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Research and Development Technical Report
DELET-TR-79-0270-1

INSTANT START THYRATRON SWITCH

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Spencer Merz
David Turnquist
EG&G, INC.
35 Congress Street
Salem, MA 01970

January 1981

First and Second Interim Report for Period 1 September 1979 - 1 May 1980

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Efforts into the development of a megawatt instant-on hydrogen thyratron are underway. The design work has been divided into three major areas: (1) cathode development, (2) envelope design, and (3) reservoir development.

Two experimental thyratrons have been fabricated in order to study the cold emission characteristics of a tungsten matrix cathode material. Design work has been completed on a new, lightweight envelope assembly. Finally, efforts into the development of a reservoir system are described.

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First and Second Triannual Report
Instant-Start Thyratron Switch
Period September 1, 1979 through May 1, 1980

A

Submitted: Rod Petr

Approved: David Turnquist

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1. INTRODUCTION

The hydrogen thyratron is a gaseous switch which exhibits rapid commutation times, high pulse current capability, and long life. Necessary peak currents have been supplied by an indirectly heated thermionic emitter, and hydrogen pressure has been maintained by an indirectly heated, metal-hydride reservoir. A disadvantage of the thyratron is the need to provide regulated power to the cathode and reservoir, along with necessary warmup times.

Interest in portable, lightweight systems that require little or no standby power, yet are capable of instant start, have accented the shortcomings of the conventional hydrogen thyratron. Therefore, an instant-start thyratron is being developed which incorporates a cathode and reservoir that require no warmup time.

2. DESIGN GOALS FOR THE INSTANT-START THYRATRON

Design goals for the instant-start thyratron were established as:

1) Operating capabilities and triggering characteristics comparable to a conventional thyratron of equivalent size;

2) Ability to start instantly and repeatedly at full power, without standby power or initial warmup;

3) Reasonable requirements on trigger energy, keep-alive current, or other measures needed to obtain proper triggering characteristics.

Specific operating conditions established as design goals were:

Peak Anode Voltage (epy)	40 kV
Peak Anode Current (i_b)	40 kA
Pulse Width (tp) typical	10 μs
Pulse Repetition Rate (prr) Typical	125 hz
Anode Delay Time Drift (Δtad)	0.1 μs
Burst Mode Operation	120 sec

The design goals set forth require the thyratron to switch a megawatt of average power. The thyratron, therefore, would have to operate without arcing because an arc at this power level would damage the cathode and grid structure. The possibility of an arc is greatest at startup, when the emission capability of a cold cathode is minimal. Earlier studies have shown that using glow-mode or various other emitters for thyratron cathodes is impractical, thus it was decided that a cathode design must revolve around a practical cold emitter.

3. PLASMA HEATED CATHODE

A viable solution for a cold cathode has proven to be impregnated tungsten. This material, a porous tungsten matrix filled with barium aluminate, has emission properties which result from a barium monolayer formed on the surface by suitable activation.

Since the barium monolayer exhibits a low work function and a low resistivity, heavy pulse currents can be drawn, at least initially, without arcing. Arcs, if they do occur, do not alter cathode properties. Not only is the tungsten matrix resistant to arc damage, but arc-sputtering uncovers a substrate of the same composition and emission capability as the original surface.

During cold emission the barium replacement mechanism — tungsten reduction of the aluminate — does not occur. In cold cathode devices that were deliberately arced, the barium monolayer is renewed due to intense local heating by arc spots. In thyratron applications, this option is not available simply because the tube cannot be allowed to arc.

The concept of plasma heating provides a means of maintaining cathode activity in a hydrogen thyratron. If the cathode is configured in such a manner that energy dissipated at the cathode will heat the tungsten matrix, it will, upon reaching activation temperature, renew the barium monolayer automatically, all without need of an external power supply. At shutdown, the monolayer remains to provide emission capability for the next cold start.

The concept of plasma discharge heating has produced the desired results, in terms of cold cathode emission.(1) Once a practical instant-starting thyratron was realized, measurements were needed to document the conduction characteristics of the tungsten matrix material. This information would then be used to scale up the cold-start cathode to meet final instant-starting thyratron requirements.

