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INTERRUPTER AND HYBRID-SWITCH TESTING FOR FUSION DEVICES[*]

by

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Summary

This paper discusses recent and ongoing switch testing for fusion devices. The first part describes testing for the TFTR ohmic-heating circuit. In this set of tests, which simulated the stresses produced during a plasma initiation pulse, circuit breakers were required to interrupt a current of 24 kA with an associated recovery voltage of 25 kV. Two interrupter systems were tested for over 1000 operations each, and both appear to satisfy TFTR requirements.

The second part discusses hybrid-switch development for superconducting coil protection. These switching systems must be capable of carrying large currents on a continuous basis as well as performing interruption duties. One such switching system, rated at 25 kA and 2.5 kV, is currently being developed for the Large Coil Project at the Oak Ridge National Laboratory. This switch assembly consists of a high-current by-pass switch in parallel with a magnetic blowout interrupter. Another switch for this type of application is being developed for use with large tokamak induction coils. This switch is a vacuum interrupter with water-cooled electrodes. Test results at 13 kA continuous current and future plans for extending the steady-state rating to 25 kA are presented.

The third part presents preliminary results on an early-counterpulse technique applied to vacuum interrupters. Implementation of this technique has resulted in large increases in interruptible current as well as a marked reduction in contact erosion.

Introduction

The Los Alamos Scientific Laboratory (LASL) has been engaged in switch testing for fusion devices since 1974.[1] At that time, one facility existed with an installed capability of 10 kA steady-state and 25 kA pulsed. Presently three facilities are operative, the largest has an installed capacity of 100 kA steady-state and 280 kA pulsed.[2] This increase has been necessary due to the larger and more continuous current requirements conceived for modern fusion devices such as ETF and INTOR.

TFTR Ohmic-Heating Circuit Switchgear Tests

The Tokamak Fusion Test Reactor (TFTR) project at the Princeton Plasma Physics Laboratory requires the insertion of a resistor in an excited ohmic-heating coil circuit to produce a plasma initiation pulse (PIP). The maximum duty for the switching system will be an interruption of 24 kA with an associated recovery voltage of 25 kV. Vacuum interrupters were selected as the most economical means to satisfy these requirements. However, some testing of available systems needed to be performed to determine their reliability.[3]

Westinghouse System

One system tested consisted of two series-connected Westinghouse WL-33552 interrupters with external axial-fields and a 75 μF counterpulse bank. These interrupters are shown in Fig. 1. The actuators used were Ross Engineering Model HA-75. Figure 2 is a schematic of the circuit used to test these interrupters. The homopolar generator, HP, was used to supply 6×10^7 A^2 - s of heating prior to current interruption on each test. This closely simulated the heating seen by the interrupters during charging of the ohmic-heating coil. Figure 3 shows a partial current waveform for a typical test. The homopolar current (10 kA) is brought to zero a few milliseconds before the high-current pulse is initiated. The current level just prior to the counterpulse is 24 kA.

Over 1000 tests were performed on the Westinghouse interrupter system at 24 kA and 25 kV. Only one failure to interrupt was observed, this being partially attributed to a broken bolt in one actuator that was discovered just after that particular test. Three single-interrupter restrikes were observed during this testing, none of which led to an interruption failure. The total contact erosion during the more than 1000 interruptions was less than 0.010 in. indicating that a projected life of 10^4 operations is feasible.

Toshiba System

The other system tested was a Toshiba Model VGB2-D20 interrupter system. This system had two interrupters connected in series with axial-field coils built into the electrodes themselves. Both interrupters were actuated from a single spring-loaded mechanism supplied by Toshiba. A picture of this system in the test facility is shown in Fig. 4. The manufacturer specified the characteristics of the saturable reactor to be used during these tests. As a result of the large saturated inductance of this component, a 450 μF counterpulse bank was required for commutation.

A schematic of the circuit used for the Toshiba testing is shown in Fig. 5. The heating requirements prior to interruption were relaxed for this set of tests, so there was no homopolar generator in the test circuit.

Over 1000 tests were run on the Toshiba system at 24 kA and 25 kV. A typical current waveform showing an expansion of the reduced di/dt just prior to current zero is shown in Fig. 6. There were neither failures to interrupt nor single interrupter restrikes

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[*] Work performed under the auspices of Department of Energy.

