Status of the DAΦNE RF System

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Abstract

The DAΦNE RF System consists of one quarter wave resonator in the pre-accumulator ring fed by a 73.65 MHz - 30 kW channel and one cavity per each main ring powered by a 368.25 MHz - 150 kW klystron. The main ring cavities are equipped with waveguides terminated by means of broadband adapters to 50 Ω loads to damp the High Order cavity Modes. This paper gives an overview of the status of the RF system and also briefly describes the low level RF control electronics.

1. INTRODUCTION

The Frascati Φ-Factory project DAΦNE [1] is now in a very advanced stage. The machine consists of two intersecting storage rings, for electrons and positrons respectively, to provide 1020 MeV e^+/e^- center of mass collisions at a maximum current of 5 Amps per beam with 120 bunches per ring. Full energy injection in both rings is performed with a 50 Hz linear accelerator [2] and a pre-accumulator damping ring. The positrons or electrons injected in the pre-accumulator are stored in a single bunch and extracted at 1 Hz and injected in the main rings.

Parameters and architecture of most components of the DAΦNE RF system are well defined. The prototypes of the RF cavities have been low power tested and ordered to the industry. The RF power supplies have been commissioned to industry as well.

2. THE ACCUMULATOR RING RF SYSTEM

The main parameters of the accumulator RF system are reported in Table I.

Table I
The Accumulator RF System Parameters

RF Frequency	73.65 MHz
Harmonic Number	8
Cavity Impedance ($V^2/2P$)	1.50 MΩ
Cavity Unloaded Q	22000
RF Peak Voltage	200 kV
Cavity Power	13.3 kW
Beam Current	130 mA
Beam Power	1.2 kW
Tetrode Power	30 kW

The cavity, made of oxygen free, high conductivity (OFHC) copper, is a 73.65 MHz quarter wave resonator [3] and is being manufactured by industry (CERCA, Romans, France). The shape of the cavity has been carefully studied to reduce the probability of vacuum resonant discharges (e.g. multipactoring) at high field levels. Tuning is accomplished by a plunger placed in the magnetic field region of the resonator; RF power is coupled with a magnetic loop. A drawing of the cavity is shown in Figure 1.

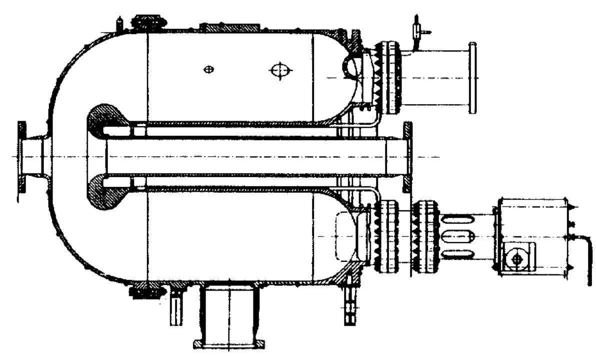

Figure 1. The Accumulator Ring RF Cavity

The RF power supply, to be placed 30 meters from the accumulator hall, is a 30 kW continuous wave (CW) water cooled tetrode tube driven by a 2 kW solid state amplifier (R&S, Berlin, Germany). It is connected to the cavity with a 6-1/8" coaxial line through a three port ferrite circulator which allows to safely operate the power final stage and reduces the risk of oscillations when the cavity is detuned to lower frequencies to meet the Robinson stability criterion.

The amplitude and phase of the RF cavity voltage together with the cavity tuning are controlled by dedicated servo loops. The frequency response of the amplitude and phase control loops has been improved by selecting fast and linear devices and a typical result is shown in Figure 2.

A gain higher than 60 dB at 50 Hz can be reached; any spurious modulation at that frequency can be reduced by a factor larger than 1000. Full computer interfacing of the RF chain is being developed. A current-feedback voltage-gain-controlled operational amplifier (Comlinear CLC 520) allows to remotely control the loop gains to improve the RF control system flexibility. Full control circuit tests have been performed on a low power cavity prototype.

