# DAΦNE  TECHNICAL  NOTE

INFN - LNF,  Accelerator Division

## THE RADIOFREQUENCY  SYSTEM  FOR  DAΦNE: FIRST REMARKS

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## INTRODUCTION

This note presents some considerations on the Radiofrequency System (RFS) for DAΦNE. It is worthed to mention that the RFS has to supply to the beams the energy lost by synchrotron radiation and parasitic losses.

We propose two different solutions, based on the following preliminary parameters[1]:

| | |
|---|---|
| Frequency | ≈ 350 MHz |
| RF Peak Voltage | ≈ 500 kV/ring |
| Maximum Beam Power | ≈ 100 kW/ring |

We have investigated which power source would be the most suitable to our purposes.

The RF market can essentially offer two kinds of devices in the frequency and power range of interest:

- the Klystron is a wideworld diffused RF source and can perform reliably with high power gain;

- the Klystrode[2] is a novel design source developed in the latest years and has some more efficiency and compactness despite less power gain.

In consideration that the machine design should be based, as much as possible, on a conventional technology, we believe the klystron to be the best choice from this point of view. Some manufacturers, who have been consulted, are available to produce an RF source capable of supplying the required power in the 350 MHz range.

A safety margin has been considered for the maximum peak voltage. An additional RF system operating at the third harmonic of the main RFS is foreseen to control the bunch length; this involves an increase in the main RFS voltage  to obtain adequate Touschek and quantum lifetime. The needed peak voltage of the main RFS also would increase if the parasitic losses were higher than expected.

An RF peak voltage of 500 kV per ring is therefore considered in a preliminary design.

We consider two different RF layouts and then we will compare the pros and cons in the conclusions.

## 1) Double cavity system

This solution foresees the installation of two accelerating resonators in each ring, whose main characteristics are:

| | | |
|---|---|---|
| RF peak voltage per cavity | $V_c$ = | 250 kV |
| Cavity impedance * | $R_c$ = $ZT^2/2$ = | 2.5 MΩ |
| Cavity power dissipation | $P_c$ = | 12.5 kW |
| Beam power per cavity | $P_{bc}$ = | 50 kW |
| Max input power per cavity | $P_{ic}$ = | 62.5 kW |
| Max Klystron output power (including  feeding line losses and  safety margin) | $P_k$ = | 80 kW |

Two klystrons will separately feed the cavities, with 9-3/16" coaxial lines, through RF Isolators or Y-Junction Circulators (see Fig.1) which protect the RF sources against high power reflection when standing wave regime occurs.

The resonators are presently subjects of a research program whose goal is the development of RF cavities having the fewest high order mode (HOM) resonances. This result could be achieved by means of different methods like large beam tubes and/or particular cavity profile and/or absorbers of HOM which can detrimentally contribute to the longitudinal and transverse impedance. The relatively low impedance value taken for the calculations is therefore justified.
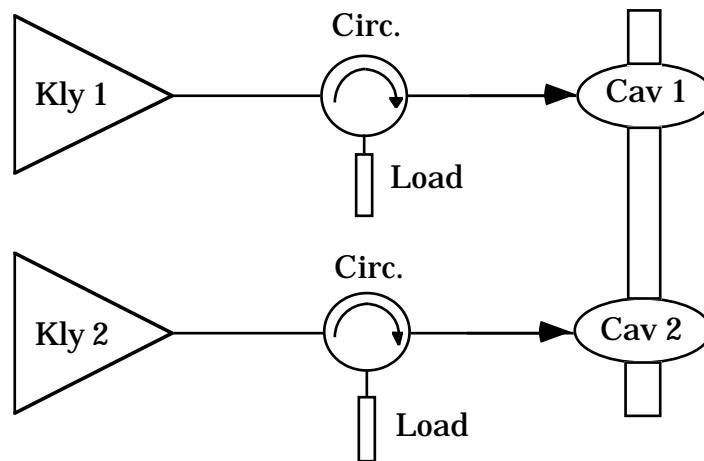
*Fig. 1 - Schematic layout of the RF system with 2 cavities per ring.*

- *Beam loading*

For an overall radiated energy of 20 keV, the synchronous phase angle in each cavity, see Fig. 2, is:

