CPI 100KW KLYSTRONS OPERATION EXPERIENCES IN NSRRC*

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Abstract

In 2004, National Synchrotron Radiation Research Center (NSRRC) had decided to upgrade its traditional copper cavity in storage ring of Taiwan Light Source (TLS) to superconducting cavity. To achieve this, the RF power source-the klystron had been upgraded by intensive cooperation with CPI (Communication & Power Industries) from 70kW to 100kW with model number of VKB-7953B. The same 100kW klystron would then be also adopted as the RF source in booster in 3GeV Taiwan Photon Source (TPS). In this article, four CPI klystrons have been tested in detail as basic characteristic understanding in custom test stand in NSRRC. Five power measurement methods were applied and showed consistent between them for accurate enough results. Some encountered phenomenon would be discussed and the results show that these klystrons from CPI have obvious performance variation of on-site tests in NSRRC.

INTRODUCTION

Before 2004, the storage ring of Taiwan Light Source (TLS) uses room temperature copper Doris cavities for 1.5GeV, 240mA beam operation. At that time, the RF power was provided by two 70kW CPI klystrons (VKB-7953) using crowbar type high voltage power supplies. For the growing beam line and beam current requirement of scientific users, the Science Council of Taiwan had agreed to upgrade the room temperature copper cavity to superconducting RF cavity [1]. For the enhanced RF power requirement of the SRF cavity for maximum electron beam current of 500mA and doubled gap voltage of 1600kV, the klystron power needs to be upgraded to 100kW to satisfy such operation condition. Since the on duty klystrons were designed and manufactured by CPI (Communication and Power Industries) in American, the NSRRC had started intensive cooperation with CPI for upgrading the klystron power from 70kW to 100kW (VKB-7953B) by modifying the old klystron design with beam voltage/current enhancement. The picture of CPI VKB-7953B 100kW klystron is shown in Fig. 1. The specifications of the klystrons are listed in Table I. Also, we also upgraded the power availability of the present crowbar type HV power supply from 24.5kV, 5.5A to 30kV, 8A. After the above two major upgrading, the new klystron shall generate enough RF power to SRF cavity loading with the improved synchrotron beam current.

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Table 1: Specification of CPI Klystron for NSRRC—Before and After Upgrade

	VKB-7953 (SN F1-02)	VKB-7953B (SN 101)
Center frequency	499.66 MHz	499.65 MHz
Output power, Saturated	70 kW	100 kW
Beam voltage	24.5 kV	28 kV
Beam current	5.5 A	7 A
Mod-Anode voltage	19.5 kV	24 kV
Solenoid current	31 A	33 A
Drive power	8.8 W	7.63 W
Efficiency	52 %	50.8 %
Bandwidth	3 MHz	5.4 MHz
Heater current	17.6 A	17.9 A
Max load VSWR	1.1	1.1

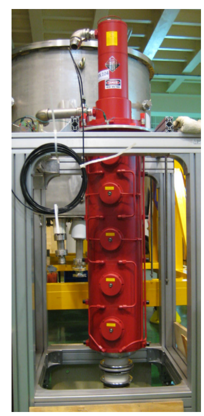

Figure 1: The CPI 100kW klystron on the supporter.

After successful commission, TLS has been operated for about twenty years [2] while the technology also has progressed much in the accelerator field, especially the global trend in construction higher beam energy and current for the advanced science study requirement of beam line users. The plan for higher brightness synchrotron facility was emerged and then started to design for several years [3]. The new Taiwan Photon Source (TPS) had ground-breaking ceremony in 2009 and still in good progress at present. The booster of TPS plans to adopt the same 100kW transmitter system as TLS storage ring. To support the simultaneous operation of two synchrotrons, at least four klystrons are needed for reliable operation for both systems. Hence, five CPI 100kW klystrons were purchased and one of them is left for test purpose in the RF lab.

During the usage of the first CPI 100kW klystron for SRF operation at TLS, the on-site test of the output power was found to be difficult to reach the claimed 100kW saturation power in CPI factory. To clarify the actual performance of each 100kW CPI klystrons on the RF test stand in NSRRC, four CPI klystrons have serial numbers from 101-104 are test in succession.

