HIGH CURRENT MAKING SWITCH

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HIGH CURRENT MAKING SWITCH

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SUMMARY

A fast making (closing) switch for high currents is described. It was built to test a homopolar generator developed at the University of Texas. The switch is laid out to carry 300 kA for 3 seconds. It is pneumatically operated and can be tripped without transferring any valves; consequently timing is precise and fast. The contacts are designed to avoid arcings and for minimal inductance. Contact pressure is enhanced by the electromagnetic forces of the current. Tests on the prototype were carried to 550 kA. Oscillograms of the tests are shown. This prototype confirmed the validity of the design criteria and forms the basis for future designs.

INTRODUCTION

The use of homopolar generators as a source for pulse power in fusion experiments requires a making switch capable of safely closing the circuit. Such a switch has to be highly reliable, capable of precise timing, and depending upon the application, must be capable of initiating and carrying a current ranging from 100 kA to one million amperes for durations ranging from one to 10 seconds. The switch must have a low inductance as well as a low internal resistance, so as to complement the very low impedance characteristics of the generator.

Commercial switches, such as those used in power systems, are not suitable for this type of service, with the possible exception of making switches of the type used in circuit breaker testing plants.

The switch described in this paper was built for the testing of a homopolar generator which has been developed at the University of Texas.[1] This homopolar machine stored 5 MJ of energy at 43 V corresponding to a capacitance of 5400 F. The discharge current depends on the load circuit. The rated current of the machine is 100 kA, although tests up to 550 kA have been performed.

Specification and Choice of Design

The switch was designed for the following specifications:

1. Use: making duty only; no breaking ability
2. Test voltage: 2000 V
3. Maximum current: 300 kA for 3 s
4. Maximum rate of rise of current: 50 kA/ms
5. Mechanical life expectancy: 10,000 operations
6. Contact life expectancy: 500 operations
7. Function: pneumatically operated, mechanically latched in the open position, electrically triggered.

The Problem of Contact Closing in High Current Circuits

The ideal making switch can initiate a current without any arcing or excessive local heating.

As the contacts approach the closed position, a prestrike will occur if the driving voltage exceeds a certain minimum (e.g., in air < 300 V). The ensuing arc is a cause of contact wear and can result in welding of the closed switch. The effects of prestrike are minimized by high contact velocity and submersion of the contacts in insulating media with high dielectric strength (e.g., compressed air, SF_6, etc.).

The initial metallic contact has a high resistance which decreases rapidly with progressive engagement. Assuming the contact resistance to decrease with contact force P as:[2,3]

$$R \propto P^{-\frac{1}{2}}$$

(e.g., for copper $R=10^{-4}P^{\frac{1}{2}}$ where R is Ω and P is N)

one can show that the energy deposition during the insertion time t is:

$$W = K \cdot R \cdot A^2 \cdot t^3$$

where: $A = di/dt$ at $t=0$ (the initial rate of rise of the current)

t = insertion time (time from first galvanic contact to full contact engagement)

R = the resistance of the fully engaged contact

K = a modelling constant

This relation is the result of a simplified model and neglects second order effects such as the temperature dependence of resistivity, etc. Nonetheless, it shows that a high rate of rise of the current greatly increases the energy deposition during contact engagement. Also, the t^3 dependence indicates the importance of fast contact closure.

Arcing can also result from mechanical contact bounce. This almost always involves the current carrying faces of the contact. If the current rises fast enough, the arc can prevent a successful closure.

These considerations led to the choice of a sliding contact system with a large number of contact fingers, a high initial contact pressure reinforced by the magnetic effects of the current and a drive system providing a high contact entry velocity.

Description of the Design

The cross section drawing, Fig. 1, shows the two terminal plates (1 and 2) with stationary gliding contacts (3), a cylindrical moving contact (4) operated by a pneumatic cylinder (5) and restrained in the open position by a latching system (6) which can be tripped by a solenoid (7). The cross section ($35.5\ cm^2$), and thus the mass of the moving contact, is the minimum allowed by contact area and heating considerations. Velocity of contact entry (6.5 m/s) and rate of rise of current are such that the contacts are fully engaged before the current reaches 100 kA. To avoid contact bouncing at this high speed, the stationary contacts are designed as two clusters of 24 spring loaded fingers [contact force 106 N (24 lbs)] mating with the cylindrical movable contact. One set of fingers is continuously engaged; the other rides on an insulating sleeve and makes contact when the cylinder is shifted to the closed position with no appreciable radial motion of the contact fingers.

