The Effect of Spring Pressure on Carbon Brush Wear Rate
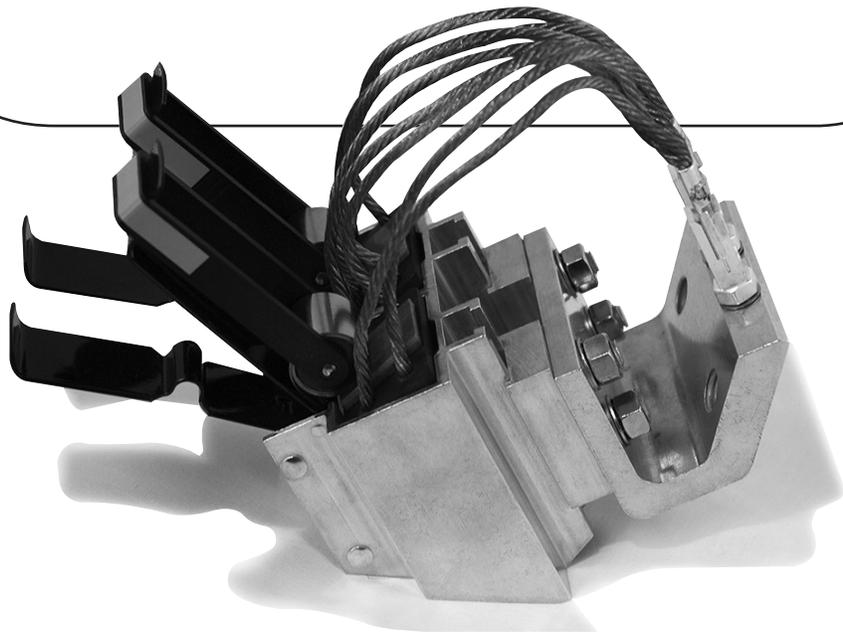
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Preface 2008

For decades there was extensive testing of countless different carbon brush contact materials to increase life on continually evolving machines. This "Black Art" led many to continually pursue the ideal grade. Meanwhile, brushholders received little attention. The standard procedure for the adjustable force holders was to reduce the force until arcing was noticed and then adjust up to the next notch. Checking of spring force usually involved only the feel of the index finger under the spring arm. Literature suggested spring pressure of 2.0 to 2.5 PSI (140 to 175 g/cm^2) for industrial machines. Clearly there was a need for more testing to determine reliable standards for spring pressure.

Over 25 years has now passed since the original presentation of "The Effect of Spring Pressure on Carbon Brush Wear Rate" at the annual Open Pit Mining Association meeting in St. Louis, MO in June 1983. The initial reactions to the paper, which suggested that spring pressures needed to almost double from existing standards, were primarily one of skepticism. However, the concept was understandable, believable, and of sufficient benefit that many tried the new recommended spring pressure during the following years. The results exceeded all expectations. When the spring pressure was increased to the new recommended level, the typical brush life improved by 50% and dramatically reduced the need for resurfacing of brush contact surfaces. Today almost all standard recommendations for spring pressure have been increased in reaction to this test and the subsequent improved field results.

As one reflects back on the impact of the increased awareness of spring pressure and the higher contact force implementations, it could be concluded that the product life cycle for carbon brushes may have been extended as a result. It is with this significance in mind that this technical paper is reissued with some enhancements. We hope that today's users of carbon brushes can hereby grow in understanding of the product function and in awareness of maintenance needed to keep machines operating efficiently.

INTRODUCTION

A carbon brush is a sliding electrical contact that carries current to, or from, a moving surface. It performs this electrical duty while operating within the constraints of a mechanical system. Unlike most other electrical contacts, brushes require more frequent replacement, making increased brush life a vital concern. Brushes wear due to the combination of mechanical wear resulting from friction and electrical wear resulting from excessive resistance at the contact surface (arcing). The primary purpose and scope of this paper is to examine considerations for reducing wear rates to a minimum and thereby extending the life of the brush and the contact surface.

