Asian Journal of Information Technology 6 (5): 631-639, 2007

Suppression of Sparking at the Brushless of DC Machines

S. Sellami, S. Belkacem and F. Naceri
Department of Electrical Engineering, University of Batna, Batna, Algeria

Abstract: Recent developments in switching by means of electronic devices such as thyristors offer more possibilities to assist commutation in DC generators or motors. It is this latter aspect that has been utilised in an attempt to suppress the sparking that occurs between the trailing edge of a brash and the commutator of direct current machines. The semiconductor device chosen for the investigation was the asymmetric thyristor is used to switch into circuit an auxiliary brush whenever sparking occurs. The auxiliary brush is positioned trailing the main brush and electrically isolated by a small intervening layer of insulation. The auxiliary brush provides a path for the uncommutated current and associated energy to be dissipated in series connected resistors. The research has addressed the design of the brushes, brush gear, thyristor triggering and spark energy dissipating resistors. The realisation and testing of the system shows promising results.

Key words: DC machine, assisted commutation, suppression of sparking, brushless, auxiliary brush

INTRODUCTION

One of the major problems facing the design of DC machines for example traction motors is the obtention of a satisfactory transference of the current between the stationary brushes and the moving peripheral surface of the commutator. This problem manifests itself in a form of sparking which predominantly occurs at the trailing edges of the brushes leading to the erosion of the commutator surface.The power handing capacity of early DC machines was limited by this commutation problem i.e., sparking, but the implementation of carbon brushes and the interpoles (or commutating poles) has improved the performance. Furthermore, improved insulation materials have increased the capability of DC motors to withstand higher temperatures and thereby increased their output rating. Unfortunately these advances have not been matched totally by improvements to the method used for current collection, thus restricting the power handling capacity (Lightband and Bicknell, 1970; Sponner, 1985). Bates *et al.* (1960) initiated research in the field of thyristors assisted commutation in DC machines and also suggested modifications to the machine design by incorporating a commutator arrangement having active and inactive segments (Bates, 1968; Bates *et al.*, 1970; Bates and Stanway, 1976, 1977; Bates and Sfcanway, 1976). However, recent developments in thyristor technology, particularly in the fast turn-off asymmetrical thyristor have opened a new possible way to the use of solid-state devices to facilitate commutation with no major modifications required to the existing machine design.

PROPOSED NEW METHOD OF ARC SUPPRESSION OF SPARKING AT THE TRAILLINGEDGE OF BRUSH

General description: In DC machines the coil current is constant while it passes under the main pole from one interpolar zone to the next one, when armature coil passes through the interpolar zone, the direction of its current changes rapidly from full positive value ($+i_a$) to full reversed value ($-i_a$) in a time t_c usually less than 1ms, but dependent on the rotational speed. As soon as the coil reaches the interpolar zone, it is short circuited by the brush. Although the dynamically induced voltage is low here, the current starts at full value and the sharp change gives a high value of self induced voltage Ldi_s/dt, tending to retain the original current direction and prevent the completion of the change. When the coil is eventually subjected to the influence of the next pole, its current will have to complete the transition to ($-i_a$) suddenly, as a result of the relatively high forcing voltages which maintain the current in the new circuit. Furthermore, the current (i_s) in the coil which has just cleared the short circuit, will almost certainly have reversed from the positive direction, but has not yet reached ($-i_a$) so that (i_s) is not zero and it will be forced to flow a as to the brush through a path in air constituting a spark in Fig. 1 and 2.

Our objective is to achieve a current transition without sparking by using a new concept, comprising a modified two parts or compound brush which is constituted of the main brush and the trailing auxiliary brush and a thyristor, which can be turned on when

Corresponding Author: S. Sellami, Department of Electrical Engineering, University of Batna, Batna, Algeria

