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IGNITRON LONG PULSE TESTING

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Ignitron Long Pulse Testing*

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ABSTRACT

The PLT and other future research machines will require fast turn-on switching devices capable of high current operation at dc pulse durations of several seconds. High voltage standoff and low voltage drop during conduction are additional requirements.

The ignitron is apparently the best commercially available component for use in such service. However, ignitron manufacturers' data are not published for ratings under the proposed applications' electrical - time environments.

This report describes tests made with the specific object of selecting one or more ignitron types suitable for use in the PLT ohmic heating system. Completion of the detailed design of this system was possible as a result of the subject testing.

Tests were performed on three types of ignitrons at current levels of from 2500 to 5000 Amperes and

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conduction periods of up to 5 seconds. Both mechanical deterioration and changes in certain electrical static characteristics were observed and used as criteria for test terminations.

Significant results were the selection of a moderately priced tube type for the PLT ohmic heating system and the choice of a conductor connection arrangement which extends tube life.

I. TEST OBJECTIVES

These tests were made to obtain information on the ratings of some typical "off the shelf" type ignitrons when used under the high current, long pulse conditions to be encountered in future CTR machine applications. A particular objective was to find an ignitron suitable for use in the ohmic heating system of the Princeton Large Torus (PLT).

II. TUBE TYPES TESTED

A. Type 5555

Listed as a power rectifier by the manufacturer, the published ratings for such service are: 900 peak anode volts, 1800 peak amperes, and an average direct current of 250 amperes. It is liquid cooled.

B. Type 1059

Manufacturer's catalog lists this tube under "Switching Service" and published ratings are: peak anode volts = 20 kV, peak current = 100 kA, average direct current = 200 amperes. It is liquid cooled.

C. Type 1053

The data for this tube are listed under "Resistance Welder Service" and are: max. demand kVA = 3000, corres. current = 224 dc amperes, max. current = 400 dc amperes, corres. demand kVA = 1000, max. averaging time = 11 seconds. It is also liquid cooled and was the largest type tested.

Type 1053 was the main subject of detailed investigation after initial pulsed current tests indicated it to be the best of the three types for future applications.

III. PRELIMINARY TESTS

These tests were conducted prior to the pulsed current tests in order to determine manufacturing quality and eliminate any substandard tubes. They included:

A. Visual Inspection

Each tube was carefully scrutinized to insure the absence of obvious mechanical defects prior to electrical tests.

B. Ignitor Resistance

This resistance was measured for each tube and used as the essential criterion for test termination (tube failure), in the absence of physical damage, after it had decreased to a nominal 4 ohms.

C. Static Breakdown Voltage

(hipot from anode to pool)

D. Auxiliary Anode

Each tube type tested was equipped with this additional electrode, purpose of which is to prevent arc extinction at low anode current. As later testing showed that evidently it was not a contributor to tube failure or arc maintenance under the test conditions used, no effort was made to investigate its operation in detail. Resistance to the pool from this anode was measured.

IV. PULSED HIGH CURRENT TEST CIRCUIT AND ASSOCIATED PARAMETERS

A. Circuit and Physical Configurations

Figures 1 through 4 show the circuit and physical configurations used.

B. Test Currents, Pulse Durations, and Repetition Rates

Test currents of 2.5, 3, 4, and 5 kA were used at durations of from 3 to 5 seconds. Repetition rate was once per 30 seconds.

C. Cooling

1. An existing water system with a flow rate of 7 gallons per minute and an input temperature of about 70°F was used for most of the testing.

2. At the manufacturer's (National Electronics) suggestion, some tests were made with the inlet water heated to approximately 95°F (Fig. 4) since ignitrons have often been observed to fire improperly below 30°C.

3. Temperature was indicated by a meter driven from a thermocouple (Fig. 3) attached to the braid connection at the

test tube anode. At 250°F the pulsing was stopped until the temperature returned to room range.

4. An outer cooling jacket (Fig. 5) was used in some cases for possible elimination of tube jacket burn spots which had occurred in previous tube testing.

D. Special Test

The tube skin voltage drop was measured across the outer jacket of each tube to determine the existence of sufficient arc transfer to cause tube damage. This voltage was proportional to the skin current and is shown in Table 1 and Curve 2. Curve 3 shows this drop versus number of pulses.