MECHANICAL WEAR

Mechanical wear caused by friction is the abrasion or "tearing out" of particles from the contact surface. The action is similar to that of chalk on a board. Friction is proportional to the force perpendicular to the contact surface. Increased downward pressure on a surface causes increased friction opposite to the direction of motion (As shown in Figure 1).

ROTATION
FIGURE 1
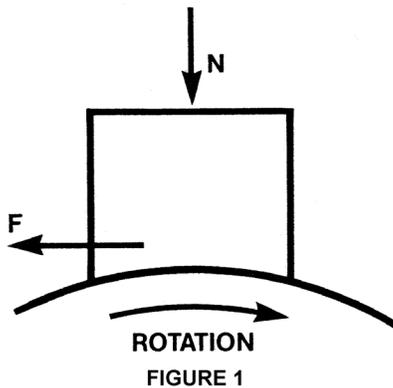
MATHEMATICALLY FRICTION IS
$$F = \mu \cdot N$$
WHERE
F = FRICTION FORCE
N = NORMAL FORCE (Spring Pressure)
μ = COEFFICIENT OF FRICTION

Thus friction (F) and thereby mechanical wear increases directly with increasing spring pressure which applies the normal force (N). The coefficient of friction (μ) determines the relation of spring pressure (N) to friction force (F). This value is primarily dependent upon the materials involved and the temperature at the moving surface.

Clearly, the movement of a rubber material across a wood surface would involve a very high coefficient of friction. Conversely, carbon brushes on a commutator or ring characteristically form a low coefficient of friction surface called a film.

The desired film thickness on the contact surface is only 40-60 angstroms (50 x 10-8 cm or 0.2 millionths of an inch.) A proper film is composed of metal oxide, water, and micro-graphite particles. These substances have low coefficients of friction which contribute to low brush friction and low mechanical wear. The primary considerations for the formation of a proper film are brush grade, level of current load per brush, absolute humidity and contamination in the atmosphere. Based on the friction formula previously mentioned, the following graph of mechanical wear vs. spring pressure is derived. (Figure 2)

FIGURE 2
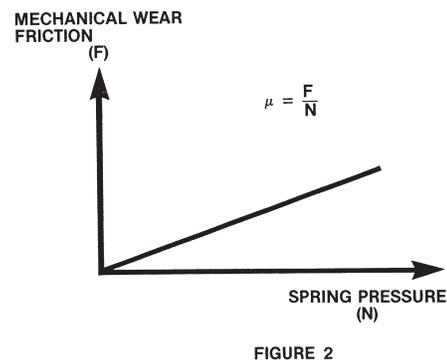
In addition to the coefficient of friction, it is also important to note that the mechanical wear will be influenced by speed at the interface of the sliding electrical contact. In fact, the rate of change in mechanical wear, or the slope of the graph, will change proportionately with either an increase or decrease of these two variables.

In any case, increasing spring pressure causes constantly increasing mechanical brush wear.

ELECTRICAL WEAR

Electrical wear results from resistance at the dynamic sliding interface between the carbon brush and the contact surface. If the film is contaminated with dust, oil, smoke, caustic fumes or corrosive chemicals, all of which are poor conductors, then the brush to contact surface resistance increases. The separation of a brush from the contact surface across the high resistance of an air gap is the most obvious condition to cause electrical wear and arcing. In this case rough commutators or rings and unstable brushholder systems are often the fault. Regardless of the cause, conduction of current through a high resistance will result in high energy, high temperature, destructive arcing and thereby fast wear of the brush and the contact surface.

As with mechanical wear, a change in spring pressure has a significant effect on the electrical wear rate. Higher spring pressure causes lower voltage drop and thereby lower electrical wear as in the following graph.