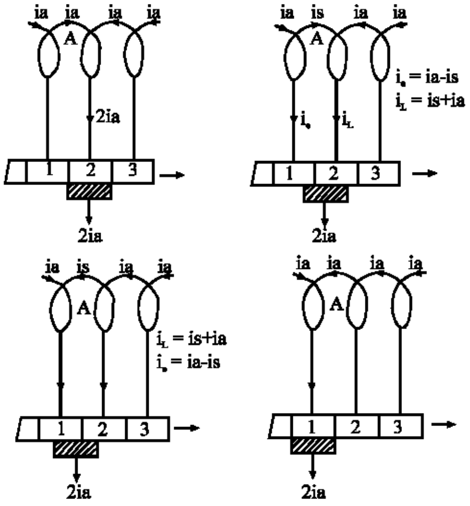


Fig. 1: Process of reversing current in the coil A

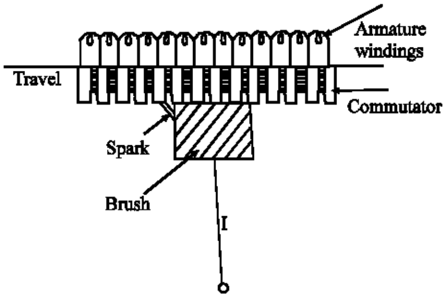


Fig. 2: Simple arrangement of armature winding

arcing is present. The sparking suppression may be achieved by providing an alternative path through the trailing auxiliary brush for the uncommutated current which is about 5 Amperes (Padmanabham and Srin, 1956). The width of the trailing auxiliary brush can be either increased or decreased to give more time for the uncommutated current to complete its reversing process. The current in the trailing auxiliary brush can be limited by the thyristor. As far as the triggering circuit of the thyristor is concerned, two circuits which are indicated in Fig. 3-5 and may be used.

The principal features of the scheme for our new concept are:

- The simplicity of the circuitry suggests a low cost and high reliability system which may be incorporated in existing machine designs.
- The thyristors will not be subjected to arduous duties, being required to carry only a portion of the load current for short intervals.

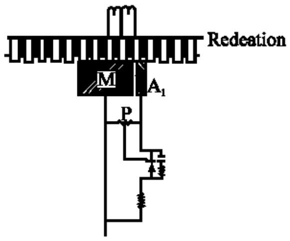


Fig. 3: Thyristor trigger circuit arrangement (i)

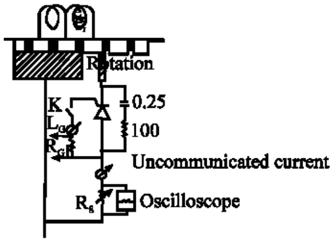


Fig. 4: Thyristor trigger circuit arrangement (ii) positive brush

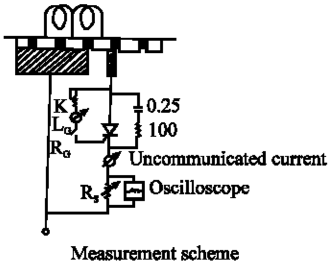


Fig. 5: Thyristor trigger circuit arrangement (iii) negative brush

- In the event of the failure of the thyristor network, the commutation process will continue but with sparking. There will be no intermediate interruption of the load caring capability of the machine; it is possible to include a detection and warning device.
- The operation of the system will be not limited by the speed of the machine. These points to the possibility of the suppression of the sparking being more readily obtained over the full range of design speeds.

OUTLINE OF NEW METHOD OF ARC SUPPRESSION

In ac circuits the use of thyristor to suppress arcing across current breaking and making switches is well known (Roberts and Ashman, 1969). It is proposed to carry out an investigation into the use of solid state devices for the purposes of controlling the sparking at the edges of the brushes of DC machines by following