TEST STAND SETUP AND SOME EFFORTS FOR MINIMUM VSWR

Before starting the successive tests for these klystrons, there is a RF test stand containing a high voltage power supply cabinet and a klystron cabinet in basement of RF lab, a vertical waveguide piping to the first floor, a 150kW circulator and a 100kW water load on 1st floor. The total VSWR from water load to the doorknob interface of klystron in basement was measured. Hence, the VSWR would include the sum effects of bending waveguides, waveguide bellows, circulator and the water load. Then, we found the total VSWR is not good enough for best klystron power operation. Hence, the water load was replaced by a ferrite load while the high VSWR bending sweep waveguide was replaced by a good one. After these optimization, the VSWR can be lower than 1.07 (S11<-29dB). The final version test stand setup is shown in Fig. 2.

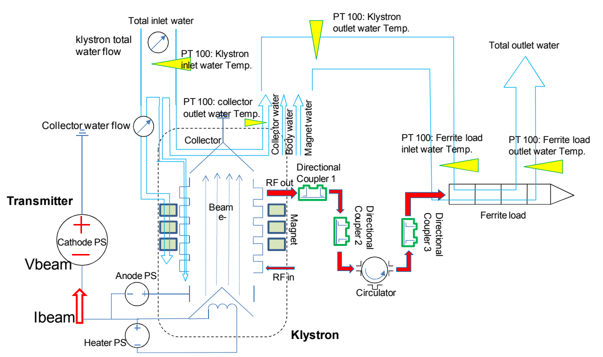

Figure 2: RF test stand for CPI 100kw klystrons with improved VSWR.

As shown in Fig. 2, while the klystron operated with full beam power without RF, the collector water, magnet water and body water cools the klystron and then flows to the ferrite load. Thus, the inlet temperature of the load would be higher than the inlet water temperature of klystron. This is the reason for replacing water load by ferrite load for removing the temperature relating VSWR of water load. Besides, five PT-100 accurate temperature sensors (the yellow arrow shown in Fig. 2) are immersed inside water flow pipe for real time and accurate water temperature measurement. The water flow rates are also read by variable-area type water flow meter (also named rotameter and is a glass tube with a float inside for flow rate indication). These water flow rate and temperature variation of water would later then be used for power measurement and calibration. In addition, three RF directional couplers are also installed along the RF feed line. The first one is just next to the output doorknob of klystron, the second is positioned at input port of circulator and the third one is just put at input port of the ferrite load. These directional couplers would then be used for forward power measurement of klystron power.

PARAMETERS CALIBRATION FOR POWER MEASUREMENT

For a CW power measurement, the most convincing method is calorimetric method which adopting the water flow rate times the difference of inlet and outlet temperature for calorific capacity measurement. Before doing calorimetric measurement, some parameters were calibrated first: the cathode voltage/current. The cathode voltage generated by the crowbar type HV power supply is calibrated by three HV probes and the meter on a low power HV power supply (by Glassman) and average these values as the calibrated cathode voltage. For cathode current for klystron, the values on a clamp current meter, multi-meter in series connection and the meter on a current power supply are averaged as the calibrated cathode current. The accurate HV voltage and cathode current are then be used to calibrate water flow rate as klystron is operated at Beam On state (no RF input). For water flow rate calibration, the readings of PT-100 temperature sensors are also calibrated by recording the initial temperature values. Thus, the water flow rate can be calibrated by (Eq. 1) where $\varDelta T_{collector}$ is the difference of inlet and outlet water temperature and $Q_{collector}$ is the dissipated power on water and m_w is the water flow rate per second. The power unbalance between beam power and calorimetric power in water is less than 2%.

$$P_{beam} = V_{beam} \cdot I_{beam} = Q_{collector} = 4.18 \cdot \dot{m}_w \cdot \Delta T_{collector} \quad (1)$$

After carefully calibrating the water flow rate, the calorific capacity is then used to find the dissipated RF power out of collector and on ferrite load. Thus, the RF power by calorimetric method would then have two ways to be obtained: beam power (V_{beam}*I_{beam}) subtract collector dissipated power ($Q_{collector}$) (Eq. 2) and the calorific capacity of ferrite load water (Eq. 3). $P_{RF}1$ is the first calorimetric method of RF power by subtracting collector power from beam power and $P_{RF}2$ is the second calorimetric RF power of the ferrite dummy load.

$$P_{RF}1 = P_{beam} - Q_{collector} \quad (2)$$

$$P_{RF}2 = 4.18 \cdot m_W \cdot \Delta T_{Load} \quad (3)$$

Besides, three directional coupler using factory given coupling coefficient are adopted for direct RF power measurement by power meter (Agilent E4419B).

