PHASE CONTROL SYSTEM OF THE KEK 2.5 GeV ELECTRON LINAC

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Abstract: The automatic control system was developed for the phasing of 41 klystrons in the KEK linac. The method of phasing is based on the phase comparison between the beam induced wave and the acceleration wave. The phase detector was newly developed and composed of a precise hybrid power divider and a well-balanced pair of diodes. The phase detection error at a null output signal is kept within ±0.5° over a 30 dB range of the input power. The phasing unit has a single board computer to realize intelligent functions, so that the phasing procedure can be carried out automatically in response to a request from the control room through the communication loops. The 5 phasing units were installed in the 5 sub-control rooms, respectively, and each unit controls 8 or 9 phase shifters for klystrons. As a result of the auto-phasing, easy operation of the phasing system has been achieved and the adjusting time was reduced to about a half of that for the manual procedure.

Introduction

The KEK 2.5GeV linac has the phase control system to accomplish maximization of the accelerated beam energy and minimization of the energy spread. In the usual operation we use following three methods of phasing:

(1) beam energy method,
(2) beam loading method,
(3) beam induction method.[1]

The first method means phase adjustment with measuring the accelerated beam energy directly. The phasing of the second method is done by maximization of the beam loading effect on an acceleration wave. These two methods can be carried out easily without special equipments, although the accuracy is insufficient. The third technique is phase comparison between a beam induced wave and an rf wave from a klystron power source through an accelerator guide. At the optimum phase, the phase difference should be 180° and its phase detection sensitivity becomes maximum. However the wave to be compared are mixed in the accelerator guide and cannot be divided into each other. In order to compare these waves, it is necessary to separate them by shifting the pulse timing of the klystron. To obtain correlation between these phases, another cw signal (coherent reference signal) is required. The delayed position of the klystron pulse timing is referred to as the "standby" position. At that position its corresponding acceleration unit does not accelerate the beam; consequently the beam energy decreases. This is the only disadvantage of the beam-induction method, however, this method has a number of advantages. The most exceeding one is its high sensitivity. This method is most appropriate for fine tuning and is adopted at most long linacs.

RF system and phase control system

Rf system

An outline of the rf system and the phase control system[2] is illustrated in Fig. 1. The 41 klystrons are divided into 5 sectors, each of which has a sub-booster and sub-control station. The first sector has 9 klystrons and each of the other sectors has 8 ones.

The master oscillator generates 119 MHz rf signal which is fed to both the main-booster and the sub-harmonic buncher amplifier. The main booster multiplies the frequency to 476 MHz and amplifies the power to 1 kW cw by a solid state amplifier and a cw klystron. A part of the output power is supplied to the positron generator, and the rest is to the sub-boosters in the electron linac. In the sub-booster, a frequency multiplier which multiplies the rf from 476 MHz to 2856 MHz, a solid state S band amplifier, an "isolator, phase shifter and attenuator (IΦA)" unit, two sub-booster klystrons and the pulse modulators are installed. These klystrons are in double pulse operation. The first pulse is used for the beam acceleration and the second pulse delayed 84 μsec after the first one for the standby. The output power from one sub-booster klystron is divided and fed to four high power klystrons through their respective IΦA units, which are mounted in klystron modulators. The 2856 MHz rf power is amplified up to max. 30 MW by the klystrons and is transmitted to each of four accelerator wave guides.

All the IΦA units are controlled by intelligent modulator control units. The control unit communicates with a minicomputer in the sub-control station through a communication loop called LOOP II. The minicomputers also interface to a fast loop (LOOP I) coupled with a central minicomputer, so that the IΦA units and the klystron modulators can be remotely operated in response to requests from a main console.