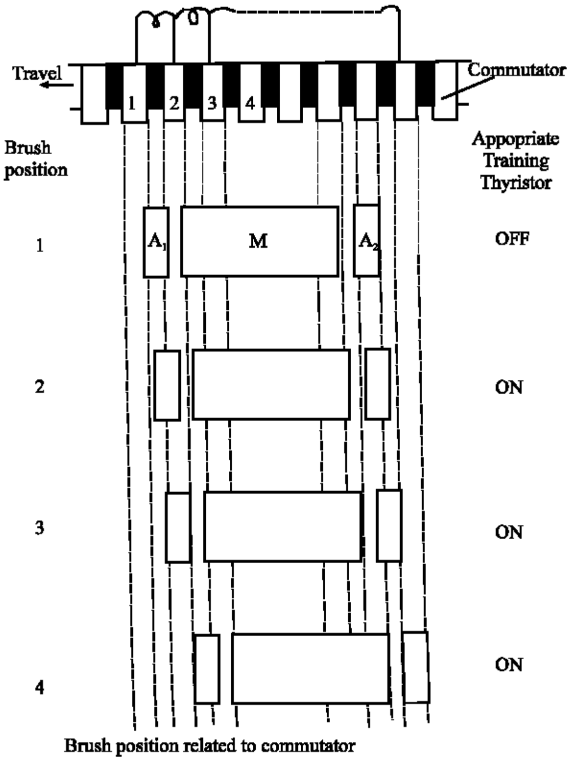


Fig. 6: Operating cycle of the; ain and the auxiliary brushes

method. Figure 2 shows the simple arrangement of armature winding and commutator with the brush sparking at the trailing edge. Figure 4 and 5 shows the new arrangement to studied; the two part brush has a main element M electrically insulated from the auxiliary element A. The auxiliary brush A is connected to the main current carrying terminal through a semiconductor switch (shown as a thyristor) and an energy dissipating resistor. The thyristor will be switched on automatically so as to provide an alternative path during the time in which arcing would normally occur. This is achieved by tapping off a proportion of the reactance voltage appearing across the potentiometer P (shown dotted) and using this voltage to trigger the thyristor. Figure 6 illustrates the sequence of brush position relative to the commutator in 4 stages.

Stage 1: The coil connected to the commutator segments 2 and 3 is approaching the end of its short circuit or commutation period by the main brush M.

Stage 2: The main brush leaves segment 2 and at this instant any reactance voltage and corresponding arcing current will occur between the main brush M and segment 2. This reactance voltage is used to trigger the thyristor and allow the arcing current to divert to the auxiliary brush A.

Stage 3: The auxiliary brush remains in contact with segment 2 and the previously arcing current is allowed to dissipate via the resister R and the thyristor.

Stage 4: It is essential that the current flowing via auxiliary brush and thyristor reaches zero before the auxiliary brush leaves contact with segment 2.

If it is found that there is insufficient reactance voltage to trigger the thyristor, the thyristor could be maintained in the continuous on state by the application from a separate source of a continuous gate current. Under conditions of sufficient reactance e.m.f. the thyristor will conduct to facilitate arc suppression. The need to match the operational characteristics of the thyristor network to the requirements of the machine are recognised and should be achieved by adjustment of the circuit parameters including the energy dissipating resister.

The research programme will therefore need to investigate:

- The triggering aspects of the thyristor
- The requirements of the suppression resistor and
- The auxiliary brush parameters.

Figure 7 shows the brushes and thyristor required for a universal brush arrangement and in Fig. 8.

A simple switch arrangement reduces the number of thyristor required. The universal arrangement will be able to cope with both motoring and generating in either direction of rotation. The overall layout of new method of assisted commutation is shown in Fig. 9.

Design of new brushes and brush gear for test: Design of new brushes and brush gear for test machine: The proposed compound brush (Fig. 10).

Consists of a main element M electrically insulated from an auxiliary element A which is supposed to carry the uncommutated current of about 5 amps. This arrangement is adopted although it is subjected to the well known difficulty of the variation of the contact pressure over the brush face. Consequently a rubber is sandwiched between the insulated material and a material insulating paper over the brush top face to absorb the brush vibration and to make a uniform contact pressure over the brush face. The dimensions of both the main and auxiliary brushes are derived from the conventional ones with only a different auxiliary brush width. The brushes are carbon based and the brush holders are prepared by a trial purpose as indicated in Fig. 11.

The specifications of the DC machine are the following:

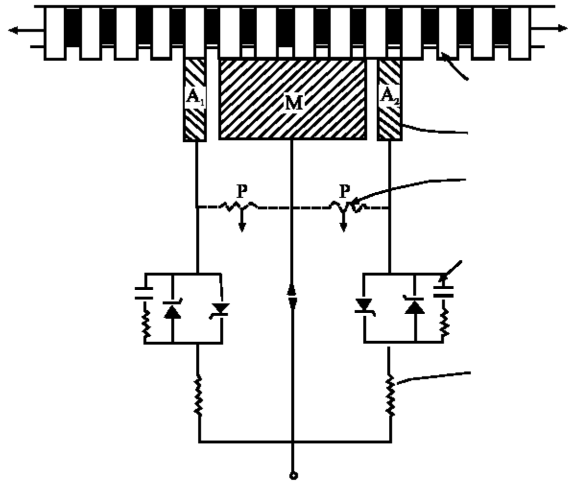


Fig. 7: Universal brush arrangement for either motor or generator

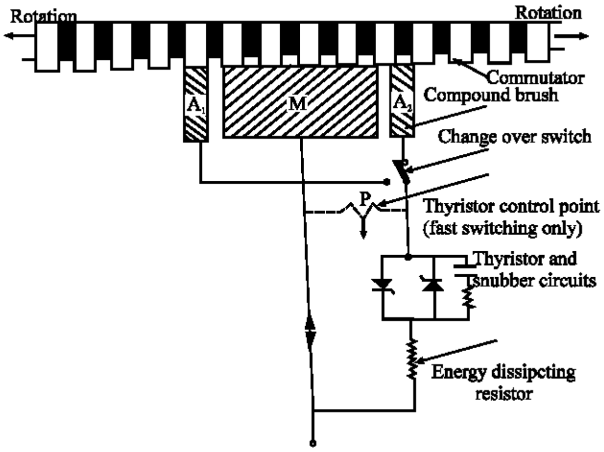


Fig. 8: Simple switch arrangement

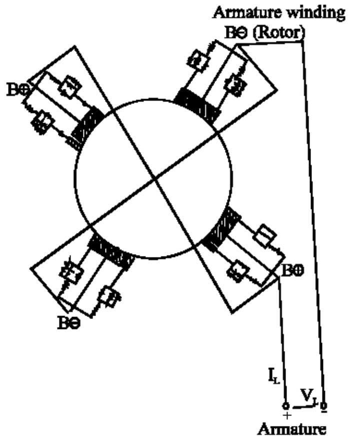


Fig. 9: The overall layout of new method of assisted commutation

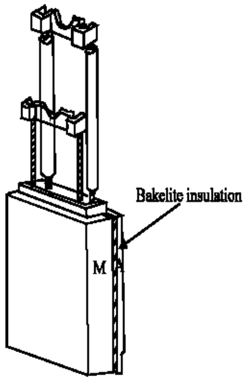


Fig. 10: Main and auxiliary brushes glued together and with flat tops

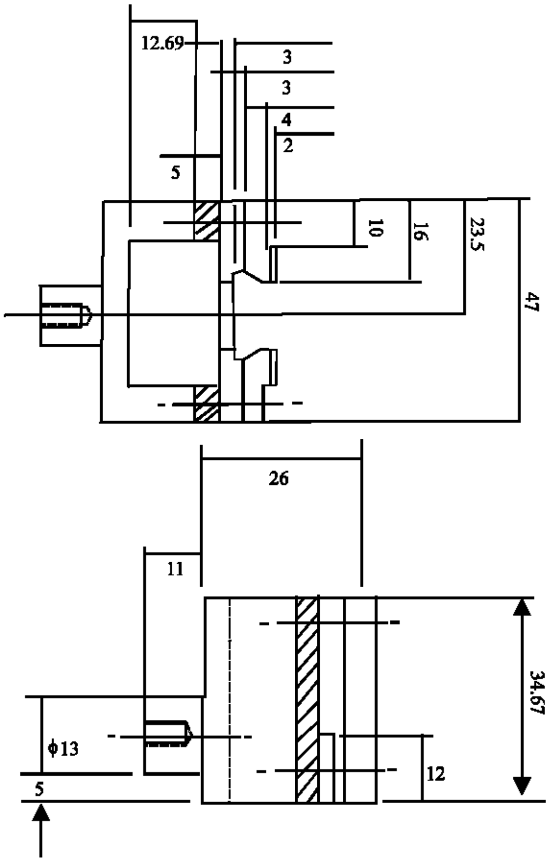


Fig. 11: Side and top view of a new brush holder for the negative brush,all dimensions are given in mm

HP = 6112, U = 230 [V], 1 = 23.2/45.5 [A], n = 800/1600 rpm
Number of commutator segments = 165 Gap width between commutator segments = 1 mm
Number of brushes = 4, Width of brush = 13 mm
Derived data:, Maximum bar frequency is:

For 800 rpm the maximum rate 165×800/60 =2.2 kHz or 454 μs. For 1600 rpm = 165×1600/60 = 4.4 kHz.

The voltage between two segments Uba = 230×4/165 = 5.57 V for non compensated machines.

Bar pitch τc = 3+1 = 4 mm with the width of the segment = 3 mm. The number of segment are spanned by the brush γ = b/τc = 13/4 = 3.25.