4. EXPERIMENTAL INSTANT-START THYRATRONS

In order to develop a hydrogen thyratron to meet specified design objectives, the emission capability of the impregnated tungsten cathode had to be established. The practicality of a cathode design, such as geometry, warmup, and heat balance, depended on these values. Since the emission capability of a cold cathode is at a minimum at switch-on, the cold cathode arcing limit would define the maximum emission current density that the impregnated tungsten could supply under worst-case conditions.

A large planar cathode was operated as a hydrogen-filled diode over a range of pulse currents using a 1-μs flat-topped pulse to determine the cold-cathode arcing limit. Single, isolated pulses were used to prevent cathode heating. As the pulse current was increased, arcing was readily detected by step discontinuities in the oscilloscope trace of the diode voltage drop.

The arc condition at cold operation was 80 A/cm^2 for this 1-inch diameter cathode. However, arcing was evident in about one out of every ten pulses at this current density. Since cathode utilization in a workable thyratron would be unknown, the cathode design current density was arbitrarily set around 50 A/cm^2.

With the maximum cold emission current density established, two experimental thyratrons were fabricated to determine if the impregnated tungsten cathode could provide high pulse currents under cold conditions. The first tube, which was contained in a 2-inch diameter envelope, employed an "arch" cathode geometry with a surface area of 1.5 cm^2. This particular thyratron was denoted as DHB-102, and the tube is illustrated by Figure 1.

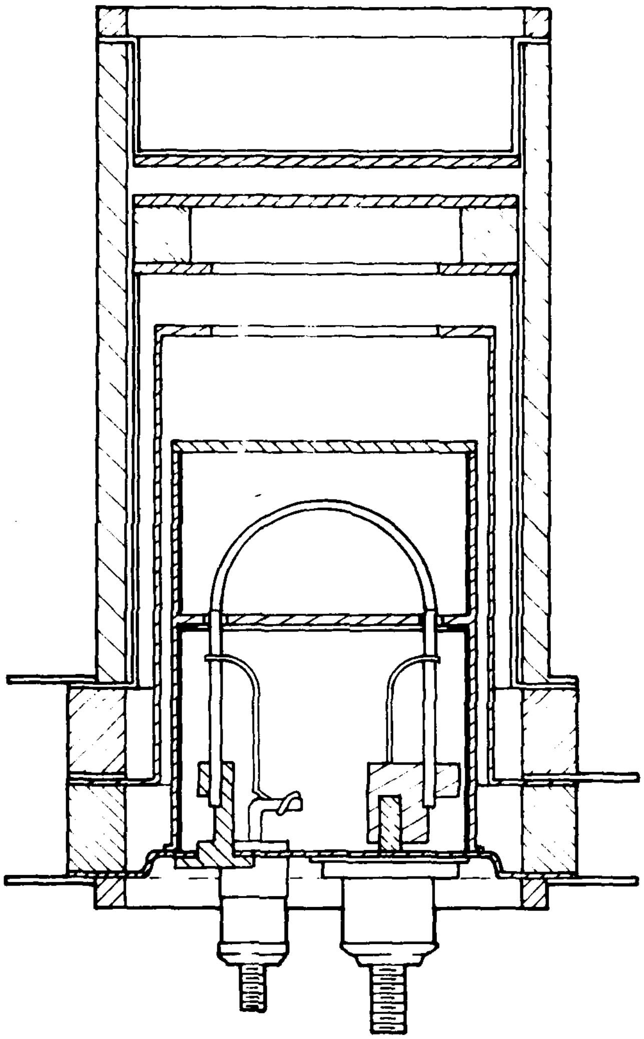


Figure 1. DHB-102 thyratron tube.

The second thyratron, identified as DHB-5, was contained in a 5-inch envelope. The DHB-5 used a "jib vane" cathode geometry with a surface area of 80 cm^2. This jib vane geometry is illustrated by Figure 2.

The cathode surface areas for the respective thyratrons indicate that, for cold starts, the DHB-102 can conduct peak currents around 70 to 80 amperes and the DHB-5 can pass around 4 kiloamperes before arcing. This is not to say that these current levels are the maximum limits for the tubes because discharge heating would eventually raise the cathode temperature and enhance emission.

