CONF-791102--76

GA-A15660

FUNCTION AND OPERATION OF THE DOUBLET III E-COIL VACUUM BREAKER SYSTEM

by

R. W. CALLIS, G. JACKSON, J. DeGRASSIE,
P. PETERSON, and F. LeVINE

MASTER

NOVEMBER 1979

GENERAL ATOMIC COMPANY

DISCLAIMER

GA-A15660

FUNCTION AND OPERATION OF THE DOUBLET III E-COIL VACUUM BREAKER SYSTEM

by

R. W. CALLIS, G. JACKSON, J. DeGRASSIE,
P. PETERSON, and F. LeVINE

This is a preprint of a paper to be presented at the 8th Symposium on Engineering Problems of Fusion Research, November 13-16, 1979, San Francisco, California.

Work supported by
Department of Energy
Contract DE-AT03-76ET51011

GENERAL ATOMIC PROJECT 3235.803.461
NOVEMBER 1979

GENERAL ATOMIC COMPANY

FUNCTION AND OPERATION OF THE DOUBLET III E-COIL VACUUM BREAKER SYSTEM*

R. W. Callis, G. Jackson, J. deGrassie, P. Peterson, F. LeVine
General Atomic Co.
Box 81608
San Diego, CA 92138

Abstract

The ohmic heating system for the Doublet III fusion research device at General Atomic is required to provide the voltage for the initial breakdown phase (there is no preionization) along with the energy to drive the plasma current to a value of 2.5 MA or greater. This requires a peak one turn voltage of 250 volts (16 kV across coil terminals) and a magnetic flux swing of 5 volt-seconds (peak coil current of 110 kA). This voltage and flux swing is acccomplished by reverse biasing the ohmic heating coil (E-coil) where, upon reaching a value of 110 kA the coil current is interrupted and commutated into a RC network producing 16 kV across the coil. When the E-coil current passes through zero the power supply is reconnected and drives the current higher reaching a peak forward current of 110 kA, completing a full 5 volt-second flux swing.

The interruption of the E-coil current is accomplished by the use of an array of Vacuum Circuit Breakers (VCB's) and a counter pulse netowrk. The VCB array consists of four parallel legs with two VCB's per leg. These VCB's are of a special design having an internally generated axial magnet field which allows each VCB to interrupt 32 kA. The counter pulse network consists of a 2.5 mFarad capacitor bank, a 10 to 20 micro henry inductor and an ignitron switch. This circuit is adjusted to provide the appropriate di/dt and dv/dt values at the current zero for proper arc interruption.

A description is given of the ohmic heating circuit and the performance of the vacuum circuit breaker array and its counter pulse system.

Introduction

Doublet III is a noncircular cross section toroidal plasma magnetic confinement experiment being tested at General Atomic as part of its research program in nuclear fusion. This report describes the performance and operation of the ohmic heating system for Doublet III, in particular the performance of its circuit breaker system.

The high peak voltage and power required to initiate the plasma discharge is obtained with an inductive storage and power supply system. In this system the ohmic heating coil (E-coil) functions as an inductive energy storage coil. Prior to the discharge, an external power supply is used to establish a dc bias current in the E-coil. At the desired instant, an interrupter switch (vacuum circuit breaker system) is used to transfer the E-coil current from the power supply to a high impedence RC network. The resulting RLC oscillation generates an initial peak voltage of 16 kVdc (250 volts/turn) across the E-coil, inducing a rapid build up of plasma current. Eventually the capacitance in the RC network reverses the E-coil current, and auxillary switching is used to reconnect the power supply with opposite polarity to further increase the current which sustains the plasma current flattop.