For the alternator: Type: AG5626, Poles = 6, Voltage = 230 [V], 1 = 12.6 [A], Cycle = 50, PH3, Speed = 1000 rpm, Excitation: V = 205 [V]; 1 = 1.2 [A]

Rating: constant, Brush ref 82/326

Design of semiconductor switches and their mounting: The basic objective of this design is to develop a diagram of a commutating circuit to reduce the sparking at the trailing edge of the brushes of DC machine. The diagram shown in Fig. 2 gives a simple arrangement of the armature windings, the associated commutator and the brush (as illustrated in Fig. 3 which corresponds to 3.25 segments. As the commutator moves in the direction shown in Fig. 2, arcing occurs predominantly at the brush trailing edge. As mentioned earlier, the spark suppression may be achieved using thyristors (th) as a switch which conducts the uncommitted current through its power terminals (a) and (b). This thyristor can become conductive by automatic synchronised switching. This method involves tapping off a proportion of voltage between the two brushes when the voltage rises before arcing occurs. The proposed operating cycle is shown in Fig. 6. The affore mentioned voltage normally exists at a time corresponding to the position (3) with the correct polarity to trigger. Adjustment of the circuit parameters, particularly the value of the energy dissipating resistor, facilitates modification of the value and the time constant of the current through the trailing auxiliary brush element, so that it decreases to about zero by the time it reaches position (1) and the thyristor switches off. However, it is anticipated that the produced voltage may not be sufficient to trigger the thyristors.

In order to synchronise the bars frequency with the thyristor commutation, the maximum operation rate of thyristor is approximately 5kHz. Furthermore, a symmetric fast turn off thyristor is used since the thyristor is ON for about 113 μs which is sufficient to cover the normal sparking duration of about 10 to 20 μs (Radmanabham and Srin, 1965; Le, 1987). The type of thyristor used is known as ACR 25 with a maximum operation current equal to the uncommitted current which is about 5 amperes in the test machine (Padmanabham and Srin, 1965).

TEST PROCEDURES

Loading variation using the alternator: A rectifier voltage is supplied to the armature of the separately-excited DC machine which drives an alternator, this alternator supplies a symmetrical resistive load, as shown in Fig. 12.

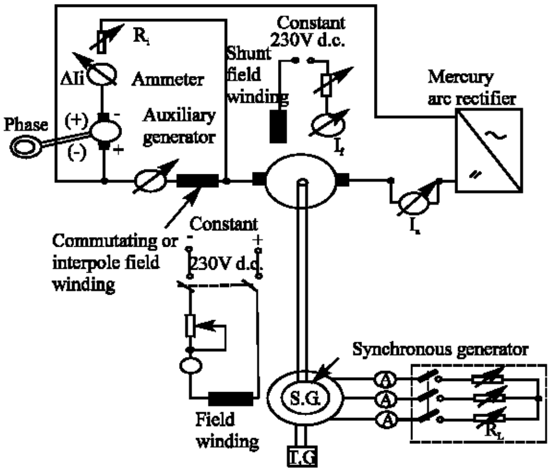


Fig. 12: Test rig

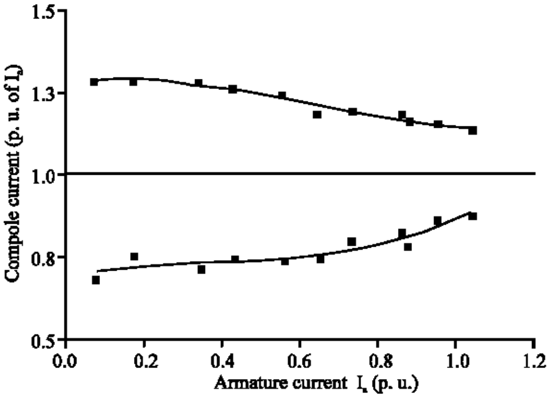


Fig. 13: Black band tsest

Black band test: Actually, there are several methods for the detection of sparking phenomena, but the most used ones are: Visual observation of sparking (the black band test); for the present study, the black-band method of commutation observation is used since it is adequate for the existing and available equipment. This method of assessing the commutation performance derives its name from the zone of variable commutating field strength at any load in which the commutation is sparkles or black. This zone is obtained by first opposing (bucking) then aiding (boosting) the load current flowing through the commutating field coils at any value of the load on the machine. Then, the curves are plotted against both bucking and boosting current loads in which light sparks occur. The resulting curves represent a band between the limits in which the commutation is a black-band Fig. 13.

Table 1: Compole current (p.u) of Ia and armature current Ia (p.u)

+ $\Delta I/I_a$ %	I_a/I_{an}	- $\Delta I/I_a$ %
12.3	1.04	12.56
14.7	0.95	14.56
15.2	0.875	22.17
16.9	0.86	17.8
18.01	0.73	20.6
18.2	0.65	26.52
23.3	0.56	26.73
25.2	0.42	26.08
27.17	0.347	28.91
28.40	0.173	24.34
28.47	0.08	31.7

In a black-band commutation, a machine may operate at all loads. However, an effective commutation does not necessarily need to be a black-band on process. An efficient machine is one which has no sparking may be harmful to both the commutator and the brushes. Hence, the operation of a machine outside its black band may be satisfactory as long as the sparking is harmless in such a way a frequent maintenance of both the commutator and the brush is not needed. This is true since some factors such as the loading and the atmospheric conditions may be so variable that one adjustment cannot fulfill the requirements of the other conditions.