On the other hand, there is a sharp increase in electrical wear when the spring pressure decreases to the left of the elbow in the curve (POINT A) in figure 3.
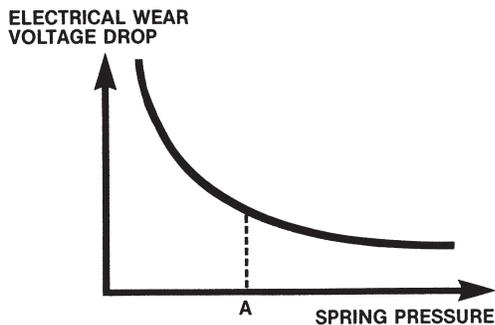

FIGURE 3

The level of electrical wear is directly related to the I^2R loss at the brush to contact surface interface. The electrical wear curve will shift up or down in proportion to the contact resistance and according to the square of the load amps through the brush. It is important to note that while mechanical wear is primarily abrasion of the brush material, electrical wear involves erosion of both the brush and the contact surface. Electrical wear therefore has the potential to cause more serious high cost problems up to and including flashover.

TOTAL BRUSH WEAR

For the purpose of quantifying brush wear it is concluded that friction is the primary measureable indicator of mechanical wear and that the voltage drop is the primary measureable indicator of electrical wear. At any time during operation, a carbon brush is wearing both mechanically and electrically simultaneously. Therefore total bush wear is the summation of mechanical and electrical wear. The combination of graphs in Figures 2 and 3 results in the total brush wear rate as related to spring pressure in Figure 4.
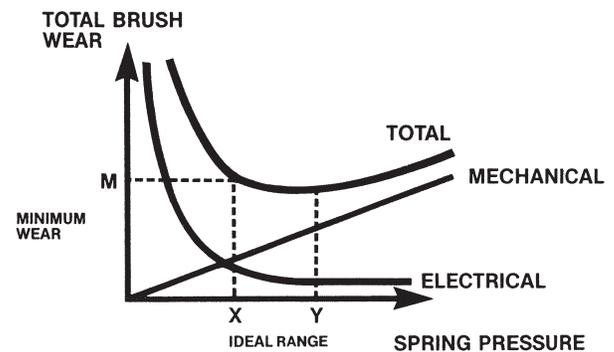

FIGURE 4

The "U-SHAPED" curve of total wear in Figure 4 indicates that there is a range of spring pressure between points X and Y where the total brush wear rate is at a minimum (M). It is also important to note that often there is a slow rate of increase in total brush wear with higher spring pressures. It has been a common recommendation to decrease spring pressure until arcing becomes visible and then increase the pressure adjustment to the next notch. Much of the previously published literature indicates that this ideal pressure range is between two and three pounds per square inch of brush area (140-210 g/cm²). However, performance on many units in the field, particularly those with so-called constant pressure springs, has raised question as to the correctness of these recommendations. For this reason, a laboratory test has been conducted to more scientifically determine the spring force range for optimum brush life.

LABORATORY TEST

The purpose of the test is to measure the levels of friction and voltage drop for brushes at various spring pressures so that the ideal range of minimum brush wear can be determined for a typical industrial brush application.

The test was conducted using the electro-graphite grade E57, commonly applied on high voltage DC equipment. The humidity, atmosphere, and temperature were strictly controlled in order to isolate the desired parameters. The brushes were "run-in" for three hours preceding each voltage drop and friction measurement. The commutator film was cleaned between each measurement and the following "run-in" period.

The spring pressures tested were 2.0 PSI (140g/cm²), 4.0 PSI (280 g/cm²), 8.0 PSI (420 g/cm²), and 12.0 PSI (560g/cm²). At each respective spring pressure, measurements were made at four controlled temperature levels in order to simulate typical commutator and ambient conditions; 160°F (71°C), 180°F, (82°C), 200°F, (93°C) and 220°F (104°C).

LABORATORY RESULTS

The results of the friction test of mechanical wear are shown in Graph I, (see appendix A for methods of measurement and calculation). As predicted in previous the discussion, there was a near straight line relation between friction and spring pressure. Increased levels of spring pressure do, in fact, cause increased friction and mechanical wear. Therefore, Point Y on Figure 4 is the upper limit for the optimum range. It is at this point and beyond where spring pressure is primarily responsible for these mechanical effects.