A commonly used approximation for predicting the energy dissipated in discharge electrodes, and thereby giving a rough estimation of heat flux, has been

$$P_k = I_b V_s + Ip2\ (R_o/a + R_c/3) \quad (1)$$

where

P_k = heating power

I_b = average tube current

V_s = cathode sheath voltage

Ip = rms tube current

R_o = specific surface resistance

R_c = cathode internal resistance

a = cathode area

It was uncertain whether this expression is valid for any cathode geometry, and therefore a temperature measurement scheme, called the 4-point resistance technique, was used to determine cathode temperature.

The 4-point resistance method used the cathode as a resistance thermometer. The cathodes were fitted with separate potential leads, as shown by Figure 3. Since the points where leads contacted the cathode structure were very close to the emission material, the error in measured resistance caused by the internal cathode supports was minimized.

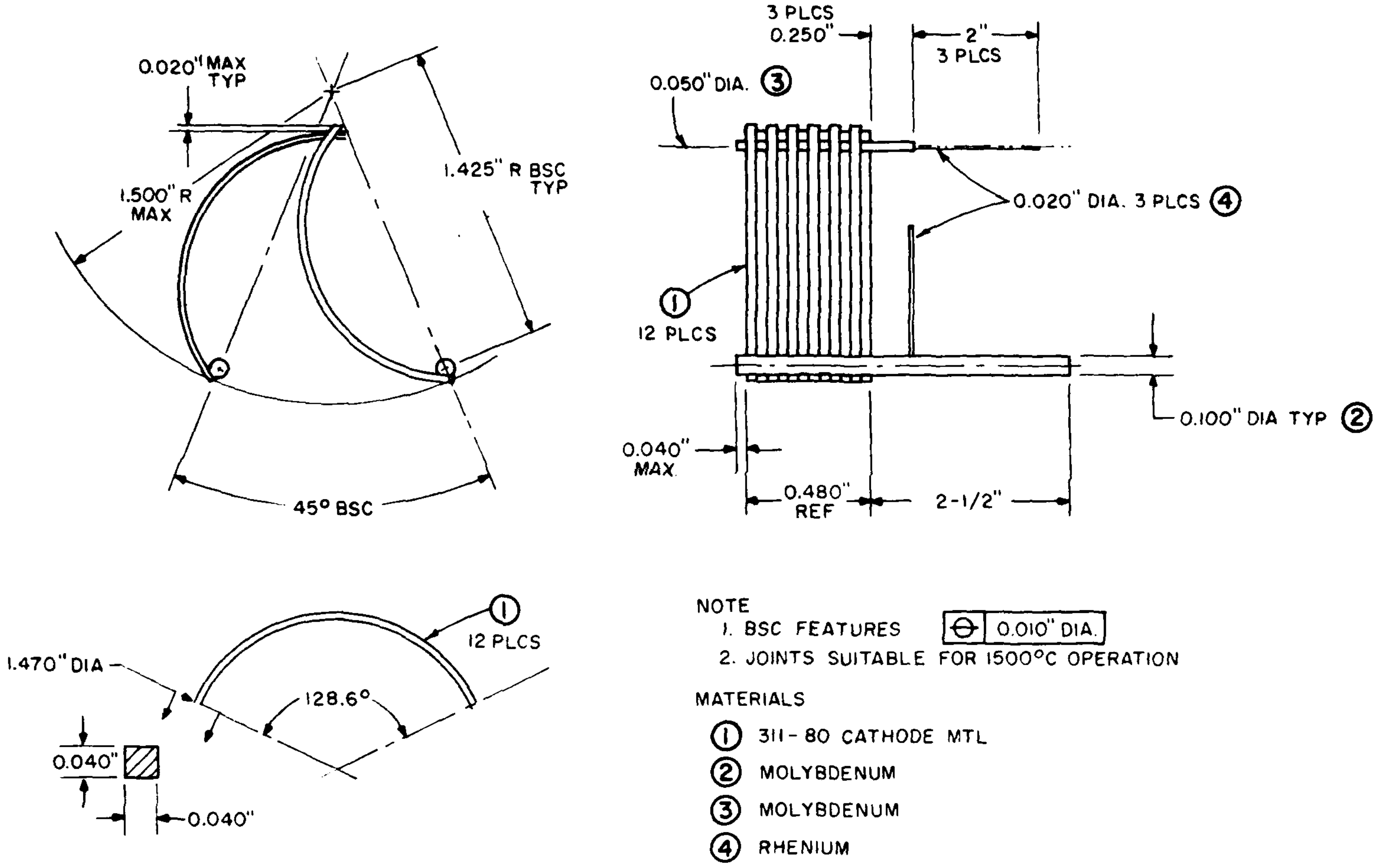
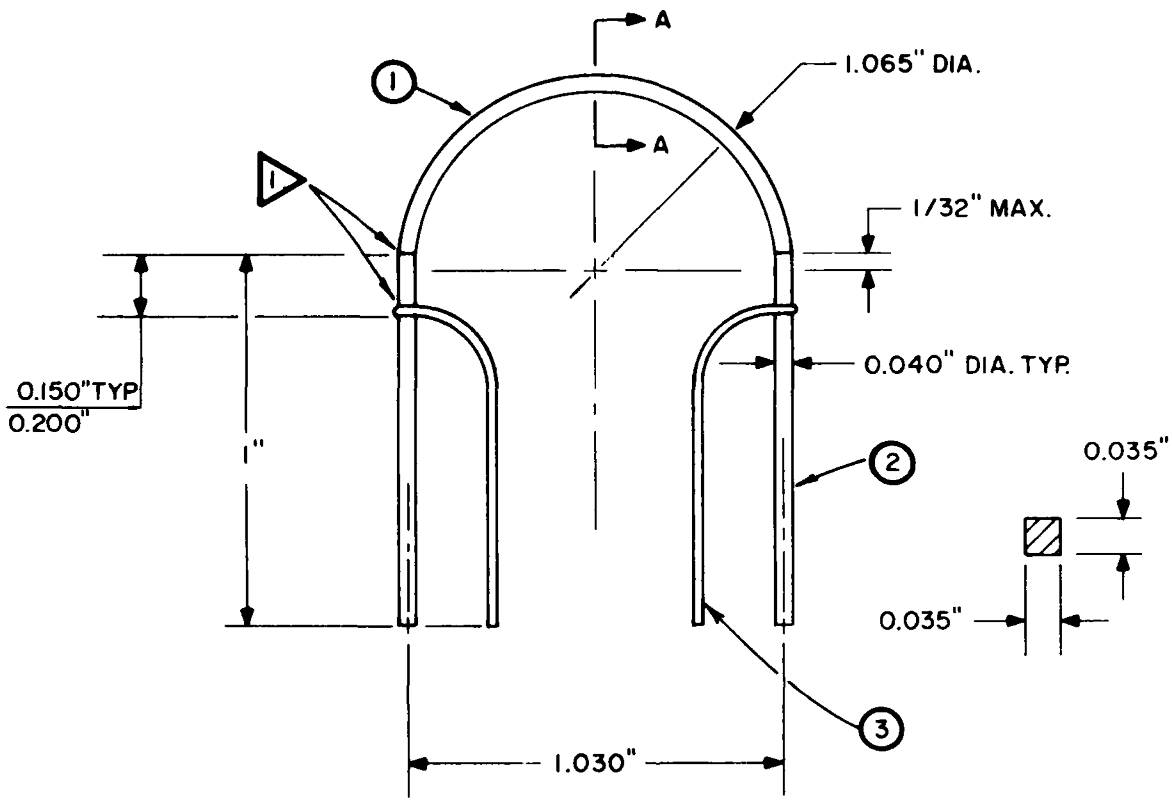


Figure 2. Jib vane cathode.



MATERIALS

1. 3/1/1-80 CATHODE MTL.
2. MOLYBDENUM
3. 0.020"DIA RHENIUM 2 PLACES

NOTE

1. JOINTS SUITABLE FOR 1500°C OPERATION
2. SHIP CATHODE WITH SUPPORT CLAMP ATTACHED (A313505)
3. PUT EG&G PART NO. ON AT LEAST INNERMOST CATHODE CONTAINER

Figure 3. Arch cathode.