[+] Industrial Staff Member, Westinghouse Research Laboratory.

[++] Contributed to TFTR testing only.

during any of these tests. The actuator stroke was carefully monitored for over 2000 operations and found to be extremely consistent. Total contact erosion during the tests was found to be less than 0.010 in.

In addition to these tests, permission was granted by Toshiba to test a single interrupter for its maximum interruptible current. This was found to be about 41 kA at 30 kV for a 90% reliability.

Superconducting Coil Protection Switches

Due to the large energies and the substantial capital investment associated with large superconducting inductors, protection devices are usually designed into the coil circuit that allow rapid dissipation of coil current in an emergency situation. A typical protection circuit consists of an interrupting switch and a dump resistor. When the interrupter operates, the coil current is diverted into the dump resistor while the charging power supply is disconnected. The coil current then decays with an associated L/R time constant.

Such a switching circuit will be tested for the Oak Ridge National Laboratory (ORNL) Large Coil Project (LCP). Figure 7 shows the details of the LCP circuit. Both the primary and back-up interrupters consist of a modified, commercially available,[4] high-current, by-pass switch in parallel with a magnetic blowout dc circuit breaker. The high-current by-pass switch handles the continuous 25 kA due to steady-state current limitations of the dc interrupter. If the coil under test goes normal, or a failure occurs in the power supply, helium liquifier, dewar, or other critical component, the by-pass switch opens and transfers the current to the dc interrupter. The interrupter then operates and diverts the coil current into the dump resistor where it is quickly dissipated. LASL will be testing a prototype interrupter system for ORNL during mid 1980. Questions such as reliability, lifetime, and maintenance will be addressed during this testing program.

For the same general application, a special interrupter[5] is currently being developed that requires no external by-pass switch. This is a vacuum interrupter with water-cooled electrodes and very high contact closing forces. Presently, the continuous current rating for a seven-inch interrupter has been increased from 1.2 kA to 13 kA. Implementation of a new high-pressure actuator developed at LASL and a modification in contact material will hopefully increase the continuous current rating to 25 kA. The steady-state current rating will then match the interruption rating. The units may then be connected in parallel for higher currents.

Early Counterpulse Technique

The conventional[6] approach towards current commutation in dc interrupters requires that the electrodes be separated substantially before the counterpulse is applied. This necessitates a period of full-current arcing during each interruption sequence. This arcing heats the electrodes and can cause hot spots to form on the electrode surfaces. Thermionic emission from these hot spots is believed to cause reignition of the arc and limits the maximum interruptible current for a particular device. In addition, this arcing period erodes the electrodes, causes pitting and deformation, and deposits a metallic film on shields and insulators within the vacuum space. Another method for commutation, called the early counterpulse technique (ECT), shows promise not only of increasing the maximum current ratings for an interrupter but also of substantially decreasing electrode erosion. With this technique, the current is commutated to a near-zero level before the electrodes are separated. Figure 8 shows a comparison of the normal and early counterpulse current waveforms.

A four-inch vacuum interrupter whose normal maximum interruption level was about 6 kA was tested using ECT. This interrupter was able to interrupt currents as high as 25 kA. In addition, 1200 interruptions were performed at 10 kA with no failures. The interrupter was then opened and the contacts were inspected. Virtually no erosion had occurred. An extrapolated contact lifetime of 10^5 to 10^6 operations could be anticipated using this technique.

Implementation of ECT requires three special components. The first is a very fast actuator. The commutation bank must hold the interrupter current near zero while the contacts separate. A fast separation requires less time at low current levels and thus reduces the size of the commutation bank. The second component is a large saturable reactor to insure that the counterpulse current does not exceed the interruption current by more than a few hundred amperes. The third component is a larger-than-normal counterpulse bank whose size, as mentioned, is determined by actuator speed.

Conclusions

The switching program has contributed to the national fusion effort in several ways. First, by testing commercial switching systems, such as those tested for use in TFTR. Secondly, by modifying commercial switches for special applications. The hybrid interrupter system to be tested for use in LCP at ORNL is an example of such a modification. Finally, research and development efforts are under way for future fusion devices by developing water-cooled interrupters for superconducting coil protection and the early-counterpulse technique for extending the lifetime of conventional interrupters.

