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THE PHOTON FACTORY 2.5 GEV INJECTOR ELECTRON LINAC

J. Tanaka, I. Sato, K. Nakahara, S. Anami, S. Fukuda, K. Matsumoto, T. Shidara and A. Enomoto
National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 300-32, Japan

Summary

The KEK Photon Factory was financed from the 1978 fiscal year, and the project will be completed at the end of the 1981 fiscal year. The accelerator of this facility consists of a 2.5 GeV injector electron linac and a 2.5 GeV storage ring. The linac will also be used as the electron and positron injector of the KEK future project "TRISTAN" and for other purposes. A prototype accelerator unit ,which is composed of four 2 m long accelerator guides, a supporting girder and waveguide system, klystron modulator and other components of the linac,was completed at the end of March 1979 and is now under test.

The general picture of injector design, the status of construction and the results of tests are reported in detail.

Introduction

The Photon Factory (P.F.) is a dedicated facility at KEK for the production of Synchrotron Orbital Radiation (SOR). As an intense source of photons with wavelengths ranging from soft X-rays up to 0.1 Å hard X-rays it will be exceedingly valuable for research on various photo-induced phenomena in widely diverse scientific fields: crystal physics, molecular physics,surface physics, materials science, chemistry, biology, etc.

In 1977,preliminary planning and preparatory studies for the P.F. accelerator were begun with 40M yen taken out of KEK's own budget. The Photon Factory as a KEK facility was later officially established when in fiscal 1978 the government approved the construction of the Photon Factory. Approximatly 8000M yen was appropriated for the accelerator (injector linac and storage ring) and its experimental apparatus with an additional 8000M yen for buildings and supporting facilities. The entire construction phase is targeted for completion in 1981. These facilites are planned to be constructed on the west side of KEK's grounds. The 2.5 GeV injector linac housing is sited running south to north to allow connection in the future with project TRISTAN. The 2.5 GeV storage ring building is located at the injector-end in the northwest part of the site. The overall layout of the facility is shown in Fig. 1. Groundbreaking ceremonies for the injector tunnel were conducted in Feb. 1978.

The Photon Factory accelerator is composed of a 2.5 GeV linac and a 2.5 GeV storage ring. The ring will serve as a dedicated machine for "SOR" experiments with 6 channels including one for hard X-rays produced by a wiggler.

An electron linac was chosen for the injector not only because it can easily inject an intense beam into the storage ring, but also because it provides great flexibility; various energy beams, 400 MeV, 1 GeV etc.,can be extracted for injection into lower energy storage rings dedicated for soft X-ray studies, lithography and so forth. It will also be capable of producing very short (picosecond range) single pulses of light, and,of course,eventually it can serve as the electron-positron injector for TRISTAN.

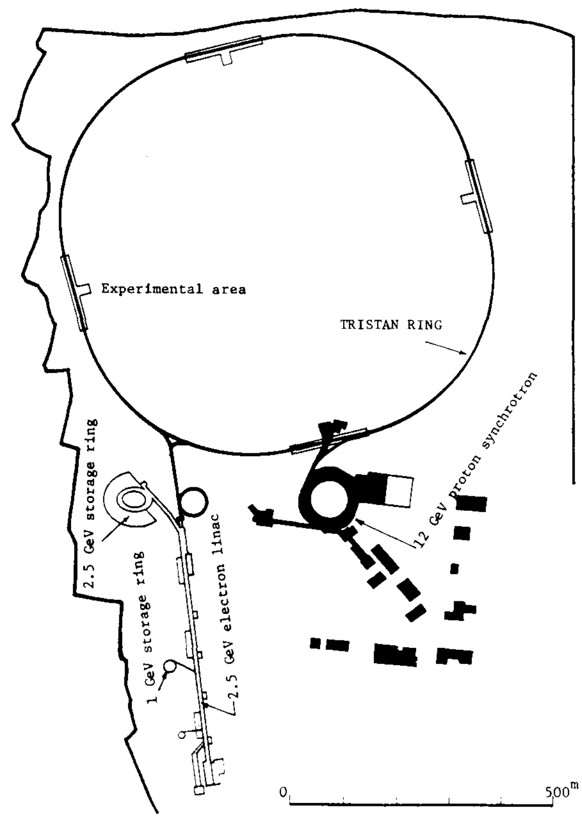

Fig.1 Overall layout of the KEK facility

General Picture of the Linac

The injector housing is a long slender two-storied building of about 500 m length, a view of the cross-section is shown in Fig. 2. The two stories are separated by a 2.5 m concrete floor for radiation shielding. The first floor is an underground tunnel housing the accelerator guides, the second floor is the klystron gallery housing the rf power supplies.