V. DESCRIPTION OF TESTS, OBSERVATIONS AND RESULTS

A. Test Tube #1 - Type 5555

1. This tube was pulsed first at 2500 amperes and 5 seconds duration without the auxiliary anode connected. No noticeable change occurred after 1000 operations.

2. Another 1000 operations with the auxiliary anode connected also resulted in no noticeable change.

3. The current level was raised to 5000 amperes with the auxiliary anode connected (still at 5 seconds duration). No deterioration was indicated after 30 operations. At the end of 250 operations the ignitor resistance had decreased to 2 ohms and the test was terminated.

B. Test Tube #2 - Type 1053

1. After 250 operations at 5000 amperes and 5 seconds pulse duration, the ignitor resistance had decreased from 30 ohms to 15 ohms.

2. The test was terminated at this point, as examination showed a burn spot on the outer jacket (Fig. 7).

C. Test Tube #3 - Type 1053

1. Initial testing was at a current level of 3000 amperes for 5 seconds duration. No change from the original resistance values for ignitor and auxiliary anode were indicated after 1000 pulses and the current was raised to 5000 amperes at the same duration.

2. After 200 operations at this new level the ignitor resistance had decreased to 17.5 ohms from the original 35 ohms. As with Test Tube #2, burn spots appeared on the outer jacket (see Figs. 6, 8, & 9). At the end of 646 pulses the ignitor resistance was measured at 4 ohms and the test was terminated.

D. Test Tube #4 - Type 1059

1. This tube was tested at 5000 amperes and 5 seconds duration.

2. A sharp decrease in ignitor resistance was exhibited at 119 pulses (from 130 ohms to 90 ohms). The testing was continued to 635 operations with a final ignitor resistance of 25 ohms. No burn spots appeared.

3. The skin voltage drop was 300 millivolts at 5000 amperes and 150 millivolts at 2500 amperes. These drops were not

considered significant at the time, since a higher drop had been expected for an arc transfer large enough to be harmful.

E. Test Tube #5 - Type 1053

1. The duration for this test was reduced to 3 seconds with the same current level of 5000 amperes.

2. The outer jacket displayed a burn spot after only 12 pulses. At 36 operations the ignitor resistance was 4 ohms, down 87%. Testing was terminated at 175 operations with an ignitor resistance of 0.7 ohm.

F. Test Tube #6 - Type 1059

1. This tube was mounted in a new location adjacent to the original one, allowing alternate testing and preventing "dead time" when one tube exceeded the temperature limit.

2. A current of 5000 amperes and duration of 3 seconds were used for this test.

3. A loud "hissing" sound and bright glow were evidenced after 5 pulses, suggesting a leaky tube. Measurement indicated a short from anode to cathode and the test was terminated.

G. Test Tube #7 - Type 1059

1. Mounted also in the new location, the tube was tested at 4000 amperes and 5 seconds.

2. The possibility of unnecessary forces due to cable layout was investigated for both test setups and found insignificant in both of them.

3. 54 operations on this tube resulted in an anode to cathode short circuit.

Observations upon cutting this tube open for inspection are given in Section H, this Part.

H. Test Tube #4 Reinstalled

1. This tube was retested with the intention of discovering whether the new location could possibly be the cause of anode to cathode shorts, as with tubes #6 and #7.

2. Test Tubes #6 and #7 were cut open and inspected. It was noted that each anode was off-center and close (about 1/8 inch) to the tube jacket. It had been suspected that the anodes would be touching the respective tube jacket walls in view of the zero resistance measurements made. It was surmised that mercury drops could have bridged the small gaps.

3. Test Tube #4 was tested at 4000 amperes and 5 seconds.

4. After 402 pulses the tube hipotted to 25 kV and there was nothing to indicate that the test location had anything to do with tube failure(s). The test was terminated.

I. Test Tube #8 - Type 1053)

1. A current pulse of 4000 amperes at 5 seconds duration was used in this test. The tube was mounted in the original setup.

2. This was the first tube to produce satisfactory results after 1000 pulses at these values of current and duration. No evidence of approaching failure were noticed until 3381 operations.

3. Testing was terminated at 4377 pulses. The ignitor resistance had decreased to 16.5 ohms from an initial value of 29 ohms.

J. Test Tube #9 - Type 1053

This tube failed the hipot test and was returned to the manufacturer for replacement or repair.