Ohmic Heating Circuit

A simplified circuit diagram of the ohmic heating system is shown in Figure 1. The E-coil power supply V, is a thyristor controlled rectifier system (850 v, 150 kA) that is used to drive the initial dc bias current in the E-coil and is also used with feedback control to maintain plasma current flattop after

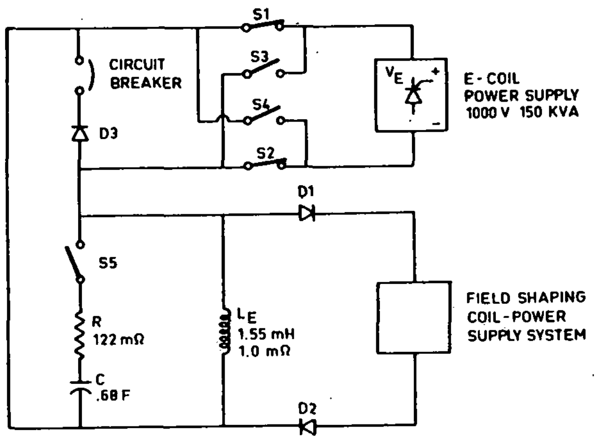
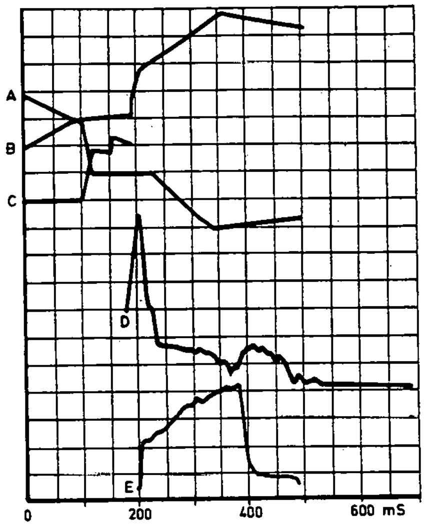


FIG 1. OHMIC HEATING CIRCUIT DIAGRAM

plasma initiation. Switches S1 through S4 are reversing switch that changes the connection polarity of the E-coil power supply during the shot. Switch S5 is a high speed making switch [1] that connects the RC network across the E-coil just prior to circuit interruption. Diodes D1 and D2 are blocking diodes that prevent current to flow to the field shaping coil/power supply system during the bias phase of the shot (The field shaping Coil/power supply system is discussed in another paper at this conference [2].

The circuit functions as follows: initially S1, S2 , and the circuit breaker are closed and all other swithces are open, and the main cap bank is precharged to 4kV. The E-coil power supply is used to drive a reverse bias current of up to-110 kA through the E-coil. Diode D_3 prevents current from flowing through the circuit breaker during this phase. When the desired reverse bias current is reached the power supply is inverted (polarity is changed by controlling the firing angle of the thyristors). Allowing the

Diode D3 to conduct thus making the circuit breaker a crowbar across the E-coil. When the current from the supply reaches zero, S1/S2 open isolating the supply from the circuit. The capacitor bank switch then closes connecting the RC network across the E-coil. This establishes the LRC network so that when the circuit breaker opens the current will be commutated to the RC network producing 16kV across the coil. The oscillation of the LRC circuit forces the E-coil current through zero at which time switches S_3 and S_4 close reconnecting the E-coil power supply which is used in a controlled manor to maintain plasma current flattop. Figure 2 shows the voltage and current waveforms of the E-coil, circuit breaker, E-coil power supply, and plasma current for shot No. 3177.



A E-coil current 25 kA/div
B E-coil power Supply current 25 kA/div
C Circuit Breaker current 25 kA/div
D E-coil voltage ~1 kV/div
E Plasma current 500 kA/div

Fig. 2 Voltage and Current waveforms shot # 3177.

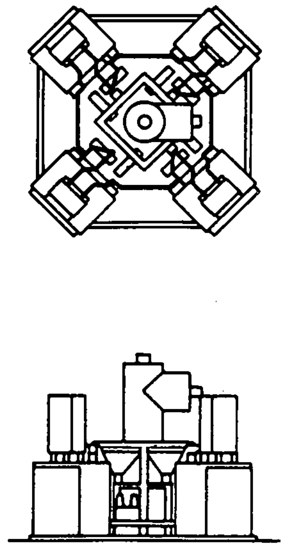


FIG. 3 MECHANICAL LAYOUT OF THE DOUBLET III CIRCUIT BREAKER.