However, the primary concern of this exercise is electrical wear, inadequate spring pressure, and the lower limit of the ideal range for maximum brush life (Point X in Fig. 4 or Point A in Fig. 3). Since at low levels of spring pressure, mechanical wear is minimal while electrical wear is dramatically increased, it can be concluded that the lower limit is determined primarily by the rates of voltage drop or electrical wear.

The results of the voltage drop test are shown in Graph II (See appendix B for method of measure

ment.) The data reflects a typical heavy load condition of 70 amps per square inch (10.8 amps/cm²).

The data indicates a sharp increase in voltage drop and electrical wear at spring pressures less than 4 PSI (280 g/cm²). Similar results were found for an underload condition of 40 amps per square inch (6.2 amps/cm²) on Graph III and for an overload condition of 100 amps per square inch (15.5 amps/cm²) on Graph IV. Again the shapes of the data curves are very close to that predicted in the previous discussion.

ANALYSIS OF RESULTS

The results of this laboratory test indicate that a **MINIMUM** recommended level of spring pressure for large DC equipment is four pounds per square inch (280 g/cm²). At pressures less than this, the voltage drop increases rapidly and thereby the probability of rapid wear of the brush and contact surface. The spring pressure of 4.0 PSI (280 g/cm²) corresponds to the elbow of the electrical wear curve, or Point A on Fig. 3. The consistency of the results at varying load conditions further lends credibility to the conclusion that 4 PSI (280 g/cm²) is a critical value.

All carbon brush applications will have wear rates related to spring pressure as shown in Figure 4. The operating conditions could cause change in the slope of the mechanical wear curve or a shift up or down in the electrical wear curve. The total brush wear curve will then change accordingly. Each particular application would have its own optimum pressure range for maximum life. Therefore, when selecting the proper strength spring for a given application, one must consider the above potential changes from the standard recommendation of 4 PSI (280 g/cm²) minimum and the potential sources for loss of pressure:

- Shock and vibration
- Decreasing pressure over life of spring
- Decreasing pressure over life of brush
- Friction in brush holder as related to top and bottom brush angles
- Weight of brushes on bottom side of a commutator

The test results were determined under ideal laboratory conditions. The resultant of the above real world sources of pressure loss is a decrease in the net spring pressure at the brush contact face. This then shifts the operating point on the graph in Figure 4 to the left, which results an increase of electrical and total brush wear.

When applications include these factors or when speeds are relatively low, the selection of spring pressure higher than 4 PSI (280 g/cm^2) would then be advantageous. On the other hand, applications with very high speed or very low current density could have lower total wear rate with less than 4 PSI (280 g/cm^2) spring pressure.

The large increase from 2 PSI (140g/cm^2) to the newly recommended 4 PSI (280 g/cm^2) as the standard for industrial DC applications is further supported by the fact that one well known manufacturer of excavating equipment has used these guidelines for many years with no report of excessive brush or commutator wear from heavy spring pressure. Based on the theory and test results presented above, the inadequate spring pressure appears to be the primary source of short brush life on many of today's motors and generators.

OTHER CONSIDERATIONS FOR EXTENDING BRUSH LIFE

Constant pressure springs are intended to maintain an even pressure over the life cycle of the brush. The constant force spring can be a significant advantage in improving the consistency of brush wear rate provided that a careful consideration is given to its limitations.
 The manufacturers of these springs state the load of the spring has a standard tolerance of plus or minus 10%. Also, springs slowly lose their force after many months of usage.

Furthermore, the rated spring pressure is not in affect until a coil, with diameter D, is extended the length of one coil diameter as shown in figure 5. With some brushholder designs, a worn brush will allow the spring to recoil to an extension of less than one spring diameter resulting in a decreasing spring force. In other words, a one inch diameter constant pressure spring loses force rapidly to

zero when the brush is worn to a length such that the spring is recoiling the last one inch. For best results, the brush should be replaced at this brush length. This concept is shown graphically in Figure 5.
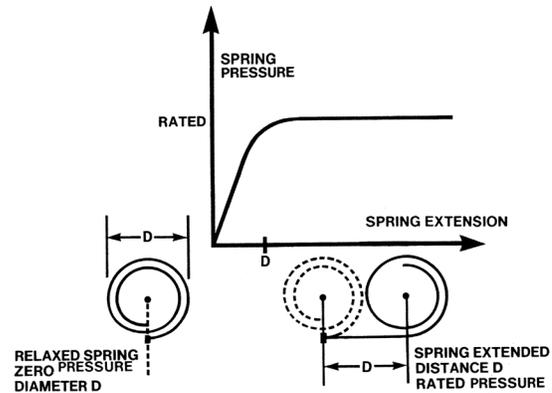

