ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEPSB20

THYRATRON OPERATING PRESSURE MONITORING SYSTEMS

V.D.Bochkov, D.V.Bochkov, V.M.Dyagilev, I.V.Vasiliev, I.A.Salynov, V.G.Ushich
Pulsed Technologies Ltd., 5, Yablochkova str., 390023, Ryazan, Russia

Abstract

The known statistics data amassed for power thyratrons in accelerators show remarkable potential of the plasma switches in terms of lifetime covering the range from several thousand up to 120 thousand hours total [1 - 3]. The gap in the lifetime can be reduced both by measures of improvements in technology and implementation of thyratron parameters monitoring systems. It is known that the thyratron lifetime mainly depends on continuity of gas pressure and cathode emission. In this paper the initial research on some effective means of gas pressure monitoring automation is described. The pressure monitoring in thyratrons TGI-, TPI- and TDI-types is possible in absence of anode voltage either by registration of triggering parameters in a new igniter design or by a special built-in high-temperature pressure gauge.

INTRODUCTION

The main objective of the presented research is to sustain competitive position of thyratrons in respect to semiconductor switches. It takes improvements in lifetime and operation stability, easier maintenance, shorter readiness time at reasonable dimensions and cost.

The lifetime of thyratrons mainly depends on stable gas pressure and cathode emission. One the of standard maintenance operations during thyratron use is the so-called “ranging” – rather complicated procedure used to adjust optimum pressure in the tube during modulator maintenance. According to SLAC (Stanford Linear Accelerator Center) it is necessary to make the ranging at least every 500 hours, according to other sources depending on operation mode it is must be made at least once in 3 months.

There are not too much known means to facilitate the procedure.

In US patent № 3822086 [4] an apparatus for recharging and maintenance of operating pressure in a transmitter-receiver tube is claimed, comprising an electrical bridge circuit having electrical resistance dependent pressure sensor (e.g. thermistor), as one of the arms of the bridge, which reacts to the thermo conductivity when the pressure is changed (alike Pirani gauge). The reduction of the pressure below the pre-set value (with a variable resistor in the opposite arm) leads to increasing resistance of the thermistor. The resulting imbalance of the bridge circuit turns on a heater of the reservoir and H_2-permeable palladium membrane. At this the hydrogen passes by diffusion through the membrane into the volume of the tube. When the operating pressure is achieved the thermistor resistance is decreased and the subsequent balancing of the bridge circuit turns out the heater and the membrane.

The lack of information on commercial application of this clear and logical way in real devices since the moment of publication in 1974 most likely can be explained by no economical effect at that time and problems with reliability of the circuit components under conditions of severe electromagnetic disturbances and extensive high-temperature baking of the tube during outgassing procedure.

This is why English thyratron manufacturer E2V recommends to entrust the automatic monitoring to a simple temperature-depended solution with a barreter, located in the tube base [5]. However this way is based on the reaction to the variations in the environmental temperature operated without any connection to the gas pressure inside the thyratron and does not provide sufficiently effective adjustment of the pressure during lifetime.

INVESTIGATION OF THE INFLUENCE OF PRESSURE ON IGNITION PARAMETERS

We describe more effective way of automatic ranging with pressure monitoring by direct measurements of trigger pulse parameters.

We intend to carry on the research in several directions with respect to the following parameters to be investigated:

1) Anode delay time and trigger parameters (amplitude and pulse duration of current between ignitor and cathode) as the function of the pressure.
2) Working gas pressure stability in thyratron tubes.

Pulse voltage is measured by oscilloscopes Tektronix 2022, Tektronix TBS1152 и Rigol DS1104 with high-voltage probes Tektronix P6015A (1000:1) and pulse current by Rogowski coil 3-01 (Stangenes Industries).

It is shown that for standard TDI4-100k/45H thyratrons with a single pin of the igniter (Trig 2 in Fig. 2) and another lead of the igniter connected to the cathode inside the tube, trigger current of the thyratron in the system of trigger electrodes does not depend on working gas pressure (Fig. 1) in the reservoir heater pressure range from 0 up to 7 V. The trigger current delay time in respect to trigger voltage is constant ~ 100 ns.