MEASUREMENT RESULTS

Before formal tests of each klystron, the accuracy of the five RF power measurement methods were confirmed in Fig. 3 which shows the derived values at different power levels. Method 1, 2 and 3 are read from the directional couplers, Method 4 is $P_{RF}1$ and Method 5 is $P_{RF}2$ as mentioned in last section. These fives independent power measurement methods shows less than 4kW uncertainty in between. Such discrepancy of power may result from the +/- 0.2deg Celsius variation with

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water flow rate of 164.8 lit/min. The water temperatures are sampled after keeping the same power level for at least 20mins. The power balance results show that the power measurements are accurate enough.

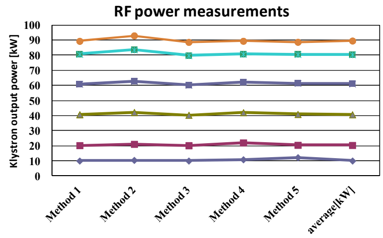

Figure 3: the power balance for RF power calibration of the klystrons.

The four CPI klystrons are all tested as driving power versus output power and using the vendor-CPI provided factory test curves as reference. Each klystron is tested till their maximum saturation power in stable situation. In Fig. 4, the klystron SN101 shows lower gain and lower saturation power than the factory result. The curve at 28kV, 7A of SN101 has sudden power drop due to certain unstable at that power level. Since this one was the first upgraded 100kW klystron, there may be some factors not in careful tuning such as VSWR tolerance at the RF coupling cavity. The maximum available power is 87.5kW for klystron SN101.

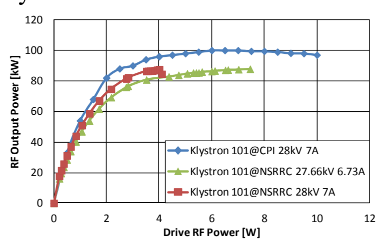

Figure 4: The comparison of drive/output power curves of klystron SN101 between NSRRC and CPI.

The klystron SN102 was also tested as shown in Fig. 5. The result presents obvious lower gain and lower saturation power of 89.4kW than the factory test data.

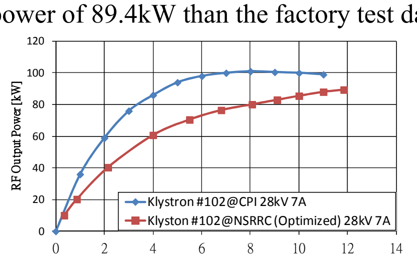

Figure 5: The comparison of drive/output power curves of klystron SN102 between NSRRC and CPI.

Later, klystron SN103 was also tested with some optimization by tuning its cavities. Hence, some output power improvement was made as shown in Fig. 6. With such minor tunings, this one showed higher gain but still lower saturation power of 93.4kW than the factory data.

The klystron SN104 showed quite similar curve as the factory data plot of Fig. 7. It has slightly lower gain and can reach 102kW output power. Although the obtained power is a little lower than the factory test data, this is the only one that most matched with the factory data. In summary, the power degradation percentages of the four klystrons are 12%, 11%, 7% and 5% in separate.

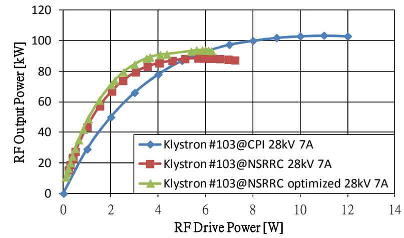

Figure 6: The comparison of drive/output power curves of klystron SN103 between NSRRC and CPI.

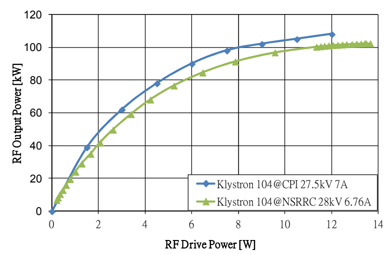

Figure 7: The comparison of drive/output power curves of klystron SN104 between NSRRC and CPI.

CONCLUSION

Several power calibration methods are implemented for accurate power measurement for four 100kW CPI klystrons in NSRRC. The measured power discrepancy between the different methods is acceptable (+/-0.2deg reading temperature variation of 4kW error). The power degradation percentage from SN#101 to SN#104 shows range from 12% to 5% when compared to factory test curves. Since the test environment in NSRRC RF lab is quite complex and contains more varying variables than CPI factory, the obtained results show us that the upgraded CPI VKB-7953B klystrons seems to have critical operation condition and there might be some systematic problems for CPI klystrons on the test stand in NSRRC. This article is not intended to depreciate the products of CPI since some R&D factors are still within. On the contrary, these tests tell us that there shall be many technical and practical factors affecting the RF power tube device to have satisfying performance.

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