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PERVEANCE MEASUREMENT OF THE TLS-LINAC KLYSTRON AND THE EVALUATION OF ITS OPERATION PERFORMANCE

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Abstract

The high power klystron is a radio frequency amplifier for TLS linac operation. It is a crucial device for electron acceleration in linac. How to evaluate its efficiency, lifetime and performance of klystron in operation is one of the major concern in this report. The key klystron parameter perveance is introduced and used for performance evaluation and operation status monitoring. It is important to execute periodic monitoring on perveance for ensuring a stable linac operation. Klystron characteristics diagnostics can be achieved through perveance measurement. A couple of klystron diagnostic parameters concerning perveance are explored for field examination purpose. Perveance comparison with factory acceptance test data is also presented.

INTRODUCTION

The high-power klystron-modulator system is the most important assembly component of microwave amplifier and pulse power source required for linac of Taiwan Light Source (TLS). The klystron's maximum output is 35MW. TH2100A klystron manufactured by THALES (Dassault Company of France) is used in the TLS-linac system. At present, the klystron in application is the third one since the first operation in 1992. [1] TH2100A klystron and its general parameters are shown in Figure 1 and Table 1 as followings. [2] In order to prevent high voltage discharge, the pulse transformer is immersed into insulating oil tank.

Table 1: Thales TH2100A Klystron Specifications

Frequency	2998 MHz
Peak rf output power	35 MW
Rf pulse duration	2 μs
Gain	50 dB
Efficiency	45 %
Anode voltage	280 KV
Beam current	300 A

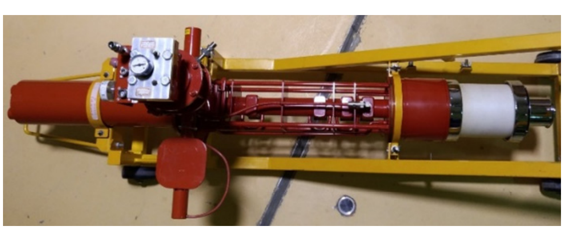

Figure 1: Thales TH2100A, 3GHz, 35MW klystron.

PERVEANCE CALCULATION

The perveance is one of the most important parameters for the characterization of klystron operation. The electrical characteristics are completely determined by the geometric structure of electron gun and the electron emission characteristics of cathode materials. When the electron gun operates in space charge limited mode, the current emission will be the function of high voltage during operation while the perveance will be the function of anode and cathode structures. The detailed equations of relevant parameters are referred in the following paragraph.

Regular diagnosis upon the klystron characteristics can provide significant index for the linac stable operation for electron beam accelerating. Through measurement of the perveance, the klystron operation status can be monitored. The operation experience shows that the perveance value changes with klystron's increasing working hour.

Child-Langmuir law is widely referenced on describing the beam emission mechanism of electron gun. It describes the current of parallel plate diode under space charge limited as follows [3]:

$$J = \frac{9}{4}\varepsilon_0(2\eta)^{\frac{1}{2}}\frac{V^{\frac{3}{2}}}{x^2} \quad (1)$$

Parameter description:

J = Current density.
ε_0 = Dielectric constant under vacuum.
η = Electron charge to mass ratio.
x = Distance from cathode.
V = Potential at position x.

For a diode with cathode-to-anode distance x = d, Equation 1 can be rewritten as Equation 2:

$$I = PV^{\frac{3}{2}} \quad (2)$$

Parameter Description
I = JA
A = Cathode area
P = Diode perveance

$$P = \frac{4}{9}\frac{A\varepsilon_0}{d^2}(2\eta)^{\frac{1}{2}} = 2.33 \times 10^{-6}\frac{A}{d^2} \quad (3)$$

Note: A is cathode area for the effective electron emission and changes for different working conditions.

Equation 3 shows that the perveance of klystron is determined by electron gun geometric structure. In addition, in the alternative klystron design, it is better to choose the higher working voltage and decreasing the perveance to reduce working current. Klystron has better energy conversion efficiency with low working current design. This design is based on profiting from bunching mechanism of electron beam and microwave. When electron beam density is low, higher energy conversion efficiency can be obtained when space charge force among electron groups is small [4].

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On the other hand, low perveance causes a relevant disadvantage, higher working voltage requirement. Operation statistics shows higher working voltage causes increased malfunction rate for klystron high voltage breakdown. Therefore, appropriate perveance should be taken into consideration of the most importance for klystron stable operation.