The magnetic forces are of two kinds: repulsion due to current contraction at the actual contact point and the I x B force due to the magnetic field of the contact current on the extended contact finger. The net force is

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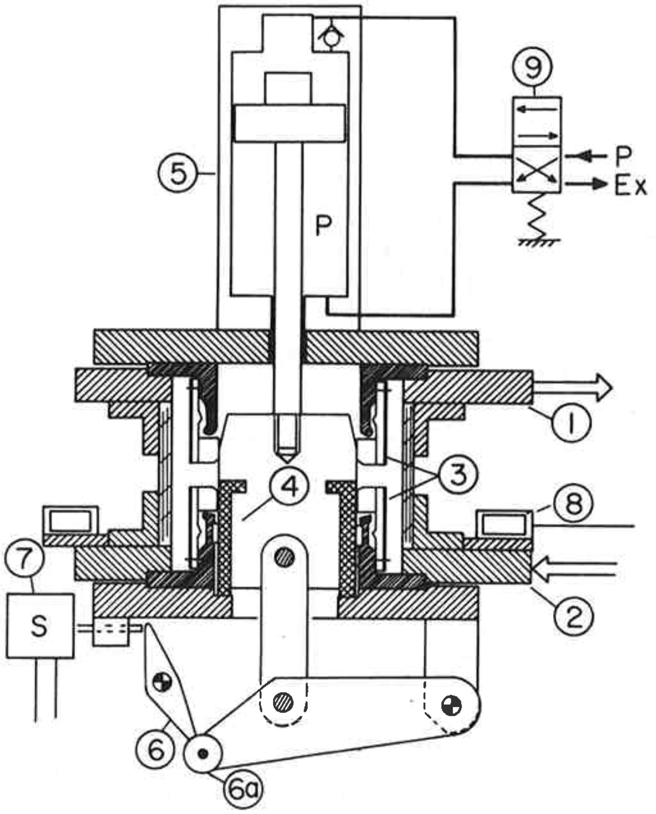

Fig. 1. Cross section; schematic; shown open, ready to close.

- 1,2 terminals
- 3 contact fingers
- 4 moving contact
- 5 operating cylinder
- 6 latch pawl
- 6a latch roller
- 7 trip solenoid
- 8 Rogowski coil
- 9 reset valve

such that the contact pressure increases with current. For a current of 300 kA the force on each contact amounts to 285 N (64 lbs) or approximately 3 times the preload. Since no arcing occurs the contacts are made of copper. Due to their sliding motion they are self cleaning.

The very high acceleration of the moving contact calls for a low mass, high force operating mechanism. The solution chosen consists of a pressurized cylinder restrained by a fast mechanical latch. When the latch is released the full force of the piston [8340 N(1875 lbs)] is available for contact acceleration. This avoids the gradual pressure buildup of conventional pneumatic drives and results in a dead time of 6.5 ms between energization of the trip latch and the beginning of contact motion. Total contact stroke is 5 cm; the contacts touch after 2 cm of motion and overlap 1.2 cm in the fully engaged position.

The latch (Figs. 1 and 3) consists of a roller resting of a cylindrically ground pawl. The release solenoid

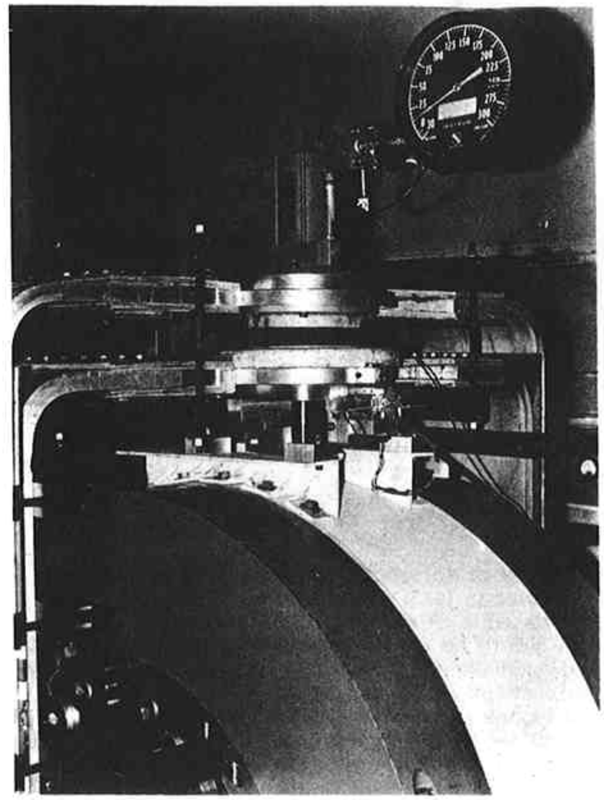

Fig. 2. Switch mounted on top of homopolar generator.

which is actuated by a 50 J capacitor discharge rotates the pawl out of equilibrium and thus releases the mechanism. After each operation the switch is reset by pressurizing the head end of the cylinder through the valve, item 9 in Fig. 1.

Test Performance

Mechanical performance is shown in the oscillogram reproduced in Fig. 4. Dead time is 6.5 ms and initial acceleration 2160 m/s^2. Final velocity of 6.5 m/s is attained before contact entry.

