

THE RF SYSTEM OF THE PHOTON FACTORY INJECTOR LINAC

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Summary

The rf system of the Photon Factory 2.5 GeV injector electron linac now under construction is described. The rf system is composed of four stages: a master oscillator, a main booster amplifier (cw, 476 MHz), sub-booster amplifiers (pulse, 2856 MHz) and forty two high power klystrons. The output rf power of the klystrons is 30 MW and the rf power of each klystron is split and fed into four accelerator guides composing one acceleration unit.

Almost all of the rf equipment and components have been installed in their positions and are in the final adjustment stage.

Outline of the rf system

The Photon Factory (PF) injector electron linac consists of 160 accelerator guides, and an electron beam of 50 mA is accelerated up to the energy of 2.5 GeV. The main parameters of the rf source are as follows:

| | |
|---|-------------|
| Number of klystrons | 42 |
| (including 2 klystrons for the injector and de-buncher) | |
| Peak power per klystron | 30 MW max. |
| RF pulse length (flat top) | 2 μ sec |
| RF repetition rate | 50 pps max. |
| Operating frequency | 2856 MHz |

It is necessary to adjust the rf phase of the drive signal to each klystron to the correct acceleration angle with respect to the rf wave crest of the electron bunch to within $\pm 2^\circ$. The system which transmits the coherent rf wave to each klystron is the "drive system". After various studies, the drive system was decided to be as shown in Fig. 1. The frequency of the master oscillator was chosen to be 476 MHz, the sixth sub-harmonic of the accelerator frequency, this reduces transmission loss in

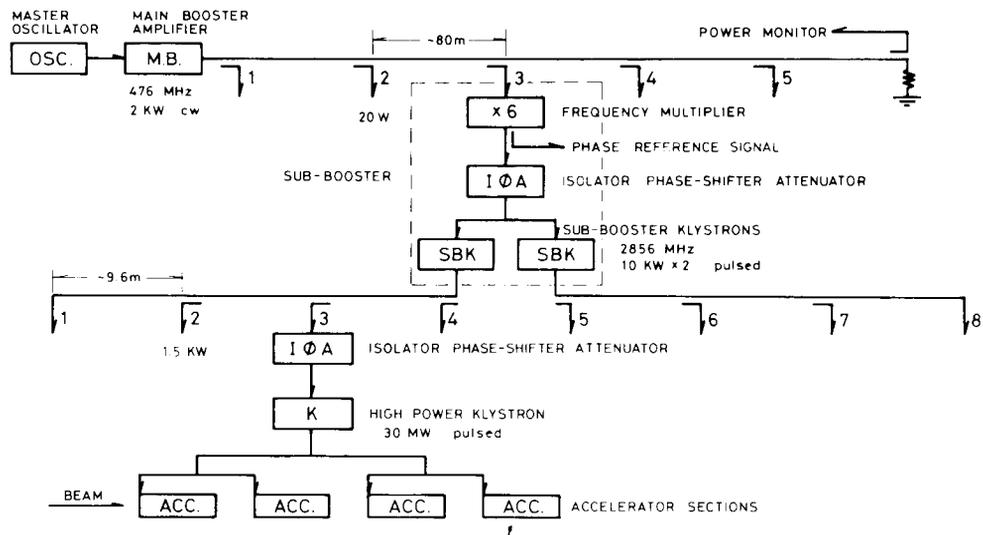
the 400 m main drive line. A main booster amplifies the 476 MHz rf power to 2 kW (cw). The main drive line with five directional couplers corresponding to each of the five "sectors" transmits this rf power to frequency multipliers. The rf multiplied from 476 MHz to 2856 MHz by frequency multipliers is amplified to two 10 kW pulses by a sub-booster installed at the middle of each sector. A subdrive line with three or four directional couplers transmits the 2856 MHz, 10 kW rf power to each of the four or five high power klystrons in each half sector. The 2856 MHz rf power is amplified up to 30 MW by the high power klystrons and is transmitted to each of four accelerator waveguides by high-power wave-guides.

