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OPERATIONAL EXPERIENCE WITH THE DAΦNE RADIO-FREQUENCY SYSTEMS

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Abstract

The RF systems of the Frascati double ring (e^+/e^-) Φ-Factory DAΦNE are fully operative since the autumn 1997. The RF complex consists of one 73.65 MHz system for the damping ring and one 368.26 MHz system per each ring. The accelerating cavities are room-temperature single cell copper resonators, broadband loaded by waveguides to reduce the impedances of their High Order Modes and, consequently, the coupled-bunch instability growth rates.

The main operational features of the DAΦNE radiofrequency systems are reported in this article, including the performances observed under heavy beam loading conditions.

1 INTRODUCTION

The commissioning of DAΦNE, the 510 MeV double ring e^+/e^- Φ-Factory [1], is in its final stage at the Frascati laboratories of the INFN. A maximum of 120 electron-positron bunches can be stored in each ring. Being DAΦNE a multibunch machine, intense R&D was dedicated to design the RF cavities since they can cause coupled bunch instabilities because of undamped high order modes (HOM) [2].

The DAΦNE injector is a full energy system composed by a Linac [3] and a damping ring (DR) [4]. Herein, the operational experience with the DAΦNE RF systems, together with some remarks about their behavior under high current, multibunch operation, are reported. The Main Ring (MR) RF frequency is 368.26 MHz while the DR one is 73.652 MHz, i.e. the MR frequency divided by 5.

2 DAMPING RING RF SYSTEM

The aim of the DAΦNE DR is to reduce the beam energy spread and emittance before injection in the MR. The e^+/e^- beams are accelerated to 510 MeV with a 2856 MHz linear accelerator, injected at 50 pps in one DR bucket and extracted at 1 pps for transportation to the MR. The DR cavity is a single ended copper coaxial resonator with an internal profile designed to minimize the probability of resonant discharge (multipacting) [5]. The cavity is fed by a 50 kW tetrode amplifier through a 6-1/8" coaxial line. The cavity shunt impedance is ≈1.6 MΩ, and the required accelerating voltage for the operation is in the 150÷200 kV range.

A ferrite circulator protects the tube from reflected power bursts due to transient beam loading caused by the continuous 50 Hz injection/1 Hz extraction process during the injection sequence into the MRs. To prevent continuous activity of the plunger gear, the tuning servo-loop is usually kept off during the injection sequence. The circulator also allows to set safely a large Robinson detuning.

In the initial DR commissioning phase, longitudinal instabilities have been occasionally observed. Two cavity HOMs were found to lay very close to unstable synchrotron sidebands of the revolution harmonics and might be responsible for such instabilities. Anyway, after a small correction to the RF frequency to synchronize the DR to the MRs and a small change of the cavity temperature set point, longitudinal instabilities have not been observed anymore. So far, no significant faults or incorrect function of the whole RF system have occurred.

3 MAIN RINGS RF SYSTEMS

3.1 The Damped Cavities

The most relevant parameters of the MR DAΦNE RF systems are reported in Table 1.

Table 1: Main ring cavity parameters

f_{RF}	Resonant frequency	368.26 MHz
V_c	Accelerating voltage	250 kV
Q_0	Unloaded quality factor	33,000
R_{sh}	Shunt impedance	2 MΩ
P_c	Power loss	16 kW
β	Input coupling factor	2.5
P_k	Non saturated klystron RF power	150 kW
I_b	Max beam current	5 Amps
E_t	Beam energy loss per turn	≈15 keV
P_{HOM}	HOM power	≈ 3 kW
Δf_{bl}	Max. beam loading detuning	≈ - 500 kHz

The cavities are room-temperature single cell resonators, designed with the aim to reduce at the most their contribution to the ring broadband and narrowband impedances. The cavities have rounded profiles and are connected to the ring pipe with long tapered tubes to reduce the longitudinal and transverse HOM R/Q's and the loss factor. Further damping of HOM shunt impedances is obtained by connecting to the cavity 3 rectangular waveguides (wg), with cut-off at 500 MHz, which couple out the parasitic mode energy in the TE10 mode. The coupled waves are transformed into standard 7/8" coaxial TEM waves by means of broadband transitions [6]. The HOM energy is then dissipated on external 50 Ω commercial attenuators via wideband ceramic feedthroughs. Each attenuator output is connected through a cable to the accelerator control area, where the waveguide outcoming signals can be analyzed. Damping is more effective on monopoles because they couple better to the rectangular waveguide apertures. Two additional wg's with 1.2 GHz cut-off are placed on the tapers with a 90° relative position. They can couple those HOMs that mainly resonate in the tapers. The longitudinal HOMs have been measured up to 3 GHz on bench with the wire technique, and the results are shown in Fig. 1. The upper plot is obtained with all the waveguides terminated on 50 Ω loads.

