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AUTOMATIC CORRECTION SYSTEM FOR THE TLS BOOSTER LINAC KLYSTRON MODULATOR

S. J. Huang†, Y. K. Lin
National Synchrotron Radiation Research Center (NSRRC), Hsinchu, Taiwan

Abstract

The aim of this article is to analyse the performance output of the klystron modulator, which is based on the observation of the output voltage and current performance of the linear-accelerator klystron modulator; we modify the operating-point parameters based on those results or assess whether the klystron needs to be replaced. For this purpose, we collect the observation data of the klystron performance; we then develop a program to adjust automatically the high-voltage setting of the klystron to ensure that the storage current maintains beam current 360 mA in the top-up mode operation.

MOTIVATION

In accelerator Taiwan Light Source (TLS), the power of the low-level radio frequency (LLRF) is amplified and guided by the modulator into the linear-acceleration section, in which the energy of the electron bunch is increased from 140 keV to 50 MeV. The electron beam is then introduced into the booster ring under the guidance of the transmission line (Linac to Booster, LTB), which contains a bending magnet with a 60o turn. If the energy of the electron beam provided by the linear-acceleration section does not meet 50 MeV, it fails to pass this bending magnet. It is hence important to stabilize the electromagnetic wave amplified by the modulator.

When a klystron (Fig. 1) has been in use for nearly eight years, its performance gradually deteriorates [1]; so the electron beam passing through the linear acceleration does not obtain the energy appropriate to pass the bending magnet. This phenomenon has also been experienced in other accelerator facilities [2].

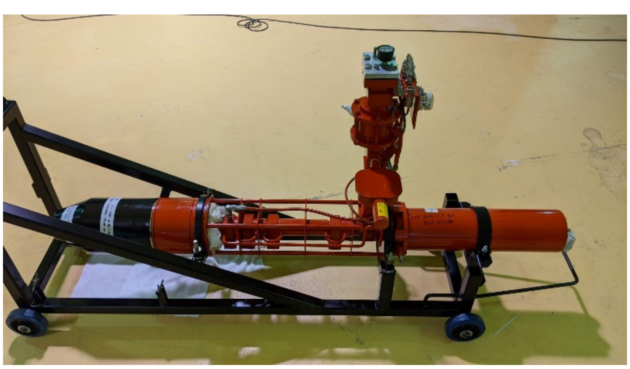

Figure 1: High-power klystron: Thales TH2100A.

We therefore purchased a spare klystron to replace the old one. However, because of the impact of COVID-19, the transport has been delayed, so we could not replace it in time, while the performance of the old klystron then becomes unstable. An operator must therefore adjust the operating parameters according to the variation of the output state.

To decrease the burden on the operators, we used the output data of the klystron to develop a program to correct the system automatically, which is described in the following sections.

WAVEFORM DATA COLLECTED FOR THE ANALYSIS

A klystron modulator was installed in the linear-acceleration section of the TLS booster ring as shown in Fig. 2; we describe the data used in the analysis in this section.

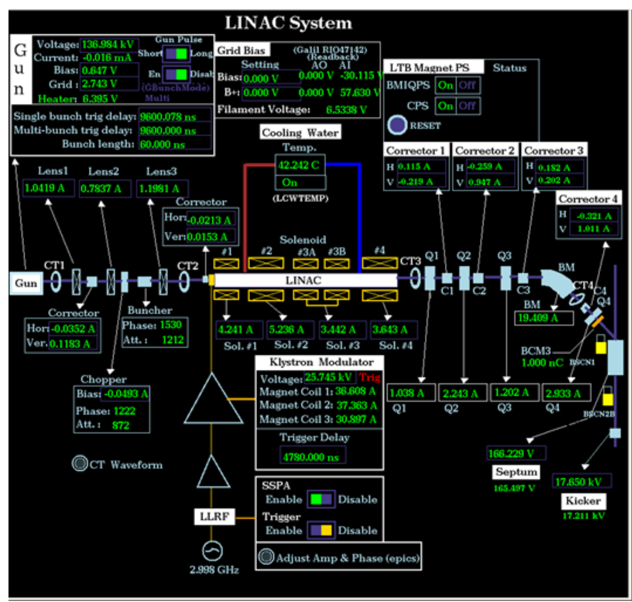

Figure 2: Linear-acceleration section configuration.

Among many monitoring systems developed by the instrument control group [3], the four waveforms that we used in the analysis are the klystron output current, the klystron output voltage, the klystron output power and the current transformers (current transformer, CT), as shown in Fig. 3. The installed positions of the CT can be seen in Fig. 2.