In the course of tests run on the homopolar generator the switch has been repeatedly operated under conditions exceeding its design rating. The maximum values to which the switch was subjected were:

Peak Current kA	Rate of Rise of Current (at 0 Current) kA/ms	Duration of Current Above 50% of Peak s
160	3	.60
357	50	.22
550	62	.21

Figure 5 shows current vs. time retraced from a typical oscillogram.

Inspection of the contacts after all these tests

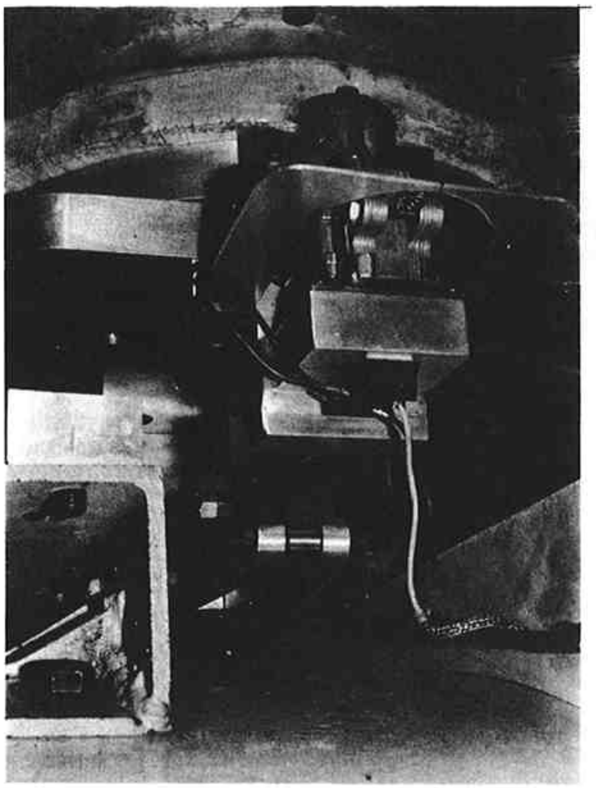

Fig. 3. Detail of latching system.

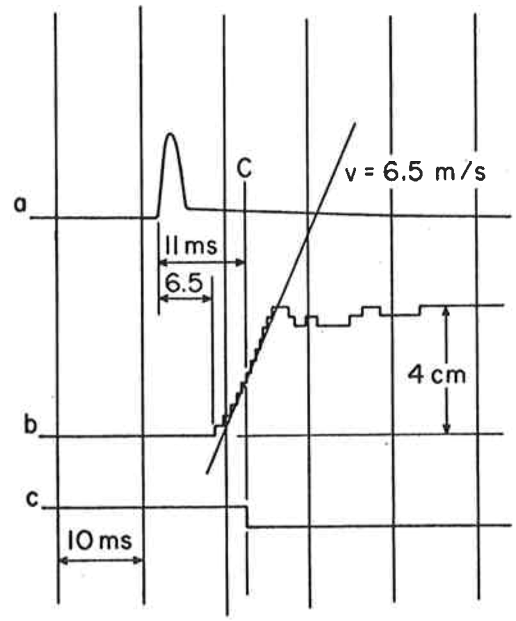

Fig. 4. Oscillogram, mechanical operation.
Traces: a) trip current
b) motion
c) contact indication

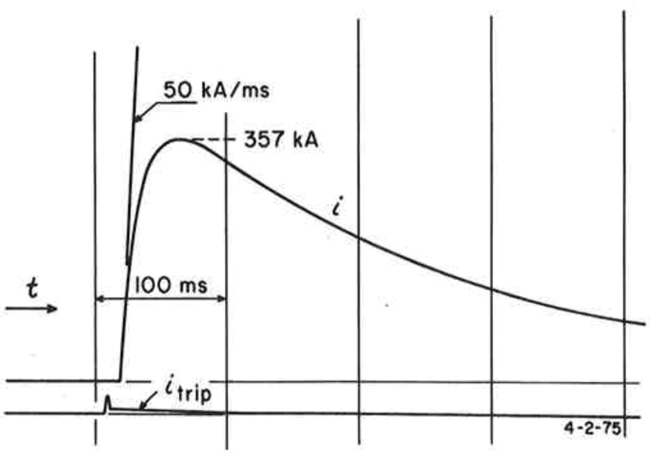

Fig. 5. Oscillogram, typical discharge.

showed that the switch is capable of fully entering the contacts even at the highest rate of current rise and carrying all the currents to which it has so far been subjected without any burns on the contacts.

Conclusions

The experience gained with this prototype forms the basis for future making switches, crowbar switches, etc. We are presently developing a closing switch for 1.75 MA and a rise time of 1.3 ms, and conducting studies on how to minimize prestrikes at higher voltages.

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