IMPLEMENTATION AND PERFORMANCE OF THE DAΦNE TIMING SYSTEM

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Abstract

In the high luminosity Phi-Factory DAΦNE, a timing system has been provided for the control and proper synchronization of the injection process from the Linac, through an Accumulator/Damping Ring, into the e^+/e^- Main Rings, for the minimization of phase oscillations at injection and for the stability control of the Interaction Point. The Linac beam (e^+ or e^-, alternatively) is injected at ≤ 50 pps into an intermediate ring until the required intensity and emittances are reached, then the extraction from the damping ring and injection into a single bucket of the e+ or e- ring takes place at ≤ 2 pps. The accumulator RF phase, the firing instant of the Linac, of the injection/extraction kickers in the accumulator ring and of the injection kickers in the main ring must be properly synchronized in order to fill the selected bucket. In this paper we describe the operative procedures and the control programs, along with the hardware solutions and the technologies employed to get the synchronization signals within the required precisions, according to the type of timed element, down to a few picoseconds in the RF chains.

1 INTRODUCTION

DAΦNE is a Phi-Factory [1] with high luminosity at 1020 MeV in the center of mass and large currents distributed in ≤120 bunches. The collider proper consists of two storage rings, one for electrons, the other for positrons, intersecting in two interaction regions. The intense current needed for high luminosity is supplied by a powerful injection system composed of an e^+/e^- Linac [2], a small intermediate storage ring (Accumulator-Damping Ring) [3] and transfer lines ~180 m long.

Injection from the Linac through the Accumulator takes place at the collider operating energy of 510 MeV. The "top-up" injection has been demonstrated during the commissioning.

The injector commissioning started in 1995 with short periods of operation as the major components and services became available. The main rings construction has been completed in July 1997. At the end of 1997 the first collisions have been observed and now the single bunch luminosity commissioning is in progress.

2 DAΦNE REQUIREMENTS

The Linac beam (e^+ or e^-, alternatively) is ~10 nsec FWHM long. It is injected in single turn/single bucket at ≤ 50 pps into the Accumulator/Damping Ring (DR) until the required current is reached. At this point the Linac injection stops and ≥100 msec are left to the stored beam to damp down to the equilibrium dimensions and emittance. The "cooled" beam is then extracted in a single turn and transferred to the main ring (MR), where injection in the desired single bucket takes place at ≤ 2 pps.

The sequence of operations may be different for electrons and positrons. The execution of a required command sequence is performed under control of a timing system. Four resonant discharge coil kickers [4] provide the ~ 200 nsec long injection and extraction pulses in the DR. Different kicker voltages and trigger timing have to be provided between injection and extraction. Similar kickers are used for the injection into either one of the MR's.

It is noteworthy that the e^+/e^- beams to and from the DR pass through portions of the same transfer line in opposite directions, hence the necessity of pulsed magnets [5]. One of these magnets (DHPTT02) is normally off during the DR injection and must be on during the transfer to the MR. In the other pulsed magnet (DHPTT01) the bending field must be reversed between DR and MR injection. The field reversal occurs during the same ~100 msec when the DR beam is being damped. In addition, a third pulsed magnet (DHPTS01) is used to send the Linac beam into a spectrometer branch to measure the mean energy and energy spread. This is done by stealing one Linac pulse onto the spectrometer typically at the same time when the cooled beam is extracted from the DR into the MR.

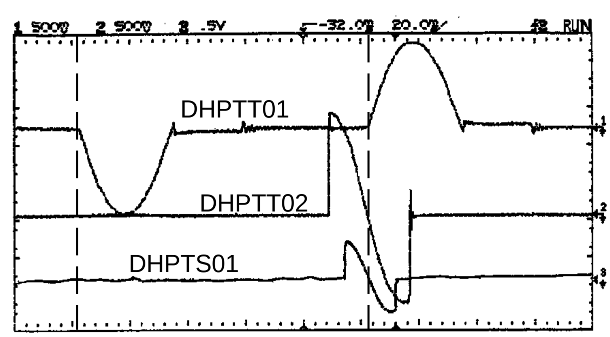

Figure 1 - Pulsed Magnets: dB/dt

In order to fill the selected MR bucket with good efficiency, the firing instant of the Linac modulators and gun, of the injection/extraction kickers in the DR and in the MR, and of the three pulsed magnets must be properly synchronized. The main ring RF drive (368.26 MHz) is provided by a master oscillator; the accumulator RF drive is derived from the master by digital division and phase shift by the timing system.