The linac was designed to be able to accelerate electron beam currents of 50 mA to energies of 2.5 GeV with the application of 840 megawatts of pulsed power from 40 klystrons fed to 160 accelerator guides. The relation between beam energy and current as a function of rf power was calculated,as shown in Fig. 3.

The general parameters of the linac and the storage ring are shown in Table 1.

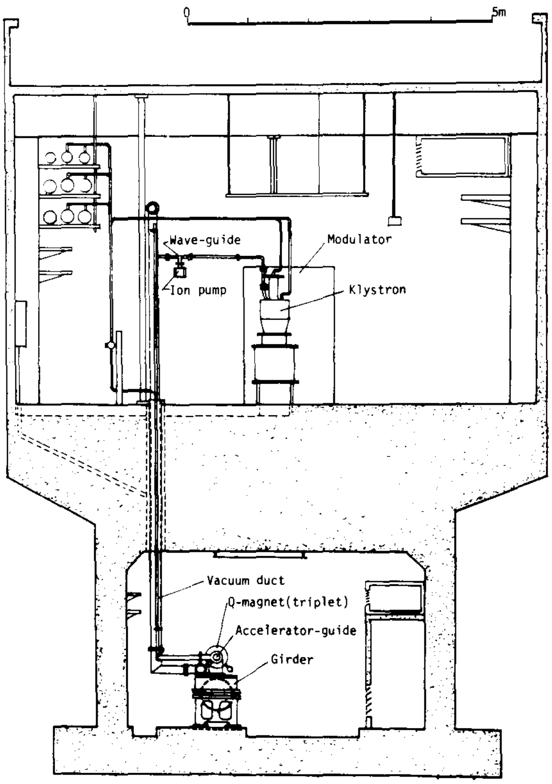

Fig.2 Cross-section of the linac building

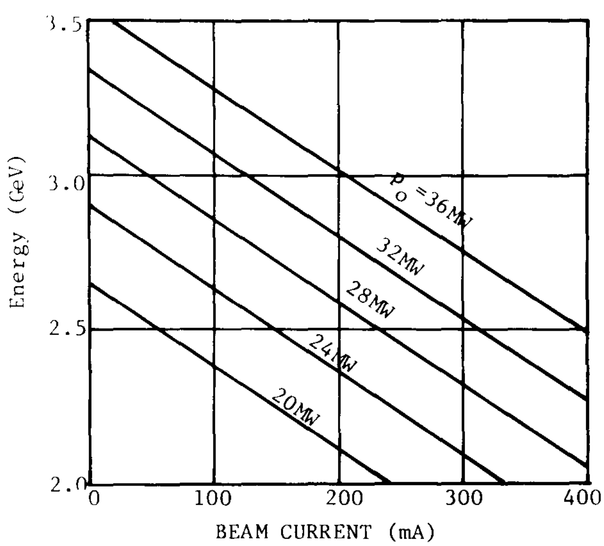

Fig.3 Relation between beam energy and current as function of rf power

A conventional disk loaded traveling wave type accelerator guide was chosen in order to facilitate manufacturing, operation and maintenance, as well as to be able to complete the linac within a limited budget, with a limited staff and short scheduled construction period. As the linac is an injector, an Energy Compression System (E.C.S.) is added downstream of the linac to improve both the stability and spread of beam energy. In addition to ordinary microsecond pulse beams, a single bunch beam can also be accelerated.

The linac is divided into five sectors and each sector is composed of eight acceleration units. One acceleration unit consists of four 2 m long accelerator guides mounted on a cylindrical supporting girder, one klystron and high power waveguide system. All the various power supplies, including the 42 klystron modulators, are installed in modular standard unit cabinets, constructed of panels.