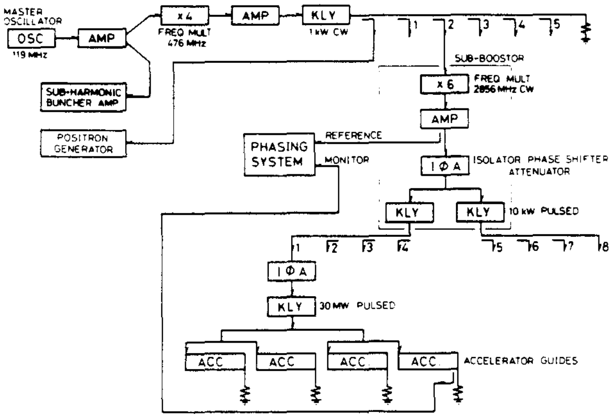

Fig. 1 Outline of the rf system and the phasing system.

Phasing system

Eight rf signals picked up at output ports of the accelerator guides are sent to a coaxial switch box in the sub-control station and two of them are selected for monitor or phasing. A reference signal from the S band amplifier and the selected rf signal from the switch box are fed to a phasing unit as shown in Fig. 2. In the phasing unit, phase difference between two input signals is converted to a pulse voltage signal by a phase detector. This output pulse is amplified and held by a sample and hold circuit which is triggered by a pulse synchronized with a trigger pulse of the klystron modulator. All functions of this unit are controlled by a phasing unit controller which has a microprocessor, a communication controller, a digital I/O circuit and an A/D converter for the phase signal. A small personal computer also communicates with the phasing unit controller through an RS-232C serial line. The program for auto-phasing is loaded on the computer automatically at reset of the system and the procedure can be easily executed in response to a request from an operator in the main control room.

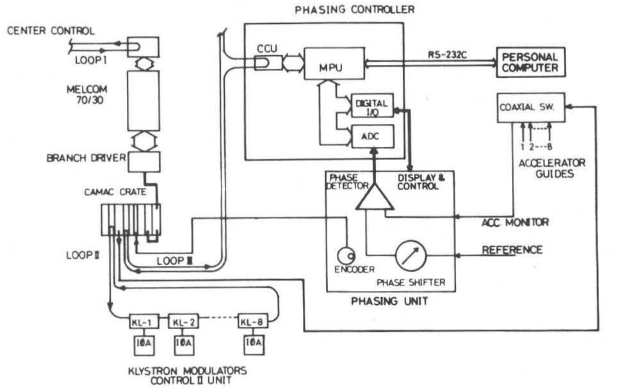

Fig. 2 Block diagrams of the phasing unit, the phasing controller and the communication system.

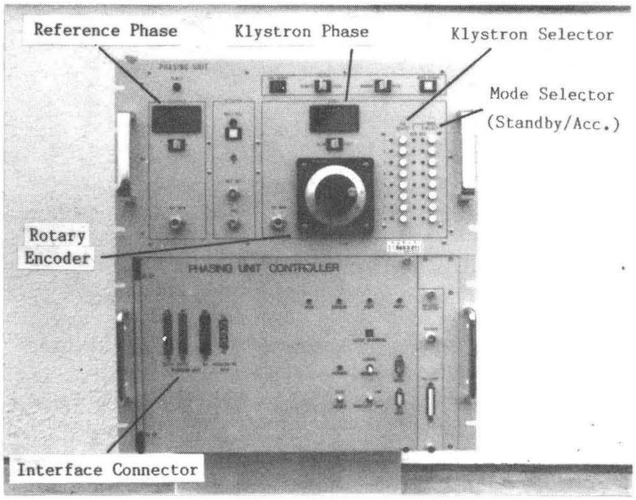

Fig. 3 Front view of the phasing unit and the phasing controller.

Phase Detector

The phase detector for this system was required to have accurate null output at the 90° phase difference. In order to satisfy this requirement the precise phase detector was newly developed.

This detector consists of a precise 3 dB microwave power divider and well-matched pair diodes. The power divider is of the micro-strip line type and has completely symmetric structure as shown in Fig. 4. The input signal is divided into two signals that have exactly equal amplitudes and phase difference of 90°.