RF driver

Main booster The main booster consists of a 10 W driver amplifier and a cw klystron amplifier, which amplify a 476 MHz rf signal from a master oscillator to 2 kW cw. For the main booster klystron the Varian 3KM3000LA is used. This tube is a UHF TV klystron which has three external cavities, it is capable of 2.3 kW cw output power and 30 dB gain at 476 MHz. The collector high voltage power supply is very well-regulated by series regulating transistors, with an output of 9 kV at 620 mA. The stability of the rf output is kept to better than 0.1 %/hour.

Sub-booster The sub-booster amplifier is required to provide 20 kW in order to be to drive eight or nine main klystrons. The use of a pair of Thomson CSF TH2436 klystrons was decided upon, each of which drives the upstream or downstream four or five main klystrons. This tube has four integral tuneable cavities and uses a permanent focusing magnet. It is rated at 10 kW for our application. Stringent specifications for the sub-booster modulator are

Fig. 1
Block diagram of rf system.



imposed on the rise and fall times and amplitude tolerance of the output pulse, because the pulse shape determines the rf output and any change in the amplitude causes phase shift in the rf output. The phase shift caused by variation in acceleration voltage applied to the klystron is 8 degrees/percent. Wave forms of the phase detector output and the rf output pulse are shown in Fig. 2. The modulator is of the hard tube type, it consists of two pulsers with a storage capacitor and switching tubes (Eimac 4 PR-60), a high voltage power supply, G_1 , G_2 power supplies and a grid driver.

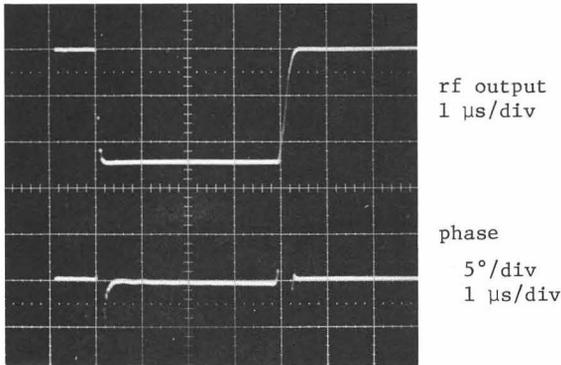


Fig. 2 Wave forms of the phase detector output and the rf output pulse.

Drive line The main drive line transmits the output power of the main booster, installed at the injector head, to the end of the klystron gallery 400 m away. The power split by five directional couplers spaced about 80 m apart, is fed to the frequency multiplier in each sub-booster. For high phase stability in spite of environmental changes a $1\frac{1}{8}$ in. semirigid phase stabilized coaxial cable is used for the main drive line. The cable is filled with N_2 kept at a constant pressure. Its electrical length temperature coefficient and attenuation are $3 \times 10^{-6}/^\circ C$ and 0.024 dB/m, respectively at 476 MHz.

The sub-drive line transmits the 10 kW output power from one sub-booster klystron equally divided to drive four or five main klystrons, each receiving the drive power in an IΦA unit. The same cable as for the main drive line is also used here.

Isolator, phase shifter and attenuator unit (IΦA)

The functions of this unit are: 1) to adjust the phase relation between the rf accelerating field and beam bunch, 2) to protect the klystron output window and waveguide window by only gradually increasing the klystron input power on start up, and 3) to adjust the rf input power level to the following klystron in the sub-booster or main modulator. Typical measurements give an isolation greater than 25 dB, insertion loss less than 3 dB and linearity between the electrical phase shift deviation versus mechanical rotation angle of within ± 2 degrees.

