HIGH POWER KLYSTRON AMPLIFIERS FOR THE PLS AND PLS-II STORAGE RING *

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Abstract

The RF system of the Pohang Light Source-II (PLS-II) storage ring is operating at the 3.0 GeV/340 mA with three superconducting RF (SRF) cavities. PLS-II RF system was upgraded to 3.0 GeV/400 mA(max.) beam storage from 2.5 GeV/ 200mA of PLS. Each high power RF (HPRF) station is composed of a 300 kW klystron with power supplies, transmission components including a 350 kW circulator and load, and water cooling system. The klystrons are generally operated as a RF power source with high gain amplification for RF system of light sources. This paper describes the present operation status of 300 kW klystron amplifier and experiences of the former PLS 75 kW klystron amplifiers as well as RF system.

INTRODUCTION

The PLS-II machine of 3.0GeV is the upgraded third synchrotron light source from PLS of 2.5GeV. PLS-II has a full energy Linac and a storage ring. The PLS RF system was five independent RF stations. Each station was consisted of a modified 75kW klystron amplifier, a circulator, a single-cell normal conducting RF cavity with precise controlled water cooling system, all connected by 6-1/8" coaxial transmission lines and analogue type low level RF system [1][2]. But the upgraded PLS-II RF system in 2015 is operating for beam current of 340mA with three superconducting RF cavities supplied RF power through WR1800 waveguides from three 300kW klystron amplifiers with high voltage power supplies, and digital type LLRF control system [3]. Figure 1 shows the block diagram of PLS-II RF system with 300kW klystron amplifiers.

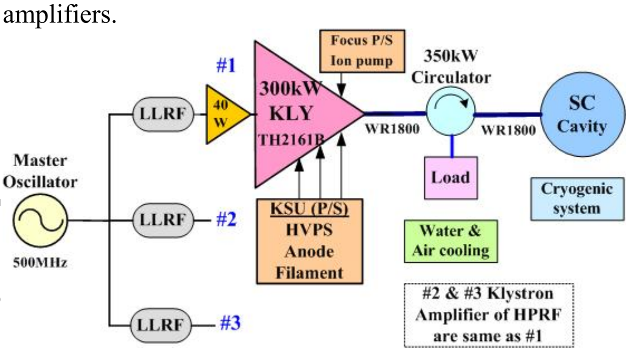

Figure 1: Klystron Amplifier at PLS-II RF system.

Also table 1 shows comparison of main parameters for PLS and PLS-II storage ring.

Table 1: Comparison of PLS and PLS-II

Specification	PLS(~2010)	PLS-II(2015)
Energy/Current	2.5GeV/200mA	3.0GeV/400mA
Emittance	18.9 nm-rad	5.8 nm-rad
Circumference	280.56 m	281.82 m
Total RF Power	200 kW	480 kW
RF Frequency	500.082MHz	499.964MHz
RF Power Sources	75kWx5	300kWx3
RF Voltage/Cavity	1.6MV, 4 NC	4.8MV, 3 SC

KLYSTRONS AS RF SOURCES

Klystrons have been used as RF sources for almost particle accelerators because of high power capacity and efficiency. Three 300kW high power klystron amplifiers are operating for PLS-II and some 60~75kW klystrons were used for PLS RF system. The TH2161B klystrons are operating some light sources such as SLS, IHEP, CLS, SSRF, TPS and NSLS-II storage rings. Table 2 shows comparison of klystron parameters: TH2161B of 300kW for PLS-II and K3773BCD of 75kW for PLS storage ring RF system [4].

Table 2: Comparison of CW Klystrons

Specification	TH2161B	K3773BCD
Frequency (B/W)	500MHz(2MHz)	470~860MHz (7MHz)
RF output (CW)	310 kW(max)	75 kW(max)
Beam V/I (peak)	54kV/9.5A	26.5kV/6.3A
Gain/Efficiency	40dB / 60%	35dB / 45%
μ-Perveance	1.62	2.00
Cavities	5 Integrated	4 External
Maker	Thales (France)	EEV (UK)

K3773BCD klystron was originally manufactured for UHF-TV transmitter application, and to be modified to CW operation for light sources. Similar UHF-TV klystrons of K3672BCD and K3775BCD are still operating at Elettra and Bessy-II [5].