Acknowledgement

The LASL staff is grateful for permission to perform extended tests on the Toshiba interrupter.

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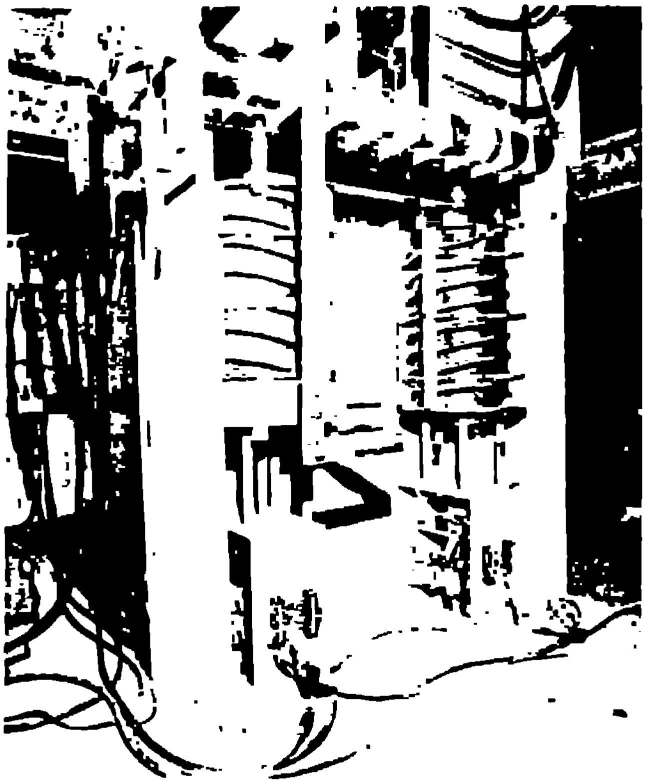

Fig. 1.
Westinghouse interrupter.

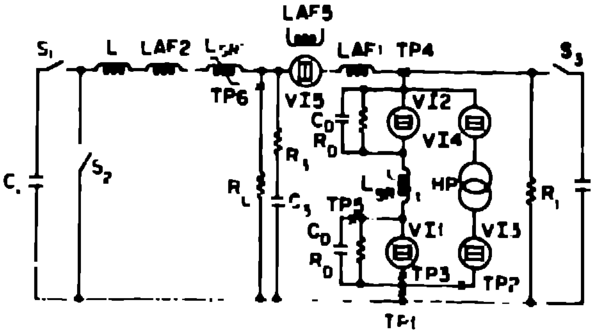

Fig. 2.
Westinghouse Interrupter Test Circuit.

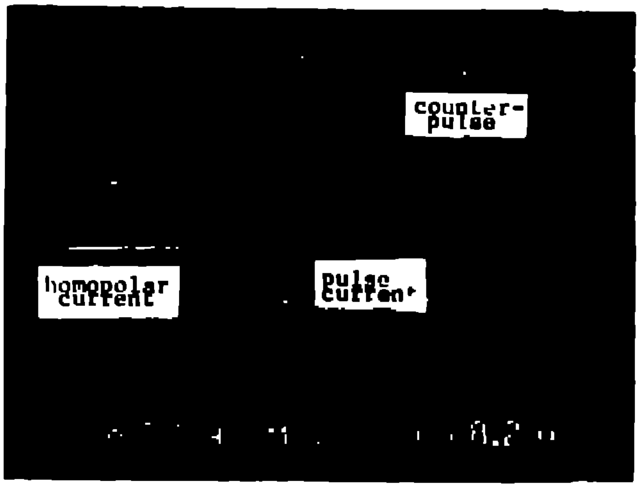

Fig. 3.
Westinghouse interrupter current waveform.

