The Effect of Spring Pressure on Carbon Brush Wear Rate

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"Carbon Brushes and Brushholders for Excavating Equipment"

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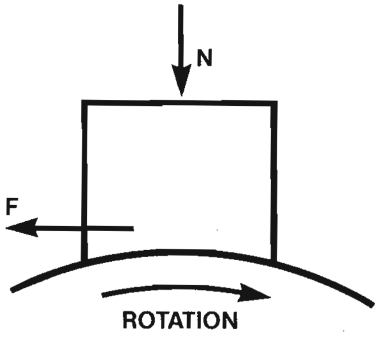
INTRODUCTION

A carbon brush may be defined as an electrical contact that carries current to or from a moving surface. It performs this electrical duty while operating within the restraints of a mechanical system. Unlike most other contacts, brushes require 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 brush and commutator life.

MECHANICAL WEAR

Mechanical wear caused by friction is the "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).



MATHEMATICALLY FRICTION IS

$$F = \mu \cdot N$$

WHERE F = **FRICTION FORCE**
N = **NORMAL FORCE (Spring Pressure)**
μ = **COEFFICIENT OF FRICTION**

FIGURE 1

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 characteristically form a low coefficient of friction surface called a film.

The desired film thickness on a commutator is only 40-60 angstroms (50×10^{-8}CM) or about 0.2 millionths of an inch. A proper film is composed of copper 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)

The rate of increase in mechanical wear or the slope of the graph is dependent on the coefficient of friction, which in turn is related to the film on the commutator.

In any case, increasing spring pressure causes constantly increasing mechanical brush wear and/or commutator wear.

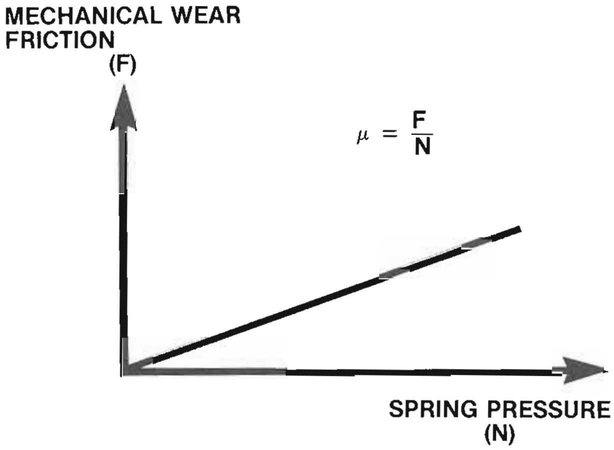


FIGURE 2

ELECTRICAL WEAR

Electrical wear results from high resistance in the contact surface area of the circuit. When the film is contaminated with dust, oil, smoke, caustic fumes, or corrosive chemicals, all of which are poor conductors, the brush to commutator resistance increases. The separation of a brush from the commutator across the high resistance of an air gap is the most obvious condition to cause electrical wear and arcing. In this case rough commutators 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 brush and commutator wear.

As with mechanical wear, spring pressure is closely related to the electrical wear rate. Higher spring tension causes rapid decreases in the voltage drop and thereby lower electrical wear as in the following graph.

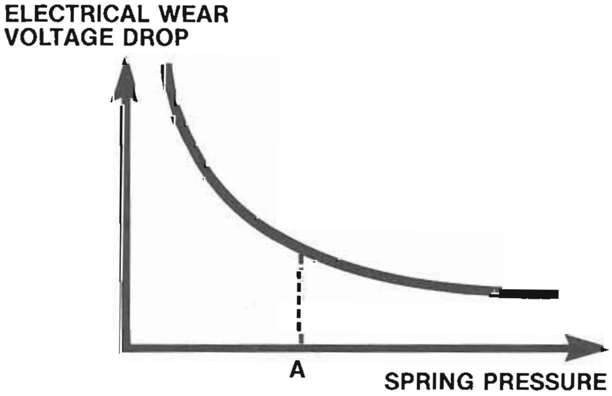


FIGURE 3

Note the sharp increase in electrical wear at low spring pressure to the left of the elbow in the curve (POINT A).

