

# CHARACTERISTICS OF METAL-GRAPHITE BRUSHES MADE BY THE POWDER METALLURGY TECHNIQUE

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## Abstract

The paper deals with the development of the metal-graphite brushes and the materials used in their manufacture. After dealing briefly with the process of manufacture of such brushes, the authors discuss their electrical and mechanical characteristics under different conditions of operation. These characteristics are many times conflicting in nature, and a proper selection of the brush grade has to be made to get optimum working conditions. The choice of a particular type of brush depends upon the voltage and current ratings of the machine. In the end mention is made of the authors' work on the manufacture of metal-graphite brushes on the laboratory and the pilot plant scale.

## Introduction

**C**ARBON, graphite and metal-graphite brushes are used in a large number of rotating electrical machinery. These conducting brushes serve to provide at the sliding surface of the commutator or slipping an electrical contact to carry electric current to the rotating part of the machinery, from the external electrical circuit or vice versa. In the early days of the electrical industry such contacts at sliding surfaces were made from copper wires which resembled a brush. Hence such contacts came to be known as brushes. With the development of the electrical industry, brushes used on primitive machines also went through the process of development. Copper gauze brushes and laminated brushes containing graphite were used to meet the fresh demands.

These metallic brushes were found unsuitable on high-voltage machines, partly due to their high inertia and partly to their low voltage drop.

The high inertia of these brushes made it difficult to have a good physical contact with a revolving commutator running at high peripheral speeds. The low voltage drop at the brushes allowed heavy currents to circulate in the armature windings connected to the commutator bars shorted by the brushes, and thus created commutation troubles. These difficulties were overcome by the development of carbon and graphite brushes and these have now mostly replaced the old metallic ones for the high-voltage machines.

## Manufacture of Metal-graphite Brushes

Metal-graphite brushes are now used on machines where the use of metallic brushes is found more advantageous than the use of the carbon or graphite ones. Such brushes are now made by the powder metallurgy technique, by mixing metal and graphite powders in the desired proportions. The development of these brushes represents one of the oldest phases of the powder metallurgy technique. Continued progress in this technique has resulted in the development of the present-day metal-graphite brushes, giving the desired fine-grained texture and satisfying the electrical, mechanical and thermal requirements. There are perhaps no other articles made by the powder metallurgy technique where such exacting demands are made both on the mechanical and electrical properties. The metal powder mostly used is that of copper, but in certain grades of brushes, lead, zinc, tin and silver powders are also used. In most metal-graphite brushes copper is the main constituent.

Silver has recently been used in certain cases in place of copper. Such brushes would naturally be costlier. These find use in machines where the higher conductivity of silver and its better lubricating properties are called for to give a superior performance. Materials like tin and zinc are added to increase the bending strength and wear resistance of the material. Lead is added to give smoothness of operation and silver to increase the conductivity.

Metallic powders are obtained either by electrolysis, hammering, ball milling, atomizing or by reduction of metallic oxides. The graphite used is the natural flake variety. Powders of desired fineness are taken and mixed, and pressed in suitable moulds under high pressures. The pressed blocks are then sintered in furnaces in reducing atmosphere. The baked blocks are then cut to required size and the shunt leads are fixed to the cut pieces, and the brushes then become ready for use. The method used is similar to that for the manufacture of copper graphite bearings, when high percentages of copper are used. In such brushes the bond developed between the metallic particles is sufficient to give the brush blocks the necessary strength. When the metallic content is not high, coal-tar and coal-tar pitch are used as binders. The characteristics of metal-graphite brushes vary with the contents of the metal powder.

In subsequent paragraphs the characteristics of such brushes and the experimental work done by the authors in connection with the manufacture are dealt with.

### Characteristics of Metal-graphite Brushes

The properties of metal-graphite brushes which make them unsuitable for the high-voltage and high-speed machines are found advantageous for low-voltage and medium or low peripheral speed machines.

Low-tension D.C. generators are widely used for electro-chemical work. Low-tension

dynamos and motors are used in almost all motor vehicles and aeroplanes. Such machines use metal-graphite brushes. These are also used many times on slip-rings of A.C. motors and generators.

Table 1 summarizes the different characteristics of the various types of brushes. The important points to be considered in studying the characteristics of brushes are the smooth passage of current and the friction at the sliding surfaces. It is not possible to have a fluid film at the contact surface as in bearings to reduce the frictional effects, as presence of such a film might detrimentally affect the electrical contact between the two surfaces. It is necessary to assure satisfactory performance under such exacting conditions.

### Electrical Characteristics

*Contact Drop* — The contact drop of the carbon and graphite brushes varies from 1.5 to 2.5 volts. If such loss is allowed in low-voltage machines, the losses at the brushes may be a high percentage of the total output of the machine. This would cause abnormal heating of the commutator and the brushes and give a lower efficiency for the machine. To keep down these losses and have a high efficiency it is desirable to keep this contact drop very low. With metallic brushes this drop varies from 0.5 to 1.0 volt depending upon the composition of the brush.

