R&D OF THE LONG-LIFE THYRATRON-TUBE

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Abstract

Long lifetime over 50,000 hours for the thyratron is essential requirement to provide reasonable availability of the C-band e+e- linear collider. The lifetime and reliability of a solid-state device are not well confirmed yet. There are some examples that show long life of a thyratron. Many thyratrons were dead due to several common causes related to circuits and operation environment rather than intrinsic problems of a device itself. The C-band smart modulator uses an inverter charging method and this scheme affects so much the life of a thyratron. Several valuable feedback systems are easily adopted to enhance the lifetime. There are still unidentified questions to be verified in the thyratron. Close collaboration between laboratories and companies is strongly requested in order to improve the lifetime and performance of a thyratron.

INTRODUCTION

A solid-state device is emerging device that seems to have potential to provide such a long life. However, it is catastrophic to any kind of faults. It needs rather complicated auxiliary system that should be more robust and reliable than the device. The lifetime and reliability of these devices are not well confirmed yet. The cost is very high and difficult to reduce due to the small scale of semiconductor business. Solid state devices such as IGBT or SI thyristor are might be better for the applications that require rather low voltage, high average current, high average power.

The thyratron parameters are well suited to high power pulse applications that require high peak voltage, high peak current, high peak di/dt, and high efficiency. A matching driver circuit of the thyratron is very simple due to the simple structure of the thyratron tube. Many thyratrons were dead due to several common causes that are related to circuits and operation environment rather than intrinsic problems of a device itself. There are some researches to improve the performance and lifetime but those results are not well combined and proved well. Even though the low inverse voltage of the thyratron anode is important, it is not tightly controlled.

When build the normal conducting e+e- linear collider is consisted of about 4,000 thyratrons for smart klystron-modulators. In order to provide reasonable availability of the linear collider, long lifetime over 50,000 hours for the thyratron is essential requirement [1].

POTENTIAL OF THYRATRON TUBES

There are three major development series through the history of SLAC thyratron for about 30 years since 1964. The Wagner model CH191 tubes had been delivered since 1964 and rebuilt as ITT F143, Omniwave 1002. From the beginning of SLC era in 1984, ITT F241 tubes had been used and rebuilt as ITT F310. In the 1992, EEV tubes such as CX1836A and CX2410 had been adopted [2].

About 1600 tubes of Wagner model CH1191 had been used in SLAC for 10 years since 1964. The operational statistics of CH1191 thyratron tubes is shown in the figure 1. This data analysis includes only 35% tubes since 1985. From 1964 to 1984, operational parameters of thyratrons are 46 kV, 4.2 kA, 3.8 us, 360 pps, 5.7 A. From 1985 to 1994, operational parameters of thyratrons are 46 kV, 6.3 kA, 5.4 us, 120 pps, 4.1 A. Amazingly 20 tubes are still active in 1994 with ages between 75 ~ 120 kHours. We can confirm wide distribution of age and lifetime profile from the figure.

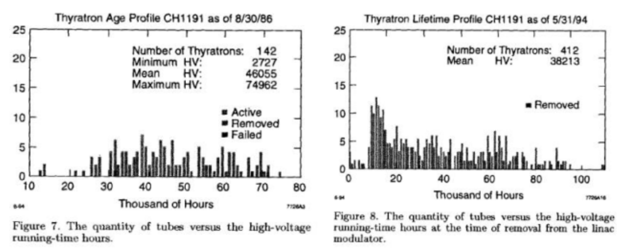

Figure 1: Operational statistics of CH1191 thyratron tubes.

CRITICAL ISSUES OF A THYRATRON

Cathode

The thermionic cathode is one of the key features that will determine the life. The oxide cathode is preferred over the smaller BA counterpart simply on the grounds of cost. Operation at a reduced average anode current is believed to be an effective way of increasing the tube lifetime to over 50,000 hours [5].

Reservoir and Ranging

The switching performance of the thyratron is very sensitive to the internal gas pressure. Gas pressure of about 0.5 Torr is maintained by heating titanium hydride (TiH_2) in porous nickel capsules (reservoir) loaded with several hundred tube-volumes of hydrogen. A high capacity reservoir system minimizes gas pressure adjustments throughout tube life. Intensive checking and adjustment of the optimum pressure (ranging) is a time-consuming part of modulator operation and maintenance. Automatic tracking of the optimum pressure against changes in applied reservoir voltage and back-heating conditions is provided in the E2V thyratron, which has a temperature-sensitive regulation circuit (barretter) in the tube base.

Triggering

An additional grid between the control grid and the cathode can be adopted to generate pre-ionizing discharges by using either a D.C. or a pulsed current. This tetrode tube has a performance that is satisfactory for a linear collider: very low switching jitter (typically 1 nsec) and drift, faster switching, and a smaller grid spike. The traditional D.C. pre-ionizing current of a few hundred milli-amperes is insufficient to ionize fully all the cathode area. A thyratron double-trigger system could produce a pulsed current of several tens of amperes to ionize fully the cathode space.