Figure 5

Constant force springs will decline in force prematurely if they conduct current, even at low levels. With constant force springs, it is therefore highly recommended that the top of the brush be insulated to ensure that no current flows through the spring thereby preventing deterioration of spring pressure.

 A pad, or Red Top, on the top of the brush not only has this insulating benefit but also has the ability to absorb shock and vibration. Therefore, electrical wear is minimized with more stable brush contact and a lower voltage drop. It also allows for easier brush installation as split brushes are held together in a single unit form. The importance of the padded brush in extending brush life is well known throughout industry.

Finally, it is critical for maximum brush life that proper brush grades are applied for the specific type of application, the operating loads and environmental conditions.

Carbon brushes are often blamed for many of the problems on motors and generators. However, they are merely reacting to the mechanical and electrical conditions to which they are subjected. Analysis and corrective action for these conditions will allow the realization of maximum brush life.

APPENDIX A:
MEASUREMENT OF FRICTION

A ten inch diameter commutator at 1200 RPM was used with four brushes per set. Each brush had a normal force (N) applied which in turn caused a frictional force (F) at the brush face according to the equation $F = \mu N$.

The total friction force from the four brushes is then $F_T = 4 \cdot \mu \cdot N$. The torque at a known radius R, is $T_{brush} = F_T \cdot R$. In this test R=5" so that $T_{brush} = 4 \cdot \mu \cdot N \cdot 5$.

The resisting torque is measured experimentally using a spring scale at a given distance, D. In this test D was set at 10 inches from the center of the commutator. Thus $T_{resist} = F_{scale} \cdot D$ or $T_{resist} = F_{scale} \cdot 10$.

Since the system is stable, the frictional torque of the brush is equal to the resisting torque at the spring scale.

$$T_{brush} = T_{resist}$$
$$4 \cdot \mu \cdot N \cdot 5 = F_{scale} \cdot 10$$
$$2\mu \cdot N = F_{scale}$$
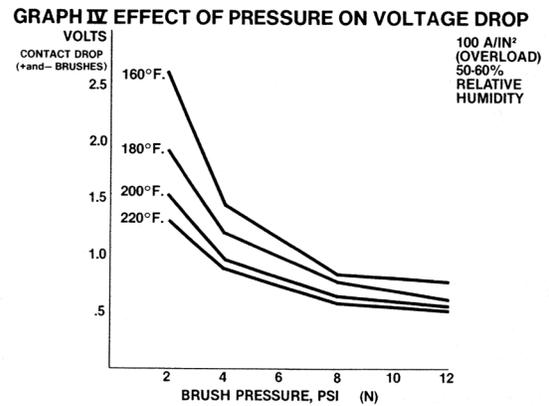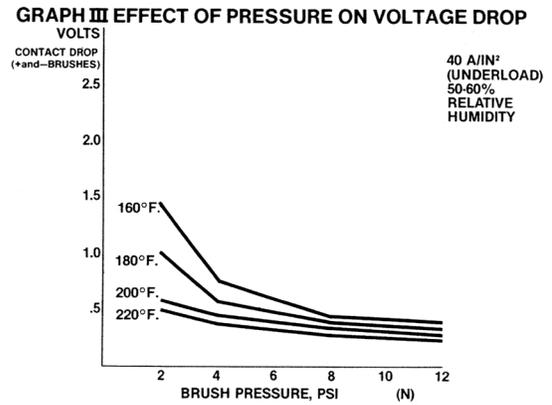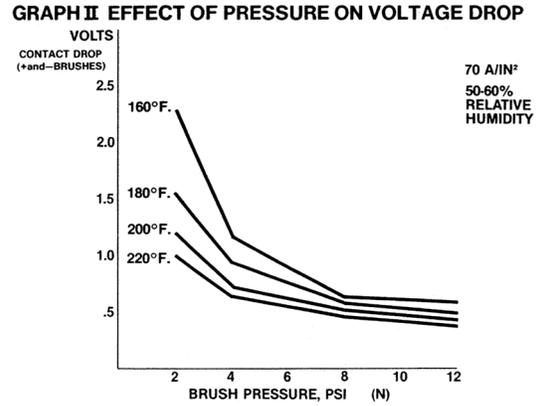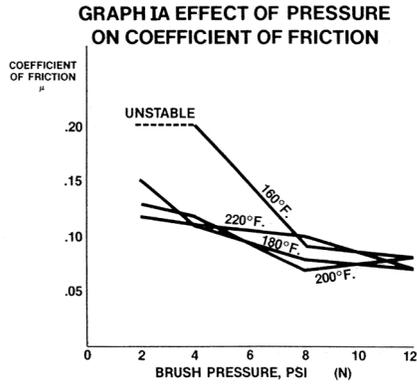$$\mu = \frac{F_{scale}}{2 \cdot N}$$

