RESULTS OF A HIGH-POWER KLYSTRON DIP TEST IN THE KEK LINAC

K. Nakao#, H. Katagiri, T. Matsumoto, S. Michizono, T. Takenaka, Y. Yano, M. Yoshida, S. Fukuda
High Energy Accelerator Research Organization, 1-1 Oho, Tukuba, Ibaraki, 305-0801

Abstract

A dip test, which is a measurement of klystron heater activity, was recently adopted as a standard method to determine the klystron heater power in the KEKB electron-positron linac. Before we adopted a dip measurement, it took about half a day to measure the emission as a function of the heater wattage for one klystron. Two years ago, we began to use the dip test as a quick way to measure the emission characteristics from the klystron cathode; it took only 10 to 15 minutes. After achieving successful results, we made dedicated measuring systems and measured the dips of the cathode emission of 60 operating klystrons in the KEKB electron-positron linac. These data are important to estimate the klystron cathode life, and are used to select candidate klystrons for replacement in the summer shut down period.

INTRODUCTION

In the KEKB electron-positron linac at the High Energy Accelerator Research Organization (KEK), 60-high power S-band klystrons are operating. For stable operation of those klystrons, it is necessary to keep the operation point of the klystron heater power in the space-charge limited region. More than 10 years have passed since KEKB started, and some klystrons showed the emission degradation, and had to be replaced. Sudden emission degradation forced us to replace the klystron during the operation run, and some cases resulted in an interruption of beam injection to the KEKB ring. We thus need to know the operation status of the heater power of each klystron. The standard measurement used to determine this operation point is to measure several points of the cathode emission current as a function of the heater voltage (current). It takes 30 minutes for one heater voltage to confirm the thermal equilibrium, and it takes about half a day to have a full curve of the emission characteristics. Thus, generally, it is difficult to measure it during beam injection; therefore, routine measurements are performed during the summer shutdown period; it takes more than one week. Two years ago we introduced the so-called "dip measurement" to determine the heater operation range. This is the way to measure the dip of the emission current after a sudden off-interval of feeding the heater power; it gives us an estimation of the operating points of the heater power quickly. We took trial data of several klystrons two years ago and obtained good results. Therefore, we adopted this measurement as the standard method to set the heater wattage [1]. This paper describes this dip measuring.

DIP MEASURING OF THE KLYSTRON EMISSION

In the KEKB linac, 60 high-power 50-MW klystrons (frequency of 2856MHz, pulse width of 4µs, repetition rate of 50 pps) are operated to accelerate an 8.0 GeV electron and a 3.5 GeV positron [2][3]. Recent operation hours per year are about 7000 hours, and continuous injection to the KEKB ring started from 2004. Every year it is necessary to replace about 5-8 tubes due to klystron failures. Causes of the failures cover various reasons, such as an electric discharge in a tube, the breakdown of a ceramic window, and some other causes. The recent prime cause of failures is due to the emission degradation of the klystrons.

We have been measuring the emission characteristics of all the operating klystrons twice a year to accumulate any trend of changing performance. The usual way to measure the activity of the klystron cathode is to measure the cathode emission current as a function of the heater voltage (current). The proper operation point is reduced from the shoulder characteristics of the emission or Miram plot [4]. Since each measurement has to be done after thermal equilibrium of the cathode, after changing the heater voltage, it takes half an hour for one measurement, and it takes half a day to complete one klystron measurement.

A quick way to measure the cathode activity is realized by introducing the dip measurement of the emission current after a sudden off-interval for applying the heater power. The emission current decreases as the temperature of the cathode goes low, and after turning on the heater, the emission starts to increase with a certain delay time. Figure 1 shows the schematic relation of a dip test and the

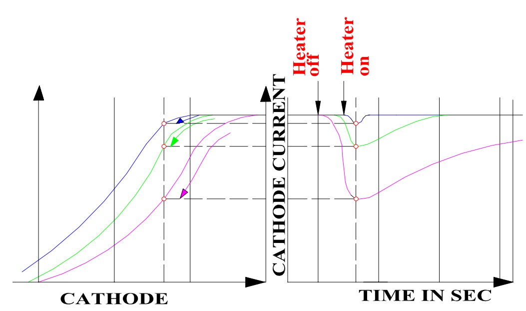

Figure 1: Miram plot and dip test.

