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BUCKET SELECTOR AND TRANSFER TIMING IN TRISTAN

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Abstract

The bucket selection system making use of PLL and the system of transfer timing are described. The bunch of the accumulation ring could be transferred to arbitrarily selected bucket of the main ring. Timing accuracy of the bucket selection system is less than $\pm1°$ in 508 MHz rf frequency.

Introduction

The main ring (MR) of TRISTAN has four collision points and the electron and the positron beams are filled into the two bunches respectively so as to collide at the correct points. The accumulation ring (AR) accumulates positrons and electrons in a single bunch and transfers them to the selected bunch. The AR and the MR have the rf frequencies of 508.58 MHz and the harmonic number of 640 and 5120 respectively. The MR has an circumference of eight times of that of the AR. Since the time width of a bucket is 2 nsec, timing accuracy required for the transfer from the AR to the MR is less than 100 psec in order to suppress the synchrotron oscillation of injected beam and it is necessary to be able to select arbitrarily any one of 5120 buckets into which the bunch of the AR is transferred. In this paper we describe the bucket selection system and the system of transfer timing.

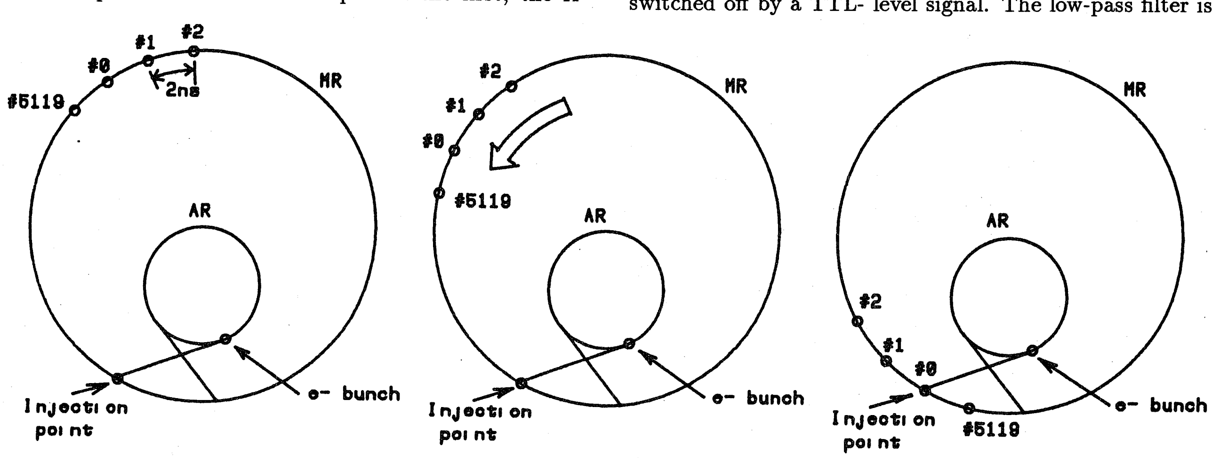
Bucket selection system

The AR and the MR have 640 and 5120 stable rf phase (bucket) in their orbits at the intervals of 2 nsec. The buckets move around the ring with a speed of the beams, however, if we looked at the ring under the *stroboscopic* light with a repetition frequency of the revolution frequency of the ring, they would seem as if stooped at fixed locations (see Fig. 1a). So once a fixed standard revolution frequency was defined, each bucket can be uniquely identified by its time displacement from the standard revolution signal and can be named as #0, #1,.., etc. Actually the standard revolution frequency is made dividing the rf frequency by the harmonics. In this paper the *injection bucket* or *selected bucket* means the bucket into which the bunch in the AR should be transferred, whereas the *injection point* means the bucket into which the bunch is transferred. The injection point is always fixed with respect to the bunch of the AR (see Fig. 1). The purpose of the present bucket selector is to move the arbitrarily selected bucket to the injection point. We assume that the bunch of the AR to be transferred is at a fixed location with respect to the standard revolution frequency $f_{rev}(AR)$.

