short has a difference of potential across it's ends, severe sparking can occur between the brush and the commutator. The commutator then can burn and pit and brush life is reduced. It is thus necessary to insure that voltage is not induced in the commutator loop at the time of the momentary short. If the short occurs when the active conductors in the armature loop are moving in parallel to the field, magnetic lines of force will not be cut and voltage will not be induced in the armature loop. This vertical axis occupied by the shorted armature loop is the geometric neutral plane. In theory, this is where sparkles or black commutation takes place. But life is not that simple! Due to the self induced e.m.f. and changes in load, the situation is somewhat more involved and beyond the scope of this article. In the end however, electrical neutral must be properly set to assure good commutation and good brush life.

Table II. Commutator In Service Limits

Maximum allowable commutator eccentricity varies with motor design, the following limits in inches are typical for standard industrial motors:		
	Medium hp	Large hp
Max Total Indicated Runout in 360�	0.001,5	0.003
Max Total Indicated Runout in any 90�	0.001	0.001,5
Max Bar to Bar Runout	0.000,5	0.000,5
Max Taper, inches per foot	0.002	0.002

When we talk of a motor's ability to commutate we are also referring to the motor's armature current handling capability. Standard industrial DC motors are required to successfully commutate 150% of the nameplate full load current for one minute at any speed within the motor's nameplate speed range. There is no exact definition of successful commutation and commutation can be considered successful even if sparking occurs provided that it does not result in excessive maintenance. Intermittent sparking due to overloads or a slight amount of sparking does not necessarily indicate poor commutation. The cause of excessive sparking should be determined and the problem corrected. It is common to refer to the amount of sparking as the degree of sparking along with a reference number such as 1, 1 1/4, 1 1/2, 2 etc. The enclosed drawing SK-10817 is an example of a degree of sparking numbering system. Numbering systems vary with motor manufacturers. The lower numbers represent a few small sparks. The higher numbers indicate more sparks and larger sparks which do the most damage to the brushes and commutator. Desirable is black commutation in which there is no visible sparking. The degree of sparking drawing is somewhat misleading in that both the small or pin point sparks and the large sparks are smaller than shown on the drawing.

A wear rate factor is sometimes assigned to the degree of sparking reference number. The wear rate factor would be 1.00 for a given motor on a given application when commutation is in the black. If this condition provides 7,000 hours brush life for example, and a change in the degree of sparking occurs such that the degree of sparking reference number is now 2 with a 1.75 wear rate factor, the new expected brush life would be 7,000 hours1.75 or 4,000 hours. The following degree of sparking guide can be used with drawing SK-10817 to determine the degree of sparking and to provide an insight to brush life.

Table III. Degree of Sparking Guide

No.	Description	Wear Rate Factor
1	Black with no visible sparking	1.00
1 1/4	Light intermittent sparking	>1.00
1 1/2	Light continuous sparking over half of the brush length	>1.00
2	Light continuous sparking over the entire brush length	1.75
3	Light continuous sparking with one or two heavy sparks	2.50
4	Light continuous sparking with three heavy sparks	5.00
5	Heavy continuous sparking with few small sparks	12.50
6	Heavy continuous sparking with glowing spots; approaching flash-over	50.00

Table IV. Brush Life Example

Load Type	Amps/in^2	Hours, Life
Intermittent, Light	down to 30	750 - 2,000
Within Rated Load	45 to 85	3,000 - 7,500
Intermittent, Heavy	up to 125	1,000 - 4,000

Table V. Factors That Affect Brush Life

Application and duty cycle
Atmospheric conditions
Commutator condition which includes film, runout, quality of the undercut, etc.
Brush assembly design which includes brush grade, brush length, holder design, spring pressure, etc.
Motor building practices including the accuracy to which neutral is set
Power supply and motor design

V. What Is Normal Brush Life

As an estimate, 7,500 hours brush life could be considered normal for general purpose, medium horsepower DC motors with good commutator film operating with commutator surface speeds in the range of 2,500 to 4,000 fpm. The minimum life might be 2,000 to 5,000 hours with 10,000 hours being about maximum. It is not uncommon however, for motors with light or variable loads, such as machine tool motors, to have brush life that is less than 2,000 hours. Brush life is even further reduced at higher commutator surface speeds. As a rule of thumb, brush life at 3,600 rpm is half that at 1,800 rpm. Brush life is also affected by load. The brush life of a 50 hp, 1,750 rpm, motor with a commutator surface speed of 2,620 fpm, could vary with load as shown in Table IV.

VI. When To Replace Brushes

Brushes should be replaced before the tamped shunt or pigtail lead has a chance to score the commutator and before the brush is at the end of the spring travel. Some brushes have three wear lines so that brush life can be monitored. When the brushes wear to the third line, the brushes should be replaced. Brush probes that contact the commutator and provide a voltage signal equal to the armature voltage and mechanical devices that move with the brush spring and close a contact are also available on some motors to tell you that it is time to change brushes.

VII. What We Can Do To Achieve Longer Brush Life

To identify all of the variables and then determine brush life gets to be quite a job, especially when the variables are changing. What we can do is identify the current problems and take corrective action. By monitoring the conditions that affect brush life, along with or as part of a maintenance program, we will have information that can alert us to potential or developing brush and commutator problems. Just as commutator filming is a continuous process, so is the monitoring and corrective action process continuous. Through monitoring and corrective action, down time may be reduced and longer, trouble free motor life achieved.

References

This paper is a compilation of my written responses over the past twenty years, to numerous brush and commutator questions.

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Note: This material is not intended to provide operational instructions. Appropriate Reliance Industrial Company instruction manuals and precautions should be studied prior to installation, operation, or maintenance of equipment.