Table 1
General Parameters of the 2.5 GeV Linac

Energy (50 mA loaded)	2.5 GeV
Peak current	50 mA
Beam pulse width	>1 μs
Repetition rate	50 pps
Eenrgy spread(without E.C.S.)	<0.5 %
Energy spread(with E.C.S.)	0.1 %
Normalized emittance	<10 cm·mrad
Short pulse operation	
peak current	<500 mA
Pulse width	2 ns, 10 ns
Single bunch operation	
Max charge	1 nc
Bunch width	16 ps
Accelerator guide (main accelerator)	
Type of structure	5 types TW Quasi-C.G.
Frequency	2856 MHz
Type of Mode	$2/3\pi$
Length of acceleration guide	1.9 m
Total number of guide	160
Attenuation parameter	0.5∿0.6
Length of acceleration unit (Composed of 4 acc. guides)	9.6 m
Number of Acc. unit	40
Number of Sector	5
RF power	
Peak power per klystron	30 MW
Number of klystrons (Including of Inj. and E.C.S.)	42
RF pulse width	3 μs
Freq. of master osc.	476 MHz
Injection system	
Gun voltage	-100 kV
Type of Gun	Triode
Gun pulse width	2 ns ∿2 μs
Out put Energy	30 MeV
Number of Acc. guides	2
E.C.S.	
Magnetic field	1.6 T
Accep. phase angle	30°
Number of Acc. guides	4

General Parameter of the Storage Ring

Energy	2.5 GeV(max 3 GeV)
Intensity	500 mA
Mean radius	29.77 m
Radius of curvature	8.66 m
Betatron number νx	6.25
νy	5.25
Bending magnet field	9.6 kG(max 12 kG)

Length of bending magnet	1.85 m
Aperture	70 x 120 mm
Length of quadrupole magnet	0.5 m
RF frequency	500 MHz
Harmonic number	312
Synchrotron radiation loss	400keV/turn (w/o wiggler)
Radiated power	208 kW
RF voltage	2.1 MV
Synchronous phase	10°
Average pressure	10^{-9} Torr
Expected storage lifetime	5 hrs

Acceleration Unit

An acceleration unit consists of 4 accelerator guides mounted on a cylindrical supporting girder, vacuum manifolds and cooling water piping. A high power klystron and waveguide feeder system is shown in Fig. 4

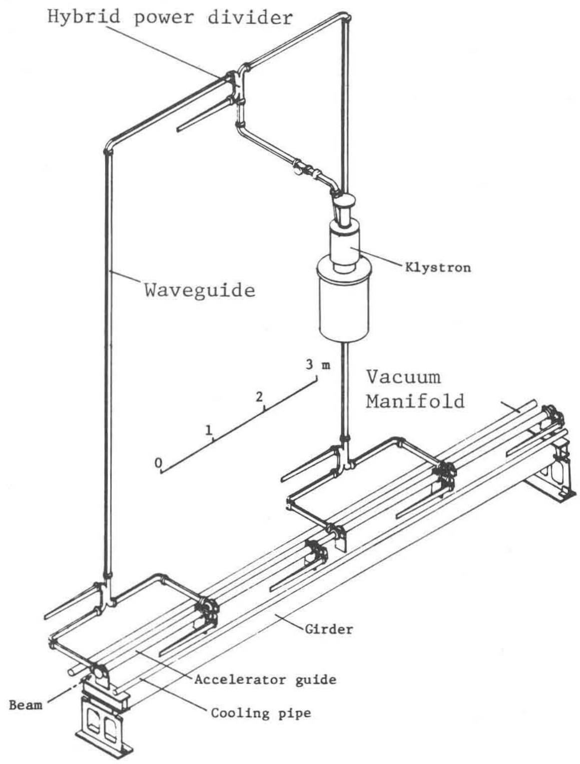

Fig.4 Acceleration unit

The accelerator guide structure was designed to have a quasi-constant gradient; the disk hole diameters decrease linearly along the length to facilitate manufacturing many accelerator guides. However, in order to reduce beam blow-up difficulties, five different structures (Types A-E) will be prepared for the accelerator guides.