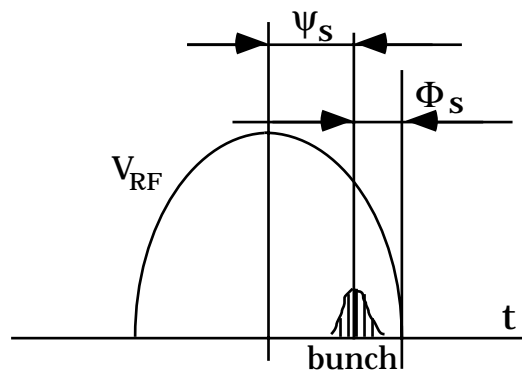$$\sin\phi_s = \frac{10 \, keV}{250 \, kV} = 0.04$$

$$\phi_s = (2.3)^0$$



*Fig. 2 - Synchronous phase angle of the bunch.*

The beam loading is given by :

$$R_b = \frac{V_C^2}{2P_{bc}} = 0.625 \ M\Omega \tag{1}$$

The expression (1) is only the real part of the beam loading because the cavity tuning system usually compensates for the reactive part.
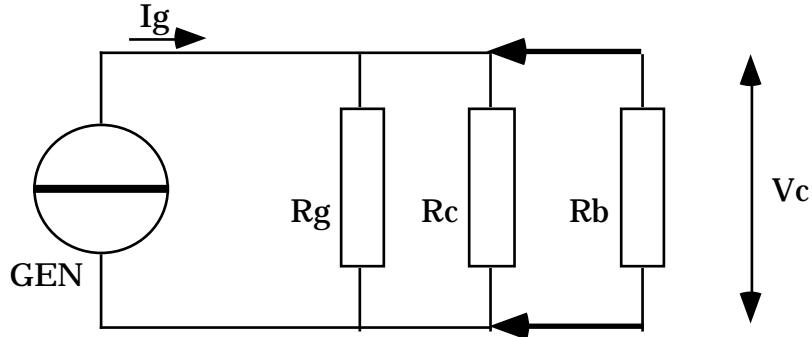


*Fig. 3 - The Beam-RFS complex*

The generator load is then (see Fig. 3):

$$R_L = \frac{R_C R_b}{R_C + R_b} = 0.5 M\Omega \tag{2}$$

The generator delivers the maximum power to the beam when $R_g$ = $R_L$. This condition is guaranteed for $P_b$ = 50 kW if the generator-cavity coupling factor is set, in the absence of beam, to:

$$\beta = \frac{R_C}{R_g} = 1 + \frac{P_{bMAX}}{P_C} = 5 \tag{3}$$

Without stored beam, high reverse RF power is then dissipated in the circulator load as shown in Fig. 4 for $V_c$ = constant; $P_{out}$ is the output klystron power given by the formula:

$$P_{OUT} = (P_C + P_b) \cdot \frac{(1 + \beta_X)^2}{4\beta_X} \tag{4}$$

where:

$$\beta_X = \frac{P_C + P_{bMAX}}{P_C + P_b}$$

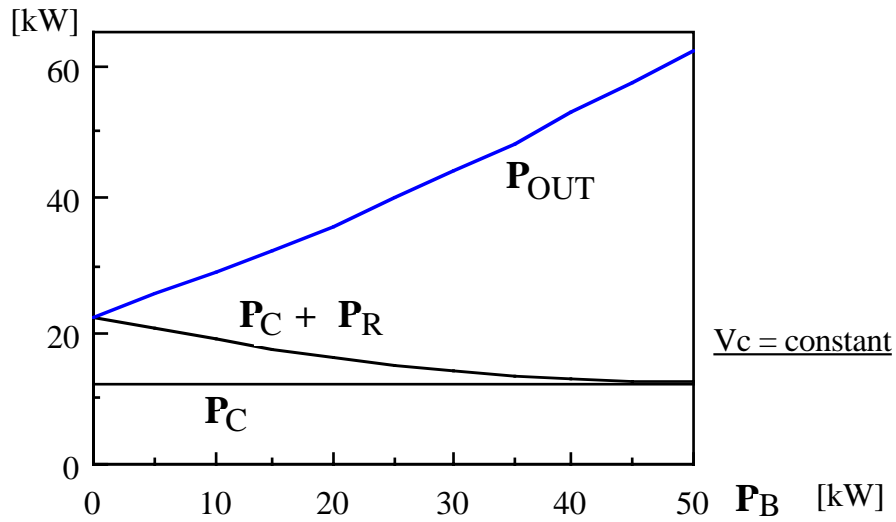is the actual coupling factor with $P_{bMAX}$ = 50 kW.

*Fig. 4 - RF power diagram (the cavity dissipation is kept
constant through a feedback system).*

- *<u>Beam stability condition</u>*

With reference to Fig. 3, one can define the "source impedance" as:

$$R_S = \frac{R_g R_C}{R_g + R_C} \tag{5}$$

that is the impedance "seen" by the beam.

In our case $R_S$ = 0.416 M$\Omega$.

The Robinson stability criterion[3],[4] for bunch coherent phase motion
requires that:

$$R_S < R_b = \frac{V_C^2}{2P_b} = \frac{V_C}{2 <i_b> \sin \phi_S} \tag{6}$$

In our case the above condition is largely fulfilled and the maximum
average stored current $<i_b>$ is only limited by the available RF power.

