DAΦNE TECHNICAL NOTE

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Note: **RF-8**

ESTIMATE OF THE HOM POWER DISSIPATION FOR THE DAΦNE MAIN RING CAVITY

A. Gallo, F. Marcellini

1. Introduction.

Crossing the gap of an accelerating cavity, a beam of particles structured in bunches induces an e. m. field (the so called wake field) in the volume enclosed by the cavity.

If the wake field excited by the passage of a bunch survives long enough to interact with the following bunches and if the interaction occurs with a proper phase relation, dangerous oscillations can rapidly grow up.

In the frequency domain this interaction can be described in terms of overlapping of the beam and cavity spectra. The beam spectrum presents its lines in correspondence to the revolution frequency harmonics, and if at least one of these lines overlaps the HOM cavity spectrum an interaction beam-cavity occurs. The higher is the mode shunt impedance, the stronger is the interaction.

However it is interesting to observe that a reduction of the HOM Q values, obtained with external couplers, from one hand reduces the instability growth rate while on the other hand increases the coupling probability between the beam and the parasitic modes.

2. HOM Power Estimate.

It is possible to quantify the interaction between the beam current and the impedances of the cavity high order monopoles, by estimating the power released to HOMs by the beam. This information is essential to define the characteristics of the external loads in a damped cavity.

This estimate is based on the following analytical considerations. In the time domain the beam current is given by:

$$i(t) = \sum_{k=-\infty}^{\infty} i_0(t - kT_0) \tag{1}$$

with:

$$i_0(t) = \sum_{i=1}^{N_1} q_i \delta\left(t - \frac{iT_0}{N_1}\right)$$

where q_i is the ith bunch charge, N_1 is the number of buckets (120 in the DAΦNE case), T_0 is the bunch revolution period and T_0/N_1 is the minimum time distance between two bunches. The periodic function (1) can be expanded in a Fourier Series with the following two-sided spectrum amplitudes[1]:

$$I_n = \frac{1}{T_0}\int_0^{T_0} i_0(t)\exp\left(j\frac{2\pi n}{T_0}t\right)dt = \sum_{i=1}^{N_1}\frac{q_i}{T_0}\exp(-j\frac{2\pi n i}{N_1}t) \equiv \text{beam } n^{th} \text{ harmonic amplitude.}$$

The real part of the impedance of the rth cavity HOM characterized by the resonant frequency ω_r, the quality factor Q_r and the shunt impedance R_r is given by:

$$\Re[Z(\omega)] = \frac{(R/Q)_r Q_r}{1 + Q_r^2\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right)^2}$$

Then the beam nth harmonic releases the following power to the cavity rth mode:

$$P_{n,r} = \frac{2(R/Q)_r Q_{Lr} I_n^2}{1 + Q_{Lr}^2\left(\frac{n\omega_0}{\omega_r} - \frac{\omega_r}{n\omega_0}\right)^2}$$

where Q_{Lr} is the loaded Q of the considered mode. As a consequence the whole power released by the beam to the cavity HOMs is given by:

$$P_{Tot} = \sum_{n=0}^{\infty} \sum\nolimits_{all\ the\ HOMs} \left(\frac{2(R/Q)\ Q\ I_n^2}{1 + Q^2\left(\frac{n\omega_0}{\omega_r} - \frac{\omega_r}{n\omega_0}\right)^2}\right) \tag{2}$$

It's worth to observe at this point that the power dissipation given by (2) has to be computed in the actual operative condition where, due to the thermal drifts and the automatic beam loading compensation of the fundamental mode tuning system, the HOM resonant frequencies are subject to some degree of uncertainty. Therefore the calculation has to be made in a statistic way, considering a wide number of results corresponding to a random spread of the HOM frequencies within a certain range around the nominal values.

In order to obtain information for the DAΦNE case the expression (2) has be implemented in a simple code based on the graphic programming language LABVIEW[2].

3. Description of the Code.

The code consists of three sections:

a) construction of beam structure;

b) calculation of beam spectrum;

c) calculation of dissipated power of each HOM.

a) CONSTRUCTION OF THE BEAM STRUCTURE.

- A divider of 120, N, is defined to establish the basic structure (120, 60, 40, 30, 24, ... buckets). For instance, N=4 means a 30 bunch basic structure.

- A number K of identical subgroups giving rise to the structure is defined.

- The basic subgroup is built by using 3 windows which may be chosen at will. Every window allows to define how many buckets are filled starting from a certain reference bucket.

- Buckets are filled with a certain maximum charge which can be optionally reduced of a random amount within a chosen range. This option allows to simulate the realistic scenario of unequally filled bunches.

b) CALCULATION OF THE BEAM SPECTRUM.

The calculation is based on the previously written formulas.

c) CALCULATION OF THE DISSIPATED POWER OF EACH HOM.

