

HIGH POWER VERY LONG PULSE TESTING OF A 200 KV. TETRODE REGULATION TUBE

Jere D. Stabley, RCA

Bob Gray, Rome Air Development Center

ABSTRACT

Tests at very long pulse lengths were conducted to evaluate the design concepts of the S94000E regulator tube at the Rome Air Development Center. Voltages as high as 200 KV have been switched for pulse lengths of 0.5 seconds and at anode dissipation levels that exceeded 2.0 million Watts. Tubes similar to the one tested will be employed as series regulators in the TOKAMAK¹ Fusion Test Reactor. This paper discusses the tube, test results, and operational experiences associated with those tests.

INTRODUCTION

A high voltage beam power tetrode designated as the S94000E has been developed² by the Power Devices group of RCA and was tested at the High Power Laboratory of the Rome Air Development Center. This tube shown in Fig. 1 represents an advancement in the state of the art in terms of voltage hold-off and anode dissipation at the long pulse lengths involved.

Tubes similar to the one tested will be employed as series regulator tubes providing pulse voltages for Neutral Beam Ion sources. The use of neutral beams has proven to be a very effective way of raising plasma temperatures in previous Fusion experiments and will be used extensively in the TOKAMAK Fusion Test Reactor. This work was funded by DOE and contracted through the Plasma Physics Laboratory of Princeton University.

TUBE REQUIREMENTS FOR TFTR

Tube Type.....	Tetrode
D.C. Anode Voltage.....	200 KV
Anode Current.....	125 Amps
Anode Dissipation.....	2.0 Megawatts
Instantaneous Grid No. 1 Voltage..	Less than Zero
Screen Voltage.....	D.C.
Pulse Length.....	1 Second

GENERAL TUBE DESCRIPTION

The S94000E is a liquid-cooled ceramic to metal beam power tetrode that utilizes thoriated tungsten filaments in a circular array of unit electron optical systems. The tube contains sixty-six individual electron guns each using a directly heated ribbon filament. The control grid and screen grid are comprised of small tungsten wires that are embedded into water-cooled copper blocks. The unique anode structure



Fig. 1 - RCA S94000E Tetrode

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE JUN 1979	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE High Power Very Long Pulse Testing Of A 200 Kv. Tetrode Regulation Tube		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) RCA; Rome Air Development Center		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License			
14. ABSTRACT Tests at very long pulse lengths were conducted to evaluate the design concepts of the S94000E regulator tube at the Rome Air Development Center. Voltages as high as 200 KV have been switched for pulse lengths of 0.5 seconds and at anode dissipation levels that exceeded 2.0 million Watts. Tubes similar to the one tested will be employed as series regulators in the TOKAMAK! Fusion Test Reactor. This paper discusses the tube, test results, and operational experiences associated with those tests.			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	
			18. NUMBER OF PAGES 4
			19a. NAME OF RESPONSIBLE PERSON

is centrally located and is comprised of sixty-six individually cooled structures that are set at an oblique angle to the electron beam axis. This angle is effective in greatly enhancing the bombarded anode area. Fig. 2 shows a simplified cross section of one electron gun.

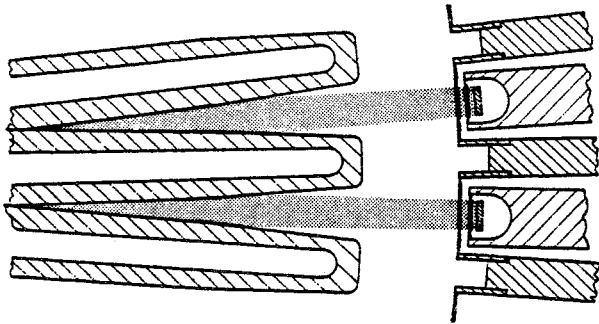


Fig. 2 - Electron Gun - Anode Crosssection

RADC TEST FACILITY

In order to evaluate the tube under long pulse, high voltage conditions, it was necessary to make arrangements for the use of facilities other than those available at the Lancaster, PA location. At this point in time, the facility most capable of providing 25 Megawatts of power at 200 KV is located at Griffiss Air Force Base in Rome, NY. A view of the facility is shown in Fig. 3. It is very complete and contains within one building six 65 KV 9 Amp power supplies, a high power load resistor, a complete demineralized water system, crowbar protection devices and various power supplies, both D.C. and pulse that can be incorporated for tube evaluation.