A prototype acceleration unit was built in order to get basic data on both the structure and electrical characteristics of the accelerator guide and waveguide feeder system, and to check the alignment of the long supporting girder and the conductance of the vacuum duct system. The unit was completed at the end of March of this year. As a result of cold test measurements, the maximum phase shifts of respective accelerator guides were within ±2.5°. A panoramatic photograph of the prototype acceleration unit is shown in Fig. 5.

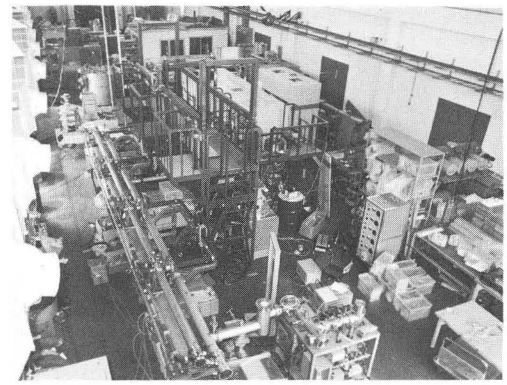

Fig.5 Prototype acceleration unit

The accelerator guides are made by means of an electro-plating method. In order to manufacture many accelerator guides in a limited period, automatic lathes, a measuring system and electroplating plant were prepared.

Recent improvements in machining were realized to automate the final precision machining of the accelerator guide parts. In this process, disks and cylinders are machined by special diamond bit lathes. The surface roughness of the finish is less than 0.1 μ and the over all dimensional accuracy of the disks and cylinders is within ±2 μ.

The precision in machining is accomplished by reducing rotational vibrations of the lathe spindle as a result of using hydraulic bearings.

The machined disks and cylinders are then stacked alternately on a stacking jig and the assembly is compressed to a specified pressure with a long mandrel put through the center holes.

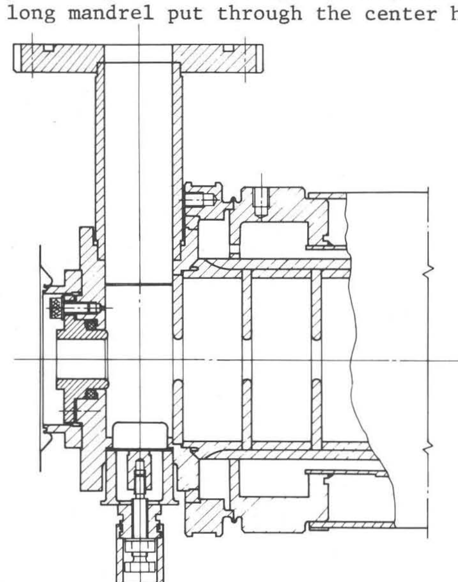

Fig.6 Cross-section of the accelerator guide waveguide coupler

The assembly is copper plated on the outside in an R-1 copper plating bath forming a solid tube of 6 mm of deposited copper. Improvements in the R-1 copper plating process enabled a uniform, smooth and high speed deposition of the copper layer.

Accelerator guide waveguide couplers are of the cavity type. The coupler has two adjusting mechanisms as shown in Fig. 6; one of them makes the coupler field symmetrical with the beam axis and the other is for tuning of the coupler cavity. The adjusting mechanisms facilitate the final tuning of the couplers connected to the accelerator guides.

In each acceleration unit, output power from the klystron is split and fed into 4 accelerator guides. The phase lengths of the 4 branch waveguide feeds from the klystron to the 4 accelerator guides are made precisely equal by precision machining and electron beam welding. Consequently, the feed system needs no high power phase shifters.

RF Power Source

The design principle for the entire power source is based not only on obtaining reliable and stable operation but also on facilitating maintenance and reducing cost.

The rf system is composed of four main stages: the master oscillator, the main booster, the sub-boosters and the main klystrons, as shown in the block diagram of Fig. 7.