The principle of the present bucket selection system is shown in Fig. 1, where two rings of the AR and the MR are seen under a *stroboscopic* light with a repetition frequency of *one eighth* of the standard revolution frequency of the AR ($1/8f_{rev}(AR)$). The bucket selection procedure has three steps. In the first, the rf frequency of the AR (f_{AR}) is equal to that of the MR (f_{MR}). The buckets of the AR and the MR are stopped and the bunch of the AR stays at the extraction point. The selected bucket named, for example, as #0 exists elsewhere in the MR (see Fig. 1a). In the next stage (Fig. 1b), the f_{AR} is slightly changed from the f_{MR} by Δf , then the buckets of the MR will start to move clockwise or counter-clockwise according to the polarity of the Δf with a speed of Δf [bucket(2ns)/sec] ; it takes 5.12 sec for one turn if $\Delta f = 1$ kHz . Finally the selected bucket reaches the injection point, where the bunch of the AR can be transferred to the selected bucket. At that instant, the f_{AR} is again set to be equal to the f_{MR} and the buckets of the MR cease to move. In the last stage (Fig. 1c) the situation is the same as the first stage except that the selected bucket is now at the injection point.

In the above explanation we have neglected the timing accuracy. In fact , if the timing of that the f_{AR} is set equal to the f_{MR} was slightly delayed by Δt, the bucket will run over the destination by $\Delta t \cdot \Delta f$ [bucket]. Therefore required accuracy of ±100 psec demands that the timing accuracy (Δt) for the change of frequency should be $\pm5 \times 10^{-2}/\Delta f$ [sec], *i.e.*, ±50 μsec for $\Delta f = 1$ kHz. In the actual system , however as described below , the phase locked loop (PLL) is worked between the f_{AR} and the f_{MR} in the first and the last stage. The PLL assures that the relative rf phase of the MR to the AR does not vary during the first and the last stage and the final accuracy of the system is governed by that of PLL. Therefore required timing accuracy for changing the frequency is reduced to only $1/\Delta f$, so, if the Δf is 1 kHz, for example, required accuracy is 1 msec.

In Fig. 2, the block diagram of the system is shown. Master oscillators for the AR and the MR (Anritsu MG655A) have a common clock of 10MHz with a stability of 5×10^{-10} and can be set a frequency with a resolution of 1 Hz. When the f_{AR} is set equal to the f_{MR}, the relative rf phase of between the f_{AR} and the f_{MR} is dropped into a fixed phase angle ϕ_0 because the PLL is worked between them. A block in Fig. 2 enclosed by a dashed line constitutes a PLL network. The phase difference between the f_{AR} and the f_{MR} is detected after their frequencies are converted to an intermediate frequency of 1 MHz by mixers (frequency converter)[1]. The local oscillator provides the frequency converters with signal of a frequency just 1 MHz below the f_{AR}. The phase detector[1] thus always works at 1 MHz even if the frequency was changed. The error of the phase detector system is less than $\pm1°$. The electronic phase shifter module shifts the rf phase by $\pm180°$ at maximum according to a control voltage of ±10 V. In the present PLL system two phase shifter modules are cascaded and the cover the phase of $\pm360°$. The feedback controller puts out a control voltage to the phase shifter so that the phase difference of the two rf's is zero with an accuracy of $\pm1°$. The feedback can be switched off by a TTL- level signal. The low-pass filter is an RC



(a) $f_{AR} = f_{MR}$ (b) $f_{AR} \neq f_{MR}$ (c) $f_{AR} = f_{MR}$

Fig.1 Scheme of bucket selection. (for the case of electrons) filter which suppress the phase noise of higher frequency of PLL system. The loop gain of the PLL is approximately 30 dB. The master oscillator is controlled by a computer through the CAMAC interfaced GPIB and it have an external port that accepts a TTL signal to step up/down the frequency.