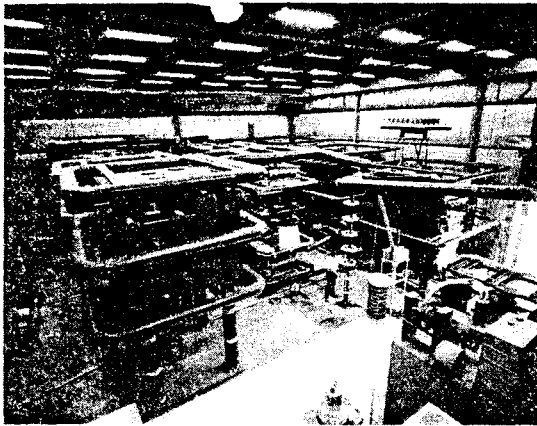


Fig. 3 - RADC Power Supply and Test Facility

For the tests on the RCA tube, the power supplies were connected in a series parallel arrangement that yielded 200 KV at 18 Amps of continuous current. RADC engineers determined after consultation with the power supply designer and the solid-state diode manufacturers that the current rating could be nearly tripled (50 Amps) if the pulse length did not exceed 0.5 seconds. Consequently, the test conditions were tailored to the RADC equipment.

The dummy load resistor that absorbs the major portion of the power during the 0.5 second pulse is located on the high side of the power supply. It is comprised of four sections of glass tubing filled with a solution of sodium chloride and water. The solution serves as a load resistor which can be changed by changing the water to solution ratio. The dummy load and its water to air heat exchanger are shown in Fig. 4. The crow-

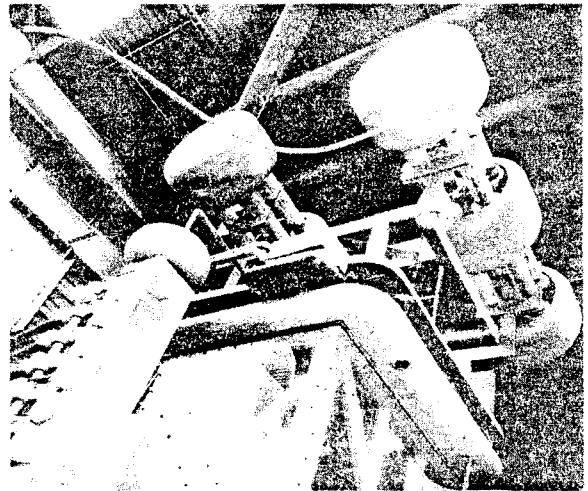


Fig. 4 - Water Load and Triggered Spark Gap

bar device³ is a series of Air Gaps that are activated by applying a high pulse voltage to each Gap, which in turn breaks down and shorts the Power Supply under tube fault conditions. Detection of tube faults is accomplished by using eighty UDD5 Unitrode diodes that are immersed in oil. The diodes are back biased until the Anode Voltage drops below a pre-set reference value which represents a plate arc in the tube. A similar arrangement is used to detect screen faults. The tube

itself is contained, anode up, in a rectangular lead shielded tank that is filled with transformer oil to prevent arcing across the output ceramic. The tank is raised from the floor to allow access to the tube for connection of the leads that carry the 4000 Amps of filament current and for connection of the auxiliary water hoses. The anode water which flows at a rate of 230 GPM reaches the tube through approximately 60 feet of three inch PVC pipe. The tube in its lead shielded enclosure is shown in Fig. 5. Fig. 6 shows a simplified schematic of the test circuit that was used.