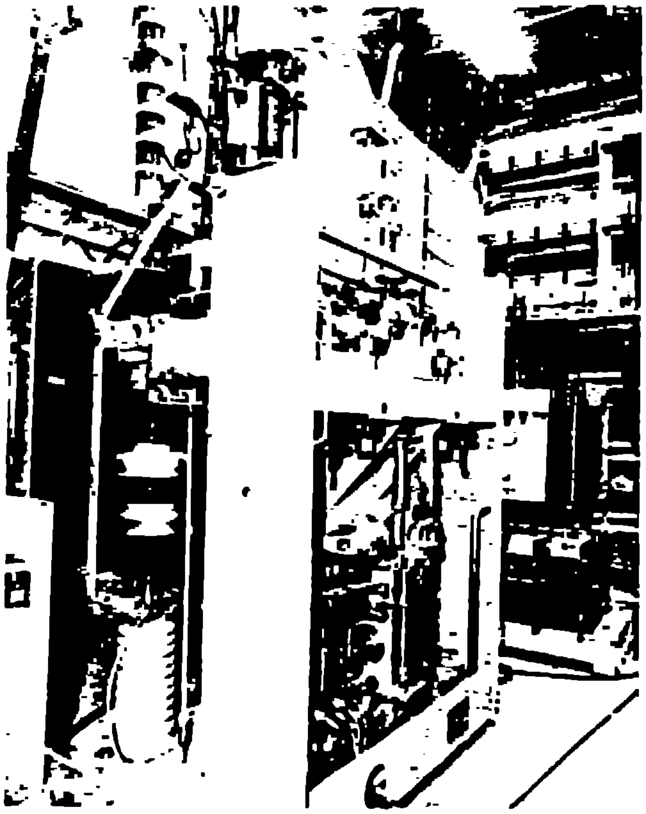

Fig. 4.
Toshiba interrupter.

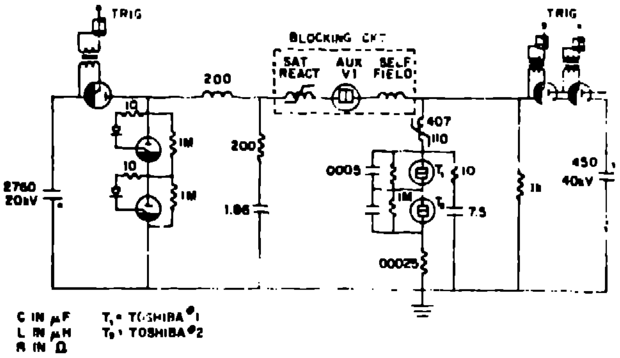

Fig. 5.
Toshiba interrupter test circuit.

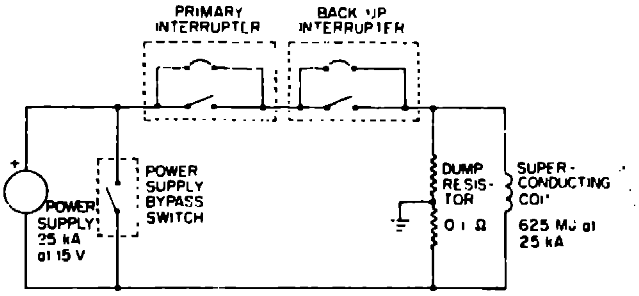

Fig. 7.
ORNL SCP coil protection circuit.

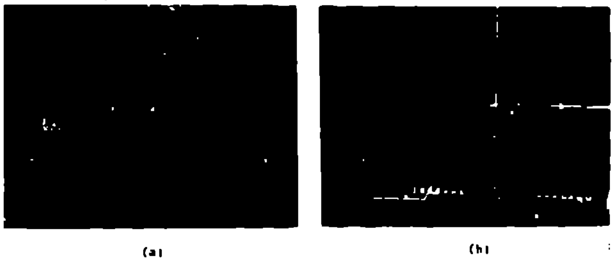

Fig. 6.
Toshiba interrupter current waveform.
(a) Full waveform.
(b) Expansion near current zero.

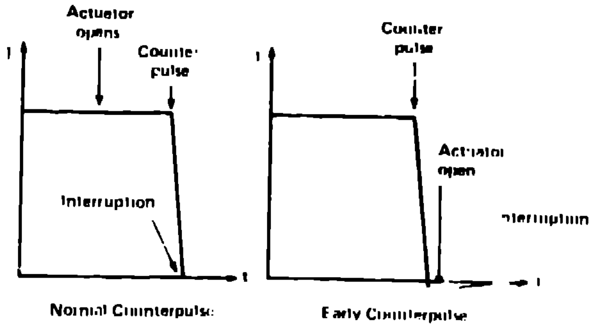

Fig. 8.
Comparison of normal and early counterpulse current waveforms.