PERVEANCE MEASUREMENT

The klystron's real-time working condition including reading values of voltage and current is provided by calibrated voltage divider and current transformer. Klystron voltage value can be measured with oscilloscope measuring the divider signal and the voltage value of pulse forming network PFN can be double confirmed on computer as shown in Figure 2 and Figure 3.

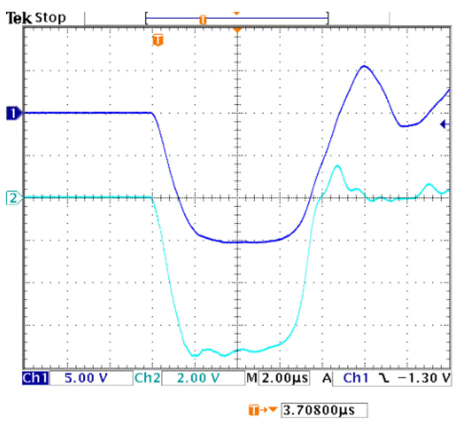

Figure 2: Klystron voltage and current (Ch1 and Ch2).

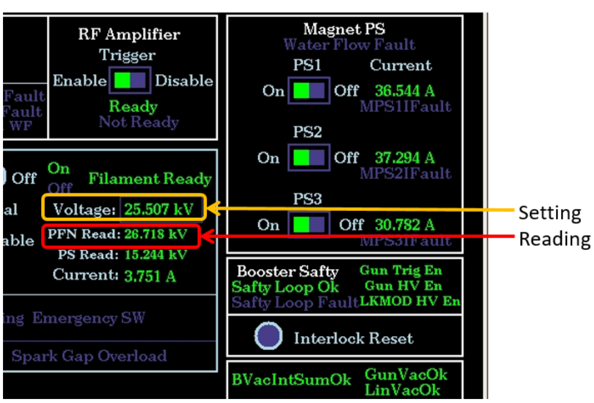

Figure 3: Real-time PFN voltage on control panel.

The klystron voltage was measured together with pulse form network voltage and klystron current with oscilloscope measurement listed in Table 2.

Klystron power system circuit diagram is shown in Figure 4. Modulator charging voltage is defined by the charging power supply setting value. When the the circuit loop is turned on, voltage is divided into half for impedance matching of the modulator and the pulse transformer at both ends of the transmission line. The voltage provided to klystron by pulsed transformer 20 times boosting. And klystron current is measured through the current converter which was corrected previously. Klystron voltage and current are both converted with converter ratio in circuit. Figure 5 shows the klystron picture on linac.

Table 2: Klystron Current Measured

Modulator voltage KV	PFN voltage KV	Klystron current V
2	4.7	0.92
3	6.9	1.48
4	9.0	2.04
5	11.1	2.58
6	13.2	3.16
7	15.3	3.78
8	17.3	4.40
9	19.3	5.00
10	21.2	5.60
11	23.2	6.20
12	25.1	6.80
13	27.1	7.56

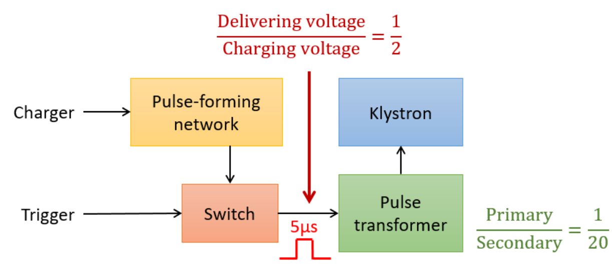

Figure 4: Pulse power and klystron modulator circuit.

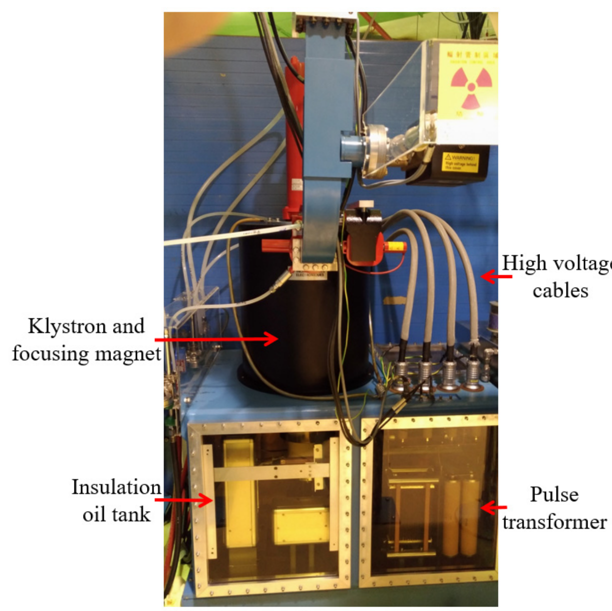

Figure 5: Klystron on TLS linac.