K. Test Tube #10 - Type 1053

1. A current of 4000 amperes at 5 seconds was the testing condition for this tube.

2. The tube did well for 4252 operations. The ignitor resistance had decreased gradually. The test was terminated because the glass anode envelope shattered at the above count.

3. Evidence of water in the tube indicated a leak due to heating from arc transfer had occurred in the inner cooling coil. This was verified when the tube was cut open (Fig. 10). The holes in the coil were not, however, seen to be related to the location of burn spots on the outer jacket as they had been with Test Tube #3.

L. Test Tube #11 - Type 1053

1. This tube was mounted with a coaxial connection and the inlet water heated to 95°F. (Fig.4).

2. The initial ignitor resistance was 22 ohms. Hipot values were 20kV forward and 17 kV inverse. The tube was operated at 5000 amperes and failed after only 16 pulses. The skin voltage drop had been measured at 400 millivolts during the test. There was an indication of water vapor in the anode glass enclosure and the ignitor resistance was 10000 ohms after failure.

3. Inspection revealed burn holes in the water cooling coil and evidence of overheating in an area adjacent to the closest

distance between an off-centered anode and the cooling coil. The damage was apparently the result of arc transfer. The measured 400 millivolt skin drop was not suspect at this time.

M. Test Tube #12 - Type 1053

1. The tube was placed in operation at 5000 amperes with an outer water cooling jacket installed (see Fig. 5) to see if it would eliminate burn spots. The skin voltage drop was 400 millivolts.
2. 56 operations caused the ignitor resistance to decrease from 22 ohms to 12.5 ohms. At 383 pulses, the ignitor resistance was down to 1.5 ohms and the test terminated.
3. The outer cooling jacket was removed and four burn spots, each about 1/4 inch in diameter, were present.

N. Test Tubes #13 and #14 - each Type 1053

1. The lack of successful results at the higher values of current suggested that ensuing tests should be run at 3000 amperes. This current was used in testing tubes #13 and #14.
 - a. Test Tube #13 was installed in the initial setup with no pre-heated water and was tested under the original conditions used.
 - b. Test Tube #14 was installed with an outer water cooling jacket, inner cooling coil water preheated to 95°F, and a coaxial connecting arrangement.
2. Skin voltage drops for both tubes were measured at 500, 1500, 3000, and 5000 amperes. The drop was found to be proportional to current over the test range.

a. Test Tube #14 showed no ignitor resistance change after 18,646 pulses, at which the test was terminated for this tube.

b. Test Tube #13 was pulsed 4041 times before the ignitor resistance displayed a slight reduction from the initial value (22.5 ohms to 17.5 ohms). The resistance stayed constant until 7062 operations. However, it proceeded downward from that point and had dropped to 3.6 ohms after 9813 pulses. No burn spots appeared on either jacket, indicating that the outer cooling jacket is not required.

3. Performance data for this test is plotted and shown as Curve 1.

O. Test Tube #15 - Type 1053

1. This tube was installed with a coaxial connection, but with no outer cooling jacket or heated inlet cooling water. It was tested at 3000 amperes, the object being to obtain data for operation with the coaxial connection alone.

2. There was no deterioration of the tube after 6686 operations and the testing was terminated.

P. Consultations with the Manufacturer

Due to the inconsistencies in electrical test results and apparently in manufacturing quality too, after test #10 had been completed, a meeting was arranged and held with a representative of the manufacturer, National Electronics, Inc. (a Varian Subsidiary) of Geneva, Illinois. The results of this meeting

follow :

1. The use of the type 1053 at about 1500 amperes per tube in the PLT OH system was proposed by PPL and deemed satisfactory by the manufacturer.

2. Ignitron water cooling was discussed and the following points were noted:

a. Water inlet temperature should be no lower than 30°C (40° to 50°C is recommended) for reliable operation. Some units have been inoperable at or below this minimum according to the manufacturer. Ignitor Mercury wetting accentuates the condition. Arc transfer frequently is worse at lower temperatures, probably due to ion bombardment.

b. Tubes, on occasion, have been found sensitive to water flow direction (also according to the manufacturer) such that tube life was jeopardized when the wrong direction was used. This apparently has not been a problem in these tests, as burn holes have always been in the center area no matter the flow direction.

c. The manufacturer also stated that the limited anode temperature of 250°F used was probably not important, since an anode can be operated at much higher temperatures.

