HIGH POWER KLYSTRON STATUS AT THE PHOTON FACTORY INJECTOR LINAC

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ABSTRACT

The status of the high power klystron at the photon factory injector linac is reported. Klystrons have been stably running and their MTBF during 2 years exceed more than 13,000 hours. Several troubles, failures and instabilities encountered are described in detail. Some trials to improve the tubes are also reported.

INTRODUCTION

The injector electron linac of the photon factory had completed the end of the March ,1982 and 2 years has passed since the scheduled operation began in June,1982. In this facility total 41 high power klystrons are operated as the microwave source of the linac and elecron beam of 50 mA is accelerated up to a 2.5 GeV energy. Generally speaking, operation of these klystrons have been satisfactorily working but several troubles or failures occured in this period. Continuous efforts to improve the klystron have been done to have more stable klystrons. This report describes the characteristics of the klystrons, operation status and hours, main failures and the improvements under going.

THE CHRACTERISTICS OF THE KLYSTRON

At the beginning of this project, 41 tubes with output power 21 MW were required for the 2.5 GeV acceleration. Our request for the klystron power was settled 30 MW taking account of the fault rate, total performance and future possibility of energy up plan. Those days the commercial tube with maximum output power was ITT tube (8840) with 28 MW, while SLAC had already developed the 38 MW klystrons (XK-5) and been operating for the high energy electron linac rf source. As it seemed to be very difficult to develop the new klystron with high power and high quality for a short term, our specifications of this tube were based on the XK-5. Resultant high power klystron was a MELCO (Mitsubishi Electric Corporation) PV-3030A, which was basically same design with the XK-5. Table 1 shows the specification of our klystron and the typical operating condition.

Table 1 Specification and opreating condition

	specification	operation
Max. beam voltage	270 kV	240-260 kV
Max. beam current	295 A	
Pervience	2.1±0.1 A/V $^{-3/2}$	
Average beam power	30 kW	
Beam pulse width	>4 us	3.5 us
RF pulse width	>4 us	1.0 us
Pulse repetition rate	100 pps	10 pps
RF frequency	2,856 MHz	2,856 MHz
Peak output power	>30 MW	20-30 MW
Efficiency	>40 %	35-40 %
Gain	>51 dB	45-52 dB
Focusing magnet	electromagnet	permanent

The vendor(MELCO) prefers to use the electromagnet as focusing the klystron electron beam and has been testing with it. On the otherhand our facility adopted to use the permanent magnet because it gives the advantages of easy maintenance and minimum operating cost. Its large disadvantage is uneasiness of changing the magnetic field. It was found that obtaining the complete matching between tubes and magnetic field was rather hard work. Also weak transverse magnetic field of the permanent magnet and cylindrical asymmetry give the large effects to the performance of klystrons. Almost all magnets are adjusted their effects by means of attaching the magnetic shunt (iron plate). Some of the magnets have small field shaping solenoids under the bottom york to vary the magnetic field across the cathode plane. Intense study for the magnetic field has been continued but still remains problems because of the frequent interruption due to the other troubles .(see below). Therefore resultant output power of test division in our facility is lower than that of specifications or the vendor's test results. Figure 1 shows the summary of our test results at the first setting in 1982.

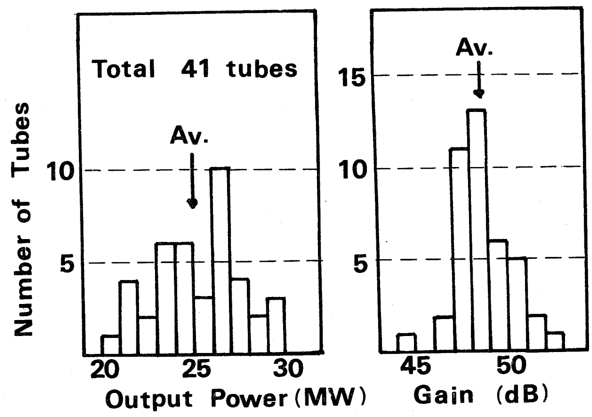


Figure 1. Test results with the permanent magnet.