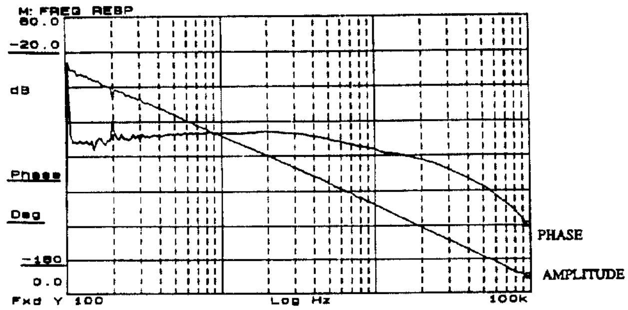

Figure 2. Accumulator RF System: the RF Amplitude Loop Frequency Response

3. THE MAIN RINGS RF SYSTEM

One RF cavity will be installed on each intersecting storage ring. The resonators, made of OFHC copper, are equipped with high order mode (HOM) suppressors. The RF power source consists of a 150 kW/CW klystron amplifier; a high power ferrite circulator is used to protect the klystron when high standing wave regime occurs. The parameters of the main RF system, for 30 bunches operation, are shown in Table II.

Table II
The Main Ring RF Parameters with 30 Bunches

RF Frequency	368.25 MHz
Harmonic Number	120
Cavity Impedance ($V^2/2P$)	2.40 MΩ
Cavity Q_o (with WGs)	40000
RF Peak Voltage	260 kV
Cavity Power	15 kW
Beam Current	1.41 A
Beam Power (with Parasitic Losses)	28 kW
Klystron Power	150 kW

3.1 The DAΦNE RF Cavity

The design of the RF cavity has been conceived with the aim of reducing the coupling of the HOMs to the beam spectrum lines [4]. The cavity is connected to the beam pipe with large and long tapered tubes which yield a significant reduction of the HOM R/Q impedances. Moreover, three waveguides with cut-off above the fundamental mode (FM) frequency are incorporated in the resonator to convey the beam induced HOM energy out and to dissipate it on an external 50 Ω load. This is accomplished by means of broadband (0.5÷3 GHz) waveguide to coaxial transitions (BTHD) which have been developed at LNF [5] to this purpose. The damping system, which also includes two additional 1.1÷3GHz BTHDs connected to the tapered tubes, has been tested on a cavity prototype and the measured HOM Qs are listed in Table III. They are below the calculated Q values [6] required to initially operate the machine with 30 bunches together with a bunch-to-bunch digital feedback system. The WG damping system yields a reduction of the FM frequency and Q of about 2% and 12% respectively.

Table III
The Cavity Prototype HOM Quality Factors

F (MHz)	R/Q (Ω)	Unload. Q	Loaded Q	Target Q
745.7	16	24000	70	85
796.8	0.5	40000	210	2500
1023.6	0.9	28000	90	300
1121.1	0.3	12000	300	3500
1175.9	0.6	5000	90	1650
1201.5	0.2	9000	180	4300
1369.0	2.0	5000	170	450
1431.7	1.0	4000	550	870
490.0 °	5.1 *	30500	150	9200
491.3 °	5.1 *	28500	830	9200
523.5 °	14.0 *	31500	150	6200
549.7 °	14.0 *	3200	50	6200

° Dipoles -
* Normalized Impedance -

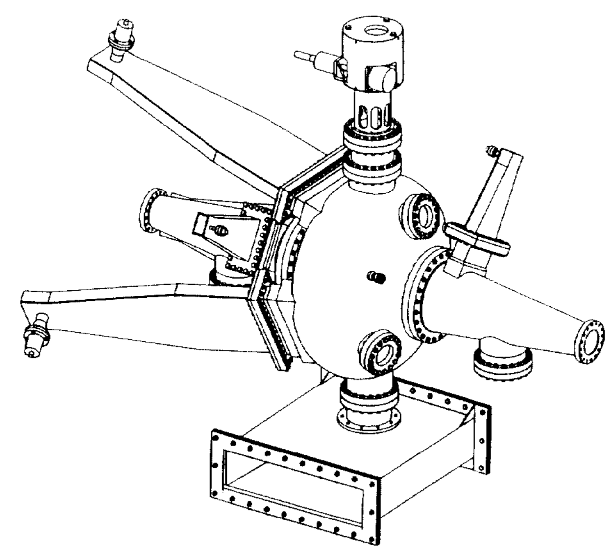

Figure 3. Skecth of the DAΦNE RF Cavity.

