STATUS AND PERFORMANCE OF PF INJECTOR LINAC

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ABSTRACT

PF injector linac has been improved on a buncher section for accelerating of intense electron beam, and reinforced a focusing system of the positron generator linac for the expansion of phase space. In this presentation, I shall report present status and performance of PF injector linac, and discuss its upgrade program for B-factory project.

1. INTRODUCTION

Operation of the PF 2.5 GeV injector linac was satisfactorily performed during the 5 period from FY 1987 to FY 1992 as shown in Table1. Several improvements have as following: Improvements in the high power klystrons started for the extend of its life time in 1985. In addition, improvements in the focusing system just downstream from the position of geranium target have been done for reinforcement of positron beam since 1989. Preparation for the replacement of the control system which has been used since 1983 on the operation of the injector is in progress. Improvements in the operator's console system using NetWare system has been developed. In addition to these improvements, research concerning highbrightness beam generation at the test linac, and production of slow positron beams using the PF 2.5 GeV injector linac, has been performed.

Research and development for the injector linac has been advanced for B-factory project, which is presently under consideration as the next project in KEK. The injection system (pre-injector) of the PF 2.5-GeV linac was extensively upgraded during the summer of 1992 so that intense beam acceleration can be investigated. This represents the first step toward upgrading the linac in order to meet the requirements of the B-factory. It requires intense beams in order to achieve a practically short injection time. It is therefore important to understand how high-intensity electron beams, which will be used for positron production, can be accelerated up to 4.5 GeV in the injector linac. Studies concerning high-current beam will be performed using the upgrade linac.

Reinforcement of the electron-beam energy from 2.5 to 8.0 GeV is also an important factor of this project. If this large increase in the energy is possible, both 8-GeV electrons and 3.5 GeV positrons can be injected directly to asymmetric rings. High-power microwave sources, power multiplying techniques, such as a traveling-wave resonantring or SLED(SLAC energy doubler), and are being investigated.

Accurate beam tuning is important for high-current beam acceleration in order to avoid any beam instability due to wakefields and precise beam-position monitors which are indispensable for this purpose are under development. The results of these studies concerning the B-factory during this period are described.

Table 1 Operation and failure time of injector linac

Period FY	operation time (hr)	failure time (hr)	operation rate (%)
1987	4,016	179.8	95.5
1988	5,108	236.7	95.4
1989	4,542	58.7	98.7
1990	5,303	89.3	98.3
1991	5,234	130.0	97.5
1992	5,116	71.2	98.6
total	29,319	765.7	97.4

2. OPERATION

During the long period from October of 1987 to September of 1992, the PF 2.5-GeV injector linac has been stably operated with a total operation time of 29,319 hours and an operation rate of 97.4%. The operation statistics for this period are given in Table 1. There were no severe failures which would take a comparatively long recovering time during the period from FY 1992 to FY 1993.

The electron gun of the PF 2.5-GeV injector linac was replaced from the oxide type to the barium impregnated(BI) type (expecting a long lifetime) during the scheduled maintenance in November, 1991.

Klystron with BI cathode have been introduced into the PF 2.5-GeV injector linac since 1987, and replacement was completed by end of July, 1991. A very low fault rate of the BI tubes at a comparatively higher anode voltage was also obtained.

3. PROGRESS AND IMPROVEMENT

3-1 Positron Beam Improvements due to the use of a New Pulsed Solenoid.

The focusing system of the KEK positron generator linac was recently reconstructed in two steps. After the improvements, the positron beam was increased by a factor of 1.5, as was expected based on a general consideration.

Both the pulsed focusing solenoid and its power supply were renewed. The new power supply was installed in the summer of 1991; the pulsed solenoid was then replaced with a newly designed one in January, 1992. In order to avoid any problems, such as water leaking into the vacuum, the pulsed solenoid was required to be out side of the vacuum. Moreover, it was designed to make the solenoid angle wider and, as a result, to increase the positron yield. The parameters of the pulsed solenoid were changed, as listed in Table 5. We decreased the number of windings by half in order to make the pulsed solenoid shorter. The maximum applied current was increase from 5 to 10 kA. The field has been greatly improved from 1.2T×76 mm to 2.3T×45 mm.

