A FULLY AUTOMATED TEST BENCH FOR THE MEASUREMENT OF THE FIELD DISTRIBUTION IN RFQ AND OTHER RESONANT CAVITY

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Abstract

As part of the RF studies of the resonant cavities of the "IPHI" accelerator project ("Injector of Proton High Intensity"), a fully computer controlled bench for the field distribution measurement has been developed. Based on the perturbation method, the acquisition of the s21 transmission coefficient phase shift is synchronized with the displacement of a bead. A systematic study of the noise and uncertainties has led to a clearly enhanced signal over noise. The measured raw data are then converted to a quantity proportional to the electromagnetic field magnitude. Specifically for the RFQ tuning study, different transverse section positions where to guide the bead have been tested on our RFQ cold model.

1 INTRODUCTION

The high intensity (100 mA) of the continuous proton beam accelerated in the 8-m long IPHI [1] radio-frequency quadrupole (RFQ) from 90 keV up to 5 MeV requires the achievement of a very accurate electromagnetic voltage law. It is tuned with the adjustment of several mechanical devices mainly deduced from the analysis of the field distribution measurements. This experimental procedure must be especially efficient in the RFQ since it is accomplished through the 4 quadrants at many steps of its machining and assembly.

This paper describes the fully automated bead-pull system that has been extensively applied on our RFQ cold-model in order to validate the tuning procedure formalism that we have developed [2].

2 MEASUREMENT PRINCIPLE

Applying the classical perturbation method, the measurement of the field profile consists in acquiring the resonance frequency as a small bead is displaced through the cavity. The frequency shift $\delta\omega$ is proportional to the combination of the squared amplitudes of the electric and magnetic fields at the location of the bead.

In RFQs, high gradients of the accelerating electrical field *Eacc* that exist in the beam region make direct *Eacc* perturbation measurements too sensitive to positions errors. *Eacc* must be computed from indirect measurement of the field in the outer quadrant.

Three positions of the bead guiding-wire in our RFQ cold model equipped with the constant transverse section electrodes have been studied experimentally (Fig. 2):

1-A dielectric sphere is guided in contact with the vane tips so $\delta\omega \propto \left|E_\perp\right|^2$.

2-A metallic bead crosses the cavity on the bisector or

3- is guided close to the slug tuners side.

For the two last positions, the magnetic field H dominates and $\delta\omega \propto \left|\vec{H}\right|^2$.

