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ABSTRACT

Fusion experiments frequently have demanding switching requirements that cannot be satisfied by conventional switchgear. Two frequent requirements and specialized vacuum switches designed to meet them are presented. Experimental results from testing of prototype devices are discussed.

A frequently encountered switch application is the interruption of a high level, pulsed, dc current followed by a fast rising recovery voltage. A 7 in. vacuum interrupter with an axial magnetic field has proven to be an effective switch for currents up to 25 kA. Beyond 25 kA, a parallel configuration becomes necessary. The influence of the axial magnetic field on the behavior of parallel vacuum interrupters and test results up to 50 kA are discussed. Also, test results on experimental devices with novel electrode geometries such as the rod-array vacuum interrupter and the Amsler contact interrupter are presented.

Interrupters which can carry large dc currents on a continuous basis are frequently required in fusion applications. This requirement occurs in superconducting coil protection circuits and generally involves recovery voltages of 5 kV or less. A specially designed vacuum interrupter with water cooled electrodes has been used to extend the continuous current rating of a commercial interrupter from 1200 A to 13 kA. Two second generation devices with special electrode materials are currently being developed for use with a special actuator and are intended to extend the continuous rating to 25 kA.

I. INTRODUCTION

Fusion experiments frequently have demanding switching requirements that cannot be satisfied by conventional switchgear. This paper discusses two common requirements and specialized vacuum switches designed to meet them.

The frequent switching requirement involves the diversion of a pulsed inductive current from a circuit breaker into a resistor or capacitor. The recovery voltage resulting from this transfer is coupled to the fuel mixture of a toroidal fusion device. Upon its application, the fuel is ionized in preparation for continued heating. This process is known as a plasma initiation pulse (PIP) and generally involves circuit breaker recovery voltages from 25 kV to 50 kV and interruption currents from 25 kA to 50 kA. Future large scale tokamak machines will most likely accomplish plasma initiation by neutral beam injection or RF heating without the use of a PIP. However, high current interruption with lower recovery voltages will still be used for ohmic heating.

Another frequent switching application occurs in the area of superconducting coil protection. Many of the upcoming fusion experiments rely on superconducting induction and toroidal field systems. These systems are very complex and represent a large capital investment. Failure of a critical component during a test cycle can lead to destruction of the coil. Therefore, protective dump circuits are utilized to remove energy from the coil in an emergency. These dump circuits typically consist of a resistor in parallel with a circuit breaker. Operation of the circuit breaker introduces the resistor in series with the coil and dissipates its energy. Although recovery voltages are generally limited to about 5 kV, interruption currents may be as high as 50 kA. The most severe requirement for these circuit breakers is an unusually high continuous current rating. For induction coil systems, currents of 25 kA to 50 kA must be carried by the circuit breaker for periods as long as several minutes. Toroidal field coil circuit breakers must carry currents of 15 kA to 30 kA on a continuous basis.

II. CIRCUIT BREAKERS FOR PLASMA INITIATION

Production of a PIP requires circuit breakers that can interrupt pulsed currents from 25 kA to 50 kA and withstand recovery voltages from 25 kV to 50 kV. A commutated vacuum interrupter system is frequently selected as the most economical switchgear to satisfy these requirements. Test results for three different types of vacuum interrupters suitable for use in such circuits are discussed in this paper.

One device tested was a 7 in. vacuum interrupter with Amsler [1] contacts. The unusual electrode configuration of this interrupter keeps the conducting arc in a diffuse mode, thus preventing anode spot formation. The maximum current for a 90% interruption reliability was 32 kA with a 22 kV recovery voltage. The commutation rate was approximately 500 A/μS.

Another interrupter with an unusual electrode geometry was the rod-array vacuum interrupter which, like the Amsler contact interrupter, maintains a diffuse arc at high currents [2]. The interrupter was able to interrupt 32 kA with a 90% reliability and an 11 kV recovery voltage. A picture of this device in the Los Alamos Scientific Laboratory (LASL) 33 GVA interrupter test facility [3] is shown in Fig. 1.