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. The total brush 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.

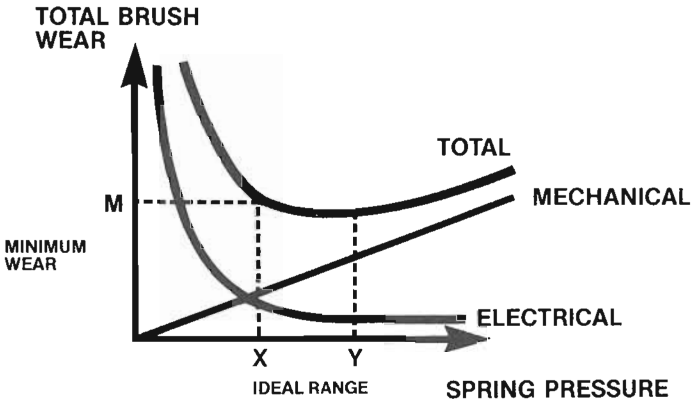


FIGURE 4

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 brush wear rate is at a minimum (M). It is also important to note the slow rate of increase in brush wear with higher spring pressures.

Much of the previously published literature indicates that this ideal pressure range is between two and three pounds per square inch of brush area. 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 determine the spring tension 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 tensions so that the ideal range for minimum brush wear can be determined.

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, 4, 8, and 12 pounds per square inch of brush area. 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 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 it follows that the upper limit of the optimum range (Point Y on Fig. 4) for spring pressure is primarily determined by these mechanical effects.

However, the primary concern of this exercise is inadequate spring pressure and the lower limit of the ideal range for maximum brush life (Point X in Fig. 4). 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 measurement.) The data reflects a typical heavy load condition of 70 amps per square inch.

The data indicates a sharp increase in voltage drop and electrical wear at spring pressures less than four PSI. Similar results were found for an underload condition of 40 amps per square inch on Graph III and for an overload condition of 100 amps per square inch on Graph IV. Again the shapes of the data curves are very close to that predicted in 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. At pressures less than this, the voltage drop increases rapidly and thereby the probability of rapid brush and commutator wear. The consistency of the results at varying load conditions further lends credibility to the conclusion that 4 PSI is a critical value.

Each particular application would have its own optimum pressure range for maximum life. Therefore, when determining the proper strength spring for a given application, in addition to the 4 PSI minimum level, one must consider the potential sources for loss of pressure:

1. Shock and vibration.
2. Decreasing pressure over life of spring.
3. Decreasing pressure over life of brush.
4. Friction in brush holder as related to top and bottom brush angles.
5. Weight of brushes on bottom side of a commutator.

One must consider that these were laboratory results under ideal conditions and that in the field many of the potential sources of pressure loss may exist. Therefore spring pressures of 5 to 8 PSI are not at all excessive, particularly on rough applications. This conclusion 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 due to heavy spring pressure. The application of 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 designed to maintain even pressure over the life cycle of the brush. 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 tension after many months of usage.

Furthermore the rated spring pressure is not effected 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 have allowed the spring extension to recoil to less than one spring diameter and thereby the brush no longer receives proper pressure.