3. Storage of ignitrons in unused condition for a length of time (such as during a weekend) may cause them to become "gassy". National has dubbed this occurrence "Monday Morning Blues". Since the units used in test at PPL had been hipotted every Monday and periodically through the weeks, it was assumed that no gas problem existed with them.

4. According to the manufacturer, type 1053 should be capable of more operations at 5000 amperes than were exhibited in any of the tests made at PPL. However, it was admitted that inconsistent manufacturing quality is often encountered, most tubes meeting the requirements at the destinations. Tubes are also shipped "green" to keep up to production schedules in many cases. Damage in handling and shipping must also be considered.

5. An important recommendation made was the use of a "coaxial" arrangement for the conductor feed connections to the tube under test. This was based upon experience with such configurations, although the specific reason for improved performance with it apparently is not actually known in detail. A tentative explanation is that the forward and return current fields partially (at least) cancel any net forces causing arc transfer.

VI. DISCUSSION OF TEST RESULTS, CONCLUSIONS

Previous testing reports have indicated that tens of thousands of pulses are possible if a tube is not over-heated and high skin current can be avoided. The unreliable operation of ignitrons caused by mercury contamination from wall surface deterioration produced from high skin current conduction is well known. However, the skin current as measured by skin voltage drop was formerly assumed not critical as long as the drop was in the region of a few hundred millivolts. The series of life tests made here has proven that assumption to be in error.

Only a few hundred operations were obtained at 5000 amperes and about 4000 operations at 4000 amperes. The reduction in current to 3000 amperes was necessary to avoid short tube life. The 3000 ampere tests still produced only 10,000 pulses without coaxial connection. The use of the coaxial connection at this test current, however, resulted in no apparent tube deterioration after 18,000 pulses.

These tests show that a skin drop as low as 300 to 400 millivolts has an important effect in reducing tube life. There is strong indication that when the skin drop is limited to 200 millivolts, there is no appreciable degradation as the result of pulsing as prescribed in this test program. This conclusion is based on the tests where 18,000 pulses were applied to Test Tube #14 and 6000 pulses to Test Tube #15 without any reduction in the ignitor resistances (see Curve 4). These tubes were both arranged in a coaxial configuration and had skin drops of less than 230 millivolts at 3000 amperes.

Despite the apparent effect of the coaxial connection on tube life, sufficient tests were not made to confirm this as being the main reason for the extended tube life when it is used. Time and cost limitations indicated that continued testing was not feasible, especially because of the fact that future application (beyond PLT) switching device requirements are not known in detail at present.

It is concluded as a result of the described test program that the following factors do not affect the tube life at pulses lasting for a few seconds:

1. Temperatures on the anode lead up to 250°F.
2. Incoming water temperature ranging from 70°F to 95°F.
3. Pulse durations from 3 to 5 seconds.
4. Cooling of outer jacket with auxiliary water at 70°F.

In addition, the tests indicated that, for the PLT OH system requirement, the commercially available and moderate cost type 1053 ignitron performs satisfactorily at 3000 amperes.

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Fig. 3. Ignitron Long Pulse Testing -
Standard Electrical Connections

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Fig. 4. Ignitron Long Pulse Testing -
Coaxial Electrical Connection

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Fig. 5. Ignitron Long Pulse Testing -
Outer Cooling Jacket

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Fig. 6. Ignitron Long Pulse Testing -
Outer Jacket Burn Spot

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Fig. 7. Burn Spot Location on Test Tube #2

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Fig. 8. Test Tube #3 Burn Spot

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Fig. 9. Test Tube #3 Burn Spot

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Fig. 10. Test Tube #10 Water Cooling Coil
Heat Damage

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Fig. 11. Test Tube #11 Water Cooling Coil
Heat Damage and Off-Centered Anode

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TABLE 1

Skin Voltage Drop Data

TYPE 1053 TEST TUBE	500 Amperes		1200 Amperes		2400 Amperes		3000 Amperes		4000 Amperes		5000 Amperes	
	Non-coax.	Coax.	Non-coax.	Coax.	Non-coax.	Coax.	Non-coax.	Coax.	Non-coax.	Coax.	Non-coax.	Coax.
#11											400 mv	
#12											400 mv	
#13	50 mv		125 mv		200 mv		250 mv					
#14		50 mv		100 mv		175 mv		225 mv				
#15							250 mv	200 mv	325 mv	250 mv		
#16							250 mv	200 mv	300 mv	250 mv		
#17							300 mv	225 mv	325 mv	250 mv		

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