In new design of thyratron TDI3-100k/45H trigger part (Fig. 2) with separate trigger pins (Trig 1 and Trig 2), disconnected from cathode, when one of the pins is connected short to cathode (e.g. Trig 1, when R_{ad} = 0 Ohm) the waveforms of trigger current remain the same as in Fig. 1. In case when to the pin Trig 1 in the igniter-cathode circuit the additional resistor R_{ad} was hooked up (Fig. 2) the waveforms obviously change and trigger cur-

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEPSB20

rent becomes a function of pressure inside the tube (Fig. 3 and 5).

The circuit with additional resistor makes it possible to divide pulse currents between igniter electrodes I'_{tr}, representing igniter volume and surface breakdown, and current in gas between igniter and cathode I''_{tr}, taken from plasma, created by breakdown between electrodes Trig 1 and Trig 2, where electrons are attracted towards cathode by potential $\Delta U = I_{tr} \cdot R_{ad}$. Trigger current amplitude I'trig, measured by RC2 in the circuit of igniter Trig 2 to cathode, when pressure of gas is low, is defined by R_{ad}.

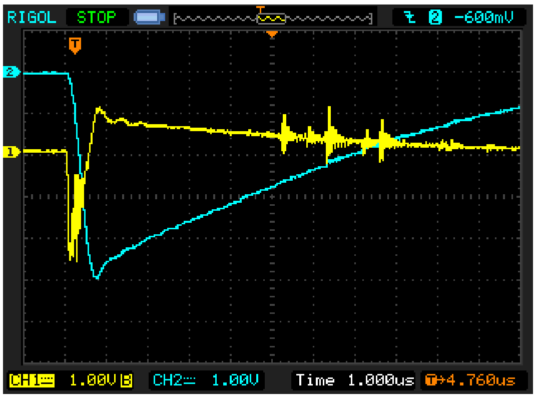

Figure 1: Oscilloscope waveforms of trigger voltage (yel - low trace 1) and current (blue trace 2) in the circuits measured by RC2. Thyratron TDI4-100k/45H. Utrig = 6 kV, Itrig = 100 A, U res – 0 – 7 V).

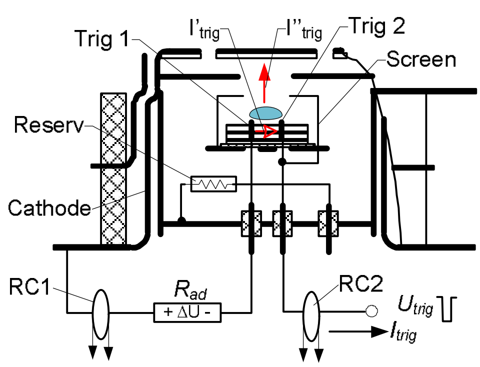

Figure 2: Circuit schematic of triggering thyratron TDI3 - 100k/45H. RC1 and RC2- Rogowski coils. Res – hydrogen reservoir, Utrig – trigger voltage, I'' trig - electron current.

When working gas (hydrogen or deuterium) is under operating pressure, the current Itrig is no more limited by R_{ad}, and consists of 2 components in the arc discharge I trig = $I'_{trig} + I''_{trig}$. A new component of the current I''trig emerges, which flows to cathode due to potential $\Delta U =$ I'trig × R_{ad}, where I'trig < I''trig. Respectively switching charge Q=Q'+Q'', where Q'<Q''.

When using automated system of thyratron pressure monitoring and adjustment it is necessary to calibrate it in the way to maintain heater voltage, exceeding value, corresponding to the pressure when the trigger current surges, by 0.5-0.7 V.