#katsumi.nakao@kek.jp

0-7803-8859-3/05/$20.00

Miram plot. As shown in figure 1, the depth of the dip relates the operating point of the cathode. The deeper is the dip, the nearer is the operating point to the shoulder region of the emission characteristic: improper setting. Thus, once after the heater wattage is properly set, the changes of the depth of the dip give us the changes of the cathode activity.

Though the dip measurement is an old technique for tube technology [5], few applications to the high-power klystron are conducted[6], since a heater turn-off during high-voltage operation is possibly harmful to the tube; in serious cases it reduces to tube failure. In fact, a too-long turn-off time causes an excessive high voltage due to impedance mismatching of a line-type modulator. We carefully tried to test and change the interlock sequence to precede the dip measurement.

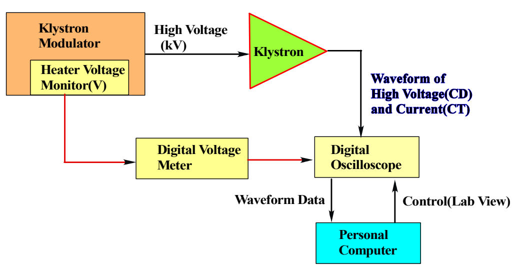

Figure 2: Equipment of dip test.

DESCRIPTION OF THE DIP TEST

After the successful trial test shown in the report of 2003, Linear Accelerator Meeting [1], we made a dedicated dip testing equipment, which consisted of a digital oscilloscope, a digital voltage meter and a mobile computer to control the oscilloscope and save data automatically by the Lab-View program through GPIB; it was possible to conduct a quick measurement [7]. We turned on and off the heater power by manually handling the NFB and inactivating the interlock sequence. The turn-off time was 60 seconds for a 50-MW klystron. A block diagram of the dip-measuring equipment is shown in Fig. 2. We aimed to make a compact system, which was mounted on a small desk with wheels; we could carry it easily in the long klystron gallery. The dip measuring time was about 15min for the 50-MW klystron, including to the recovering time to the initial thermal equilibrium. The net time of the dip measurement was only the 5 min. This quick measurement enabled us to conduct it during the short transient interval of the injection mode. Full measuring of the Miram plot, which obtains data of point-by-point heater wattage, was only performed just before the summer and winter shutdowns. After employing the dip measurement, we could diagnose the status of the each klystron easily. If a dip measurement showed a significant change, a confirmation by measuring the direct Miram plot was performed during the short maintenance time every two weeks.

We used 2 pieces of equipment for dip measurements of all 60 klystrons during the short maintenance time and long shutdown time. The operating heater voltage was 110V (step-down voltage of heater transformer was about 5:1) at the applied voltage of 270 kV (the usual operating voltage is 290-300 kV). The reason why we set to the lower value than operation voltage was to avoid any excessive high voltage during the temperature-limited region operation when the heater was off. It took about 2 to 3 days for all dip measuring at the KEK linac.

RESULT OF DIP MEASUREMENTS

Figure 3 shows examples of the dip test of one third klystrons set in the klystron galley. The vertical axis indicates the depth of a dip, expressed by percentage of the variation. In figure 3, bars show the values of the past 4 or 5 measurements, as shown in the legend of the figure. It is necessary to pay attention to the fact that our klystron cathodes employ the scandate cathode, which does not

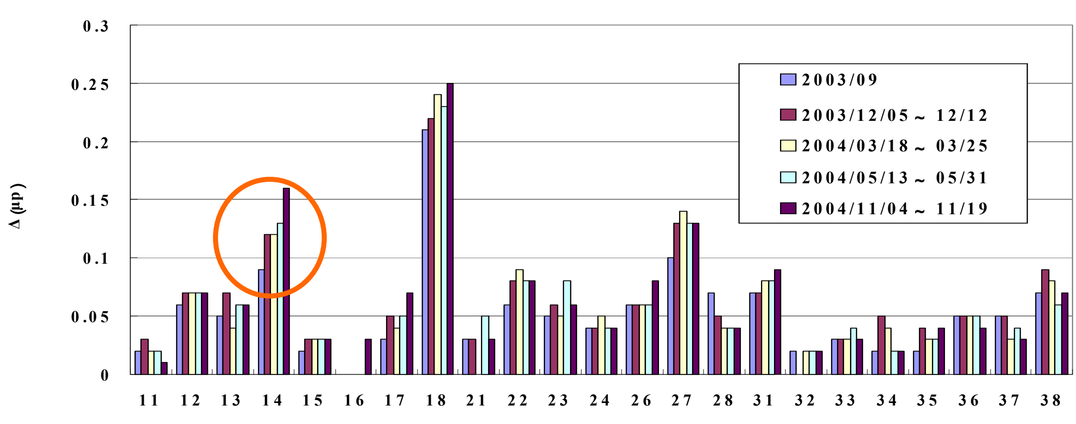

Figure 3: Result of dip test on klystron gallery.