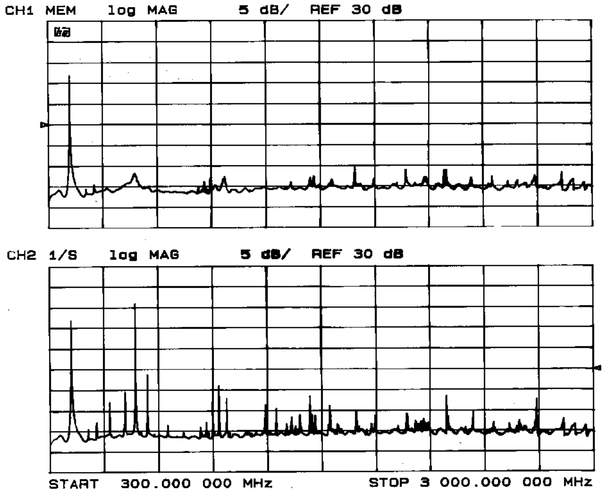

Figure 1: Cavity spectrum with the waveguides loaded with 50 Ω (up) and shorted (down).

Table 2: HOM cavity impedances measured with the wire technique.

F[MHz]	Q	$Z_{\|\|}$ [Ω]	F[MHz]	Q	$Z_{\|\|}$ [Ω]
672.5	40	110	1086.4	1650	66
728.0	47	149	1138.0	5120	300
862.8	4470	58	1142.9	1060	147
1047.0	2680	75	1172.9	510	226
1065.3	2080	94	1181.0	336	310
1074.5	340	95	1297.2	860	110

Figure 1 gives a glance of the successful HOM damping. The sole undamped line (the first one in the upper plot) represents the cavity fundamental mode. However, the wire technique perturbs significantly the mode frequencies and the unloaded quality factors, so that the measurement results have to be taken with some caution. The measured values are listed in Table 2.

It has been estimated [7] that, even being heavily damped, the RF cavity HOM's can drive longitudinal coupled bunch mode instability with rise times faster than 500 μs at the maximum machine current, calling for an efficient operation of the dedicated bunch-by-bunch feedback system [8] in order to keep the beam stable.

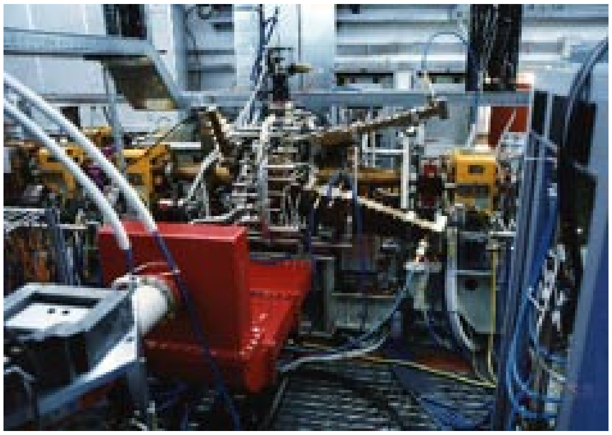

Figure 2: The RF cavity installed in the positron ring.

3.2 The RF System Assembly

A view of the positron ring cavity installed on the machine is given in Fig. 2. The cables connecting the wg's to the dummy loads are visible in the picture. Each cavity is connected to a 150 kW/cw klystron through a 3 port ferrite circulator. Such high power is needed for the full current operation.

The RF power couplers are similar to those of the LEP normal-conducting cavities and they are basically waveguide to coaxial transitions, ending with loops through a vacuum tight ceramic window which is air-water cooled and monitored with an infrared probe for temperature check. Moreover, a fast interlock turns off the power if excessive reverse to forward cavity power ratio occurs and in case of a steep cavity pressure increase. This avoids stress of the RF windows in case of sudden beam losses or arcs. One window has cracked in January '98 because of a human error and caused 2 weeks of machine shut down. So far, this window crack and a tuning plunger seizing were the only significant faults during the DAΦNE RF system operation.