The features of the new positron focusing system are as follows: (1) the shorter pulsed solenoid made the acceptance larger; (2) though the pulsed solenoid became shorter, the stronger field keeps the acceptable positron momentum($P \sim B_i L$) higher, while suppressing any debunching effects due to their velocity/orbit difference; (3) the stronger DC-coil field(B_f, which is applied just after the pulsed field, keeps the positron momentum acceptance($\delta P \sim P(B_f/B_i) \sim B_f L$)wide. The factor for the positron yield was evaluated while taking in to account the angular dependence of the positron production cross-section.

The new pulsed solenoid was installed in January, 1992. The 2 ns positron beam injected in to the TRISTAN ring was increased by about 50% after the improvements in the pulsed solenoid. The 40 ns positron beam for the PF ring was also increased by more than 50%.

3-2 CONTROL SYSTEM REJUVENATION

An upgrade of the main part of the control system is now under way. since the system resources have become inadequate and the computer company no longer supports our mini-computers, we will replace the mini-computers as well as the main computer network.

Unix-based workstations, VME-bus computers and standard communication network will be employed in the new system. A group of Unix-based workstations will be employed in the new system. A group of Unix-based workstations will serve as an interface to the operator's console system, and will manage the data bases and communications between other control components. The VME-bus computers will control the communication software will be based on the TCP protocol for scalability, since it is widely available

Since the main part of control software will also be upgrade. The system software has been developed so as to support both the old and new control schemes. Since we invested much in the operator's console system using old-formatted control messages, we will continue to support it. A new control scheme is also being developed on the basis of an object orientation concept. It includes anew control message format with device or class names, commands and realistic parameters instead of binary numbers. It will make the development of application program easier.

At the time of the upgrade, a transition from the old to the new systems must be careful to carry out a smoothly. A gateway system between the old and new systems have been developed for this purpose. It will hide most of the complexity at the transition time. The transition is expected to take place during the summer shutdown of 1993.

3-3 Operator's console system

The operator's Console Network has been install in order to replace the DSLINK systems, which have been used for a human interface in the PF 2.5 GeV injector linac control system. Most of the application programs written for the DSLINK are completely upward compatible on the new NetWare network system. The reliability of the network file sever has been improved in the new system. Although we used to experience many unexplainable faults(troubles) under the DSLINK, there has been no problems experienced with the new system during the past 4 months. A new concept of OOP(object-oriented programming) is also introduced in the PC network environment.

4. RESEARCH

4-1 Test Linac

In the test linac , emittance measurements of electron guns with three different types of cathodes (a barium-impregnated cathode, a single-crystal LaB_6 and polycrystal LaB_6) have been carried out. Details concerning the emittance-measurement system, in which a pepper-pot mask with many pinholes is used, have been reported elsewhere.

4-2 Slow-Positron Source

After the summer shutdown in 1991, the first machine study of the slow-positron source project was conducted on 19 November of 1992. By that time, since the switch-yard line to the slow-positron source chamber has been completed, we obtained each parameter for a 18-degree bending magnet, a Q-magnet and so on to transport a 2.5-Gev electron beam(a pulse-width of 2 ns)to the target chamber of the slow-positron source. During the winter shutdown, beam monitors for slow-positron were installed in the beamline. As detectors, five channel-electron multipliers were used for beam monitors within the 30-m length beamline. Together with the 20sets of steering coils, the slow positron beam would be adjusted to the proper trajectory.

From 25 February of 1992, an experiment to irradiate Ta targets by the 2.5-GeV electron beam was started. The experimental area is situated just at the north end of the klystron gallery.

Transported positrons were detected at the end of the beamline by a photomultiplier tube(HAMAMATSU H26611) with a BGO sintillator. The first result to obtain annihilation gamma rays were obtained on June. The estimated number of slow positrons which were transported from the target to the beam end was 10^3/kW. The beam parameters at that machine study time were as follows.

The electron beam had an energy of 2.0 GeV, a pulse width of 2ns and are repetition rate of 25 pulse per sec. During irradiation of the 2.0-GeV electron beam, the target is easy to heat, unless the power of irradiated beam is only about a few watts. During the summer shutdown in 1992, we modified the target moderator structure by cooling the new target assembly. The estimated number of slow positrons detected at the end of the beamline is 10^5/kW.