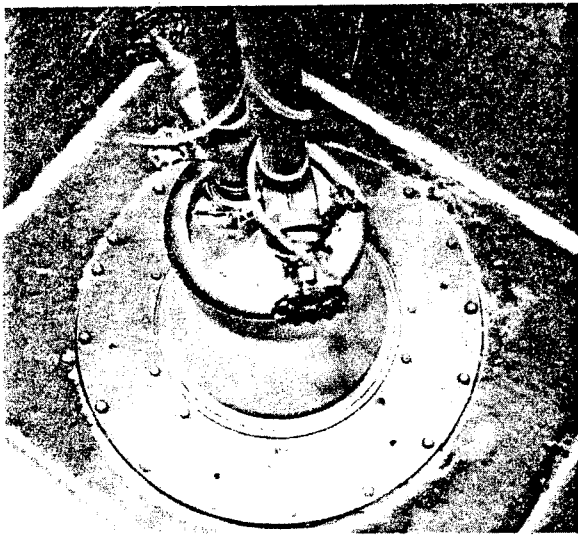


Fig. 5 - RCA S94000E in Lead Shielded Oil Container

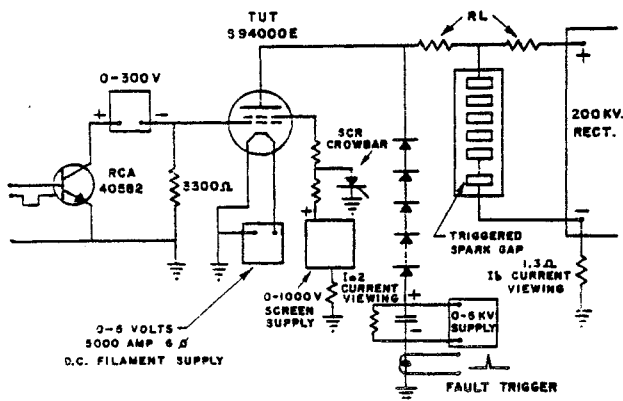


Fig. 6 - Simplified Schematic of Test Circuit

PROBLEM AREAS

Actual testing of the S94000E at Rome was scheduled to be approximately a three week exercise, however, the three weeks turned into a three month adventure. We had underestimated the problem of overstressing the RADC equipment and using it beyond its ratings. The problems associated with the equipment seemed to follow the falling domino effect that started with an exploding R/C voltage divider which caused a small fire and a considerable amount of smoke. A breaker then failed to open resulting in the power supply operating into a crowbar generated short circuit for an extended period of time. Shrapnel was a constant source of concern as sixteen high voltage capacitors either shorted or opened during the course of the tests. Last, but not least the most time consuming problem occurred when the cooling water for the dummy load leaked into the insulating plenum chamber. The noise associated with explosions that occur when 220 KV seeks a path to ground is somewhat unimaginable and after several occurrences it becomes frightening. It was apparent that the nerves of the personnel performing the tests were wearing very thin when some among us were resorting to face masks and ear plugs at the thought of applying high voltage. However, in the midst of yet another "explosion" we did inadvertently learn a very important thing about the survivability of the S94000E. It occurred during a high voltage conditioning process where the rectifier was being used with a 200 K ohm resistor and the crowbar dismantled. During this exercise, the high voltage diodes used to detect tube faults shorted which caused the series resistor to be shorted thereby applying the 200 KV rectifier to the tube with only its internal impedance. The tube faulted and hung on the line until a small 16 wire used in the set-up disintegrated. The tube had taken a serious jolt, the vac-ion pressure exceeded fifty Milliamperes, however, it did recover. It was processed to the 200 KV level in a matter of several hours and amazingly enough, the majority of the tests performed on the tube were made after this episode. We believe this is a highly significant event and

gives an indication of the ruggedness of the S94000E under very adverse conditions.