The relation between the klystron current and the voltage is shown as Equation 2. The perveance is calculated based on data in Table 3. Klystron measured current and voltage data are plotted in Figure 6. The perveance is obtained by curve matching method. The red line in figure is V-I matching curve. The calculated perveance is 0.97 $\mu A/V^{2/3}$.

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Table 3: Klystron Voltage and Current

Voltage KV	Current A
47	18.4
69	29.6
90	40.8
111	51.6
132	63.2
153	75.6
173	88.0
193	100.0
212	112.0
232	124.0
251	136.0
271	151.2

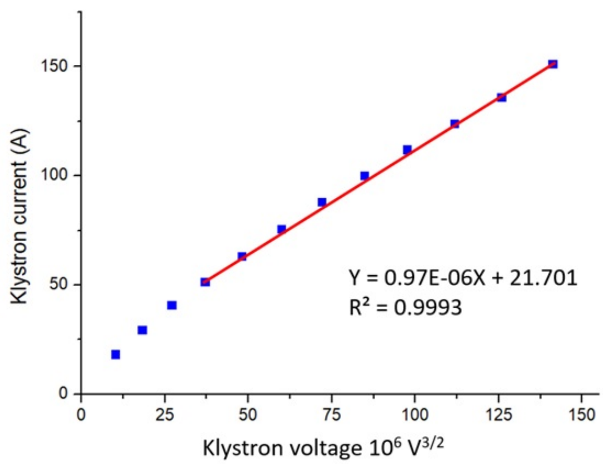

Figure 6: The perveance obtained by curve matching.

The perveance 0.97μ-perveance is much smaller than the original test specification data 2.08 μ-perveance. [5] The reason might be that klystron electron gun cathode has worked continuously for more than 52,000 hours under higher consumption.

DISCUSSION

The klystron working life and its replacement by a new product can be referenced to the tracking history of periodic perveance measurement. In order to prepare replacement and components for maintenance in advance, the working life of klystron is generally defined by the perveance value reduced to a certain percentage of the original acceptance test specification. The specific percentage value of reduced perveance should be evaluated with periodic measurement of the perveance. [6]

At present, TLS klystron has worked for over 52,000 hours since its installation in 2011. Its electron gun cathodes gradually decays with a certain amount of hour's operation. When the measured perveance decays below a certain percentage of initial value, this measurement can help to determine its remaining life. Proper life-cycle prediction can be achieved through regular measurement of the perveance which also provides reference to the overall performance of the linear accelerator. Figure 7 is a summary of perveance change records of TH2100A klystrons (TLS: 1; TPS: 3) currently used by NSRRC corresponding to working hours. The blue point is the measurement value normalized by the factory initial perveance. Since we are trying hard to look for the available document and information about the cathode. No more information about the cathode material of the electron gun was found. However, the Longo model curve is used to match the measured data, a similar result to the M-type cathode curve [7] will be obtained. This deduction maybe proved in future study.

The perveance can be chosen as one of the key parameters presented for regular operation performance. It is expected that the klystron related backup plan for linear accelerator operation will be predicted through regular tracking of the measured perveance value.

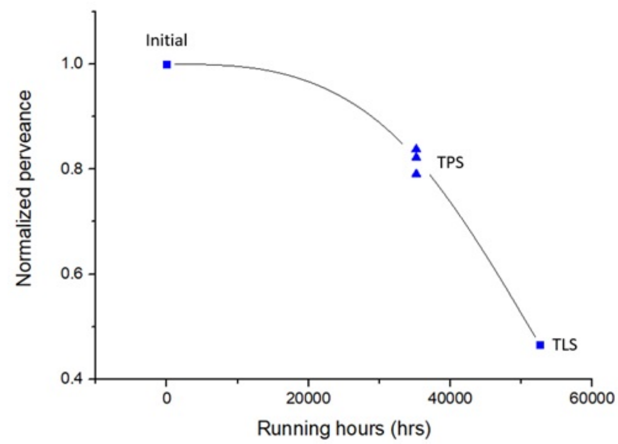

Figure 7: Perveance change records of TH2100A klystrons currently used by NSRRC.

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