The bucket selection sequence is as follows.

(1) The present position of the selected bucket into which the bunch of the AR should be injected is calculated from the selected bucket number and the time difference between the signal of one eighth of standard revolution frequency $f_{rev}(AR)$ and the $f_{rev}(MR)$. The time difference is measured by the TDC system[2].

(2) Rf frequency difference Δf is decided taking into account the time it takes for the selected bucket to the injection point ;

$$\Delta f = \begin{cases} 1\,\text{kHz}, & \text{for } 2560 \geq \Delta m > 50 \\ 100\text{Hz}, & 50 \geq \Delta m > 5 \\ 10\,\text{Hz}, & 5 \geq \Delta m > 1 \\ 1\ \text{Hz}, & \Delta m = 1, \end{cases}$$

where Δm is the time difference in unit of a bucket (2 nsec) . Then the value of the Δf is loaded to the AR oscillator. In this stage the frequency is not yet changed. Δm is loaded to the preset counter as a preset value.

(3) The PLL is switched off. Then the 'Δf-start' pulse signal is fed to the AR oscillator and it also makes to start the preset counter. The f_{AR} is stepped up (down) by Δf and the output of the phase detector begins to oscillate with saw-tooth waves. Since the clock of the preset counter is connected to the output of zero-cross detector which converts the saw-tooth waves to pulses with the same frequency, the counter is counted down every time the rf phase difference between the AR and the MR increases by 360° , *i.e.* , just one bucket ; it counts the number of buckets moved around the MR.

(4) When the counter was finally down to zero, the preset counter puts out a pulse of 'Δf-stop' to step down (up) the rf frequency of the AR and the PLL is switched on. Then the phase difference becomes a fixed value of ϕ_0 , the same as that before the bucket selection procedure started.

(5) The position of the selected bucket is measured again and if it differs from the injection point, the procedure returns to the step (1) and the sequence above is iterated until the selected bucket coincides with the injection position.

More explanations may be necessary about the iteration. Because there exists a definite time delay of about 28 ms in the master oscillator from receiving the Δf- stop to executing the change of frequency, if no compensation was done, the selected bucket would run over the destination by buckets of $28 \times 10^{-3} \cdot \Delta f$; for example, 28 buckets when $\Delta f = 1$ kHz. In actual operation the preset count loaded is modified to $\Delta m - 28 \times 10^{-3} \cdot \Delta f$. Even if this compensation was done, because of an uncertainty of about ±0.1 ms in the delay time, there still remains an error in the final position of the selected bucket. This uncertainty is the reason why the iteration is needed in the step (5). The larger Δf, the more error results ; the error in the final position is ±1, $1 or 0$, 0 bucket for the Δf of 10 kHz, 1 kHz, and, 10 Hz, respectively. Since no error is caused in the case the Δf is less or equal to 10 Hz, the procedure of iteration always converges at most two times and it takes 4 sec at most. The present bucket selector changes the AR rf frequency because the stable rf frequency is very narrow for the MR ; a few kHz whereas 100 kHz for the AR

Time measuring system using a TDC (Time to Digital Converter)[2] is shown in Fig. 3. The TDC is a CAMAC module with a resolution of 100 psec and the dynamic range of 200 nsec. In order to cover whole the range of a revolution period of the MR (10 μsec) the stop signal is delayed so that the time difference comes into the dynamic range of the TDC using digital delay module TD2. The TD2[3] is a CAMAC module and have a clock of 508 MHz rf frequency of the AR , so it delays input signal in unit of bucket. The time difference of the $1/8 f_{rev}(AR)$ and the $f_{rev}(MR)$ is given by the delay time of TD2 minus the read-out of TDC.

All the module in the bucket selector such as the master oscillator and the preset counter are able to controlled by the computer (Hitachi H80E) through GPIB and CAMAC system. The Δf- start signal is furnished by a CAMAC I/O module. Each step of the procedure of the bucket selection is controlled by the computer through the program written by a fortran-like language called PCL[4]. The program is called and executed on the KEK-NODAL system[4].