Table 1 shows data of test observation, Fig. 13 shows the black band for our testing machine in case of a conventional brush. The curve shows a normal condition of sparking.

Shows the diagram used for the measurement of the new commutation system parameters. As the main brush was covered by the auxiliary brush a swivel mirror method was used to assess the new commutation system.

SWIVEL MIRROR METHOD

A mirror was mounted on a swivel arm Fig. 14.

To view the trailing edge of the mean brush from the end of the commutator in attempt to carry out a visual black band type of test. The intervening of insulation between the main and auxiliary brush does not extend down to the commutator surface thus allowing an observation between the brushes.

This method was used to determine the optimum parameters of the auxiliary brush circuit including the gate resistor R_g and the series dissipating resistor R_s and the brush insulation width b_g.

As far as the thyristor functioning concerned, the trailing auxiliary brush current is null when K is opened (Fig. 5). whereas the triggering circuit in Fig. 3 shows that the circulation of the current from the main brush to the gate through the auxiliary brush may affect the commutation process and also it leaves the thyristor triggered all the time. Consequently, the circuit shown in Fig. 3 is transformed to the one indicated in Fig. 4 and 5.

Fig. 14: Swivel mirror method

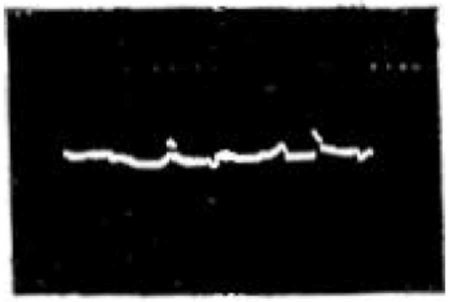


Fig. 15: Coil voltage (recorede between the main and the auxiliary brushes glued together on top by an adjoining flexible bridge with Aw = 2.1 mm; bg = 0.40 mm; Ia = 12A)

Fig. 16: Auxiliary circuit thyristor for Aw =2.1 mm; bg = 0.40 mm; Ia= 45 A; N= 1220 RPM Aw = 2.1 mm; Ia=12A

With reference to the Fig. 15 and 16 and assuming bg = 0.4 mm the minimum auxiliary brush width Aw is 2.1 mm, this will ensure that at the instant the main brush leaves segment S2 (Fig. 6), the auxiliary brush is only in contact with the Segment S2. The minimum auxiliary brush width of Aw = 1 mm, this setting is the same as the Segment gap (Sg) and will ensure that no adjacent segments are short circuited by the auxiliary brush. Any value of Aw less than 1mm would not be of any benefit since this would only reduce the contact time for assisted commutation. Small values of auxiliary brush width are also likely to cause problems with breakages and poor contact with the commutator. The auxiliary brush width setting somewhere between the maximum and minimum value.

The maximum width Aw = 2.1 mm provides the longest time for the auxiliary brush to remain in contact with the segment just commutated S2 but with the disadvantage of the longest time during which the auxiliary brush short circuits S1and S2 in Fig. 15 and 16 the voltage recorded between the main and the auxiliary brushes for armature current with the thyristor open circuited. With the thyristor connected in series with the auxiliary brush, the auxiliary circuit thyristor current recorded across the thyristor Rs of particular interest was the increase in the thyristor current part way through the conduction period it was concluded that this was due to the auxiliary brush operating in parallel with the main brush on the segment S1. Sparking was observed at the trailing edge of auxiliary brush and thus was likely to be due to the short circuiting of two commutator segments by the auxiliary brush. The minimum brush width Aw (just less than 1 mm) provides the shortest time for the auxiliary brush contact with S2 but now with no short circuiting of adjacent segments. The brush width of Aw = 1.5 mm provide indication of an auxiliary brush width setting in between the maximum and the minimum value.