5. R&D Regarding B-Factory

5-1 New High-current Pre-injector

The upgrade of the pre-injector was performed the summer shutdown of last year. The electron gun was newly designed. The gun voltage was increased up to 200 kV in order to increase the beam current without space-charge effect. A double pre-buncher and a enhanced field buncher were adopted in order to obtain short bunched beams. The pre-buncher has designed as matched with 200 kV beams, and each bunchers were designed as the traveling-wave structures.

The new system was capable of independently adjusting the phase and power level, and was rearranged so as to easily adjust the beam phase with respect to the rf in the accelerator sections. The focusing system was reinforced by the extension of solenoids to the end of buncher. The various beam monitors were provided in order to measure its emittances and sizes. The momemetum analyzer was replaced a new one which can observe to beam energy of 60 MeV. An energy monochromatic system was installed downstream the analyzer system in order to reduce a beam bunch length.

5-2 Beam Dynamics and Focusing System

The bunching scheme in pre-injector was performed a simulation study by use of the PARMELA for the optimum parameters to make the short bunch length and to keep its emittance small. The distribution of the particles in the beam was represented by several hundreds of macro particles in the six-dimensional phase space. The code takes into account the force by the electro-magnetic fields in the cavities and the focusing magnetic field and the space-charge force between particles. The emittances in the system was measured by observing the variation of the dimensions of the beam profiles on the fluorescent screen with the strength of the quadrupole. The bunch lengths are measured with the optical transition radiation emitted from a polished stainless-steel plate set on the beam line.

In the upgrade of this system, the beam transport system was reinforced the solenoidal magnetic field, the quadrupole focusing system and the energy monochromatic system(EMS) with bunch compression system. The new solenoid system with twenty-two Helmholtz coils were designed to make a magnetic field up of 1.4 kG in opposition to transverce effects of space charge.

Since electron beams with lower energies make longer detours, the bunch length will becomes shorter with trajectory compression after passing through the EMS.

For limited paper, I will skip descriptions as electron gun, pulse power supply, RF system, vacuum system, 500-MeV energy-analyzing system and monitor

5-3 Commissioning.

The injection system was install during the summer maintenance period from 11 July to 27 September of 1992. At first, almost the entire previous system in the tunnel was completely removed, then the new supporting girder tunnel was aligned on a beamline. All of the devices including two accelerator structures were set up on the girder. Test operations with electron beams were performed on 24 to 25 September. Normal operation for standing up to the machine started as scheduled. A very preliminary result is given in Fig. 1. After the upgrade of pre-injector, the beam currents increased as well as the transmission rate. The beam with pulse width of 2-ns has been increased in twice intensity and has been satisfactorily injected into the AR. The 4-ns and 15 ns beam are used only in machine studies. Some instabilities in the injector linac have been observed on the acceleration of very high charge beams. The investigations of intense beam acceleration will be served the upgrade of injector linac for the B-factory.

6. Energy Upgrade

6-1 Outline

The Upgrade of the PF 2.5-GeV injector linac for the KEK B-factory has being advanced in solemn silence. The linac length for reinforced energy of its own will be required to extend to 1.5 times by practical reasons such as the capacity limit of preset power utilities and the available high power klystrons. The extension in length of the linac has been planed the shape of J as to connect with in serial the two beamlines of the positron linac and the electron linac. This layout is effective for the mitigation of site limitation and the reduction of the housing budget, so be expanded from 300 m to 450 m in an effective length in accelerator by a slight additional extension of the present housing. A extension layout of the linac tunnel shows in Fig.1. Specification parameters for the upgrade are shown in table 2 .