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KLYSTRON AMPLIFIER OF PLS-II

A high power RF station of PLS-II is consisted of a Thales TH2161B klystron, a klystron power supply unit (KSU) and WR1800 waveguide components such as a circulator, a ferrite load. A 300kW klystron amplifier is composed a KSU and a klystron separately as figure 2. The KSU consists of a high voltage power supply up to 55kV/12A with 86 pulse step modulator (PSM) modules, a heater and a mod-anode power supply. Two focus magnets and ion pump supplies are separately installed at a 19 inches cabinet with a 40W drive amplifier. Three klystrons with KSUs have been operating about 22,539, 16,545 and 7,285 hours each so far in April, 2015 without any severe problems.

Figure 2: Three 300kW klystrons and KSUs.

Minor problems of klystron amplifiers were 40W drive amplifier faults, over-temperature at window of klystron, unnecessary arc sensing due to welding or radiations, water leakage to klystron window due to flood damage, cleaning process due to soot of local fire, V-belt stretching and breakdown of blower motor due to deterioration, and a few failures of PSM modules for 3 years long after commissioning test. Also a few over-reflected failures were happened by malfunction of TCU of circulator. After a local fire accident at tunnel in 2012, detectors of arc, smoke and over-temperature are added inside of KSU to protect klystrons. Table 3 shows present operation data of the klystron amplifier of 200kW maximum output for storage current of 340mA.

Table 3: Operation Data of Klystron Amplifier

Equipments	Specification(max)	Operation
Klystron tube	300kW(TH2161B)	200kW
High Voltage P/S	55kV/12A	48kV/7.3A
Anode P/S	46kV/5mA	27kV/1.4mA
Focus P/S	150V/20A	86~126V/10A
Ion Pump P/S	5kV/3mA	4.9kV/0.0µA
Filament P/S	35V/35A	9V/27A
Drive Amplifier	40W	9~13W

PLS-II klystron amplifiers have been operating well because KSUs and klystrons have been proven the reliability at the third generation light sources such as SLS, CLS, SSRF under continuous operation for several years, and recently improvements of some faults during commissioning at NSRRC [6].

KLYSTRON AMPLIFIER OF PLS

The klystron amplifier of PLS was a little modified the 60kW (CW) UHF-TV transmitter made by Harris Allied in UK. The normal klystron beam voltage of 25kV and the beam current of 6A had been operated within 0.5% by an automatic voltage regulator and a high tension regulator. The first CW klystron of PLS was the YK1265 made by Philips. The YK1265 was a 60kW UHF TV klystron with four external cavities which can be adjusted frequency from 470 to 860MHz for UHF transmitter operation [7]. Therefore, life time for CW operation of the TV-klystrons is not so long compare to other accelerator klystrons which are operating only single frequency with internal fixed cavities. PLS klystron amplifier performances were decreased until 45kW maximum output power from 60kW after operating more than 25,000 hours. At the time two YK1265 klystron tubes were replaced with new one. The tubes each have been operated 28,466 and 33,537 hours. But the replaced No.3 K3672 klystron was failed with breaking of the 2nd drift ceramic during RF test after installation. Also the second replaced No.3 K3672 klystron was failed again with cracking of the 4th drift ceramic after 1,337 operating hours. Finally the 75kW klystron K3773BCD was installed and operated instead of 60kW because of power upgrade plan to increase storage current. After inspection the failures in detail by manufacturer, the klystrons was warranted and replaced with new one. Five 75kW klystrons were replaced including two failed klystrons for 8 years until 2011. Average lifetime of UHF-TV klystrons was 30,030 hours except two failed klystrons, and 18,290 hours including two failed klystrons [8].