Circuit Breaker

During the design of Doublet III several types of circuit breakers have been proposed,[3] they are thyristor switches (SCR), vacuum interrupters, air blast breakers, liquid-metal plasma valves (LMPV) and active fuses. After a thorough investigation of the above devices it was determined that the best device to use for the circuit breaker was a new vacuum interrupter built by the Toshiba Electric Company.[4]

These vacuum interrupters have an internally produce axial magnetic field which promotes high current stable arcs, lower arc voltage and low erosion rates.

The circuit breaker built for Doublet III is modeled after a circuit breaker built and tested for the JT-60 program.[5] This circuit breaker system consists of connecting interrupters into four parallel legs with two series interrupters per leg (total of eight interrupters). The system is built using standard three phase A.C. circuit breaker mechanisms, were two interrupters are set into each of four units. The circuit breaker system is coaxilly configured as shown in Figure 3 to minimize magnetic interactions between buswork and interrupts. A schematic for this system is shown in Figure 4, and the performance characteristics are given in Table I.

As can be seen in Fig. 4., there are two vacuum interrupter per leg, this was done to eliminate current reignition after current interruption, a condition that could lead to severe electrode erosion and damage. Even though the vacuum interrupters used have a demonstrated reignition rate of less than 0.1%, it was determined that for maximum reliability two interrupters should be put in series per parallel leg. A life test of such a system showed no reignition during 10,000 shots.

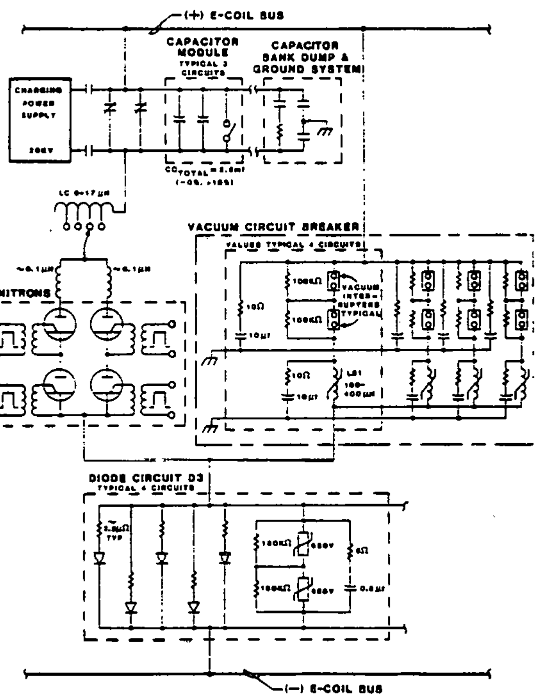
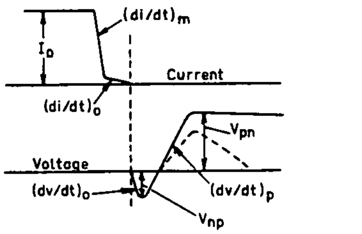


Figure 4
Schematic of Doublet III
E-coil Circuit Breaker

A generalized waveform of the current and voltage produced in the circuit breaker, just prior to and after current interuption is shown in Fig. 5. It is important to note the changes in di/dt just prior to current interruption and the slight negative voltage across the breaker immediately following current interruption. The di/dt change is caused by the saturable reactor in each leg of the circuit breaker coming out of satuation with decreasing current. The value of di/dt at current zero is a key factor in reliable current interruption, thus requiring close coordination between the staturable reactor.Ls and the counter pulse components C_c and L_c. The negative voltage appearing across the circuit breaker after current zero is caused by the residual charge on the commutation capacitor Cc that is in excess to that which is necessary to force a current zero.