Main Modulator and pulse transformer

The main modulator supplies pulse modulated power to the high power klystron. At full rating this modulator is required to generate pulses with 22.5 kV peak voltage and 3600 A peak current. To prevent phase modulation and amplitude variation from pulse-to-pulse, pulse top flatness and amplitude stability are important. Specifications of the main modulator are listed in Table 1, a simplified diagram is shown in Fig. 3. Regulation of the output pulse voltage is accomplished by the de-Q'ing circuit which controls the charging voltage to the PFN. The IVR controller unit automatically tracks the dc high voltage to keep the operating range of the de-Q'ing regulation with a constant ratio by rotating the induction voltage regulator. The RC series circuit inserted in output circuit is for lowering the spike noise produced at the pulse rise, it is effective and overall the noise is small

Table I Specifications of main modulator

| | |
|--------------------------------------|-----------|
| Peak power output | 84 MW |
| Average power output | 15 kW |
| Output pulse voltage | 22.5 kV |
| Output pulse current | 3600 A |
| Output impedance | 6 Ω |
| Pulse width (flat top) | 2.0 μs |
| Pulse rise time | 0.5 μs |
| Pulse fall time | 0.8 μs |
| Repetition rate | 50 pps |
| Pulse height deviation from flatness | 0.2 % |
| Pulse amplitude variation and drift | |
| short term | 0.2%/5min |
| long term | 0.5%/hour |

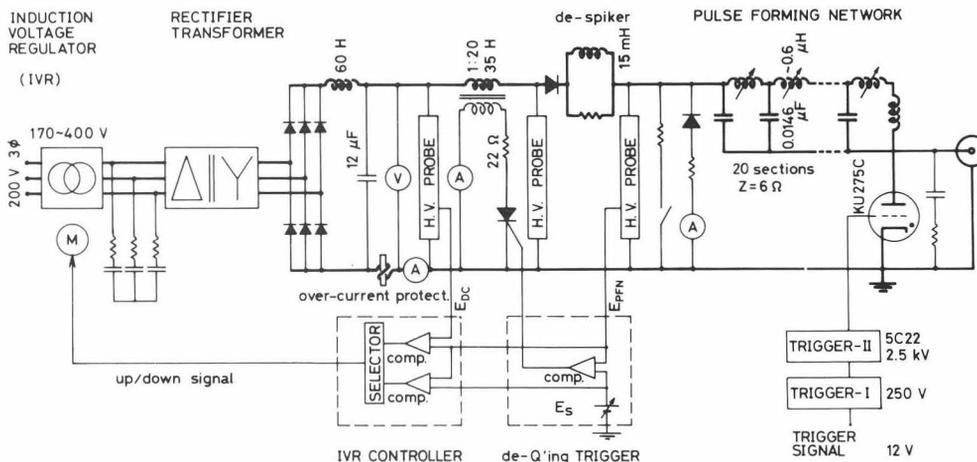


Fig. 3 Block diagram of main modulator.

enough that standard TTL circuit signal level IC's can be used for low-level control.

The equipment implementing the modulator control system can be divided into 3 groups. 1) Sensors, signal conditioners and output effectuators distributed throughout the modulator-klystron area. 2) A hardwire logic controller (relay, diode, TTL) for personnel and machine protection which allows independent operation of each klystron. And 3) Microprocessor (MC 6800) based modules for remote control and data collection. In particular, they interface to a 500 kbps serial loop network, sequence and recycle the modulator power supplies on and off, set the De-Q'ing trigger voltage and the klystron input rf phase.

The pulse transformer is to step the voltage up to the level necessary for the klystron and to match the impedance between the modulator output and klystron load. The core of the pulse transformer is wound from a 0.05 mm thick, grain-oriented silicon steel. The step-up ratio is 1:12. Even at the full 270 kV secondary voltage, it is not necessary to apply any core reset bias current.