LIFETIME MANAGEMENT

The klystron lifetime will be determined most likely by the cathode lifetime since other klystron components are operated at a moderate level. If the cathode end of life is defined as the perveance dropping to 90% of its value at t=0, one can make a reasonable prediction of 45,000 hours [9]. The klystron lifetime is mainly depended on an electron gun. The gun perveance P is determined as a coefficient of proportionality between a space-charge limited cathode current I, and the anode voltage Va, in three-half power in the Child-Langmuir law as micro-perveance $\mu P = I/ Va^{3/2}$.

The UHF-TV klystron lifetime were about 30,000 hours according to data of Elettra and PLS. But TH2161B lifetime will be expected to about 60,000 hours by experience of SLS, PLS-II and other lights sources. To extending the lifetime of the klystron maximally, careful operations should be done as follows [10]:

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- Klystron lifetime management is fast interlock and measurement to related operation parameters.
- In case of klystron parameters are over values, RF driving power or/and high voltage should be switched off.
- Klystron amplifier should detect the fault events and react as fast as possible within 300ns in order to prevent any damage inside klystron and high voltage power supplies.
- Klystron tube recovery procedure should be depended on the kind of events such as high reflection of output power, RF breakdown, high voltage breakdown, bad vacuum detection and arc detection of gun and window.
- Periodic checks of cathode emission are necessary to maximize the useable lifetime of a klystron cathode.

OPERATION OF PLS-II KLYSTRON

According to specification of TH2161B, maximum energy dissipation of klystron is 20 joules. That is the cathode power supply of 55kV/12A must imperatively be provided with a protective device to limit the energy dissipated inside the tube, in case of arcing or too abrupt current surge and reflected RF power. The following calculation shows the HVPS or drive power should be off within 30us according to fault events.

$$20W/55kV \times 12A = \sim 30 \times 10^{-6} \rightarrow 30us$$

The RF output should be switched off at 40W drive amplifier and low level RF control with PIN diode switch which is react within 2 us simultaneously for redundancy check by fast interlock signals. Also to save electricity with better efficiency of klystron, cathode and anode voltages are adjusted the maximum output RF power according to operation current of storage ring referring the amplification curve data of figure 3. For example, the klystron is operating for 200kW (max.) RF output with cathode DC supply of V_k=48kV and I_k=7.3A for 340mA of storage ring current. The klystron operation efficiency of RF power to beam over klystron output power is about 69%, and DC to RF efficiency is 54%.

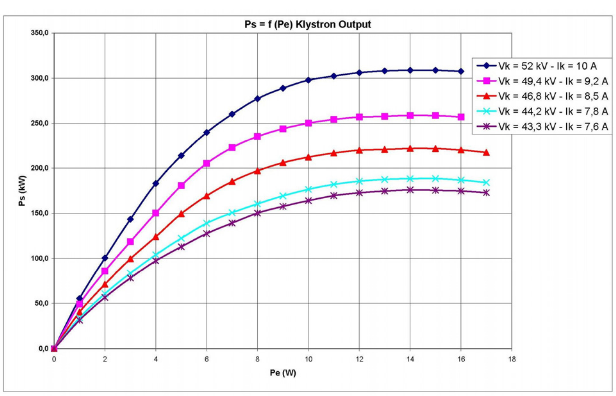

Figure 3: Klystron output power curve depend on V_k -I_k.

FUTURE WORKS

PLS-II klystron amplifiers have been operating well for 4 years with good reliability. In addition klystron operation efficiency *(P_beam/P_kly)* will be increased to more than 70% for saving electric charges within stable RF system operation. For that, RF phase variation versus beam supply and drive power with LLRF control will be studied in detail. Also machine studies to decrease harmonic sidebands and to increase lifetime of klystron amplifiers should be progressed to better operation status. Also main parameters such as efficiency, perveance, cathode emission with filament current and fast interlocks should be carefully managed. Exchange of operation information and maintenance experiences with other light sources operating the similar klystron amplifiers will be very useful mutually for stable operation of high power RF system as well as related works of high power RF system.

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