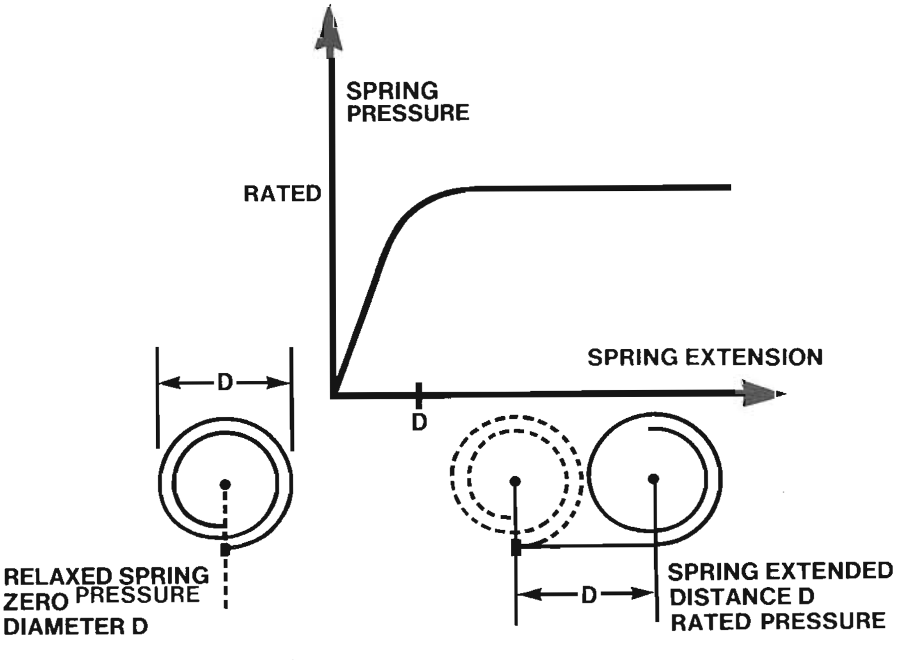
In other words, a one inch diameter constant pressure spring loses tension rapidly to zero when the brush is worn to a length such that the spring is recoiling the last one inch and for best results the brush should be replaced at this brush length.

It is highly recommended that the top of the brush be insulated to ensure that no current flows through the spring clip and thereby causes deterioration of spring tension. The constant force spring can be a significant development in improving brush performance provided careful consideration is given to its limitations.

The insulated top or Red Top pad has, in addition to its insulating benefits, the ability to absorb shock and vibration. Thereby more stable brush contact and low voltage drop are maintained resulting in minimized electrical wear. 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 the mining 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 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 $F = \mu \cdot N$. 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.

$$\begin{aligned} T_{brush} &= T_{resist} \\ 4 \cdot \mu \cdot N \cdot 5 &= F_{scale} \cdot 10 \\ 2\mu \cdot N &= F_{scale} \end{aligned}$$

$$\mu = \frac{F_{scale}}{2 \cdot N}$$

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

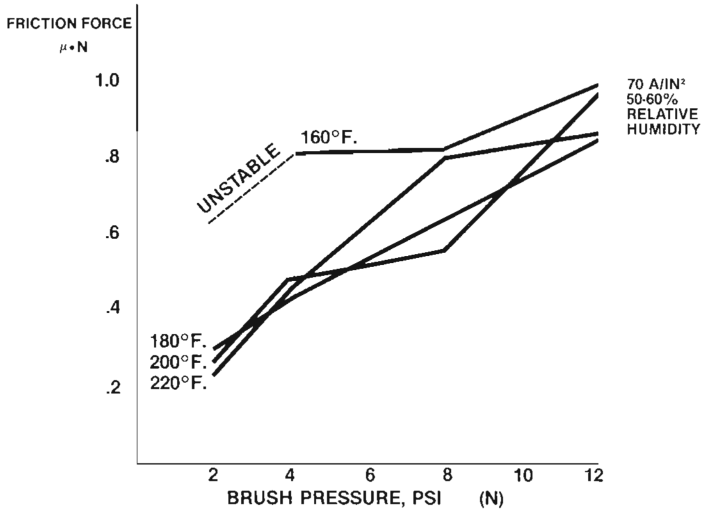
The results of these measurements and calculations are shown in Graph IA. Graph I of friction vs. spring pressure was derived from Graph IA by solving for friction (F) given the known quantities μ and N at each pressure (N) and temperature. It is interesting to note in Graph IA that at temperatures of 160°F 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 commutator 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 I EFFECT OF PRESSURE ON FRICTION



GRAPH IA EFFECT OF PRESSURE ON COEFFICIENT OF FRICTION