I_o	Current to be interrupted
$(di/dt)_m$	Mean rate of fall of current
$(di/dt)_o$	Rate of fall of current at current zero
$(dv/dt)_o$	Rate of rise of negative voltage
V_{np}	Negative peak voltage
$(dv/dt)_p$	Rate of rise of positive voltage
V_{pp}	Positive peak voltage

FIGURE 5. GENERALIZED CURRENT AND VOLTAGE WAVEFORMS FOR A VACUUM INTERRUPTER AT CURRENT ZERO.

TABLE I

DOUBLET III E-COIL CIRCUIT BREAKER PERFORMANCE CHARACTERISTICS

Resistancé of closed switch	less than .5 m ohm
Holdoff voltage of open contacts	20 kV (after interrupt)
Open time (trip signal to contact opening)	30 msec ± 2 msec
Maximum rate of voltage recovery	300 V/micro sec
Current rise time	96 A/micro sec peak
Current rise time near current zero	26 A/micro sec
Pulse repetitition rate	1 pulse per 300 sec
Saturable reactor	100 micro H saturated/each 400 micro H unsaturated/each
switch inductance	40 micro H
Peak Current	125 kA
Conduction time	100 msec peak
Time to reach voltage peak after current interruption	1.3 msec
Voltage isolation to ground	41 kVdc
Short Circuit current	1×10^6 A RC =5 msec 7×10^5 A half sine 6 msec
Restrike frequency	less than 0.5%

The excessive charging components of C_c is done to compensate for any deviation in circuit components of the parallel legs, such as; opening jitter, component resistance, etc. that cause current imbalances which may vary the time of current zero in each leg. In system operation, the negative voltage Vnp should be kept minimally small approximately 6kV to prevent reignition.

Figure 6 shows the current interrupted in each leg of the circuit breaker and the voltage developed across the open vacuum interrupter. The current sharing between legs are equal to within 5% and the opening jitter between each vacuum interrupter is less than 1 msec. For this shot the total interrupted current was 60 kA.

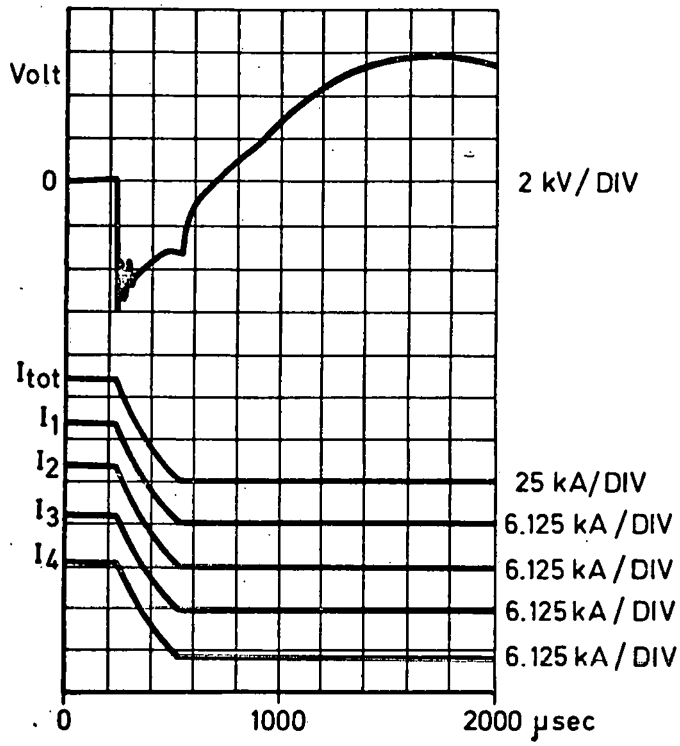


Figure 6. Voltage and Current Waveforms for the Vacuum Circuit Breaker at Current Zero, Shot #6084

Counter Pulse System

The counter pulse system is essentially an LC oscilation loop that superimposes an ac current on top of the dc current flowing through the vacuum interrupters. The charge and size of the counter pulse capacitor nomially called a commutation capacitor C_c is chosen such that a current zero is reached on the first quarter cycle after the circuit is connected across the circuit breaker.