KLYSTRON FAULTS AND OPERATION PERFORMANCE

Important factor on the operation in the klystron gallery is the fault rate due to the klystron. Too many faults lead to the interruption of the injection to the PF ring or AR ring, therefore stable operation requires the small fault rate. For example stable operation under the condition of less than 1 fault/hour probability corresponds to no fault for 41 hours per one klystron. Generally same problems became important at larger facility like SLAC.

For tube and modulator faults we prepared 4 kinds of interlock, i.e. trip off of drive rf, trigger pulse, high voltage pulse and complete operation stop. Typical fault patterns are trip off the trigger signal or high voltage pulse due to the overcurrent of integral ion pump (vacuum fault) and the overcurrent of the pulse beam (low impedance of the tube). This means that most dominant faults are due to the arcing in the tube. Sometimes applied beam voltage to the klystron must be lowered to reduce these fault rate. Also several klystrons became unstable due to the diode oscillation or other instabilities. The crite-rions of replacing the klystrons in our facility are as follows.

(a)Less than 10 MW output power due to the low beam voltage.

(b)Continuous occurence of faults even though beam voltage is decreased.

(c)Uncontrollable instabilities of the tube.

(d)Other klystron failures.

Continuous improvements described next section are making possible to decrease the fault rate year by year. Average fault rate in the beginning of 1983 was 4.8 faults/hours and recently this rate reduces to 2.6 faults /hours (i.e. 1 fault/23min.). Figure 2 shows the recent performance of gallery about the fault rate and the beam voltage to the tube .

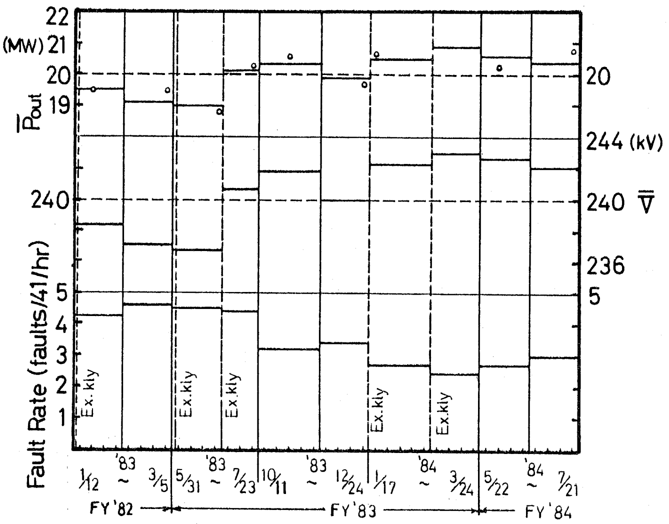


Figure 2. Recent performance about faults rate etc.

KLYSTRON USAGE AND FAILURES

OPERATION HOUR

Table 2-(a) shows the tube usage data of the past 3 years up to July,1984. Recently in each fiscal year the total operating time reached to about 2,500 hours,including high power processing of the tubes and acceralator guides. There used totally 63 high power tubes since full scale opreation began in 1982. There were 20 failures during these period giving MTBF(Mean Time Between Failures) of 13,200 hours. The mean age at failure is 2,300 hours, while the mean age of living tube is 5,100 hours. Table 2-(b) shows the historical tube difference. Obviously MTBF increases gradually year by year because of the improvements.

Table 2
(a) Cummulative usage hours of the past three years

Period	Total tubes	Failured No.	Failured Mean age	Living No.	Living Mean age	MTBF
1982/4-1983/3	53	11	1,306	42	2,933	12,505
1983/4-1984/3	63	20	2,285	43	4,169	11,247
1984/4-1984/7	63	20	2,285	43	5,075	13,195

(b) Comparison with historical lots usage

Tube	Total socket	Failured socket	Mean age(hours) Failured	Mean age(hours) Living	MTBF (hours)
1979	4	2	45	6,441	6,486
1980	20	9	2,282	6,313	9,998
1981	20	7	3,128	6,244	14,724
1982	9	2	1,586	4,102	15,944
1983	10	0	0	2,600	0

Various age distribution histograms for the high power klystrons are shown in Fig.3.