Inverse Anode Voltage

An inverse voltage level above 5 kV causes strong ion bombardment of the anode and liberates enough anode material that will be deposited on the critical insulating surface, to affect eventually the forward voltage hold-off adversely. Proper design of the tail clipper and the EOLC circuit is essential to ensure low inverse. An inverter charging power supply provides the command-charging feature that is effective way to turn-off a thyratron without an inverse voltage, which is highly recommended to guarantee a long life.

Saturating Anode Inductor

To reduce the anode heating arising from switch-on losses, and to reduce the voltage appearing across the top gap during thyratron commutation, it is proposed to use a saturating anode inductor with a thyratron. A saturating anode inductor with a volt-second product of 1-mVs will give a switch-on delay of 50 ns. It may be necessary to trade off the effect of the added saturated inductance on the current rise time against the protection afforded to the top gap. Saturating anode inductors also afford some protection against the adverse effects of inverse voltages.

R&D OF A THYRATRON SWITCH

Experimental Setup for R&D

Further deep understanding of the thyratron is necessary to enhance the performance and lifetime. First, the autopsy of failed tubes is necessary to understand the causes of failures and differences of each tube. In addition, we should study the anode circuit of the thyratron that includes anode temperature measurement, anode dV/dt measurement, anode reactor optimization, etc. Cathode circuit study will include the effect of D.C. heater vs. AC heater, cathode temperature measurement, and auto ranging of cathode heater. Grid circuit R&D is consisted of grid temperature measurement, the comparison of D.C. prime vs. pulse prime, trigger optimization of double pulse trigger. Gas circuit study will include measure of gas condition by dV/dt and/or RF pickup, stabilization of gas condition by auto ranging.

Figure 2 shows the experimental setup for the research of switching characteristics. The voltage at the anode and gradient grid electrode are measured to get dV/dt, anode delay time, and jitter. The anode temperature will be measured by a pyrometer to analyze heat loading of the anode. Variable anode reactor will be optimized to get minimum anode heating. D.C. and pulse trigger scheme will be compared to find optimum trigger condition. RF pickup coil will amplify signals that will be used as a feedback signal to control reservoir temperature. Heater circuit has a constant resistance control mode to keep constant cathode temperature.

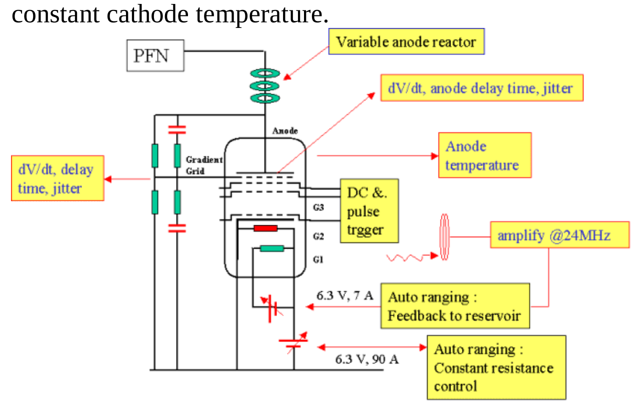

Figure 2: Experimental setup for the thyratron R&D.

Experimental Results of a Prototype Thyratron

To provide the stable operation, we adopted a new configuration of cathode structure as a klystron tube, which has improved the mechanical support structure of the cathode module, it thermal insulation layer and structure of the heater as shown in Figure 3, 4 and 5. A main specifications and a typical operation parameters are listed Table 1.

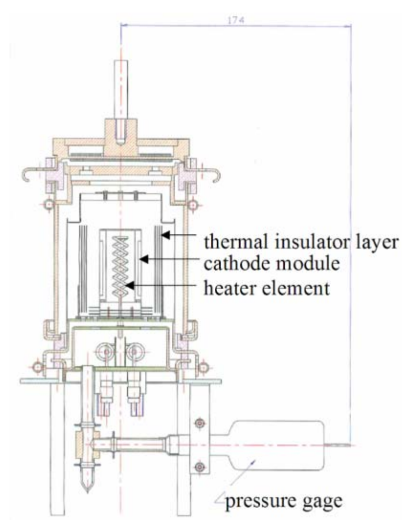

Figure 3: A prototype thyratron tube.

Table 1: A main parameters of prototype thyratron.