LONG PULSE TESTING

Testing a tube at very long pulse lengths, where conventional voltammeters can be used, is a much different experience to which those associated with power pulse systems have been accustomed. At RADC several other interesting things were observed. For instance, during each pulse the overhead lights dimmed slightly, the tube pressure as indicated by the vac-ion pump increased and then settled back to a lower level during the interpulse period. One gains an appreciation for what is required of the equipment and the tube's anode with regards to stresses that occur due to temperature change. Temperatures that would normally occur under continuous "on" conditions are now occurring and then changing to a totally "off" condition twelve times a minute or whatever the repetition rate of the pulse is.

Another interesting tube-circuit phenomenon occurred during the tests at Rome. As the tube pressure increased during the pulse "on" time, it was noticed that the instantaneous grid voltage was developing a tail and going more toward zero at the end of the pulse. The problem was the result of ion current being drawn through the control grid to ground external impedance. This effect was eliminated by lowering that impedance. If one did not have a vac-ion pump on the tube, developing the instantaneous grid voltage in a high resistant circuit could be used to detect gas within the tube under negative grid voltage operating conditions.

TEST SUMMARY AND CONCLUSIONS

The data accumulated at RADC in conjunction with the maximum tube ratings are shown in Fig. 7. It shows that 200 KV operation has been accomplished at dissipation levels that varied up to 2150 Kilowatts and at anode voltages that went as high as 62 KV. A new high water mark has been obtained with gridded tube in combining of pulse width, voltage hold-off and anode dissipation capabili-

ties. We are all proud of the performance of the S94000E which offers future extended capability for longer pulse length at higher anode voltages. The use of gridded tubes as series regulator for TFTR and future fusion reactors is an exciting new application.

TEST DATA SUMMARY

Filament Current = 4300 Amps
Pulse Length = 0.5 Seconds at 3 Per Minute
200 Microseconds Rise Time
Anode Ceramic Immersed in Oil

E_{PB} KV	E_a KV	I_B Amps	E_{G2} Volts	$-E_{G1}$ Volts	E_G Volts	Vac-Ion* μA	Anode Diss. KW
185	62	27.3	520	310	-30	300/30	1690
190	42	47.0	490	310	-10	1500/200	1980
193	53	43.0	500	310	-15	1400/180	2060
193	50	46.0	600	310	-25	1200/200	2150
200	36	50.0	590	310	-18	1500/150	1890
<u>Anode Ceramic in Air</u>							
107	36	52	590	300	-14	600/40	1871
207	26	60	740	300	-14	700/80	1560

*Tube pressure during pulse and interpulse period.

Maximum Ratings

DC Plate Voltage	200 KV
Pulsed DC Plate Current	125 Amps
DC Grid No. 2 Voltage	1800 Volts
Grid No. 2 Current	7.5 Amps
DC Grid No. 1 Bias Voltage.....	1000 Volts
Grid No. 1 Dissipation	10 KW
Grid No. 2 Dissipation	10 KW
Anode Dissipation.....	2000 KW
DC Filament Current	4700 Amps

Fig. 7 - Test Data Summary and Maximum Ratings

REFERENCES

- ¹D. Steiner, J. F. Clarke, "The TOKAMAK Model T Fusion Reactor", SCIENCE, Volume 199, 31 March 1978 pp. 1395-1403
- ²J. Eshleman, J. Mark, "Recent Development in High Power Switch Tubes for High Power Radars and Fusion Research", PROCEEDINGS INTERNATIONAL PULSED POWER CONFERENCE 1976, pp. IC5-1, IC5-5
- ³Bobby R. Gray, "High Energy Switch Device Study at RADC", CONFERENCE RECORD OF TWELFTH MODULATOR SYMPOSIUM 1976, pp. 51-57