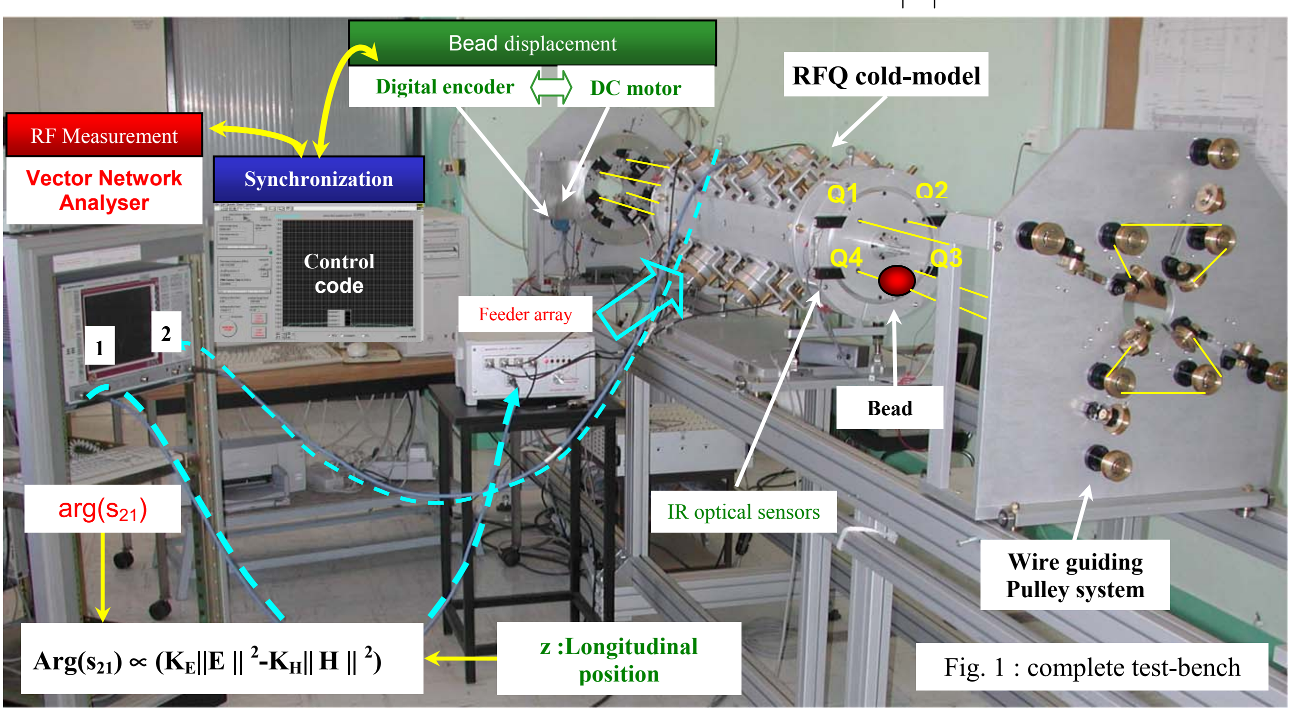

Fig. 1 : complete test-bench

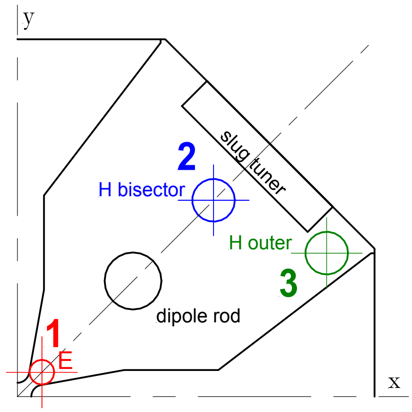

Fig. 2 : 3 tested positions in the transverse section

3 MEASUREMENT SET-UP

The test bench must provide 2 main functions:

1- The bead displacement

2- The RF measurement

Both are synchronized by a program on PC via specific electronic cards.

3.1 The bead displacement system

A complex pulleys system guides with a high mechanical accuracy the wire supporting the bead successively through the four quadrants at any of the 3 considered paths (Fig. 1). Different shapes of beads have been tested. They all consist in two hollowed mechanical pieces that overlap each other hiding the node of the wire. For H-field measurement, a titanium olive-shaped object is supported by a 0,66 mm diameter Kevlar® wire. For E-field measurement, a thinner Kevlar® wire (Ø=0,33 mm) guides a dielectric sphere (Delrin, Ø=7 mm) in contact with the vane tips.

A pneumatic jack tightens the wire during the RF measurement in each quadrant. The tension is relaxed when the bead goes through the pulleys. This system minimises the sag which is of the order 1 mm max, measured between 2 extreme pulleys distant of 8 m. It also efficiently damps the vibration of the wire.

The E-field measurement requires an additional jacks system that pulls the wire when the bead must follow a dogleg trajectory through the axial openings of the ending plates (Fig. 5).

The bead is displaced at a constant speed by a DC motor coupled to an incremental encoder that provides signal for the PID position control loop.

3.2 RF measurement

A ZVC Rohde & Schwarz vector network analyser (VNA) measures the S21 transmission coefficient through the cavity at the constant frequency f_0 of the unperturbed resonance mode. It offers a high dynamic range (>80db), an excellent stability and accuracy, and an easy control via GPIB commands. 2001 values of arg(s21) are recorded in each quadrant, within typically 44 s in a 2-m long RFQ.

The RF signal is magnetically coupled through small loops placed at the flat top side of several hollowed tuners.