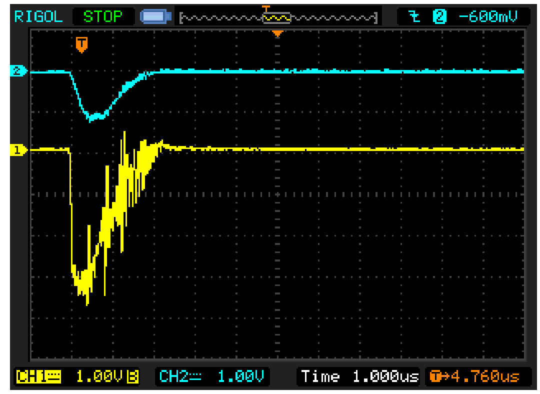

Figure 3: Trigger voltage (yellow trace 1) and current (blue trace 2) measured by RC1. Thyratron TDI3 - 100k/45H. R_{ad}=150 Ohm. Utrig= 6 kV, I' trig= 20 A,Ures = 0 – 3.5 V.

The same procedure can be implemented in thyratrons with instant readiness SN-models as well as in TGI-thyratrons with a grounded grid. For monitoring in thyratrons used in classic circuit with grounded cathode it is suggested to implement design with additional (central) cathode (Fig. 4).

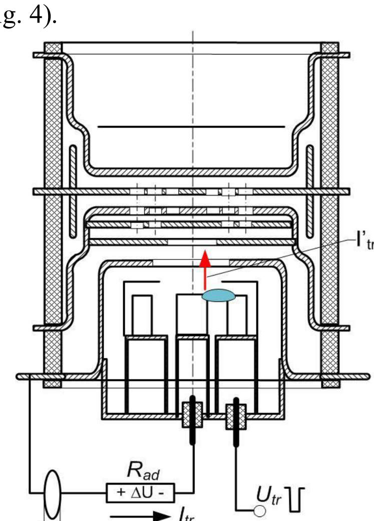

Figure 4: Circuit schematic of thyratron TGI3 - 10k/50 with thermionic cathode with cathode modules placed along the circumference and in the center.

More detailed tests have shown that by reducing Rad from 150 to 12 Ohm the difference in trigger current amplitudes is reduced roughly proportional to R_{ad}.

The results of measurements of the amplitude (Itr) and duration (Ttr) of trigger current at R_{ad} = 48 Ohm are presented in Fig.5. The data have been obtained by RC1 and RC2 as a function of working gas pressure in the tube.

According to waveform plots of trigger current (Fig. 5a - 5b) in RC1 and RC2 a clear dependence of trigger current amplitude on the working gas pressure, starting from the reservoir heater voltage 3.5 V can be noted. At that in

ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEPSB20

the circuit RC2 the current amplitude and duration have been increasing, whereas in RC1 have been decreasing with increase of Ures.

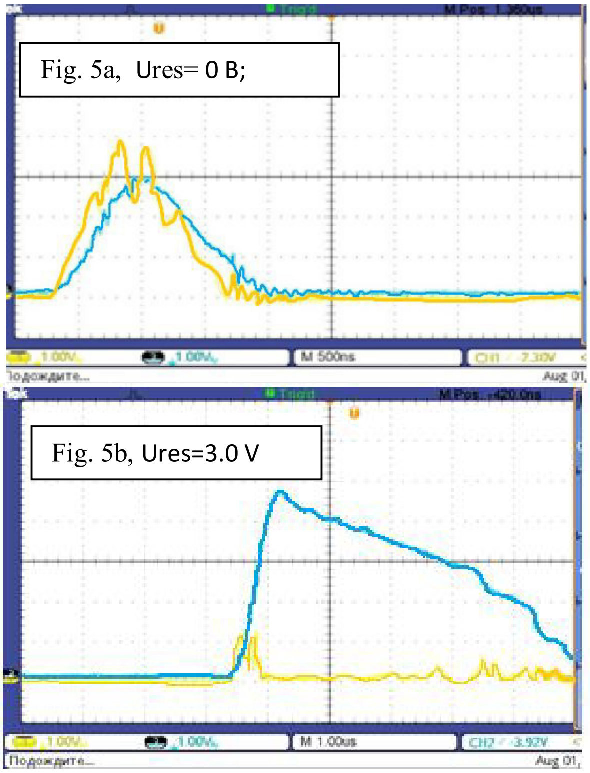

Figure 5: Trigger current, measured by RC1 (yellow trace) and RC2 (blue trace). Thyratron TDI3-100k/45H. Anode voltage Ua = 0 kV, R_{ad} = 48 Ohm.