For a given mode the algorithm calculates the dissipation due to the closest beam harmonic and goes ahead switching to its left and right side until the mode resistance becomes lower than 1Ω. In this way, for a maximum current of 5 Amps, the maximum estimate error is lower than 50 W.

Finally the frequency jitter function allows to spread in a totally random way the HOM frequencies within a programmable percentage of the nominal values.

All the functions described so far are displayed on the front-panel shown in Figs. 1 and 2.

4. Application to the DAΦNE case.

This code has been run considering various cavity shapes proposed for the main rings of DAΦNE. We report in this note the results obtained for a rounded shaped cavity loaded by 3 ridged guides terminated on match loads.

The loaded Q values put in the code are those obtained by measurements on prototype, while the resonant frequencies and R/Q values are those obtained with the 2D simulation code URMEL[3].

Our analysis is limited to the monopoles up to 1.5 GHz (9 modes) since the measurements above that value were not reliable enough. Frequency jitter has been fixed on 0.7%.

In a 30 bunch basic structure the maximum power dissipation given by the code is around 800 W, obtained by filling asymmetrically 26 bunches over 30 (see Fig. 1). This power rate can be easily handled by the loads placed in the 3 damping guides.

In view of a 60 bunch machine operation we run the code for several beam structure in which some buckets were empty. Power dissipation in this case is always lower than 2kW (see Fig. 2).

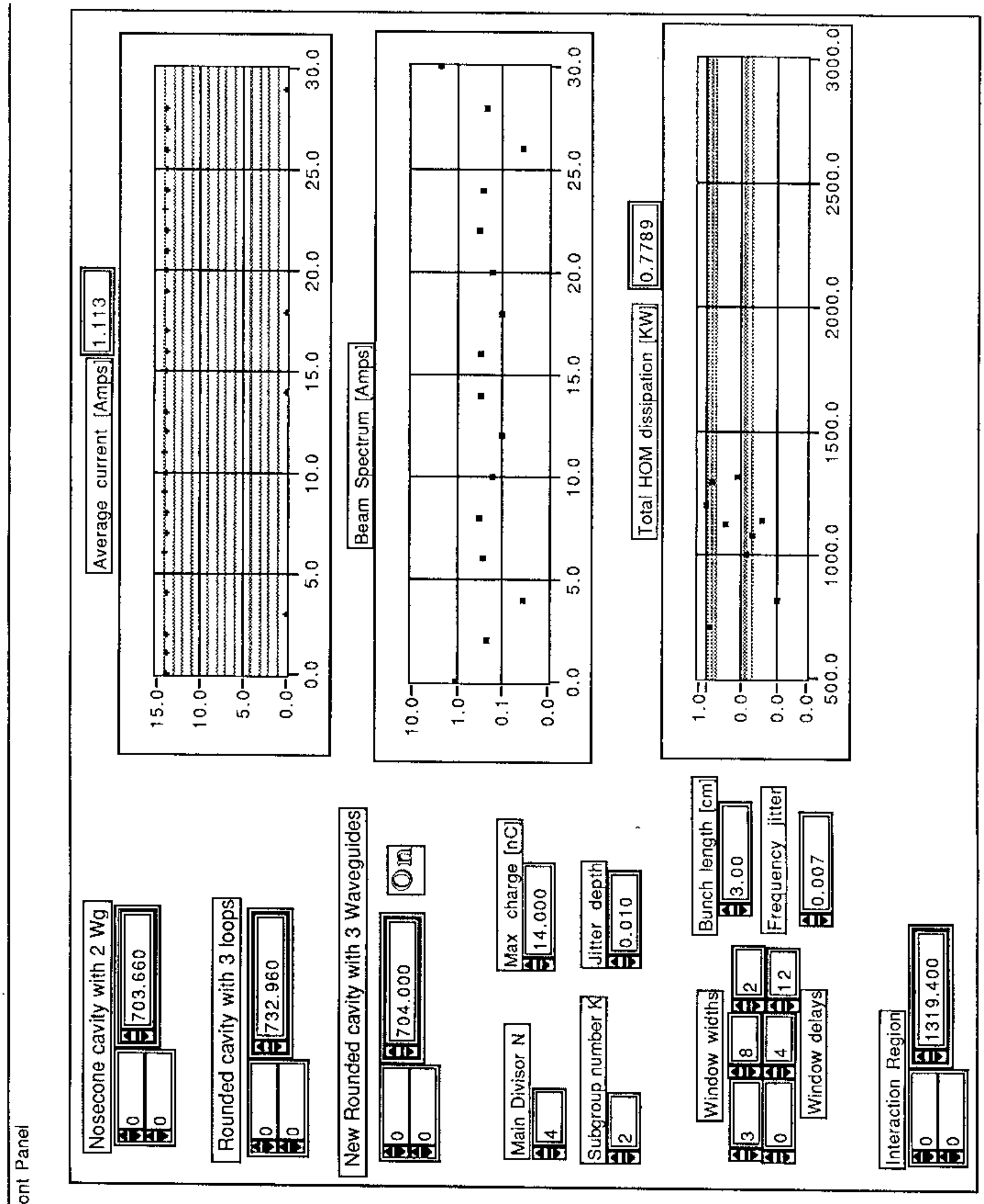

Fig.1: HOM power dissipation for a configuration of 26 bunches over 30.

