KICKERS AND POWER AMPLIFIERS FOR THE DAΦNE BUNCH-BY-BUNCH LONGITUDINAL FEEDBACK SYSTEM

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Abstract

The multibunch operation of the Frascati Φ-Factory DAΦNE calls for a very efficient longitudinal feedback system to damp the coupled bunch instabilities. A bunch-by-bunch feedback scheme, capable of kicking any bunch proportionally to the time derivative of its position error has been adopted. A special longitudinal kicker based on a waveguide overloaded pill box cavity has been designed and fabricated for this task. A broadband linear power amplifier to drive the kicker has been selected and fully characterised. A description of the power section of the longitudinal feedback system, including kicker, power amplifier, broadband circulator, fast amplitude modulator, together with time and frequency domain measurements, is reported in this paper.

1 INTRODUCTION

In DAΦNE, the Frascati Φ-Factory, up to 120 bunches, 2.7 nsec spaced one each other, can be injected. Coupled-bunch instabilities with rise time faster than the natural damping time could be driven by narrowband machine impedances.

A longitudinal feedback capable to damp all the coupled-bunch modes and the injection transient has been developed in collaboration with the B-Factory group at SLAC.

A bunch-by-bunch feedback scheme, capable of kicking any bunch proportionally to the time derivative of its position error has been adopted [1].

In reference [2,3,4] the description of the feedback chain employing DSP techniques is reported.

2 BUNCH BY BUNCH FEEDBACK BACK-END SECTION

Once the bunch phase errors from the front-end section are processed by the DSP board, the outcoming signals have to be converted in longitudinal kicks to give to the bunches the proper energy correction. The "back-end" section is the analog hardware dedicated to this task, and its schematic representation is shown in Fig. 1.

A bunch synchronous and coherent carrier signal is fast amplitude modulated by a double balanced mixer accordingly to the kick level elaborated by the DSP board. The amplitude modulated signal is then amplified by a linear, broadband power amplifier and sent to the kicker input ports through ferrite circulators.

The choice of the power amplifier is crucial for the system efficiency since an actual rise time much shorter than the bunch time spacing (2.7 nsec) is required, corresponding to a real bandwidth much larger than the RF frequency (368.32 MHz). A 250 W pure class-A linear device (mod. AS0814-250R, MILMEGA Ltd, UK) has been adopted; the amplifier frequency response nearby saturation is shown in Fig. 2.

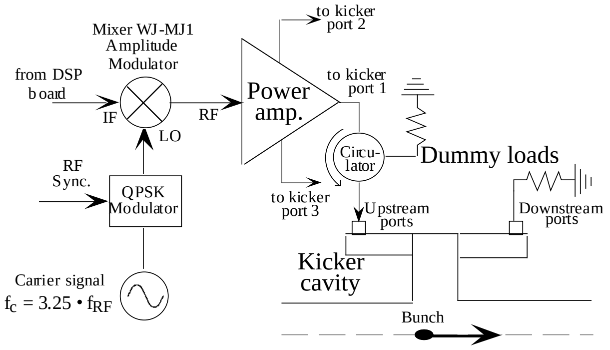

Figure 1: Back-end sketch.

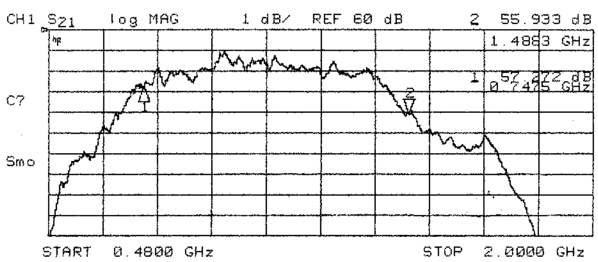

Fig. 2: Power amplifier frequency response

3 LONGITUDINAL KICKER

The longitudinal kicker, the last element of the feedback chain, is the electromagnetic structure capable of transferring the proper energy correction to each bunch.

A possible choice is to use a stripline multi-electrode device for this task [5]. In order to increase the kicker shunt impedance and decrease the parasitic High Order Mode (HOM) content, a longitudinal kicker based on a waveguide overloaded pill-box cavity has been designed and fabricated for the DAΦNE feedback system [6].

A sketch of the DAΦNE longitudinal kicker is shown in Fig. 3. The extremely large band required to fill the cavity to any kick value in a time interval corresponding to the bunch time spacing is obtained by loading the accelerating mode with three single-ridged waveguides placed 120° apart on each pill-box side.

The coupled out field is transformed in a TEM wave by a broadband waveguide-to-coaxial transition and ceramic coaxial feedthroughs allow on-air connection to inputs and output cables. Being a very broadband cavity, the kicker does not require tuning and cooling, and the input coupling is obtained by powering in-phase the three coaxial upstream ports, while the downstream ports are connected on dummy loads.