Transfer trigger system

Pulse magnets such as kickers and septums are used for the extraction and injection of the beams; three kickers and three

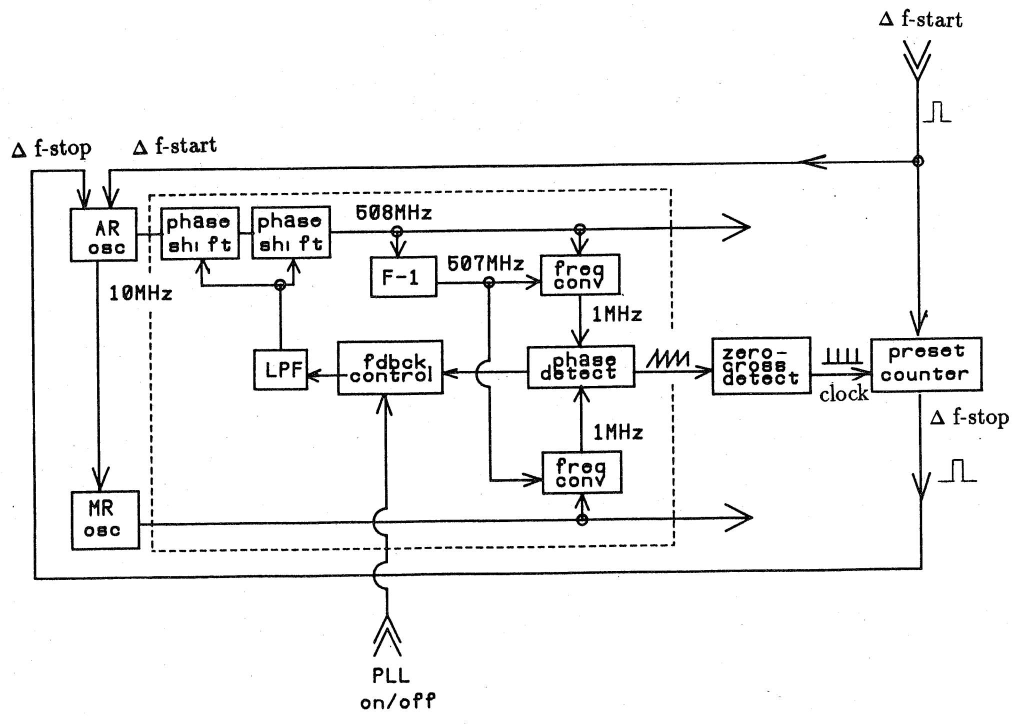


Fig. 2 Block diagram of bucket selector

septums for the extraction of each beam, and four kickers and three septums for the injection to the MR. Each magnets is excited by a half-sine-like current. The trigger timing for the power supply of the magnets must precede the beam timing just by half-width of the pulse current ; 1.25 μsec for the extraction kickers , 10 μsec for the injection kickers , 1 ms for the extraction and injection septums of type I , 2.5 ms for the extraction septums of type II , and , 2.75 ms for the injection septums of type II.