The principal parameters of DAΦNE accumulator and main rings relevant to the timing system are presented in Table 1.

Table 1: Rings parameters list

	Main rings	Accumulator
Circumference (m)	97.69	32.57
MR/DR length ratio	3	
RF frequency (MHz)	368.26	73.652
Harmonic number	120	8
Number of bunches	1÷120	1
Damping time L/T [msec]	18/36	11/21
Current/bunch (mA)	44	132

The harmonic number ratio between main rings and accumulator is 15 (factor 3 from length ratio, factor 5 from RF frequency ratio). The correct bucket selection in the accumulator is done by proper choice of Linac gun and injection kickers timing. Twenty-four main ring buckets are available for a fixed phase of the accumulator RF. In fact, injection from any of the 8 accumulator buckets into any 1/3 of the main ring is possible by proper delay of the extraction kicker timing. By shifting in phase the accumulator RF by 0 to 4 increments of $2\pi/5$, all 120 buckets in the main ring are available.

3 TIMING SYSTEM OPERATIONAL DESCRIPTION

In this chapter the main operational characteristics of the timing system are presented.

The DAΦNE timing system provides:

- triggers for all the pulsed elements;
- synchronization of the ring RF cavities;
- triggers for the bunch-by-bunch feedbacks;
- triggers for diagnostics and data acquisition system;
- control of operational sequences for all the accelerator.

During the commissioning and the operation many injection sequences have been used, according to the operation mode.

The principal devices to be synchronized and the actions performed by the timing system are listed in Table 2. The combined action of the timed devices is described by a 31 bits "state word" issued by the timing system every 20 msec. One or more state word bits [6] are associated to the specific devices to enable or disable their actions.

The synchronization of the RF cavities of the electron ring and the positron ring is crucial in order to optimize the luminosity. The bunches entering the interaction region coming from the two different rings have to cross in the longitudinal position corresponding to the minimum of the vertical betatron function. The control of the IP is accomplished by means of precision phase shifters inserted between the common master oscillator and the RF cavity drivers.

At the same time the capability of topping-up the main ring requires that the RF phase is the same for the interaction and the injection. Once the MR RF phases are properly set, the accumulator RF phase has to be corrected for the different length of the electron and positron transfer lines. This is done by introducing an offset in the bucket number and a proper delay in the accumulator RF when switching from one particle mode to the other.

Table 2 : Devices to be synchronized

Device	Trigger	Stability	Description
Linac Gun	Ø4 + (RF/120 + # bunch)	<1nsec	Trigger Linac Gun (~ 10 nsec FWHM)
Linac System	Ø4 + (RF/120 + # bunch)	<1nsec	Trigger Linac Pulse Modulators
Spectrometer	Ø2 + (RF/120 + # bunch)	<1nsec	Trigger SEM Hodoscope ADC
Pulsed Magnets	Øn + (RF/120 + # bunch)	<20μsec	Bending in the Transfer Line
Damping Ring RF	RF/5 + # bunch	<2 psec	Accumulator RF drive
Accumulator Kickers	Ø4 + (RF/120 + # bunch)	<1nsec	Accumulator inject./extract.
e^-/e^+ MR Kickers	Ø4 + (RF/120 + # bunch)	<1nsec	Inject. into e^- e^+ main rings
Injection / Extraction Diagnostics	DR Injection Trigger, MR Injection Trigger	<100ps	Beam Measurements in the DR, in the TL and in MR
Stored Beam Diagnostics	MR Injection, Fiducial	<100ps	MR and IR Beam Measurements
e^-/e^+ Long. Feedback	RF, Fiducial	<10psec	Synchronizing Bunch-by-Bunch Feedback
KLOE Experiment	RF/4	<2 psec	Machine Trigger

4 IMPLEMENTATION AND PERFORMANCE

A stable and flexible timing system [7] has been designed and realized to accomplish the DAΦNE requirements.