Intense beam loading is foreseen at full beam current. To increase the threshold of the 2nd Robinson limit, an RF feedback system has been developed and tested in the cavity test hall [9]. The final implementation of the RF feedbacks will be made as soon as we approach the full design beam current.

The low power RF control electronics includes servo loops to regulate the cavity tuning, level and phase. The RF phase stability directly impacts on that of the longitudinal position of the interaction point, as well as on the injection efficiency. In the DAΦNE MRs a long term RF phase stability within few tens of ps has been measured.

The operation of the main ring radiofrequency has been very reliable so far; also, the performances of the whole system were fully satisfactory.

4 THE FAST RF PHASE JUMP

During the first machine shifts dedicated to the luminosity tune-up, the performances were limited by injection saturation when injecting in the collision mode [1]. On the other hand, schemes of transverse beam separation (horizontal or vertical) did not work satisfactorily, due to the lack of synchronism in the variation of the fields in the corrector magnets.

In order to get over these limitations we adopted a "fast RF phase jump" technique. This consists in injecting the beams with an adequate longitudinal separation and put them suddenly in collision by fast changing the RF phase of one of the two beams.

The RF phase jump is obtained by a fast electronic delay line acting on the RF reference signal entering the positron cavity control electronics and driven by pulses of a suitable amplitude and rise time.

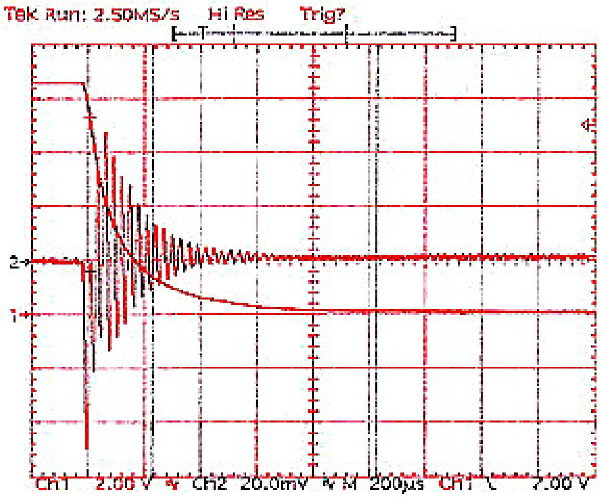

Figure 3: Driving signal (CH1, ≈ 3 rad/div vert. scale) and detected synchrotron oscillation (CH2, ≈ 58 mrad/div vert. scale) during a 4π rad. RF phase jump.

The driving signal (≈ 600 µs long) together with the induced synchrotron oscillation around the moving synchronous phase for a two-buckets (4π radians) RF phase jump are reported in Figure 3. The derivative of the phase pulse is a modulation of the RF frequency. This transient frequency modulation puts temporarily the beam on external (internal) orbits and is responsible for the increasing (decreasing) bunch delay.

The phase jump is basically a barycentric longitudinal motion of the beam, and therefore the synchrotron oscillation damping is dominated by the Robinson effect. The envelope decay shown in Fig. 3 gives a Robinson damping time of ≈ 120 µs (@ 25 mA of beam current in 1 bunch), in a fairly good agreement with the expected value. The Robinson damping is beneficial for the fast RF jump technique since it reduces the amplitude of the oscillations as well as the transient duration.

5 SOME REMARKS ON HIGH CURRENT OPERATION

The maximum achieved current during the DAΦNE commissioning is ≈ 550 mA in 30 bunches in both e^+/e^- rings. Some longitudinal and transverse coupled-bunch instabilities have been observed in the e^- and e^+ ring respectively [10], but none of them could be clearly attributed to the cavity HOMs. On the contrary, in spite of the strong Robinson damping, we occasionally observed longitudinal barycentric oscillations of the beam at high current. They were due to excessive wide band response of the RF amplitude and phase loops, an effect known in literature[11]. Once the gain and the bandwidth of the servo loops have been reduced, no more barycentric instabilities have been observed.

The performances of the RF systems under high beam loading were quite satisfactory, since no special operation difficulties have been observed. However, the 550 mA current value is still far from the 2nd Robinson limit threshold, and the implementation of the fast RF feedback system remain necessary to approach the ultimate current value.

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