Data are currently being assimilated on the rate of temperature rise for the DHB-102 cathode. This information will be used to determine, to a rough approximation, the power and time required to raise the dispenser cathode to activation temperature. A major portion of the energy dissipated at the cathode during a discharge results in volume resistive heating, so this approximation should lend insight to scaling cathodes to larger sizes.

The DHB-102 has been successfully cold-started with peak conduction currents approaching 80 amperes. The thyratron has been operated about 1 hour under cold-start conditions and has about 28 hours of operation with filament power supplied to the cathode. The jitter of the grid voltage waveform has been on the order of nanoseconds while grid breakdown voltage varied about 10% from start-to-start for a cold cathode.

The DHB-5 has recently been fabricated. The thyratron is currently being conditioned with heater power supplied to the cathode. There have been no attempts to cold-start the DHB-5 at this time.

In order to obtain information on the emission characteristics of a cold dispenser cathode, two experimental thyratrons were constructed, each containing a different cathode geometry. Temperature measurements are being taken to determine the thermal characteristics of the cathode due to plasma discharge heating. This information will be used to scale up additional cathodes to meet final design requirements. Also, the thyratrons will be studied in detail to determine critical switching parameters under cold-start conditions.

5. ENVELOPE ASSEMBLY

The final design of an instant-start hydrogen thyratron which will satisfy the requirements set forth in Section 1 will be contained in a HY-7 envelope assembly. Interest in weight reduction, along with careful analysis of thermal stress, has led to some modification of the standard HY-7 envelope.

In the redesign of the envelope for weight reduction, no major changes were incorporated. The new design has been shown to sustain approximately the same seal stress as the HY-7 envelope currently in existence. The control grid has been carefully located so that most of the energy dissipated by the thyratron during commutation will occur at the control grid assembly. Calculations have indicated that the control grid will undergo an adiabatic average temperature increase of 320°C over the 120 seconds that the tube will operate. The effects of surface vaporization will be no worse for the lightweight tube than for the proven HY-7 thyratron.

The grid to cathode compartment of the envelope has been modified so that this lower assembly, along with the cathode, may be easily separated from the upper portion of the envelope. Initially, the total envelope assembly will be tested with a standard oxide cathode. After the modified bottle has been proven mechanically sound, the envelope will be separated and a dispenser cathode will be inserted into the assembly and heliarced together. Testing will then be performed on the cold-cathode envelope.

Weight savings for the modified bottle assembly have amounted to almost 12 pounds. Table 1 describes the areas and magnitudes of the weight reduction of the new envelope and Figure 4 shows a side-by-side view of the former HY-7 bottle assembly compared to the new lightweight bottle.

Table 1. HY-7312 bottle assembly weight reductions.

	Modification	Weight Reduction (Lb.) Ceramic	Metal	Total
1.	Reduce length from anode seal to gradient grid flange from 2.3" to 1.5". (Includes shortening anode connector.)	0.96	1.29	2.25
2.	Reduce length from gradient grid flange to control grid flange from 2.3" to 1.5".	0.96	1.71	2.67
3.	Reduce length from control grid flange to auxiliary grid flange from 0.840" to 0.5".	0.41	0.51	0.92
4.	Reduce length from auxiliary grid flange to cathode baffle flange from 0.840" to 0.5".	0.41	0.25	0.66
5.	Replace anode connector with copper flange.		1.04	1.04
6.	Reduce ceramic wall thickness from 3/8" to 1/4".	1.89		1.89
7.	Reduce length of backup ring from 0.425" to 0.36".	0.06		0.06
8.	Reduce OD of copper flanges from 9" to 8.75".		0.28	0.28
9.	Reduce thickness of copper flanges from 1/16" to 1/32".		0.98	0.98
10.	Combine anode support and skirt, and increase skirt thickness from 0.020" to 0.030".		0.22	0.22
11.	Remove material from back of anode		0.48	0.48
12.	Reduce thickness of skirts (3 places) from 0.125" to 0.095"		0.29	0.29
	(Total 1-12)	(4.69)	(7.05)	(11.74)
	Original MAPS-40 weight (not including 6.2 lb. mounting flange).	30.36 lb.		
	Reductions 1-12	11.72 lb.		
	Reduction weight	18.64 lb.		