Item	Parameters
1) Anode voltage (kV):	24.0
2) Heater current (A):	65.5
3) Reservoir voltage (V):	3.1
4) Reservoir current (A):	6.7
5) Repetition rate (pps):	50
Operation load resistor (Ω): load capacitor (nF):	24.0 9.35

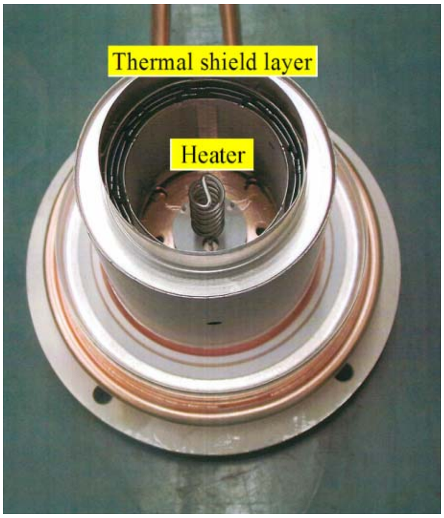

Figure 4: A cut away view of cathode heater element and thermal shield layers.

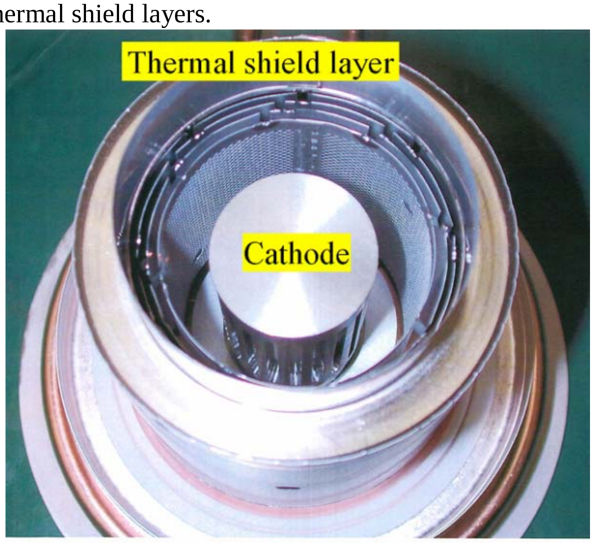

Figure 5: A cut away view of cathode module and thermal shield layers.

Figure 6 shows the various cathode temperatures according to the heater power. It was obtain the optimum cathode temperature of 940 ºC at 300-W heater power, which is low power of the current thyratrons. We confirmed that a new developed thyratron provide the good thermal insulation by multi layers of shield as usual klystron tube (see Figure 4 and 5). Figure 7 shows the second grid discharge characteristics with the combinations between second grid current and voltage. It can be seen in Figure 7, it was obtained a broad combination area for a second grid voltage and current. We believe that it provide the stable operation for a long period such as exceed 50,000 hours lifetime.

SUMMARY

Long lifetime over 50,000 hours for the thyratron is essential requirement to provide reasonable availability in the proposed C-band e+e- linear collider. Many thyratrons were dead due to several common causes related to circuits and operation environment rather than intrinsic problems of a device itself. The C-band smart modulator

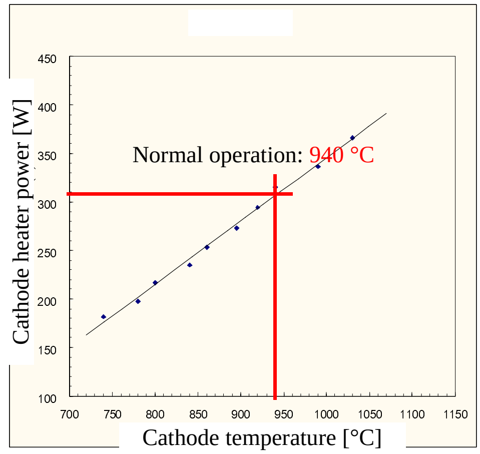

Figure 6: A various cathode temperatures according to the heater power.

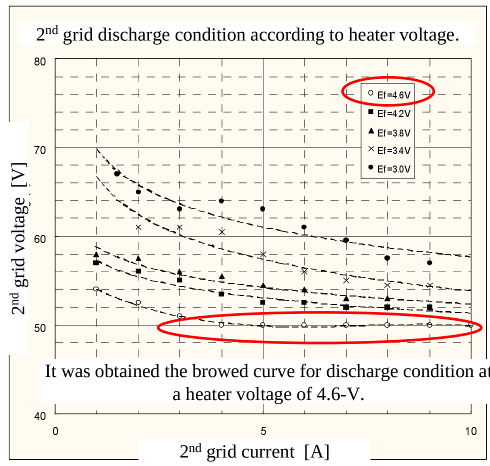

Figure 7: A second grid discharge characteristics by various combinations of a second grid voltage and current.

uses an inverter charging method instead of a traditional resonant charging circuit. Proper design of the tail clipper and the EOLC circuit ensures the low inverse voltage of the thyratron anode. Several valuable feedback systems are easily adopted to enhance the lifetime. There are still unidentified questions to be verified in the thyratron. Close collaboration between laboratories and companies is strongly requested in order to improve the lifetime and performance of a thyratron.

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[1] J.S. Oh et al., "R&D of the Long-Life Thyratron-Tube," Proceedings of Linac Meeting (Domestic), Tokyo, Japan, August, 2002.

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