TUBE FAILURES AND IMPROVEMENTS

In this section the causes of the failures ,the counter devices and improvements will be described. Main causes of the failures are as follows.
(a)High voltage seal ceramic pin hole
(b)Filament short or open
(c)Mechanical failure
(d)Window pin hole
(e)Internal arcing

At the first stage, failure (a) was dominant. This was imagined that ceramic surface was charged up by the electrons emitted from the imperfect brazing joint between ceramic and metal. Typical phenomena were flashing glow in the tube and resulted in the colored ceramic surface. This was initially avoided with the corona shielding cylinder around the brazing part and recently with the design change from cylindorical to the conical shape ceramic.

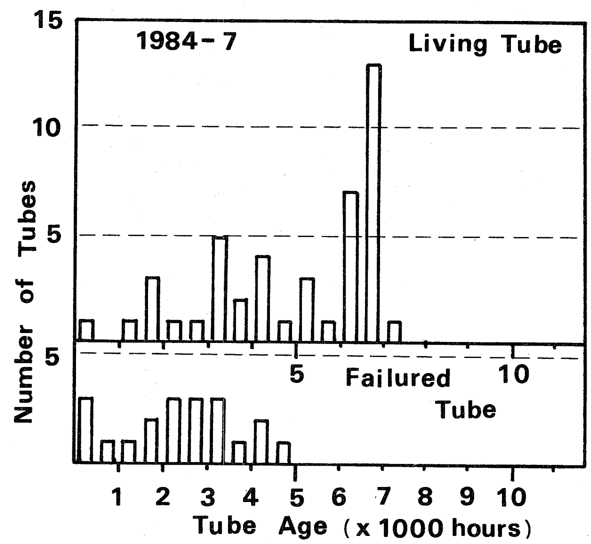


Figure 3. Age distribution of the failured and living tubes.

Failure (d) and (e) are serious and essentially not solved yet. Window pin hole or breakdown is caused by the local arcing due to the bad pressure, high reflected power or imperfect proccessing of the window ceramic. It was found that ceramic itself had rather large outgasing rate under the small output power(less than 1MW) and glow discharge was always observed. Careful operation and processing at the start-up are done currently and seems to be effective. It is said that air explosure on the ceramic surface is harmful so that nitrogen gas is filled to inside as much as possible when tubes are stored. Window study and coating work are under preparing to solve this problem.

Arcing is the most serious problem to our tubes. Common phenomena are that possible applied beam voltage between anode and cathode gradually decreases because of large fault rate. Possible one cause of these faults is due to the collector troubles. This means that collector melting occures by the imperfect beam dispersion in the collector due to the strong reverse fringing magnetic field of permanent magnet. In fact small melting copper balls were found from some of the resolved klystron cathode. This problem was solved by means of with adding the magnetic shield to the collector parts. But internal arcing still remains problems.

Basically internal arcing has strong relation to the gun structure itself, material used and how to procces the gun assembly, i.e. cleaning or outgasing process like vacuum firing or induction heating under low pressure. This kind of trouble has been pointed out for a long time and intense study to achieve the more stable electron gun has been done in SLAC. Our facility and the vendor have tried to colaborate to improve this problem and current items related are as follows.

(a) Imporvement of the oxide cathode ; Oxide cathode electron gun needs essentially so called "conversion process" and this process has excessive outgas rate. This might seem to lead the large contamination to the inside structure. Sometimes anode nose of the tube was found to be contaminated due to the initial evapolation of the Ba etc. and attached the black thick film. It is not clear that this is something to do with the internal arcing. Vendor tries to improve the oxide cathode itself by means of control the manifacture process and careful selection of nickel powder and carbonate material. Other possible trial is to use the different type of cathode like the dispensor cathode. This is also going to start.