The most effective interrupters tested were standard 7 in. vacuum interrupters with an axial magnetic field. Over twenty commercial devices have been tested, some with 90% reliability levels in excess of 40 kA. Fig. 2 is a photograph of one such device with flat contacts designed especially for extended dc current interruption service. A system utilizing a series arrangement of two of these interrupters was designed for the PIP circuit of the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory. Over 1000 tests were performed at 25 kA and 25 kV with no failures [4]. The extrapolated contact lifetime at this interruption level was 10^4 operations.

For reliable interruption of 50 kA, a parallel configuration of axial field interrupters is necessary. Parallel operation is made practical by the influence of the axial magnetic field on the arc voltage [5]. The arc has a slightly positive voltage characteristic with respect to current and, during parallel operation, induces equal current sharing without the use of external resistive or inductive elements. Tests at 50 kA, using two parallel connected interrupters, indicated that currents distributed equally to within 10%. When the opening of one interrupter was intentionally delayed, currents equalized within 1 ms. One drawback to the parallel operation mode must be noted. If one interrupter in a parallel array of n interrupters restrikes, the fault current will be n times the rated current. Besides the high contact erosion occuring during the fault, the magnetic forces, which are proportional to the current squared, may cause damage to the switchgear. For this reason, a series multiplicity is recommended in each of the parallel paths to increase the branch reliability and reduce the chances for switchgear damage.

III. CIRCUIT BREAKERS FOR SUPERCONDUCTING COIL PROTECTION

The requirements for circuit breakers used for superconducting coil protection differ from PIP requirements in two major ways. Namely, (1) the recovery voltage is generally much lower for the coil protection circuits, and (2) the current conduction time while the contacts are closed is much longer. The long conduction time creates problems that cannot be solved at low cost by commercial switchgear.

The maximum continuous current rating for [illegible] in. vacuum interrupters range from 1.2 kA to 2 kA. Toroidal and induction field coil systems require circuit breakers that can conduct as well as interrupt currents as high as 50 kA. In the past, the continuous current problem has been solved by placing a high current bypass switch in parallel with a conventional circuit breaker [6]. The bypass switch must open and transfer the current to the circuit breaker a short time b[illegible] interruption is required. The circuit breaker then performs interruption duties on the full current and initiates the transient recovery voltage.

A new vacuum interrupter has been developed by LASL and Westinghouse Electric Corporation specifically for use in superconducting coil protection circuits. This interrupter has water cooled stems and contacts and is designed for high continuous current levels. A cutaway schematic of the stem contact system is shown in Fig. 3. The first prototype, shown disassembled in Fig. 4, was tested up to 13 kA for 10 minutes. As can be seen on the photograph, some contact melting occurred. This is believed to be caused by both inadequate contact pressure from the actuator and the use of high resistance contact material within the interrupter. Two second generation devices are being built for testing in conjunction with a special high pressure actuator developed by LASL. These interrupters will have two different types of low resistance contact material and oversized water passages for increased cooling. They are designed to extend the single unit continuous current rating to 25 kA. Experiments with two interrupters in parallel at 50 kA are planned after individual testing.

IV. CONCLUSIONS

Specialized vacuum switches have been designed to satisfy demanding switching requirements for fusion devices. For plasma initiation and high current interruption these include:

1. Devices with novel electrode geometries such as the rod-array vacuum interrupter and the Amsler contact interrupter for higher single unit interrupion ratings.
2. Vacuum interrupters with axial magnetic fields for currents up to 25 kA.

3. Parallel operation of vacuum interrupters with axial magnetic fields for currents up to 50 kA.

For superconducting coil protection, a water cooled vacuum interrupter is being developed to handle the high continuous current levels. A first prototype was built and tested to 13 kA for 10 minutes. Used with a special actuator, second generation water cooled vacuum interrupters are designed to extend the continuous rating for a 7 in. interrupter from 2 kA to 25 kA.