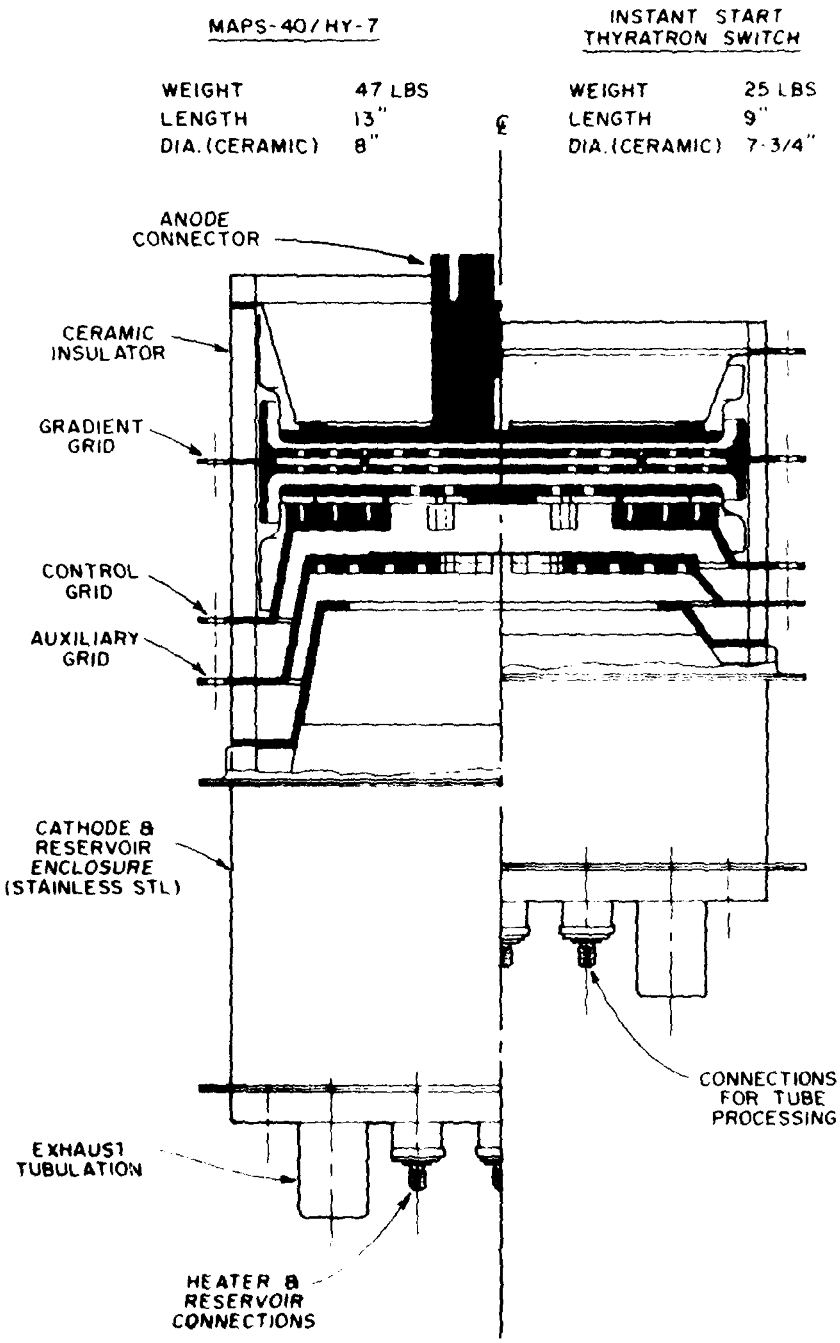


Figure 4. Comparison of envelope assemblies.

6. RESERVOIR STUDIES

A hydrogen thyratron that has an instant-on capability requires not only a cold emitter for the cathode, but also a reservoir that can maintain a cold tube gas density between 0.2 torr and 0.6 torr. Also, during thyratron operation, the reservoir must maintain the density and purity of the hydrogen gas. Investigations have been made into the feasibility of several design options for obtaining a reservoir that allows for cold-start operation of a thyratron.

One possible approach to realizing a passive reservoir is the use of substituted metal-hydride alloys, which have a large hydrogen content at room temperature and have pressure equilibrium in the range of normal thyratron operating pressures. Fe- and V-substituted zirconium-hydride alloys have been reported to have a room temperature dissociation pressure of a few hundred microns, which meet reservoir requirements.