The initial auxiliary brush width was chosen at 1.5 mm with the main and auxiliary brushes glued together with a separating insulation of 0.4 mm thickness. The oscillogram in Fig. 17 shows the auxiliary circuit thyristor current for armature current Ia = 45 A with the thyristor connected in series with the auxiliary brush. Despite the modification to the brush widths the modification to the brush widths spark still occurred at the edge of the auxiliary brush widths used namely 2.1, 1.5 mm short circuiting of two adjacent bars could not be avoided. The sparking was due to this short circuiting and could only be eliminated by reducing the auxiliary brush with below 1mm was considered likely to lead to problems poor contact and breakages due to the very thing width. As a consequence the gap between the commutator segments was modified.

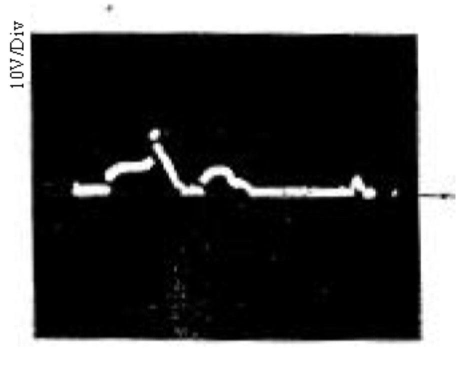


Fig. 17: Auxiliary circuit between the main and the auxiliary current thyristor current for Aw = 1.5 mm bg = 0.40 mm; N = 1220 RPM

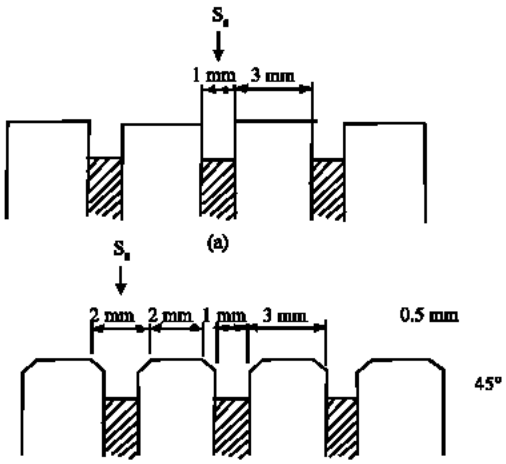


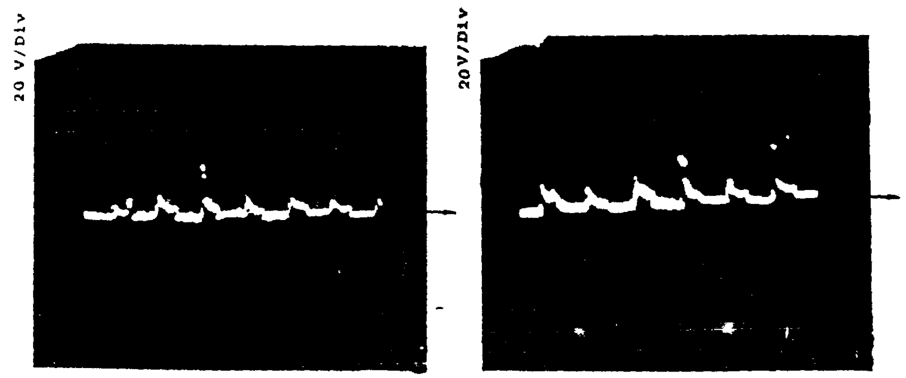
Fig. 18: The dimentions of the commutator bars (a) before and (b) after modification

Modification of commutator: The test motor used has certain inherent design features related to its age. With regard to the commutator the segments (or bars) were not undercut as is usual practice now days. To assist with the problem of reducing the auxiliary brush width to avoid short circuiting of adjacent bars to alleviate this problem. The gap between bars was found to be 2 mm in Fig. 18.

Test with modified commutator: With the modified commutator, auxiliary brush widths of up to 1.9 mm could bee used with out this brush short circuiting adjacent bars. An auxiliary brush width of 1.4 mm and a separating insulation of 0.4 mm was chosen.

The oscillograms in Fig. 19 show the voltages between the main and the auxiliary brushes for different armature currents. Whereas the voltages developed a cross, the resistor R_s by the current flowing through the thyristor in the auxiliary brush circuit for the armature currents of 4.0A and 30A, respectively (Fig. 20).