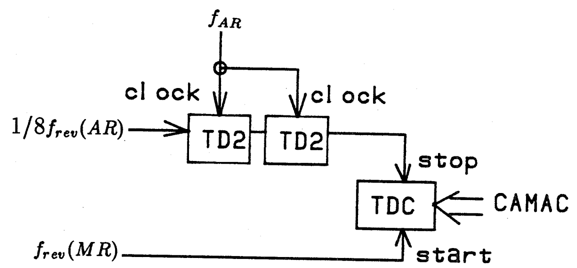


Fig. 3 Block diagram of TDC system

The trigger system is schematically shown in Fig. 4, where the gun- trigger to the Linac[5] is shown for the completeness. Standard revolution frequency $f_{rev}(AR)$, $f_{rev}(MR)$, and the one eighth of the $f_{rev}(AR)$ are generated by the frequency divider[5] from rf frequencies f_{AR} and f_{MR}. The beams from Linac is synchronized with $f_{rev}(AR)$ and the injection bucket is selected[5] by the digital delays TD2-1 and TD2-2 shown in Fig. 4. In the actual operation these digital delays are fixed and the injection buckets are named as # 0 for both of electrons and positrons. After the bucket selection was completed, the pre-pulse for the transfer trigger is generated by the synchronizer. It is synchronized with the $1/8f_{rev}(AR)$ and is put out only once when the 'injection-on' pulse is activated. The selection of e^-/e^+ mode is done through a CAMAC system. The pre-pulse is delayed by digital delays (CAMAC module) to supply the trigger pulses to pulse magnets. The delays for the kickers are higher precision modules of TD2 with a clock of 50.8 MHz and those for septums are lower precision module with a clock of 1MHz. The MR rf signal is sent to the the RF system through a phase shifter. This phase shifter makes a fine adjustment of rf phase of accelerating voltage to the beam timing so that the beam is injected just into the center of the bucket. The phase shift required for the electron is not equal to that for the positron because the transport lines for them are not symmetric ; their path length from the rf cavity of the AR to that of the MR is different by a fraction of the wave length of the rf. The phase shifter is controlled by a voltage generator which is controlled by pulse-train generator so that the phase is continuously changed.

Conclusion

The bucket selection system was constructed that makes it possible to inject a beam into any bucket arbitrarily selected with a timing accuracy less than $\pm 1^\circ$ in 508 MHz rf frequency. The bucket selection system and the trigger system for the transfer have been successfully operated for one year since the operation of TRISTAN was initiated.

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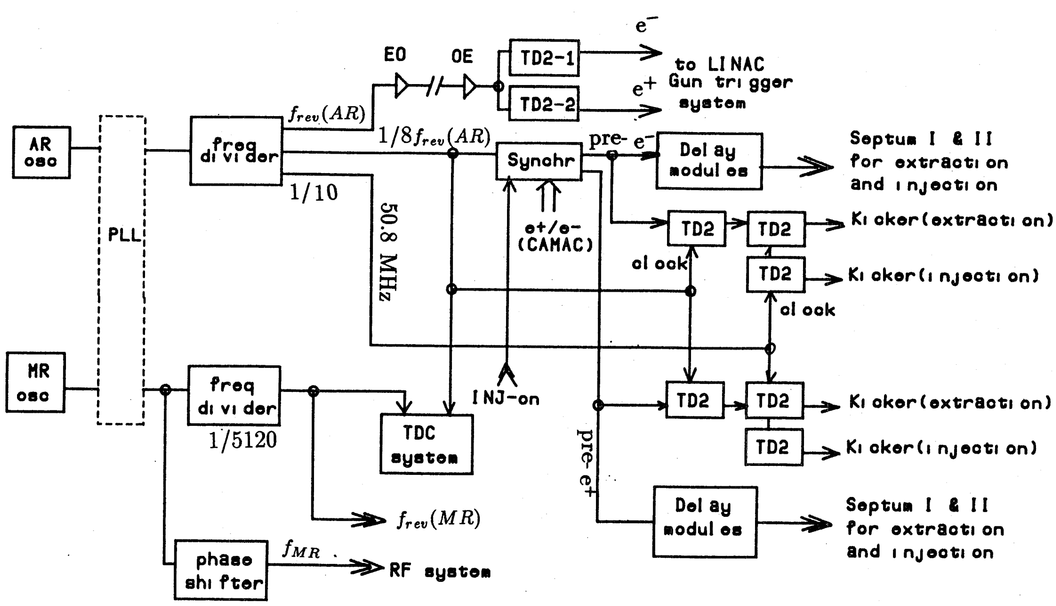

Fig. 4 Block diagram of trigger system