† huang.szujung@nsrrc.org.tw

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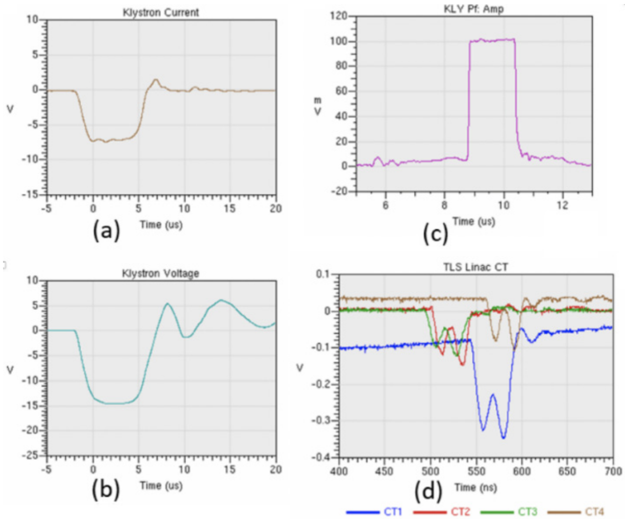

Figure 3: (a) Klystron output current, (b) klystron output voltage, (c) klystron output power and (d) CT1~CT4 waveforms.

The klystron output current (Fig. 3(a)) and the klystron output voltage (Fig. 3(b)) can be used to assess whether the klystron is working normally.

For the klystron output power (Fig. 3(c)), one can use it to assess whether the output power meets the power required by the linear-acceleration stage. If no break-down phenomenon occurs in the klystron, the output power does not change abruptly; the effective working point falls into a range 108.5 to 111, as shown in Fig. 4, which means that the electron beam can pass the bending magnet. This range might vary because of changes in the values of other components, which are fixed in this study.

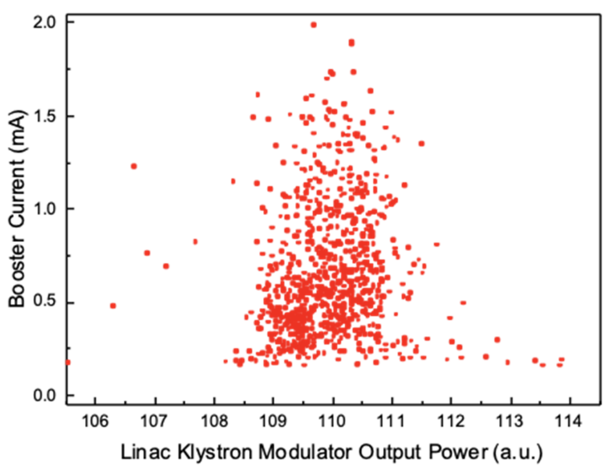

Figure 4: Relation between output power of the modulator and booster current.

The four current transformers CT1~CT4 measure the current density of the electron beam at various positions, specified as follows.

CT1: electron beam downstream of the electron gun
CT2: electron beam upstream of the linear accelerator
CT3: electron beam downstream of the linear accelerator
CT4: electron beam downstream of the 60 degrees bending magnet

CT3 and CT4 are both downstream of the linear-acceleration section, but the CT4 waveform is the main object of this analysis because the waveform of CT3 lacks energy discrimination.

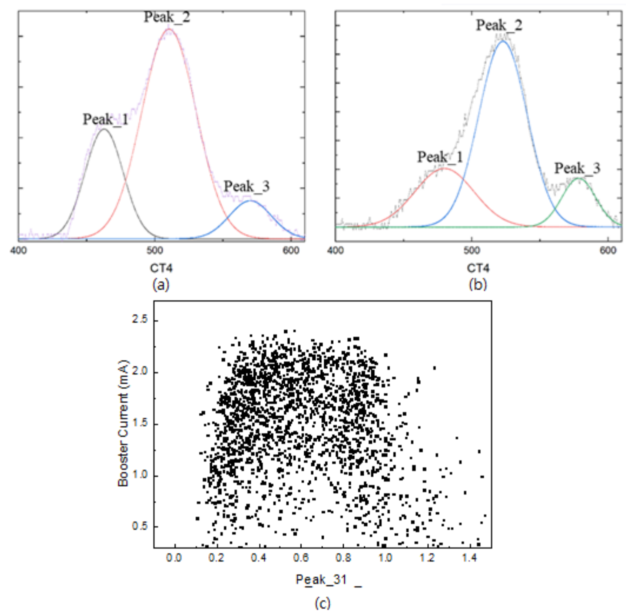

Figure 5: CT4 waveform analysis, (a) state of low output energy, (b) state of high output energy, (c) statistical relation between peak_31 ratio (peak_3 intensity/peak_1 intensity) and booster current output.

The waveforms of the CT4 are separable into several peaks with Gaussian fitting; for example, three peaks in Fig. 5(a) and (b), which are for a low-energy state and for a high-energy state respectively. In the experience of this study, if the ratio of peak 3 to peak 1 (peak_31) is outside the range 0.2~1, the output booster current becomes unstable, as the statistics show in Fig. 5. These waveforms and the range also depend on the settings of other components.