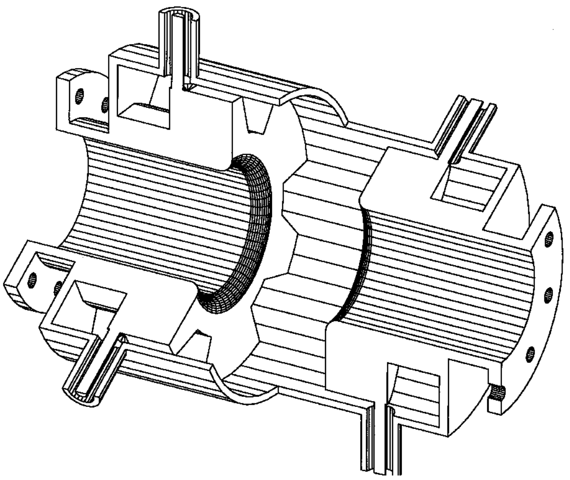

Figure 3: Kicker cavity cutview sketch.

The kicker resonant frequency f_k has been tuned to ≈1200 MHz, corresponding to 3.25 times the RF frequency (f_{RF} = 368.3 MHz). The minimum required bandwidth f_{BW} to preserve an acceptable damping efficiency on any coupled bunch mode is $f_{BW} \approx f_{RF}/2 \approx 180$ MHz. The carrier signal in the back-end section is therefore the 13/4th fractional harmonic of the master radiofrequency which needs to be fast QPSK modulated with a 90^{o} phase jump back every RF period to remain synchronised with the bunch passage when the machine is operated with all buckets filled The kicker beam coupling impedance has been measured with the wire technique and the result is shown in Fig. 4.

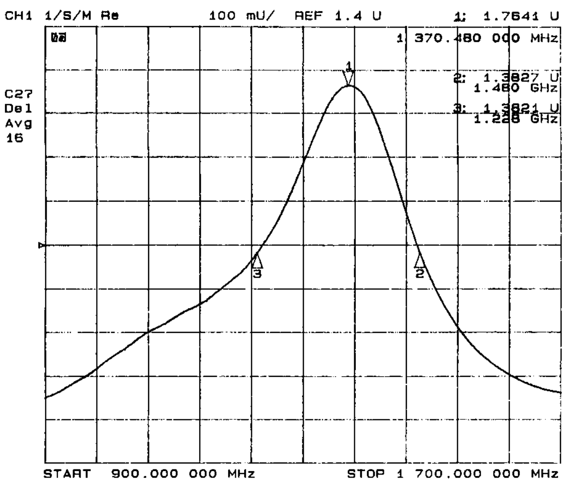

Figure 4: Kicker beam-coupling impedance wire measurement: $\Re e[1/s_{21}]$ vs. frequency.

The beam-coupling Z_{bc} impedance is related to the transmission coefficient between the wire ports s_{21} accordingly to:

$$Z_{bc} = 2\, Z_0 \left(\frac{1}{s_{21}} - 1 \right)$$

where $Z_0 \approx 202\ \Omega$ is the wire-beam tube coaxial characteristic impedance.

From Fig. 4, while taking into account that the kicker shunt impedance is twice the coupling impedance real part, a shunt impedance $R_s \approx 600\ \Omega$ and a bandwidth $f_{BW} \approx 250$ MHz have been obtained. The kicker beam-coupling impedance appears to be largely detuned by the presence of the wire in Fig. 4. The loading waveguides heavily damp the kicker HOMs; no high-order monopoles are measurable, while the first two dipole pairs are damped to values that are considered of no concern for the beam transverse dynamics.

4 POWER BUDGET

The DAΦNE maximum luminosity will be reached progressively by operating the machine with an increasing number of equispaced bunches.

Accordingly to a prudent estimate, a kick voltage of ≈ 1600 V is required to cope with an injection error of 100 psec at the maximum beam current. The required kick scales linearly with the current value.

The power and layout strategy for the different regimes is summarized in Table I.

Table I: Feedback power budget for a DAΦNE main ring

Number of bunches	30	60	120
Beam current [Amps]	1.35	2.7	5.4
Number of kickers	1	1	2
Total shunt impedance [Ω]	600	600	1000
Number of amplifiers	1	3	6
Total feedback power [W]	210	750	1500
Kick voltage [V]	500	950	1730
Beam coupled power per kicker waveguide [W]	400	800	1500

Thanks to a built-in option, the AS0814-250R power amplifier can be used as a 3x70 W triple output amplifier so that just one piece is needed in the 30 bunch operation. The 120 bunches operation foresees the installation of a second kicker cavity per ring. A 20% reduction of the shunt impedance has to be considered in 120 bunch operation because the cavity can not be completely filled in the time between two adjacent bunches.

Being mostly a standing-wave structure, the kicker cavity is not a directional device and the beam coupled power flows indifferently through both input and output ports. Since the beam coupled power may exceeds by several factors the kicker input power, dedicated broadband ferrite circulators have been developed by AFT (Germany) to protect the feedback amplifiers against backward power.