## 2) Single cavity system

The installation of one cavity per ring is investigated too.

The maximum cavity power dissipation, even with a careful design of the cooling system, should not exceed 35 kW. This limits the attainable RF peak voltage per ring to about 420 kV with an effective shunt impedance of 2.5 MΩ.

The main parameters of a single cavity system are summarized:

| | | | |
|---|---|---|---|
| RF peak voltage | $V_c$ | = | 420 kV |
| Cavity impedance | $R_c$ | $= ZT^2/2$ = | 2.5 MΩ |
| Cavity power dissipation | $P_c$ | = | 35 kW |
| Max beam power | $P_b$ | = | 100 kW |
| Max cavity input power | $P_i$ | = | 135 kW |
| Max Klystron output power | $P_k$ | = | 180 kW |

(including feeding line losses and safety margin)

Other system parameters are:

| | | | |
|---|---|---|---|
| Synchronous phase | $\sin\phi_s$ | = | 0.048 |
| Max beam loading | $R_b$ | = | 0.88 MΩ |
| Generator-cavity coupling | $\beta$ | = | 3.84 |
| Source impedance | $R_S$ | = | 0.51 MΩ |

The input power through the cavity main coupler is rather high, even though, in other laboratories, ceramic feedthroughs capable to withstand such power values, have been tested.

The Robinson condition is also fulfilled for single cavity solution.

## 3) The resonant cavities

As above mentioned, the resonators are presently subject of a research program in our laboratory. The goal is the development of a device with the fewest possible HOM's. The effort in this direction is very intense to date in many other laboratories.

Our investigation is concentrated towards two different solutions:

1) the first is a resonator with a shape similar to that proposed for ELETTRA[5]; it will have large beam holes to reduce the number of HOM's trapped inside the cavity and a tuning of HOM frequencies to avoid overlap with the beam bunches frequencies while keeping the fundamental mode frequency unchanged;

2) the second is a resonator equipped with broadband HOM coupler to suppress as many modes as possible; the coupler may be one or more waveguides with the frequency cut-off just above the fundamental as proposed by Conciauro and Massarotti[6],[7].

## 4) The damping ring RFS

Electrons and positrons will be pre-accumulated in a damping ring before the injection in DAΦNE[8].

The accumulator RFS will operate on the fifth sub-harmonic of the main radiofrequency.

A summary of its characteristics is given  below :

| | | | |
|---|---|---|---|
| Working frequency | $F_o$ | ≈ | 70 MHz |
| RF peak voltage | $V_o$ | = | 100 kV |
| Cavity impedance | $R_o$ | = | 1MΩ |
| Cavity power dissipation | $P_o$ | = | 5 kW |
| Approximate cavity length | L | ≈ | 1 m |
| Synchrotron radiation losses | $U_r$ | = | 5.5 keV |
| Max. beam power | $P_b$ | = | 385 W |
| Installed RF power | $P_k$ | = | 8 kW |

(including  feeding line losses and safety margin)

The proposed cavity is a quarter-wave resonator of coaxial type which can be fed by tetrode amplifiers, easily available on the market.

CONCLUSIONS

Two possible configurations have been discussed for the DAΦNE RFS.

The single cavity configuration should have the advantage of a lower contribution to the machine impedance, but an intense research program is however in course to develop an HOM free resonator.

The cost of a single cavity system is not much lower than the double cavity system. Indeed, more powerful RF amplifiers and circulators are needed and the use of expensive waveguides  to feed the cavity (in place of coaxial lines) is probably a safe choice due to higher driving power. Moreover the maximum achievable RF peak voltage is a little more than 400kV.

For purely technical reasons, the double cavity configuration seems much more reliable. Some parameters (cavity power dissipation and input power) are less severe in this case.

The design of the main coupler and cavity cooling system are then less complicate. Two separated RF channels allow the machine operation even in case of klystron or cavity failure and let it possible to adjust the phase of the cavity fields independently.

Moreover, we point out that a single 80 kW RFS per ring allows to inject a beam current of 2 Amps at 400 kV peak voltage with a safety margin in RF power. The second system is necessary in an up-graded machine configuration to store the maximum nominal current of 5 A.

An alternative layout could be the use of a single source for both rings and the RF power would be splitted to feed the cavities, but this solution is not very attractive because it does not allow to act upon each cavity with separate feedback loops.

In this note, the higher harmonic RF system has not been considered because it is still under study.

## REFERENCES

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(7)   A. Massarotti, M. Svandrlik: Proposal for a Broad-Band High Order Mode Suppressor for an RF Cavity - Sincrotrone Trieste Internal Report, ST/M-90/5, March 1990.

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