The difference in currents tends to be several times, which allows to define the lower limit of hydrogen pressure range. However it should be noted that starting from the ignition moment (over 3V of heater voltage) the peak current changes significantly by the duration from pulse to pulse and to get more reliable data we need to make an integral of the currents. At R_{ad} more than 100-150 Ohm the pulse duration is stabilized. This is why it is recommended to use the Rad in this range.

CONCLUSIONS

The objective to monitor thyratron readiness and carry out ranging (checking the working gas pressure in the operating range) without anode voltage by monitoring trigger current amplitude and duration can be achieved by using a specially designed thyratron TDI3-100k/45H with separated ends of the ignitor, both of which are not connected to cathode. This parameter is sufficiently informative and objective since it is changed by the amplitude and integral value approximately by 5 times with respect to the trigger current amplitude at the pressure below the lower limit of the range. In this within the range of operating pressure the difference in currents, measured in RC1 and RC2, can achieve 10 times. At R_{ad} less than 100 Ohn the current difference is higher. It is recommended to use R_{ad} ~ 100-150 Ohm.

The circuit as per Fig 2 allows to divide the current between igniter electrodes I'_{tr}, resulting in volume and surface breakdown, and current between igniter and cathode I''_{tr} ,the source of which is the plasma, emerging due to the breakdown between electrodes Trig 1 and Trig 2, where electrons are attracted towards cathode by potential $\Delta U = I_{tr} \cdot R_{ad}$.

It is also worth mentioning that this circuit allows to reduce the instability of anode delay time (jitter) down to the value of 3-5 ns [6,7].

When using automated system of thyratron pressure monitoring and adjustment it is necessary to calibrate it in the way to maintain heater voltage, exceeding value, corresponding to the pressure when the trigger current surges, by 0.5-0.7 V.

The same control can be performed in thyratrons with an incandescent cathode TGI3-5k/50 TGI3-10k/50 [2] and in thyratrons with instant readiness TDI3-100k/45HSN.

The control and monitoring of the pressure by this method does not allow to define the upper value of pressure in the tube. This value can be defined by tests with anode voltage, recorded in the specification sheet and must be specified by measurement of the pressure in this point by in-build gauge, which is supposed to be implemented in the next stage of work.

ACKNOWLEDGEMENTS

The authors thank Professor A. Kuzmichev for useful advice and comments.

REFERENCES

[1] David B. Ficklin Jr., “A History of Thyratron Lifetimes at the Stanford Linear Accelerator Center,” *SLAC-PUB-6543*, December 1994.

[2] J.S.Oh, W.Namkung, H.Matsumoto, "Lifetime issue of a thyratron for a smart modulator in the c-band linear collider", *Proceedings of APAC 2004*, Gyeongju, Korea, 2004. pp.767-769.

[3] V.D. Bochkov, D.V. Bochkov, I.A. Salynov, et al, "Study of the New Generation of Thyratrons with Average Switching Power up to 0.5 MW: Experience of Application in Electrophysical Equipment", *Physics of Particles and Nuclei Letters, 2018, Vol. 15, No. 7, pp. 888–891.*

[4] Sungik F.Paik, "Apparatus for recharging a TR tube", US Patent № 3822086, July 1974.

[5] C.A.Pirrie and H. Menown, "The Evolution of the Hydrogen Thyratron". (EEV Technical Reprint).

[6] V.D.Bochkov, D.V.Bochkov, V.M.Dyagilev, V.G.Ushich, "SN-Series Pseudospark Switches Operating Completely Without Permanent Heating. New Prospects of Application". *Acta Physica Polonica A*, No.6, Vol.115 (2009), pp.980-982.

[7] V.A.Gribkov, M.Scholz, V.D.Bochkov, et al, "Pseudosparks in nanosecond range of its operation: firing, jitter, and disconnection", *Journal of Physics D: Appl. Phys*. 37 (2004) 2107–2111.