HIGH CURRENT AND HIGH CURRENT DENSITY PULSE TESTS OF BRUSHES AND
COLLECTORS FOR HOMOPOLAR ENERGY STORES

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ABSTRACT

The incentive exists to use high collector current densities in pulsed duty homopolar generators, the current densities of interest being in the range of 15 to 45 MA/m².

Tests have been conducted in which current pulses of up to 0.25 MA with an equivalent pulse width of 0.3 s have been passed between pancake brush assemblies and flat plate collectors with collector current densities of up to 78 MA/m² and current densities in the brush fingers of 570 MA/m². The currents carried per brush have been a comparatively low 800 A.

These tests have been successful and are providing the data necessary for the design of the all-iron-rotating homopolar pulse generators.

INTRODUCTION

In homopolar generators, the collectors are essentially extensions of the flux cutting (voltage generating) conductors. For energy storage homopolars of any particular design, the rotor volume is fixed by the allowable rotor rim speed, and the required energy capacity. It follows, therefore, that smaller collector areas permit larger flux cutting areas and greater output voltages; energy transfer efficiency from homopolars generally increases with increasing machine voltage. However, reducing collector area increases collector current density (peak current divided by brush track area on the collector) and the question then arises, how highly is it desirable to rate homopolar collectors.

A recent theoretical study¹ of four different homopolar geometries has shown that for drum type homopolars, collector current densities of around 15 to 25 MA/m² are desirable while for the new all-iron-rotating machines presently being developed, collector current densities in the range 30 to 45 MA/m² enable optimum machine geometries to be employed. The gains are most pronounced for the all-iron-rotating homopolar energy store,² the general principle of which is shown in Figure 1. The interest in this arrangement stems from the fact that no back iron as such is required, each half rotor acting as the magnetic flux return path for the other half. Because there is no stationary iron, the kinetic energy stored per unit machine mass is a maximum. The interesting possibility also exists of making the two halves of the machine counterrotating. If now face brushes and collectors are employed, the brushes can be actuated by simply moving the rotor halves axially into contact with them.

Figure 1. Basic geometry of the all-iron-rotating homopolar. C is the excitation coil; R, the rotor; and I, O, the inner and outer collectors, respectively. The dashed lines indicate the magnetic flux path. Excitation slip rings have been omitted for clarity.

APPARATUS

The most convenient course of action was to design a brush tester that could be connected straight into the Center for Electromechanics' existing resistance welding jig³ which was already electrically connected to the 5 MJ homopolar generator.⁴ This made it convenient to hold the collector surfaces stationary and to rotate the brush assembly as indicated in Figure 2. The brush assembly consists of six stacks of copper chevrons with copper spacers between clamped around the rim of an aluminum carrier in such a way that an array of brush fingers projects from each side of the assembly. The pancake is then sandwiched between the two copper collector plates, each of which makes electrical contact at its rim with the flanged terminal block. The assembly is held together with insulated bolts,

Figure 2. Sectioned view of the brush tester showing,
A, doubled sided pancake brush assembly
B, copper collector plates, 20 cm OD
C, aluminum mounting blocks and terminals
D, drive shaft for brush assembly.

the space between the collector faces being determined by the thickness of the insulating spacers. This sets the magnitude of the contact force between the brush fingers and the collector faces. A photograph of the assembled tester is shown in Figure 3.

Figure 3. The assembled brush tester.

In use, current flows from one terminal, into the collector plate, through the brush assembly and out the other collector and terminal. The tester is connected to the output terminals of the 5 MJ homopolar generator as shown in Figure 4.

Figure 4. The brush tester connected to the 5 MJ homopolar generator. To the right can be seen the gear motor used to rotate the brush assembly.

THE EXPERIMENTS

Three series of tests were conducted, each using a different arrangement of chevrons in the pancake brush assembly. The first consisted of seven rows made from copper sheet 1.0 mm thick ("thick" fingers), the brush fingers being 2.6 mm wide. To enable higher collector current densities to be reached without increasing the total current being supplied to the tester, a second series was conducted using only three rows of the same chevrons used in the Series 1 tests. A third series of tests was conducted in which five rows of chevrons made from thinner copper sheet was used. The fingers in this series were 0.38 mm thick ("thin" fingers) and 2.0 mm wide.

In all the tests, the fingers of the brush assemblies were angled outwards at 45° and ground so as to sit flat when clamped between the collectors. The collector faces received no treatment prior to the tests other than to be fine machined. The only lubricant used during the tests was light machine oil which was liberally applied to the brush fingers and collectors. The brush sliding speed was so slow (15 mm/s) that the development of a hydrodynamic oil wedge was not possible.

As a simple check on the contact volt drop measurements obtained with the rotating brush tester, some simple static tests were conducted with single contact pairs using the same material and same finger sizes, current being supplied by a lead acid battery. A sketch of the apparatus is shown in Figure 5.

The contact force between each finger and the collector in the Series 3 tests and in the static tests was 3.7 N. The normal contact force in Series 1 and Series 2 tests was about twice that.

Figure 5. Static test apparatus.

RESULTS

Current pulses with peak currents in the range one hundred to two hundred kA were passed through the tester. Figure 6 shows the pulse shape used. The rise time is set by the inductance of the 5 MJ homopolar and its leads. The tail of the curve is the simple current decay that occurs as the homopolar energy dissipates in the resistances of the circuit elements. (The homopolar behaves electrically as a capacitor.)

Figure 6. Curves showing current and single contact voltage drop for shot no. 9 of the Series 3 tests.