High power klystron and focussing magnet

The high power klystron used is a MELCO (Mitsubishi Electric Corporation) PV-3030A. The specifications for this klystron were based on the XK-5 developed at SLAC for a high energy electron linac rf source. The klystron has five cavities, its perveance is $2.1 \times 10^{-6} \text{ A/V}^{3/2}$ and the peak rf output power is 30 MW, with 40 % efficiency and 51 dB gain. A permanent magnet focusses the klystron electron beam. Compared with an electromagnet, use of a permanent magnet gives the advantages of maintenance-freedom and minimum operating cost. Fig. 4 shows a cut-away view of the magnet and Fig. 5 shows its magnetic field distribution. The magnet is composed of numerous permanent magnet rods (28 mm in diameter and 47 mm in length) packed cylindrically in a stainless-steel enclosure. The magnetic material used is Alnico 9 which was made by the zone-melting method. This material has a columnar shaped magnetic anisotropy and a large maximum energy product (BH)_{max}, making it possible to design a compact magnet. The bar magnets are to compensate for the reversal field of the main magnet and to make possible fine adjustments of the field near the gun, since the region near the cathode is very critical with regard to the magnetic field distribution. Almost all of the klystrons and focussing permanent magnets have already been fabricated by their manufactures, and after their assembly with pulse transformers and oil tanks (shown in Fig. 6), high power tests using a water load have been carrying out. At 260 kV, the mean rf output power exceeds the design value of 30 MW when used with electromagnetic focussing, but with the permanent magnet it is about 25 MW. This decrease in the output power is due to a nonoptimal magnetic field distributio, which occasionally also results in breakdown and instability in the rf output power. Further improvements and development are necessary for the permanent magnet.

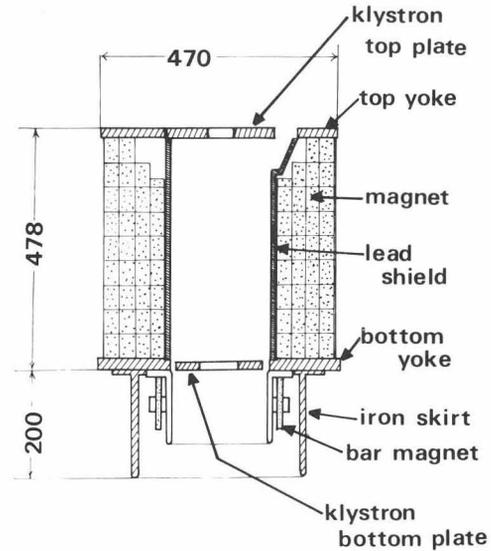


Fig. 4 Cutaway view of focussing permanent magnet.

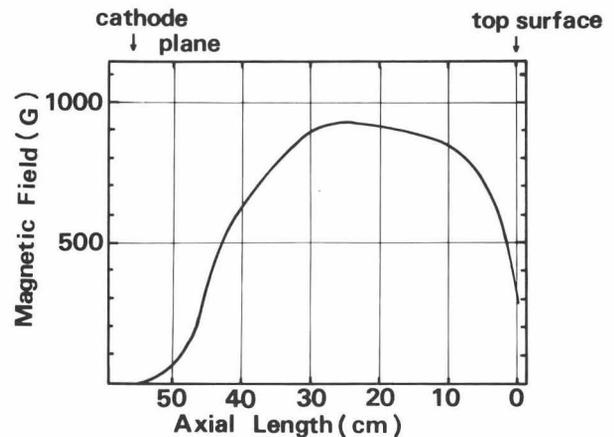


Fig. 5 Typical magnetic field distribution for klystron focussing magnet.

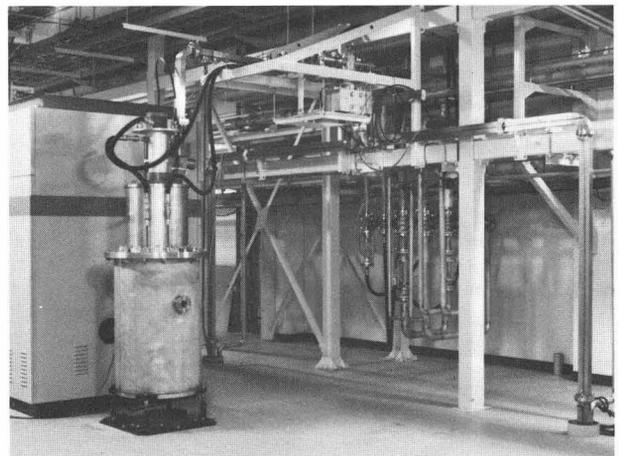


Fig. 6 Klystron assembly installation in klystron gallery.