Table 2 Parameter of present and future in the PF injector

	present			future	
	e+(PF)	e+(AR)	e-(AR)	e+(BF)	e-(BF)
Energy (GeV)	2.5	2.5	2.5	3.5	8.0
Pulse width (ns)	40	2	2	single bunch	
Particles/pulse 10^9	1.6	0.44	2.5	4	
Repetition (pps)	25	25	25	50	
Energy spread (%)	0.35	0.22	0.2	0.25	
Emittance 10^{-6} mrad	1.0		0.3	<1.0	

6-2 High-Gradient Acceleration Test

A high-gradient acceleration test has been carried out in order to prepare for a future energy upgrade project of the PF 2.5 GeV injector linac. In this project, the linac energy will be increased from 2.5 GeV to 8 GeV. Its factor is of 3.2 in energy. The energy upgrade will be performed by the methods as compression of rf power,extension of linac length and upgrade of klystron power. Regerding the upgrade of the rf power, one of the most inportant program is breakdown,such as in the rf windows and accelerator structures.

In the present acceleration unit, a klystron feeds rf power of 30 MW (max) with 3.5 s by 25 pps into four 2-m accelerator structures.

The full power from a klystron was supplied to an accelerator structure for check of the running performance under high power. The reliable test for high gradient acceleration has being continued at a level of 29 MV/m.

6-3 Modulator Upgrade

The energy upgrade of the PF 2.5-GeV injector linac demands the replacement of the present 30-MW klystrons with upgrade one. With the disposition, the existing modulator will be modified for reinforcement of power source. with upgrade modulator units. There are three limitations concerning modulator upgrade: the maximum available space at the klystron gallery, the capable electric-power capacity and the budget for the modulator. The specification of modified modulators has been proposed to two types as SLED and traveling-wave resonance ring in accelerator structure(TRA), respectively. The newly designed modulator was installed in accelerator section #4-6 and has been operated for the preparation of more practical tests utilizing SLED-type cavity.

Table 3 Specification of modified modulators

	Original	SLED	TRA
Maximum peak power (MW)	84	117	153
Maximum average power (kW)	14.7	30	30
Transformer step-up ratio	1:12	1:13.5	1:15
Output pulse voltage (kV)	23.5	23.5	23.5
Output pulse current (kA)	3600	5000	6530
PFN impedance (ohrm)	6.0	4.7	3.6
PFN total capacitance (mF)	0.3	0.6	0.6
Pulse width (micro-s)	3.5	5.6	4.3

6-4 High-peak Power Microwave

A SLED-type as microwave-pulse compressor devepoed by the JLC group t KEK has been used for a preliminary test, and it has being investigated a candidate for the more upgrade. The SLED enables a reduction in the maximum power of the rf-power source and has the advantage as the avoidance of any serious programs which may occur in development of a high-power klystron. The SLED cavity was designed so as to resonate at the TE015 mode with a Q value of 10^5 . In the accelerator guide with filling time of 0.5 s, the peak output power of the SLED in ideal calculation is 6.59-times the supplied power, and the energy multiplication factor is 2.01. In the practical operation, the multiplication factor was measured 5.9 times and its value is estimated at 97% of the calculation.

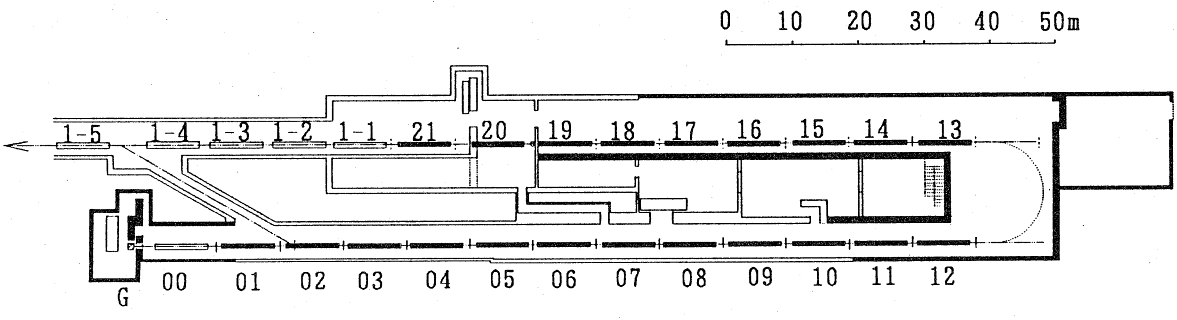

Fig.1 The extension layout of the linac tunnel.