Tests were performed on a ZrFe alloy in a 1.6-inch diameter HY-5 pancake type hydrogen thyratron reservoir. This experimental reservoir included a heater in order to study gas dynamics of the ZrVFe alloys. The alloy was able to produce the expected amount of hydrogen gas, but gas flow was in one direction only and there was no indication of pressure equilibrium. The failure of the ZrVFe alloy to serve as a suitable reservoir material may be due to poisoning of the alloy.

Another possible reservoir consisted of an electromechanical valve system, which would employ commercially available devices for control in the 0.1 torr to 1.0 torr pressure range. However, this system could not operate without an external power supply and extensive control circuitry; no further effort was spent on this reservoir system.

Since the use of both substituted metal alloys and electromechanical systems proved to be impractical at this time, emphasis has been placed on a reservoir design that uses a conventional hot titanium hydride reservoir that is separated from the tube by a palladium window. The palladium window allows the transfer of hydrogen gas only when heated. Calculations have indicated that gas transfer rates could be adequate, so that pressure equilibrium with an ordinary heated reservoir may be achieved. Because of the palladium barrier, the tube could then be shut down indefinitely and only insignificant amounts of hydrogen gas would penetrate the cold palladium barrier. Thus, pressure is maintained in the tube, lending an instant-start capability to the thyratron. Even though this system requires a power supply, it is felt that the palladium window will maintain proper tube pressure until a time when the reservoir can be heated during tube operation and the gas is reconditioned.

7. CONCLUSIONS

Efforts are underway to develop a hydrogen thyratron that has an instant-on capability while requiring little or no standby power. The design work has been divided into three main areas of activity; these areas are:

1. cathode development,
2. envelope design, and
3. reservoir development.

The development of a cold cathode has revolved around an impregnated tungsten material, which exhibits good emission characteristics at cold temperatures due to the formation of a barium monolayer. Two experimental hydrogen thyratrons have been built which employ this tungsten material as the cathode. This cathode will lend an instant-on capability to the thyratrons.

One experimental tube, the DHB-102, has been successfully cold-started at peak currents approaching 80 amperes. Thermal characteristics of the dispenser cathode are currently being studied to determine temperature rise of the cathode due to plasma discharge heating. The jitter of the grid waveform along with the grid breakdown waveform of the DHB-102 has been very consistent.

The second experimental tube, the DHB-5, has recently been fabricated and is being conditioned with filament power supplied to the cathode. No attempt has been made to cold-start the thyratron at this time.

The DHB-102 and DHB-5 contain different cathode geometries in order to determine if one geometry would prove superior in cold-start operation. The temperature measurements taken on the DHB-102 will be used to scale up future cathodes that will meet final design requirements. Finally, the two thyratrons will be studied in detail to determine critical switching parameters under cold-start operation.

The final design of the instant-start hydrogen thyratron will be contained in a modified HY-7 envelope assembly. Weight savings for this bottle have amounted to almost 12 pounds; however, the seal stress for this new envelope is approximately the same as for the conventional HY-7 envelope. For testing purposes, the grid to cathode cavity can be separated from the upper portion of the envelope. This provides the flexibility of interchanging cathodes.

Efforts into developing a reservoir system that requires no auxiliary power, yet maintains tube pressure for instant-on operations, have proven difficult. The use of metal-hydride alloys for a reservoir material may prove to be one solution, but these materials appear to be impractical at this time. Emphasis has been placed on a reservoir design that uses a conventional hot titanium hydride reservoir separated from the tube by a palladium window. The palladium allows for the transfer of hydrogen gas only when heated. Once the palladium window is cooled down, only insignificant amounts of hydrogen can penetrate the window, so that pressure is maintained in the tube, lending an instant-start capability to the thyratron.

The development of a megawatt average power hydrogen thyratron has progressed to the point where cathode and reservoir designs allow for instant-start operation. Even though more diagnostics work is required before a megawatt tube can be delivered, most of the problems involved have been defined and efforts leading to realizing practical solutions are underway.

8. REFERENCE

1. Plasma Cathode Thyratron
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