Thus the coefficient of friction is calculated from the reading of the spring scale divided by two times the normal force (spring pressure).

The results of these measurements and calculations are shown in Graph IA. Graph I of friction vs. spring pressure was derived from Graph IA by solving for friction (F) given the known quantities μ and N at each pressure (N) and temperature. It is interesting to note in Graph IA that at temperatures of 160°F (71°C) and presumably below, the coefficient of friction ran higher and increased brush wear rates would be expected.

APPENDIX B:
MEASUREMENT OF VOLTAGE DROP

Voltage drop is the summation of the voltage between the brush face and the contact surface of the positive and negative brush.

The voltage (or contact) drop was measured by using a probe imbedded in the carbon one-eighth inch from the brush face, while the reference probe was located in the hub of the commutator. Voltage drop readings were taken by direct measurement.

GRAPH II EFFECT OF PRESSURE ON VOLTAGE DROP

VOLTS
CONTACT DROP
(+and—BRUSHES)

70 A/IN²
50-60%
RELATIVE
HUMIDITY

2.5

2.0

1.5

1.0

.5

160°F.
180°F.
200°F.
220°F.

2   4   6   8   10   12
BRUSH PRESSURE, PSI   (N)

GRAPH I EFFECT OF PRESSURE ON FRICTION

FRICTION FORCE
μ • N

1.0

.8

.6

.4

.2

70 A/IN²
50-60%
RELATIVE
HUMIDITY

UNSTABLE
160°F.
180°F.
200°F.
220°F.

2   4   6   8   10   12
BRUSH PRESSURE, PSI   (N)

GRAPH IA EFFECT OF PRESSURE ON COEFFICIENT OF FRICTION

COEFFICIENT
OF FRICTION
μ

.20

.15

.10

.05

UNSTABLE
160°F.
220°F.
180°F.
200°F.

0   2   4   6   8   10   12
BRUSH PRESSURE, PSI   (N)

GRAPH III EFFECT OF PRESSURE ON VOLTAGE DROP

VOLTS
CONTACT DROP
(+and—BRUSHES)

40 A/IN²
(UNDERLOAD)
50-60%
RELATIVE
HUMIDITY

2.5

2.0

1.5

1.0

.5

160°F.
180°F.
200°F.
220°F.

2   4   6   8   10   12
BRUSH PRESSURE, PSI   (N)

GRAPH IV EFFECT OF PRESSURE ON VOLTAGE DROP

VOLTS
CONTACT DROP
(+and— BRUSHES)

100 A/IN²
(OVERLOAD)
50-60%
RELATIVE
HUMIDITY

2.5

2.0

1.5

1.0

.5

160°F.
180°F.
200°F.
220°F.

2   4   6   8   10   12
BRUSH PRESSURE, PSI   (N)

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