When two signals with amplitudes of E_s and E_r are fed respectively to two input ports, a differential output V of the diodes is expressed as

$$V \propto (E_s^2+E_r^2+2E_sE_r\cos\phi)^{n/2} - (E_s^2+E_r^2-2E_sE_r\cos\phi)^{n/2},$$

where ϕ is the phase difference between E_s and E_r, and the diodes are assumed to have the same response of $\upsilon \propto E^n$. At $\phi = 90°$, this formula gives that V is zero and sensitivity $|\partial V/\partial\phi|$ is also maximum. Figure 5 shows a typical example of phase error of the detector at $\phi = 90°$, and the measured errors exist within ±0.5° over the range of input power from 30 μW to 30 mW at the reference power of 10 mW.

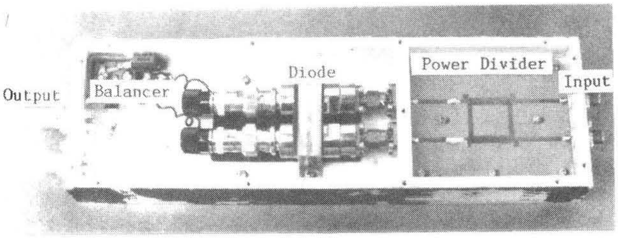

Fig. 4 Prototype phase detector.

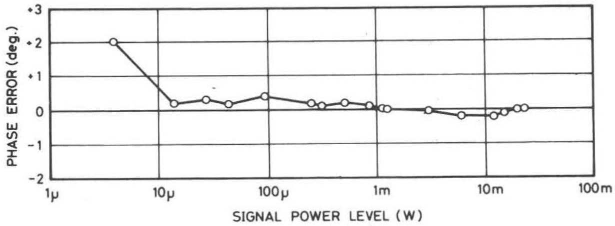

Fig. 5 Phase errors of the detector at ϕ=90° plotted as a function of signal power levels at the reference of 10 mW.

Procedure of phasing

The principle of the beam induction method is based on direct measurement of the relative phase as mentioned in the introduction. The procedure of phasing is given as follows:

1. The particular klystron is set in the standby mode, so that only the beam-induced wave comes out of the accelerator guide and is transmitted to the phasing unit.
2. The phase of the reference signal is adjusted by rotating the phase shifter in the phasing unit, so that the output of the phase detector can be zero. Thus the phase difference between the reference signal and the beam-induced wave becomes -90° (or +90°), the reference phase shifter is locked.

3. The klystron is returned to the acceleration mode from the standby mode, therefore the resultant wave composed of the one from the klystron and the beam-induced one is observed at the input port of the phasing unit.
4. The phase difference between the reference signal and the resultant wave is also adjusted to be +90° (or -90°) by operating the klystron phase shifter in the IΦA unit.

With this procedure the phase of the klystron wave results in 180° away from the phase of the beam-induced wave.

Auto-phasing

A simple idea was introduced to realize the automatic phasing system controlled by a small personal computer in accordance with the principle procedure.

In Fig. 6, the output signal V of the phase detector is illustrated as a function of the phase difference ϕ between two input signals.

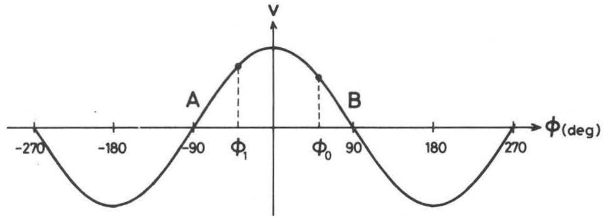

Fig. 6 Illustration of the output signal V of the phase detector vs. the phase difference ϕ.