A sketch of the DAΦNE cavity is shown in Figure 3. It includes the tuning system (upper cavity side) and the fundamental mode RF coupler (lower cavity side) whose design derives from that of the copper LEP cavities. The BTHD transitions have been successfully power tested as reported in [7]. The first main ring cavity is being fabricated by industry (ZANON, Schio, Vicenza, Italy).

3.2 The RF Power Source

The RF power source of each main ring RF system is a 150 kW/CW klystron operating at 368.25 MHz. The power to be delivered to the beam was estimated in the order of 100 kW at full beam current of 5 Amps. The new klystron TH2145 has been developed by Thomson Tube Electronique and successfully factory tested at full power.

The klystron group delay, i.e. the derivative of the output phase with respect to the angular frequency, should be kept as low as possible at the operating frequency to improve the performances of an RF feedback loop to be closed around the cavity and klystron to provide beam stability under intense beam loading conditions. The RF feedback has been proposed and positively operated in other accelerators [8,9]. A group delay of about 160 nsec has been measured in both DAΦNE klystrons. In order not to increase the group delay further, the klystrons will be positioned at short distance from the cavities (about 7 meters) in the main rings hall. The frequency and group delay responses of the klystron are shown in Figure 4.

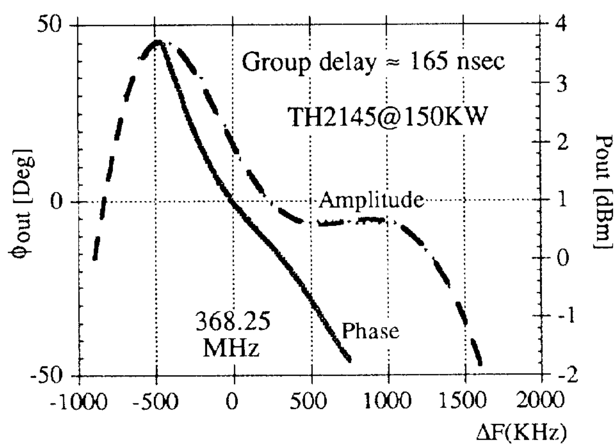

Figure 4. The Klystron TH2145 response

3.3 The Main Ring RF Feedback

To compensate for beam loading when operating the main rings at high current, an RF feedback around cavity and klystron must be implemented, otherwise the longitudinal motion of the beam can become unstable in the Robinson zero frequency mode.

A sample of the cavity RF voltage is fed to the klystron driver back and added with a proper phase to the main RF signal to get a negative feedback connection which reduces the complex impedance seen by the beam according to the following expression:

$$Z'(j\omega) = \frac{Z(j\omega)}{1+G(j\omega)Z(j\omega)} \qquad (1)$$

where $G(j\omega)$ is the feedback gain.

The reduction of the complex impedance allows to increase the instability threshold derived by Robinson [10] and, hence, the maximum storable beam current I_M, according to:

$$1 - \frac{2I_M Z(j\omega)}{V_C|\sin\phi_S|} = 0 \qquad (2)$$

where V_C is the cavity voltage and ϕ_S the synchronous phase. The maximum attainable feedback loop gain, as derived by Boussard, is limited by the group delay of the loop itself where the largest contribution is due to the klystron. In our case, a total delay of about 250 nsec, including the delay of the connecting cables, allows increasing the RF feedback gain as much as we need to reach stable operation even at full beam [11].

5. ACKNOWLEDGMENTS

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