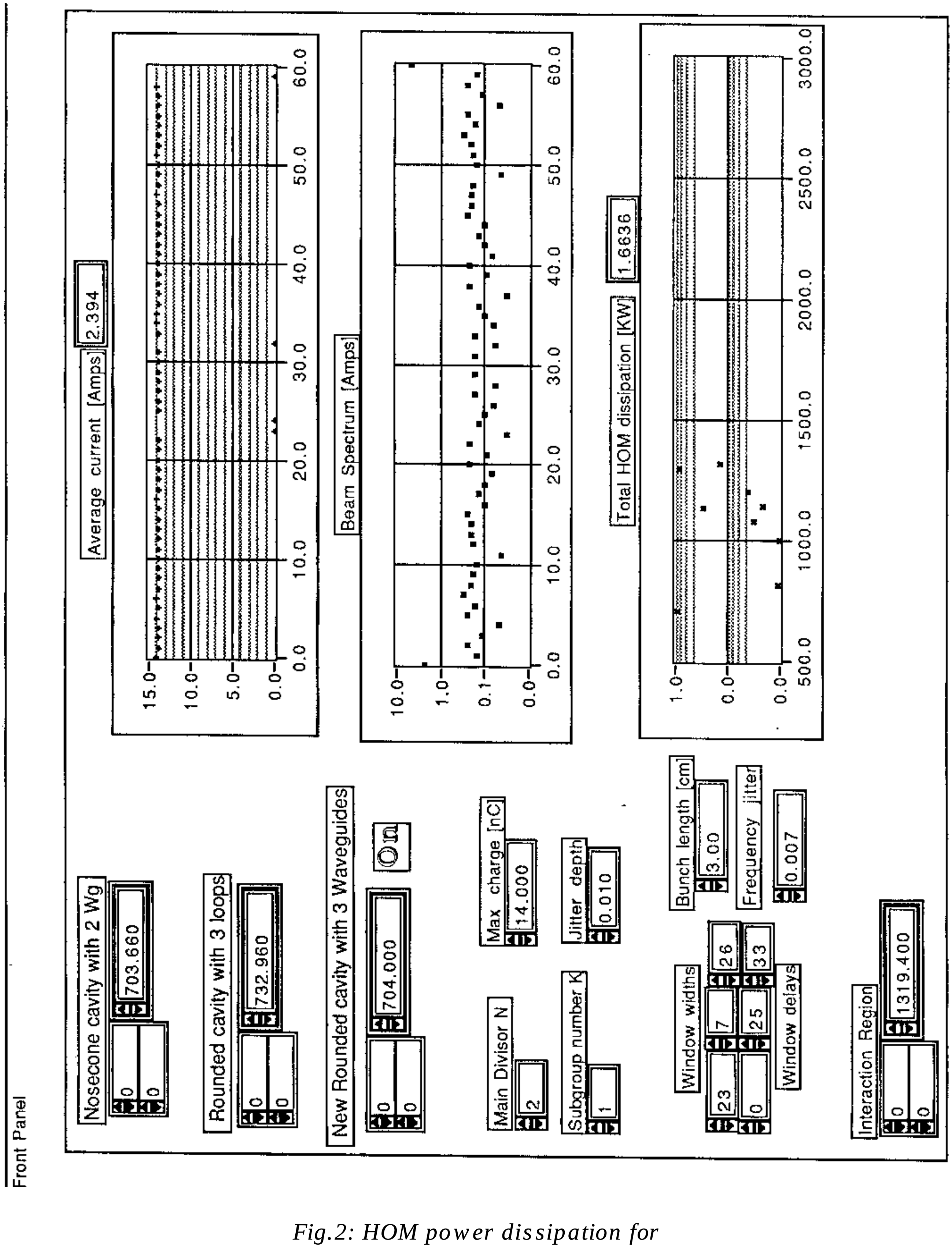

Fig.2: HOM power dissipation for
a configuration of 56 bunches over 60.

REFERENCES

[1] H.Taub, D.L. Schilling, *Principles of communication systems*, McGraw-Hill 1971.

[2] LABVIEW, National Instrument Corporation, 6504 Bridge Point Parkway, Austin, TX 78730-5039.

[3] T. Weiland, NIM 216 (1983), pp. 329-348.