*Current-carrying Capacity* — In low-voltage machines, such as 6 and 12 volt dynamos used for electroplating work and starter motors in motor vehicles, high currents are used, necessitating high current densities in the brush. Such high current densities make the carbon and graphite brushes unsuitable for the work. Metal brushes are used where high current densities are encountered. The specific resistance of carbon and graphite brushes is many times more than that of the metal brushes. At high current this would cause heating of the brush due to ohmic

TABLE 1 — CHARACTERISTICS OF BRUSHES

	CARBON GRAPHITE	NATURAL GRAPHITE	ELECTRO- GRAPHITE	METAL GRAPHITE
Specific resistance (ohms/in. <sup>2</sup> )	1100-6000	700-3000	500-1500	3-15
Breaking strength (lb./sq. in.)	4000-6000	1000-3000	2000-6000	2000-6000
Sp. gr. (g./cm. <sup>3</sup> )	1.5-1.65	1.50-1.85	1.50-1.70	2.5-5.5
Scleroscope hardness	65-80	20-35	50-70	25-50
Normal current-carrying capacity (amp./sq. in.)	30-40	50-80	50-70	70-130
Peripheral speed (ft./sec.)	3000-5000	6000-8000	7000-12000	3000-6000
Normal pressure (lb./sq. in.)	2.5-3	2.0-2.5	2.5-3.5	2.5-4.0
Coefficient of friction	0.18-0.30	0.12-0.20	0.15-0.20	0.10-0.20
Contact drop in volts per brush at maximum cur- rent density	1.9-2.5	1.5-2.50	1.9-2.5	0.5-1.0
Recessed or flush mica	Flush mica	Recessed mica	Recessed mica	Flush mica
Field of application	Small D.C. motors and generators of 220 volts up to 30 kW. capacity	Up to 200 kW. capacity D.C. high-voltage machines	Tractor motors slip- rings, high capa- city, high-voltage machines	Low-voltage D.C. ma- chines (6-12 volts) and slip-rings of A.C. motors

resistance. Moreover, metal-graphite brushes have better thermal conductivity than the carbon and graphite brushes, and thus help in keeping down the temperature at the commutator and brush surface. This factor is of considerable importance in small machines handling heavy currents such as starter motors in motor vehicles. The higher the current density, the higher would be the percentage of metal in the brush. In low-voltage machines the reactance voltage is small and satisfactory commutation can be obtained with the metallic brushes.

*Oxide Film* — The electrical and mechanical demands are many times conflicting. For example, a tough oxide film on the commutator surface is desirable to reduce the frictional effects. But such a film gives a high voltage drop, which for reasons dealt above is not desirable in low-voltage machines. Particularly in low-voltage high-capacity machines, bronze brushes, having a certain amount of polishing action, are to be employed to prevent the formation of too dense a film of oxide. Such polishing action would lead to an increase in the commutator and

brush wear. It will, therefore, be seen that the electrical and mechanical demands should be balanced to get optimum working conditions.

*Electrolytic Action* — It is well known that there is an electrolytic action taking place at the brush surface due to the passage of current. The electrolytic action depends on the humidity of the atmosphere. The polarity effects are noticeable at the brush surface. On metal-graphite brushes these effects show themselves very clearly. The electrolytic oxygen which is generated at the anodic brush has a harmful effect on the bonding of the brush. The metal particles get loosened from the brush and try to deposit on the commutator. Metal dust thus deposited on the commutator may bring about flashover on high-voltage machines. This also restricts their use in such machines. Due to the electrolytic action, the anodic brush is eaten away much faster than the cathodic one.

*High Altitude Working* — Motors and generators working at high altitudes, such as in aeroplanes, show considerable wear of the brushes. At altitudes of over 25,000 ft. above sea level, the conventional brushes



wear rapidly as if they were rubbing against some abrasive material. The reasons for the unsatisfactory working are not sufficiently clear. At high altitudes, there is low humidity and low oxygen content. At low altitudes there is a film of moisture and oxygen between the commutator or the slip-ring and the brush. This film, which has been found very helpful in giving satisfactory brush service, is absent at high altitudes. Special compositions have been developed for brushes working at high altitudes. Such brushes are also impregnated with special lubricants. These help to give a satisfactory brush life, contact drop and low coefficient of friction at high altitudes. The impregnants may be made of one or more substances. These establish a suitable film at the contact surface. The materials should be effective in small amounts. The film produced by the impregnants should have a low electrical resistance, must not pick up dirt, and should be stable under the working conditions.

*Slip-ring Brushes* — In alternating current machines such brushes find use for slip-ring working. On slip-rings the cooling surface is smaller than that obtained with the commutators and the high thermal conductivity of the metal-graphite brushes permits their use on slip-rings at high current densities.

For low-voltage D.C. motors, mostly copper-graphite brushes are used, but for slip-ring brushes, tin, zinc or lead are generally added to copper. The percentage of these metals in the composition may vary from 10 to 20 per cent. Such brushes would naturally have a higher specific resistance than those containing only copper. These are found suitable for slip-rings made of copper alloys.