PROGRAM EXECUTION RESULTS

Our program has two steps. The first step is to observe the output power (Fig. 3(c)) of a klystron in 4 s, before the electron gun is triggered, then to adjust the high- voltage setting to correct the output power back to the range 108.5 to 111 (as in Fig. 4).

The second step is to fine-tune the high-voltage setting to correct the ratio peak_31 to the range 0.2 to 1.0 (Fig. 5), after the electron gun is triggered. The programme was written in Matlab.

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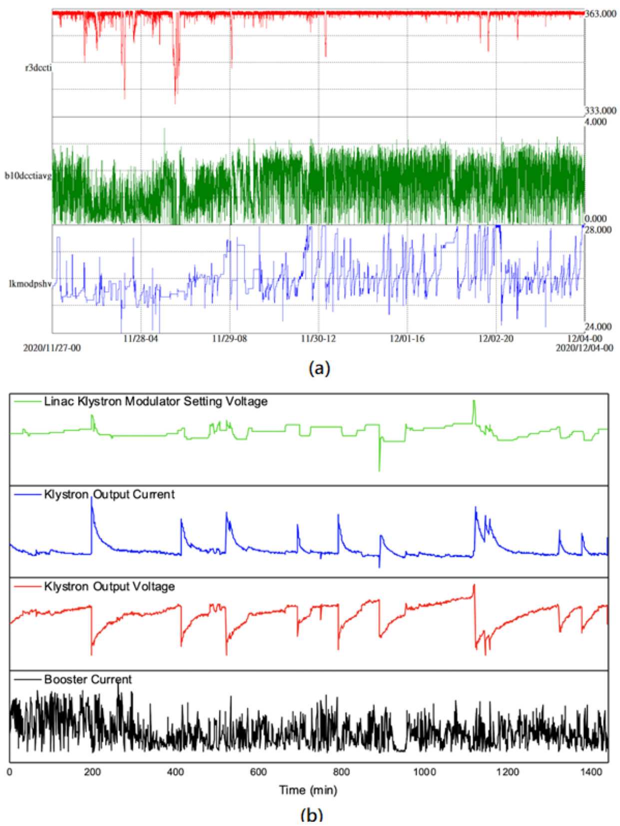

Figure 6: Monitoring the automatic tuning program; (a) one week of operating status, and (b) one day of operating status.

The performances of our program in one week and one day are shown in Fig. 6(a) and (b) respectively. One can clearly see that the booster current output can be stabilized with our program, so that it can also ensure that the storage current can maintain the rated 360 mA during the user's time period.

Also from the performance in one day, one can see the break-down phenomenon occurring at a frequency about once per hour.

CONCLUSION

Through adjusting the high-voltage setting of the modulator in time with our program, the klystron can still maintain a normal output at the end of its life, thereby increasing the final residual value of the klystron, of which the cost is approximately 20,000 Euros.

However, since we ran this program for a half year, the status of the klystron deteriorated, such that the frequency of the break-down phenomenon became once per 3 min (as shown in Fig. 7). The situation was hence beyond the ability of our program to cope; the klystron had to be replaced.

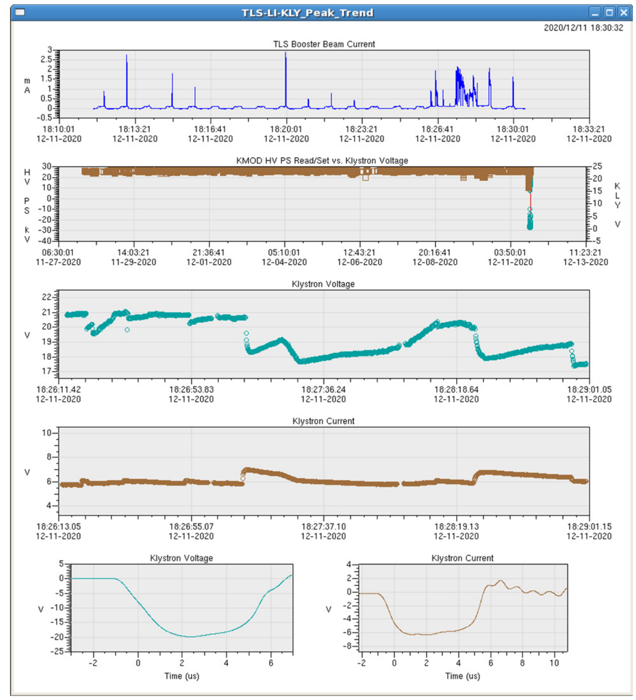

Figure 7: The klystron is in a state that must be replaced.

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