(b)Design improvement of the gun ; Arcing has strong relation to the gun structure because very high voltage is applied to rather narrow space between anode and cathode. One trial is changing the shape of focus electrode and another is developing the low gradient gun. These improved klystrons are now waiting for testing in KEK.

(c)Material used in the gun ; Materials used in the gun parts seems to be also important and there are many rooms to consider what materials are most useful. Recently it is pointed out that carbon is harmful to the gun at SLAC. Stainless steel is used to the focus electrode in our tube and currently more low carbon material(ex. SUS-316L) is begun to use.

(d)Improvement of the processing ; As all parts of the gun assembly are used in the severe circumstance like very low pressure (about 10^{-8} Torr), high temprature(about 850 ℃) and high voltage(about 270 kV), careful cleaning process becomes important to get the more reliable gun. Currently processing of the assembly is performed with more reliable oil-free pumps for the outgasing like vacuum firing and induction heating.

These current programs are performed at the vendor's facility under the colaboration between KEK and the vendor. As arcing phenomena are observed after the very long operation run, it is difficult to evaluate the rapid progress but steady improvement will be expected.

INSTABILITIES

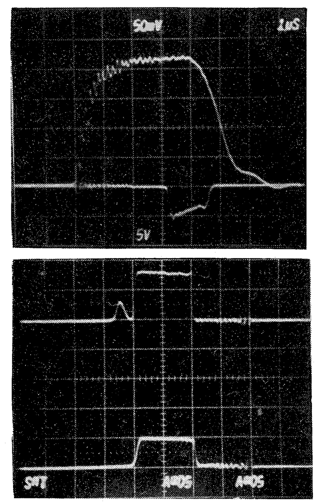
Other bothersome problems for the tube are its instabilities. These instabiliteis leads to the unfavorable modulation or unstable output and finally to the fluctuation of the accelerated beam energy. This section 3 kinds of instabilities are mentioned, i.e. diode oscillation, instability related to the harmonics and some abnormal rf pulse wave shape due to the inadequate focusing field.

Diode oscillation is observed in 5 tubes. Generally the performance of these tubes are normal at the KEK test when delivered from the vendor, but oscillation occures after a few hundred hours operation runs. This fact may mean that the cause is by getting worse the symmetricl cathode loading or the some part of the cathode. Frequency of this oscillation can be picked out from the pulse transeformer tank or input rf plug without any drive rf power and generally destribute to the range of 3.2-3.5 GHz. Theoritically this oscillation occures inevitably at the some beam voltage under the space charge limited operation of the gun. Temporary way to quit oscillation is to lower the beam voltage below the threshold or heater voltage nearly to the temperature limited operation. Almost all these oscillating tubes barely quit oscillations in this way. Figure 3 shows the photograph of the wave shape of the diode oscillation.

Second instability is associated with the 3rd harmonics of 2,856 MHz and this frequency is observed through input port of the tubes. As this frequency is not cut off in the drift tube of the klystron, something happens in the region of collector and output cavity. Also asymmetrical focusing field has some relation to this instability.

Abnormal rf pulse wave shape is sometimes observed both in gallery and test devision. Usually careful adjustment during the test excludes this kind of instability as much as possible but sometimes this leads to the unstable performance during the operation. This is mainly observed in adjusting the focusing field of the permanent magnet. Typical wave shapes are as follows. (1) Reduced pulse amplitude, with flutter in both time and amplitude. This may jump between two discrete levels with drive power variation. (2) Increased pulse amplitude with flutter in both time and amplitude componentof pulse. (3) trailing edge flutter. (4) "Glitch" wave form which sometimes contains the higher frequency beat. Similar wave shapes are known at SLAC, where the permanent magnet is also used as focusing.

These instabilities mentioned above are our future task. To solve these problem, the foundamental process concerned should be understood at first.



(a)

(b)

(c)

(d)

Figure 3. Wave shape of the diode oscillation.
(a) Pulse beam current,(b) Oscillation waveform without drive rf,observed from the input port,(c) Drive rf waveform without diode oscillation, and (d)with diode oscillation.