ACKNOWLEDGEMENTS

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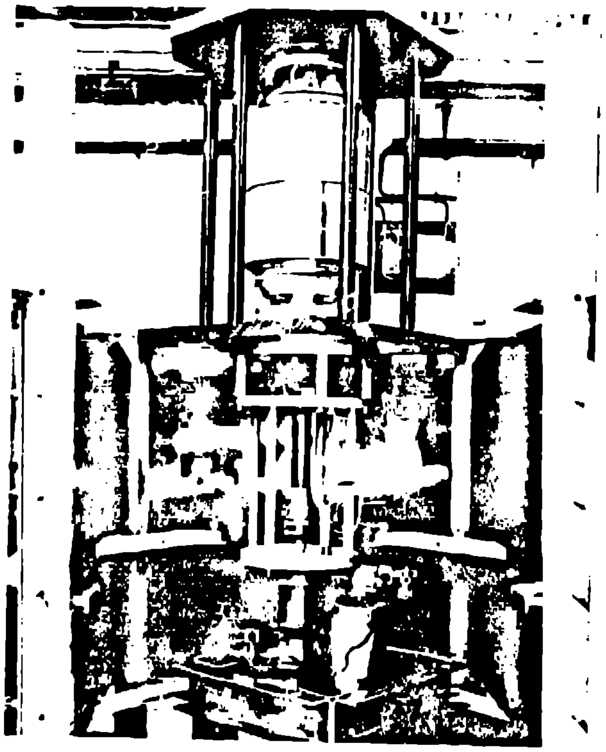

Fig. 1. Rod-array vacuum interrupter in test facility.

Fig. 2. Commercial vacuum interrupter with dc contacts.

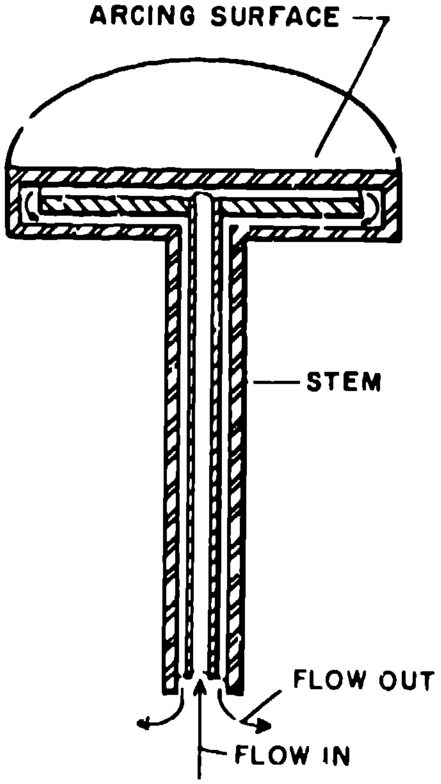

Fig. 3. Stem contact system for water cooled

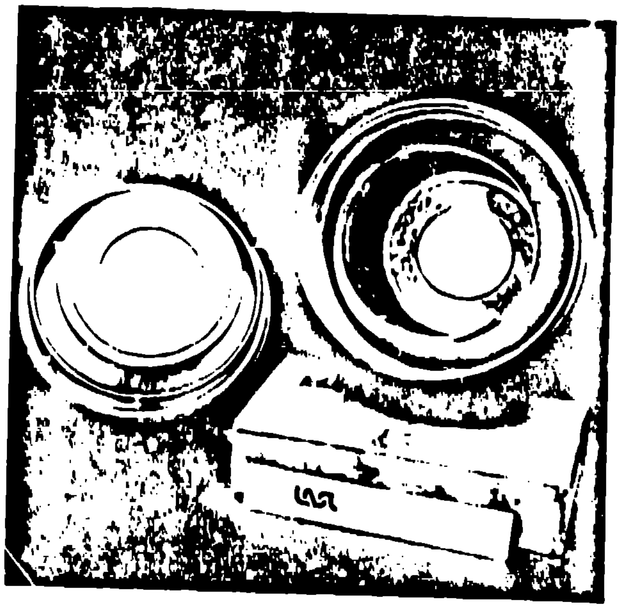

Fig. 4. Prototype water cooled vacuum interrupter

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