First, phasing of the reference signal is executed in the standby mode. We suppose that the phase difference between the beam induced wave and the reference one is adjusted at the point A, $\phi = -90°$ (or B, $\phi = 90°$) in this case. Initial phase difference ϕ_0 must exist in a region (-270°,90°). The A/D converter takes the reference phase signal V and the value is checked whether to be positive or negative.

If $V > 0$, the phase shifter should be rotated as ϕ decreases by 90°.

If $V < 0$, ϕ should increase by 90°.

This operation makes new ϕ_1 exist in a region (-180°,0°). Taking V again, the phase shifter is operated according to the measured V as follows:

If $V > 0$, ϕ decreases by 45°.

If $V < 0$, ϕ increase ϕ increase by 45°.

Then new ϕ_2 will be found in a region (-135°,45°). After ℓ times operation the new ϕ_ℓ should be $-90° \pm (180°/2^\ell)$.

Next, the klystron wave should be phased at another point B, $\phi = 90°$ (or A, $\phi = -90°$) in the acceleration mode according to the same procedure as mentioned above, but the IΦA has to be adjusted as ϕ increases if $V > 0$, inversely for the phasing of the reference signal.

The output signal from the phase detector contains pulse noise, which is caused by firing of the modulator thyratrons, random noise and dc offset as well as the pure phase signal. Therefore the system needs reduction of these components which disturb accurate phasing. In our case we made sampling of the signal in the standby mode without the beam and subtracted this value from the measured phase signal to obtain the real phase.

The output waveforms from the phase detector during the phasing procedure are shown in Fig. 7. Figures 7(a) and (b) are the phase signals before and after the reference phasing, respectivily. Those of the klystron phasing are also given in Figs. 7(c) and (d).

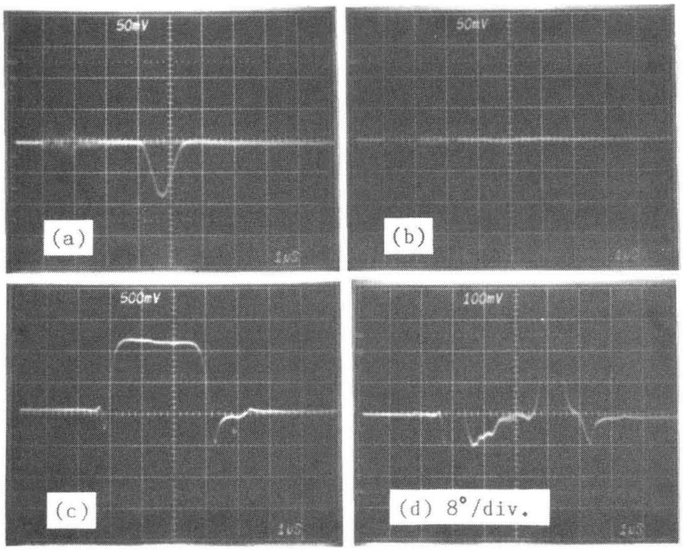

Fig. 7 Waveforms of the output signal v from the phase detector (amplified by 10):
(a) phase difference between the beam-induced wave and the reference one (in the standby mode) before the reference phasing,
(b) that after the reference phasing,
(c) phase difference between the klystron wave and the reference (in the acceleration mode) before the klystron phasing,
(d) that after the klystron phasing.

Results

Results of the autophasing for 41 klystrons are discribed as followings:

1. Easy operation of phasing is achieved.
2. The adjusting time was reduced to about a half of that for the manual procedure and was about 10 minutes per 8 klystrons.
3. The phasing error is evaluated within about ±3°.

Advantage of this phasing system is the simple construction and the simple procedure due to microcomputer control.

The long adjusting time is mainly caused by the response time of the klystron phase shifter and the reference one. However this required time does not affect the operation of our linac, because it is enough for stable beam acceleration to tune the phase once in a week.

REFERENCES

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2. Y. Saito et al., "The phasing system in PF linac, " in Proc. of the 4th Symp. on Acc. Sci. and Tech., 1982, pp.253-254.