4.1 Slow Triggers, fast triggers

To drive many devices, different triggers have to be generated from the main trigger sources (the 50 Hz and the radiofrequency at 368 MHz). It is possible to synchronize slow triggers (≤ 50 Hz) with fast triggers by circuits based on type D flip-flops. The goal is to have fast triggers as stable and precise as possible respect to the main ring RF and slow triggers also stable but following the fluctuations of the mains. This is to manage better the Linac modulator ripples. The combination between different triggers is possible because the information is basically contained in the phase and not in the frequency.

About the fast triggers, the main ring revolution frequency is obtained dividing the radiofrequency by the harmonic number: to inject in multibunch mode it is necessary to have it with two different phases, one as a fixed reference, the other as a mobile reference according to which bucket the operator wishes to fill. We call "Fiducial" the fixed phase reference, and "RF/n + # bunch" the mobile phase reference; n can be 120 or 5. The Fiducial is mainly used by the diagnostic system, the "RF/n + # bunch" is sent, combined with the convenient slow trigger, to the timed devices in the accelerator plant.

About the slow triggers, the Master Trigger Generator at 50 Hz, through a PLL locked to the mains, generates 4 phases that we call Ø1, Ø2, Ø3, Ø4. They are out of phase by exactly 90^{o}. The other slower triggers (25 Hz or less) are created by a software finite state machine based on digital signal processors.

4.2 Modules

Several different modules have been designed and implemented at LNF to perform three types of tasks.

A first group of modules creates periodic signals with frequencies derived from the RF master allowing the DAΦNE control system to change their phases in real time. The bulk of the circuits is based on 100E ECLinPS chip family working up to 1 GHz; special care has been used in the design to contain the phase jitter within few picoseconds. This is done by using delay line chips inside the boards and designing printed circuit boards with traces at controlled characteristic impedance.

The most critical part of the timing system consists in creating the signal to drive the damping ring radiofrequency cavity with phases depending on the bucket to be filled; for this signal the rms jitter standard deviation measured in laboratory is 1.4 psec for all the buckets. Besides, two independent Fiducial triggers have been compared for more than a week without showing any bucket skip.

A second group of modules distributes and receives every 20 msec synchronous commands from VME crates to VME crates in all the accelerator area, using a RS485 serial link at 1 Mbit/s. These boards are based on the digital signal processor AT&T DSP1610. The information is contained in the 31 bits state word that is distributed in real time. A local decoder module enables or disables a specific trigger depending on the current state word.

Finally, the last group of modules distributes and adapts signals between different electric levels: pure sinusoidal, differential ECL, NIM, and TTL.

4.3 Real time finite state machine

A finite state machine is implemented by the real time software running on the DSP's. Two 50 Hz phases, Ø1 and Ø2, are used by the module that has to dispatch the timing state words: in this way is possible to manage 4 states correlated with the 50 Hz phases without adding any jitter due to the software. This is important to send synchronized commands. The 4 states are useful to perform all the tasks and to transmit information without putting any device in an unwanted condition.

The command sequences cyclically executed by the finite state machine are files edited in table form. Every table corresponds to a kind of injection. The bunch selection is in another file. This is to maintain the maximum of flexibility with a minimum of files.

Another important feature is the possibility to disable from the main panel a specific trigger for a chosen device, for example to stop the damping ring extraction but not the injection. The timing system can easily do it clearing only the extraction triggers and maintaining enabled the injection ones.

ACKNOWLEDGMENTS

The authors wish to thank U. Frasacco, O. Giacinti, D. Pellegrini, F. Ronci, F. Rubeo for the efforts in realizing the boards. Special thanks to O. Coiro who has also designed the Master Trigger Generator at 50 Hz and to G. Felici for early work in the fast system. Thanks to P. Possanza to have put in final form this paper.

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