### Mechanical Characteristics

*Brush Pressure* — It has been previously stated that it is not possible to have a film of lubricant at the sliding surface, for electrical considerations. The pressure between the two surfaces, as can be seen from Table 1, varies between 2.5 and 4.0 lb. per sq. in. In

certain cases, such as in starter motors, this pressure may be as high as 8 lb. per sq. in.

*Lubrication* — It was difficult to get reliable mechanical performance from the old metallic brushes. Lubricants as a class with the exception of graphite are insulators or bad conductors of electricity and give high resistance at the contact. So by the addition of graphite to the metal powders, desired mechanical properties could be given to these types of brushes. In the new metal-graphite brushes sufficient dry lubrication is provided by the graphite in the brush. The commutator surface gets smoothened by the fine graphite particles. The adsorbed layer of moisture on the graphite also helps in reducing the friction and wear.

*Inertia of Brushes* — The inertia of the metallic brushes was very high, which made it difficult to have a good physical contact with the sliding surface, especially at high peripheral speeds. Brushes should have high elasticity in order to maintain uniform contact between the brush and the commutator. Certain amount of elasticity has been obtained by having metal-graphite brushes in place of the old metallic ones, but the desired degree of elasticity is difficult to obtain, as such an attempt would reduce the strength of the brush.

*Brush Composition* — The composition of the brush varies according to the voltage and current ratings. The higher the voltage, the higher can be the graphite content, which will ensure the desired voltage drop and keep the circulating currents between the commutator bars low. This will also ensure low wear of the commutator and the brush. Secondly, the higher the current at low voltages, the higher would be the copper content to keep down the losses and the wear of the commutator and brushes and prevent undue rise of temperature due to electrical effects. This would mean a greater polishing action and wear of the commutator due to mechanical effects arising out of the high metallic content. A balance should be made between the electrical and the mechanical losses.

## Economics

With the industrialization of the country that is now taking place, there will be a continuous growing demand for such brushes for D.C. generators used for electrolytic processes and for motors and generators used in motor vehicles and aeroplanes. At present the demand for such brushes is being met by importing the brushes.

Most of the manufacturers manufacture about twenty different metal-graphite grades to meet the particular demands of the electrical industry, but out of these generally five or six grades are commonly used. Blocks of about  $4 \times 5$  in. and  $8 \times 2$  in. size with thickness varying between  $\frac{1}{2}$  to  $1\frac{1}{2}$  in. are made. The price of such grades is nearly two to three times that of the carbon and graphite ones. The density of these brushes varies from 2.5 to 5.5.

## Experimental Work

The authors had been busy for the past few years on the development work connected with the manufacture of various carbon articles. At present, carbon and graphite brushes are being manufactured on pilot plant scale and supplied to Government departments and industrial concerns. With the successful development of this work attention was directed to the development of metal-graphite brushes.

The copper powder required for this work is being made by the electrolytic process and fractions finer than 200 mesh are used. The manufacture of copper powder by the electrolytic process is well known, and it is not considered necessary to deal with this aspect here. Copper powder made by hammering is also used by certain manufacturers to take advantage of the flakiness of such powders.

Flake graphite of suitable fineness is mixed with the copper powder. Since there is a great difference between the densities of the two materials, great care has to be taken in selecting the fineness of the two powders, so as to give minimum segregation of the

powders during mixing and subsequent handling. To ensure this, the apparent densities of the two powders should be as near as possible.

The mixing is being carried out in a double-cone mixer. The mixed powders are then premoulded in a fly press and then subsequently pressed at about 10 tons per sq. in. in a hydraulic press. The blocks thus pressed are packed in a special type of electric furnace to give reducing atmosphere.

The temperature of the furnace is slowly raised to  $600^{\circ}$ - $800^{\circ}$ C. in 7-8 hr. The sintered blocks are then allowed to cool slowly.

The above procedure is used if the copper content of the blocks is above 70 per cent. In such cases the bond provided by the sintering of the copper particles is enough to give the necessary strength to the brushes. If the copper content is reduced, coal-tar and coal-tar pitches are used as binders. The pressing of the blocks is done at  $80^{\circ}$ - $100^{\circ}$ C. and the blocks are baked more slowly to higher temperatures.

The characteristics of brushes produced in the laboratory are being regularly studied. It is now proposed to put this work on pilot plant scale with a view to supplying such brushes to the market and also to gaining field experience.

## Discussion

**MR. H. P. S. MURTHY (National Metallurgical Laboratory, Jamshedpur)**

Have the authors determined the effect of baking temperature on the specific resistivity of the graphite and metal-graphite compacts? Has any attempt been made to explore the possibility of manufacturing carbon and metal-carbon brushes from Indian bituminous coals by the well-known Delanium process?

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The higher the temperature of baking, the lower would be the electrical resistivity of the carbon articles. Articles taking advantage of the presence of tar in the coal are made in other countries; but the author is not taking advantage of this method in the manufacture of carbon articles.