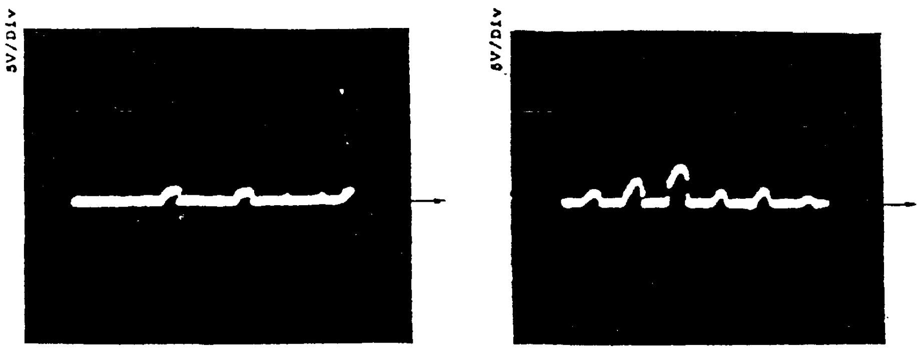
The objective of current reversal in each armature coil by using a new concept of two part of compound brush (the main and auxiliary brush) and semiconductor switch has been achieved. The insulated auxiliary brush and the semiconductor switch provides a path for any uncommutated armature coil current to flow through a dissipating resistance. The research has shown that the sparking voltage at the trailing edge of the main brush was capable of triggering the asymmetric thyristor.



0-2 m. sc/Div
(a) Coil voltage for armature current 1 = 5.5a;
rotational speed (N) 1300RPM

0-2 m. sc/Div
(b) Coil voltage for I_a = 22A;
(N) 1210RPM

Fig. 19: Coil voltage (recorded between the main and the auxiliary brushes) for different armature currents



0-2 m. sc/Div
(a) Auxiliary circuit thyristor current for
A_w = 1.4 mm; b_g = 0.40 mm; I_a = 4.0A; current
thyristor (I_a) = 0.5A

0-2 m. sc/Div
(b) Auxiliary circuit thyristor current for
A_w = 1.4 mm; current thyristor (I_a) = 1.7A;
I_a = 30A; b_g = 0.4 mm; N = 1260RPM

Fig. 20: Auxiliary circuit thyristor currents for Aw = 1.4 mm; Bg = 0.40 mm and with different armature currents

CONCLUSION

For the present investigations, the use of solid-state devices such as thyristors in assisting in the reduction of sparking at the trailing edge of the brush shows a satisfactory result in the commutation process. The reactive voltage is risen to trigger the thyristor. The firing circuit shown in Fig. 3 for a positive brush is inconvenient because the thyristor triggers (ON) all the time. As a result, a second circuit shown in Fig. 4 and 5 is proposed.

The satisfaction of the requirements of both the time of commutation and the voltage for triggering the thyristor are achieved by choosing a width of 1.4 mm of the auxiliary and also and an insulator width of <0.5 mm nevertheless, this improvement gives rise to other problems which are as follows:

- The non uniformly distribution of the pressure over the brush.
- The non-parallelism of the brushes to the bars, which affects the voltage between the brushes.
- The mechanical vibration in the machine may influence the constant space between the brushes.
- The triggering voltage is too low for certain space between the brushes.

REFERENCES

Bates, J.J., 1968. Thyristor Assisted Commutation in Electrical] Machines. Proc. IEEE., 115: 791-801.

Bates, J.J., J. Stanway and R.F. Sansum, 1970. Contact Problems in Machines Using Thyristor Assisted Commutation. Proc. IEEE., 117: 387-397.

Bates, J.J.and J. Stanway, 1976. Development of a 300 kW 3000 r.p.m. dc Machine Rising Thyristor Assisted Commutation. Proc. IEEE., 123: 76-80.

Bâtes, J. and J. Sfcanway, 1976. Commutating Time Calculations for Machine Using Thyristor Assisted Commutation. Proc. IEEE., 123: 81-84.

Bâtes, J.J. and J. Stanway, 1976. Terminal Characteristics of Machines with Thyristor Assisted Commutation. Proc. IEEE., 123: 85-88.

Bates and Stanway, 1977. Procs. IEE, 124: 380-381.

Lightband D.A. and D.A. Bicknell, 1970. The Direct Current Motor. Business Books Ltd., London, pp: 155-171.

Le Her, 1987. from British Railways Board, Research Division.

Padmanabham, K. and A. Srin Vasan, 1965. Some Important Aspects in the Phenomenon of Commutator Sparking. IEEE. Trans. Power Applied Sys., 84: 396-404.

Roberts, M.E. and W.E. Ashman, 1969. A thyristor assisted mechanical on-load Tap changer. Conf. Power Thyristors and Their Applications, IEEE., pp: 6-8.

Sponner, E., 1985. DC Traction Motor With Slot less Armature. Proc. IEEE., 132: 61-71.