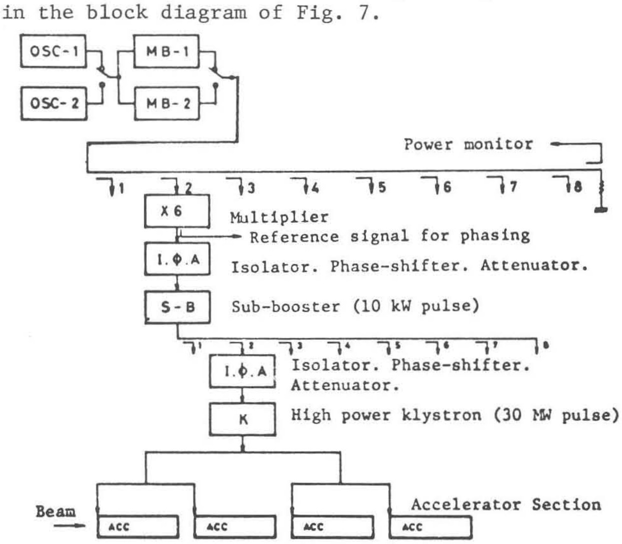

Fig.7 Block diagram of the rf power system

Almost all of the rf components have already been specified and some prototypes have been completed and are under test. The preliminary tests of the klystron modulator were successful; in particular the pulse-to-pulse amplitude variation was less than 0.1 % for a 3 % variation of the ac input voltage. Fig. 8 shows the pulse shape under those conditions.

Recently, super power klystrons with specifications similar to the SLAC XK-5 klystron have been developed commercially to operate with reasonable efficiency and costs. A prototype klystron for more than 30 MW was purchased to test with a special focusing permanent magnet. The magnetic material used is Alnico 9 which was made by the zone-melting method. This material has such a strong magnetic field that the amount of magnetic metal needed decreases by approximately one half in comparison with Alnico 8. The klystron's characteristics as an rf power source are under examination.

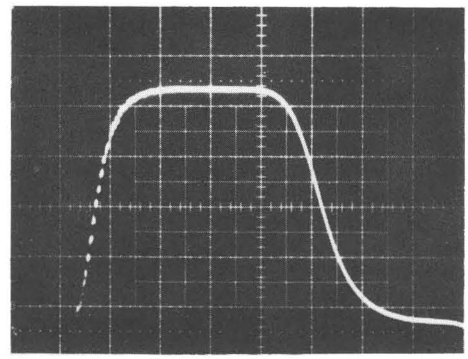

Fig.8 Output pulse shape of the klystron modulator
50 kV/div 1 μs/div

Control System

The basic design of the control system is based on local distributed processors interconnected into a network by a high speed communication loop. The entire control network is composed of a main loop for controlling the 6 accelerator subsystems, and two external loops communicating with the storage ring control center, radiation and personnel protection system, and with the environmental control plants. The accelerator subsystems control the injector, 5 regular sections, and the final energy compression section. As shown in Fig. 9, each subsystem-control station on the main loop has several subloops at the middle level, and branch loops at the lowest level. Klystron modulator controllers, vacuum equipment controllers, etc. form the nodes for the subloops.

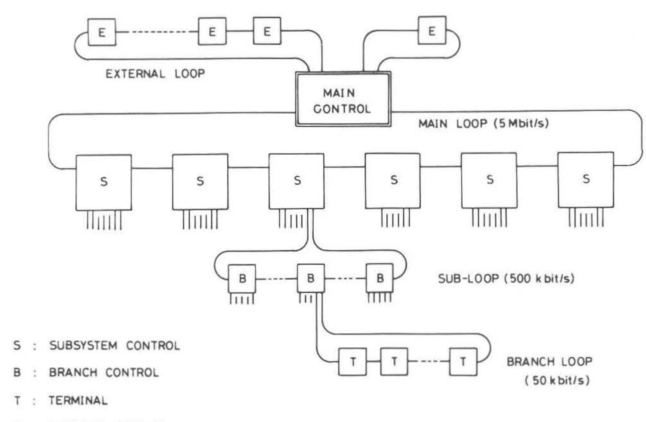

Fig.9 Block diagram of the control system

DISCUSSION

E.A. Knapp, LASL: For a given length accelerator tunnel it is possible to reduce the rf power requirements by more than a factor of two using modern standing wave accelerator cavities. Is the saving you achieve using the technology already understood by Mitshubishi Industries more important than the power saving or the length reduction possible?

Tanaka: Yes, because we have to construct the linac in a limited time.