The size of the commutating capacitor bank and commutating inductor are chosen to work in conjunction with the saturable reactor to give $(di/dt)_m$ and $(di/dt)_o$ valves within the capability of the vacuum interrupter (see Table I). The voltage capability of the commutating bank is chosen to be compatible with the peak positive recovery voltage, Vpn, which is determined by the ohmic heating coil and its parallel RC network (see Table I).

The commutating capacitor bank is a 2.5 m F ± 25 kV bank composed of 144 capacitors in parallel. The capacitors, made by Westinghouse Electric Company, are of a paper-plastic film type of construction with a Isopropyl-biphenal (Wemcol) dielectric. The average dielectric stress is 3896 volts/mil.

TABLE II

COUNTER PULSE SYSTEM PARAMETERS

Commutation Capacitor Bank	2.5 m F; ±25 kV
No Capacitors	144 units
Commutation Inductor	17 micro H with taps at 15, 12 and 9 micro H
Ignitron Switch	
size	NL-1059 type D
coulomb rating	120 coulombs
hold off voltage	20kV
Peak Current	150 kA

The switch connecting the commutation capacitor bank across the circuit breaker is composed of two parallel legs with two series ignitrons in each leg. Each ignitron is a size D ignitron with a coulomb rating of 120 coulomb, and a voltage stand off rating of 20 kV. Each leg is capable of passing the charge stored in the commutation bank, however the criticality of this system working at the moment of contact separation required a complete redundent system. The design with two ignitrons in series evolved when it was found that a single ingitron could not reliably hold off the nominal 20 kV to which the capacitor bank was charge. A condition which could lead to potential damage to the other ohmic heating circuit components; the seriesing of two ignitrons has solved this problem.

Discussion

This paper has shown that a circuit breaker capable of interrupting 125 kA at 16 kV can be made by paralleling vacuum interrupters in a 2S-4P arrangement. This system was installed and checked out in the summer of 1978 and since then has been operating on a routine basis and approximately 2000 shots have been logged so far. The operation of this circuit breaker has been very reliable and there has not been one case of current reignition in all these shots.

The Doublet III program is starting a new phase of construction in which the power systems will be doubled in capability. For the ohmic heating system a circuit breaker capable of interrupting 250 kA at 20 kV will be needed. It is again expected that by paralleling vacuum circuit breakers this goal can be met. New progress in vacuum interrupter design has increased its di/dt and dv/dt characteristics at current zero allowing for smaller commutation capacitor bank and progress is being made in reducing the reignition rate and in extending the vacuum interupters electrical and mechanical life to over 10,000 interruptions. [6] It is possible that with these newer vacuum interrupters a circuit breaker can be built with simple parallel construction (having two interrupters in series not being required) which will lead to lower initial cost and lower maintenance.

References

1. P. Wildi, E. L. Woods, "High Current Switches In The Doublet III Poloidal Field Circuit", in Proceeding of The Seventh Symposium on Engineering Problems of Fusion Research (Knoxville, Tenn.); IEEE Pub. No. 77CH1267-4-NPS, 1753 (1977).

2. P. J. Rock, J. C. Wesley, "1.2 Megawatt D. C. Chopper Power Supplies for Plasma Shape Control on Doublet III", Proceedings of the Eighth Symposium on Engineering Problems of Fusion Research (San Francisco, CA), Session 24-16, (1979)

3. R. W. Callis, "Doublet III Baseline Description", General Atomic Document GA-A139967,

June, 1976

4. M. Murano, S. Yanabo, and T. Tamagawa, "Interruption Ability of Vacuum Arc", IEEE third International Conference on Gas Discharges, Con. Pub. No. 118,648, 1979.

5. R. Shimada, et. al., "Development of High Current DC Circuit Breaker for Large Tokamak Fusion device", IEEE PES Summer Meeting, (Los Angeles), July 1978.

6. "Recent Progress about Toshiba D.C. Vacuum Circuit Breaker", Toshiba Electric Corp. Document No. KDVB-0003, March 1979.

GENERAL ATOMIC COMPANY
P. O. BOX 81608
SAN DIEGO, CALIFORNIA 92138