The circulator transmission and isolation frequency responses, as measured at low-level, are presented in Fig. 5; since the estimated beam coupled power is ≈ 1.5 KW per guide at the maximum current and the circulator isolation is ≈ 20 dB in the operating band (1÷1.4 GHz), the backward power to the amplifier input is limited to the tolerable amount of about 15 W.

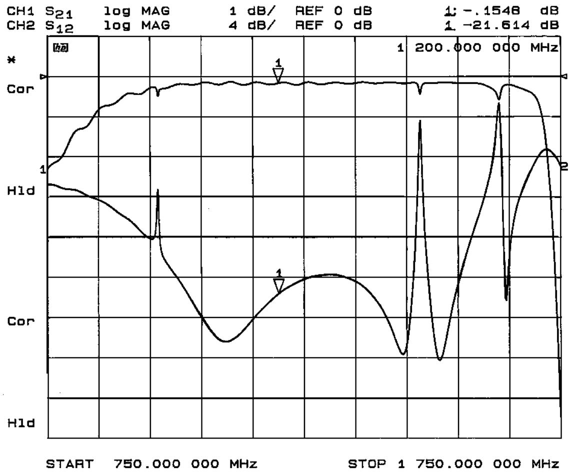

Figure 5: Custom circulator frequency response.

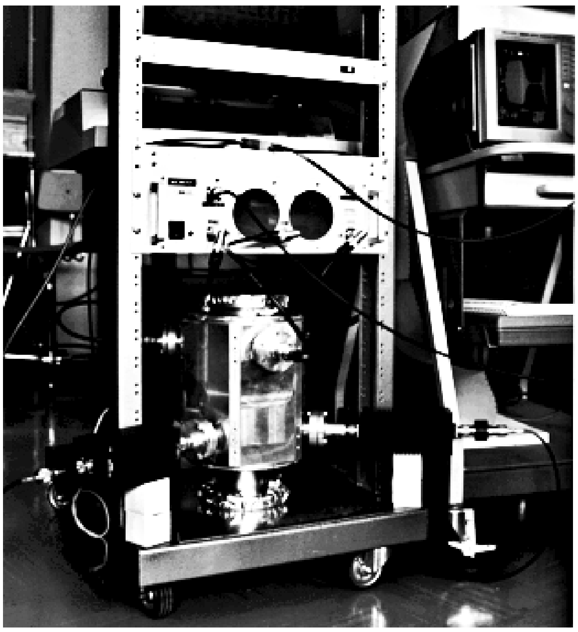

Figure 6: Kicker and power amplifier on bench.

5 TIME DOMAIN MEASUREMENTS

A bench measurement on the DAΦNE bunch-by-bunch feedback system back-end, including all the hardware but the circulators, has been recently carried out. A bench picture is shown in Fig. 6, and a typical result is reported in Fig. 7.

Referring to the Fig. 1 sketch, a modulating square wave switching from zero to a positive selected value has been sent to the mixer IF port to simulate the severe case where only one bunch over two has to be kicked, at a power rate close to the amplifier saturation. The kicker input and output signals have been captured by a fast digitalizing oscilloscope, and the result is shown in Fig. 7.

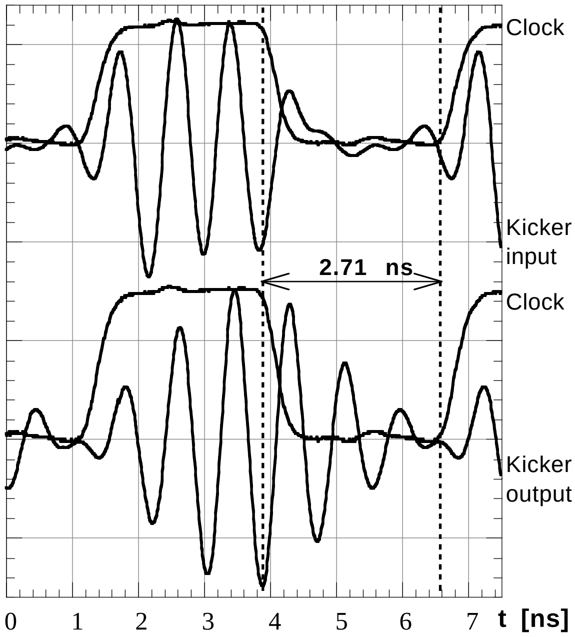

Fig. 7: Kicker input and output time-domain signals

The dynamics of the kicker input signal is comparable to that of the ECL square wave, that confirms in the time domain the excellent bandwidth features of the power amplifier. The kicker filling time is evident in the outcoming signal; even though the signal dynamics is limited in this case by the cavity bandwidth, the Fig. 7 vertical markers show that the residual kick transferred to the stable virtual bunch is a negligible fraction of the kick given to the unstable one.

CONCLUSIONS

The time domain measurements have confirmed that the overall back-end bandwidth is large enough to efficiently operate the feedback system up to the maximum DAΦNE beam current.

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