The broken line in the figure shows the duration of the square pulse of the same peak current, which has the same integral $I^2 dt$. This time of around 300 ms is close to that required to discharge energy storage machines² of interest. The lower curve of Figure 6 shows the corresponding contact volt drop between one collector

and the contacting set of fingers, with the resistive drops in the brush assembly subtracted.

The test results obtained are shown plotted in Figure 7. The results from the moving tests (Series 3) are the corresponding peak current contact drop values from separate runs. Square current pulses were used in the static tests of about a half second duration. The broken line shows the performance of the Morganite CM15 copper-graphite sintered brushes used in the inner brushes on copper slip rings in the 500 MJ Canberra homopolar generator.⁵

Figure 7. Results obtained from both static and moving tests, showing single contact drop as a function of current per finger, x for "thick" finger static tests, . for "thin" finger static tests, & o for "thin" fingers in Series 3 tests.

The maximum current densities achieved in the three series of tests using the brush tester are listed in Table I.

TABLE I. PEAK CURRENTS AND PEAK CURRENT DENSITIES IN THE BRUSH TESTER.

	Series 1 (7 row unit)	Series 2 (3 row unit)	Series 3 (5 row unit)
No. of fingers per brush face	672	288	480
Peak current (kA)	219	232	208
Current per finger (A)	326	805	433
Finger size (mm x mm)	2.6 x 1.0	2.6 x 1.0	2.0 x 0.38
Finger current density (MA/m ²)	125 (81 kA/in. ²)	312 (201 kA/in. ²)	570 (367 kA/in. ²)
Brush track OD, ID (mm)	140, 102	119, 102	116, 96
Current density on collector surface (MA/m ²)	30.2 (19.5 kA/in. ²)	78.6 (50.7 kA/in. ²)	62.5 (40.3 kA/in. ²)

The appearance of one of the collectors (both looked similar) and of the pancake brush assembly at the conclusion of the 26 shots of the Series 3 tests is shown in Figures 8 and 9.

DISCUSSION

It is no great surprise that a brush assembly of the type described can be made to carry large currents at such relatively high current densities, because current of the same magnitude (200 kA) but at much higher brush current densities (5.5 GA/m^2) have been carried in the Canberra rail gun⁶ (CRG). Further, the form of the pancake brush arrangement is a logical development from the fast switch developed for the CRG,⁷ which operated reliably many hundreds of times. The two main differences between the work reported here and the work mentioned above

Figure 8. A collector plate at the conclusion of the tests.

Figure 9. The pancake brush assembly used for Series 3 tests.

is that the brushes were run continuously on the collectors (rather than just a single pass per shot) and that high collector current densities were employed. (Collector current density was not a meaningful concept in the CRG work, because the "brush" makes a single pass only, on a long collector.) The same basic concepts were applied, however, namely that sufficient load should be applied to ensure that the brushes remain firmly in contact with the collector while current is flowing, and that the bulk temperatures of the brushes and collector surfaces should remain relatively low. The calculated temperature rise of the collector surfaces in these experiments was less than 150°C in all cases, a value clearly compatible with quiescent behavior. As far as contact force is concerned, the rule of thumb that arose from the work reported in references 5 and 6 of "one gram force per ampere carried" still provides an adequate starting point in the design of sliding contacts for high currents.

It is also interesting to note that the contact volt drops observed are not very different from those measured for CMIS on copper in spite of the fact that CMIS is 30 times more resistive than copper. A similar result was obtained from Stackpole grade W5033 brushes,⁸ which is two times more resistive still. The reason for this will be that the sintered material being softer than solid copper, a given contact force will create larger contact areas to give a reduced geometrical component to the constriction resistance.

The behavior of the contact drop for the first 10 ms of the pulses was uncertain and for that reason has been omitted from the lower curve of Figure 6. Clearly, at zero current there must be zero contact drop. It is probable, however, that the oil lubricant present at the collector brush interfaces constituted a high resistance for the initial part of the current pulse, thus causing an initial fast rise in indicated contact drop. Once good contact had been established, electrical heating at the interface prevented high resistance oil films from reestablishing for the remainder of the pulse. Contact drops for the runs of Series 1 and Series 2 are not reported because the voltage calibration was in doubt.

The contacts behaved in a consistently reliable manner and showed every indication that considerably higher ratings could be achieved. The low mass and flexibility of each brush finger makes it probable that pancake brush units of this type would run successfully at high speed as well as at the low speeds reported here. The main unknown in how to make them run at high speed is the form the collector lubrication should take to eliminate the possibility of galling or seizing, and to provide an acceptably low wear rate. These goals are not expected to prove difficult. Examination of the brush rubbing faces (Figure 9) under a microscope at the conclusion of the tests revealed no sign that they had carried any current at all, and it was

evident that while some wear had occurred, it was far from catastrophic. On the collector surface (Figure 8) faint scratches that existed before the tests could still be seen after the tests, showing that the wear had been less than the depth of the scratches.

Finally, it should be noted that although the main thrust of this work is to provide brushes for advanced homopolar machines, it will also be valuable in the designing of switches to handle the large current that such homopolars will produce.

CONCLUSIONS

We have constructed a brush tester capable of getting us into the collector current density range of 80 MA/m² (50 kA/in.²) and have used it at this rating at low sliding speeds. The work done has been in the nature of "go, no-go" type tests to see if high speed brush gear might reasonably be expected to operate at the same current densities to carry large currents for one-third of a second or so. The tests were successful and it is planned to extend the work to high rubbing speeds.

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