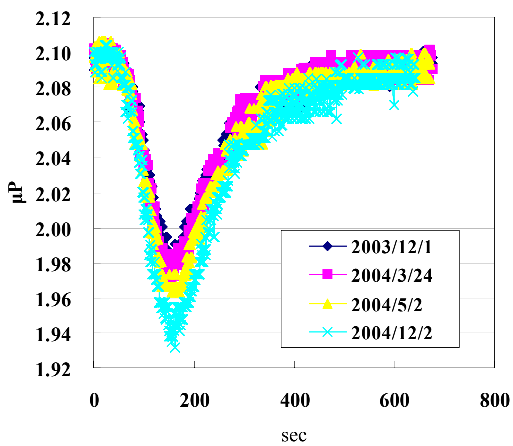

Figure 4: Changes of the dip depth of #14 klystron.

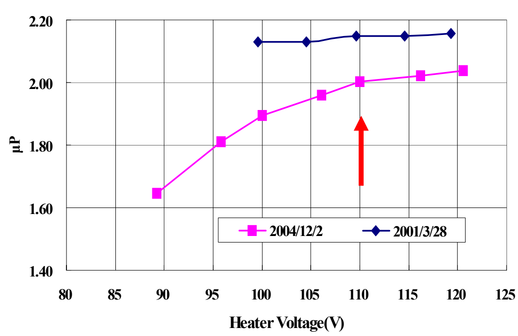

Figure 5: Emission characteristics with a function of heater voltage for the #14 klystron. Red arrow shows the operating point.

reveal any clear constant emission current during space-charge limited operation; a certain amount of dip is always measured. Therefore, it is important to compare the relative variation of the depth; the absolute value of the depth, itself, is not important. The activity of the klystron cathode is usually decreasing along with the operation time; the depth of the dip increases along with the operation time. The red circles in Fig. 3, (the units of the #14), show significant changes of the dip; this klystron was candidate of replacement. Actually, after re-measuring the Miram plot, we replaced this klystron by new one. These processes saved time to measure all of the tubes and enabled us the latest status of the cathode activities of the klystrons operated in the klystron gallery. Figure 4 shows the data of the change of dip depth measured for a year at the #14 klystron station. Figure 5 shows the corresponding emission characteristics for the same klystron. Pink line in Fig. 5 indicated that the 110 V setting was not adequate due to the emission degradation.

SUMMARY

We introduced the dip measurement of the cathode emission characteristics, and successfully saved the measuring time of judging the cathode activities. We can now always grasp the latest status of the cathode emission by performing the short time measurement of the dip during the operation. Since the average life of a klystron operated in the klystron gallery reaches to about 40,000 hours, the importance of this kind of measurement becomes more important to maintain stable operation in electron-positron linac at KEKB.

REFERENCES

[1] K. Nakao, et al., "The Results of High-Power Klystron Dip Test in the KEK Linac."(in Japanese), Proceedings of the 29th linear Accelerator Meeting in Japan, pp.272-274 (2004).

[2] I. Abe, et. al., "The KEKB injector linac", Nucl. Instr. and Methods A, Vol. 499, pp. 167-190 (2003).

[3] S. Fukuda, et. al., "Design and Evaluation of a Compact 50-MW RF Source of the PF Linac for KEKB Project", Nucl. Instr. and Methods A, Vol. 368, 3, pp. 561-571 (1996).

[4] A. S. Gilmour jr., Ch.5 of "Principles of Traveling Wave Tube", Arthch House INC. (1994).

[5] M. G. Bodmer, "Dip Testing, A New Method for Measuring Cathode Activity", IRE Trans. on Electron Device (Experimental Note and Techniques Section), Vol. ED-5, pp. 43-44 (1958).

[6] X. Y. Zhao, "A Study of the Emission Performance of High Power Klystron - SLAC XK-5", SLAC TN-81-5 (1981).

[7] H. Katagiri, et al., "Data Taking System of the RF Measurement at KEK e+/e- Injector Linac"(in Japanese), Proceedings of the 29th linear Accelerator Meeting in Japan, pp.264-266 (2004).

0-7803-8859-3/05/$20.00 ©2005 IEEE