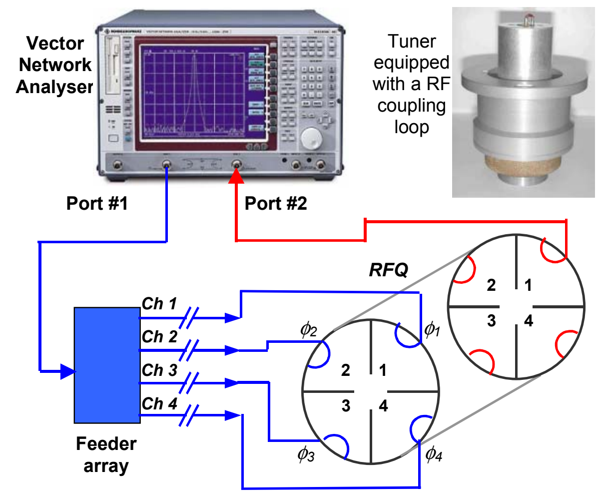

Fig. 3 : RF measurement system

A feeder array (Fig. 3) excites the four quadrants with the phase transverse distribution fitting the nature -dipole or quadrupole- of the mode being studied. This system filters the unwanted modal components within the measured voltage.

3.3 Synchronisation control

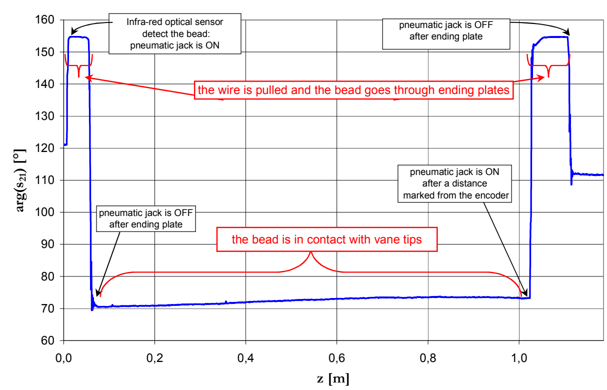

Fig. 4: measured phase for 1 quadrant (E-field)

A code written in Labview® automatically synchronises the RF measurement and the displacement of the bead through the 4 quadrants. Infra-red sensors placed at each ending sides of the cavity detect the bead approach (Fig. 1). Their signal and the position read by the encoder help the triggering of the different steps of a measurement sequence (Fig. 4).

4 RAW DATA PROCESSING

The equivalent voltage *U(z)* is proportional to the frequency shift $\delta\omega$. If $\delta\omega$ is small, $f_p - f_0 = \left(df/d\varphi\right)_{f0}(\phi-\phi_0)$ and we directly consider the phase. If ϕ vs. f is found to be non-linear, an additional measurement of the phase vs. frequency is made from which f can be interpolated.

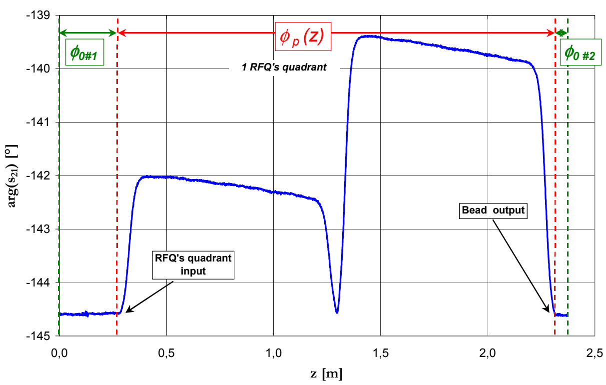

Figure 5: measured phase for 1 quadrant *(H-field)*

Two mean $\phi_{0\#1}$ and $\phi_{0\#2}$ are computed at both ends of the cavity (Fig. 5). In order to compensate any phase drift, a linear regression of the unperturbed phase is applied.

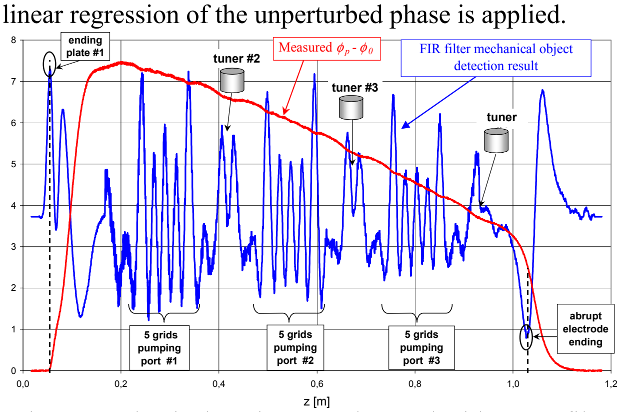

Fig. 6: mechanical equipments detected with a FIR filter

A special care has been taken of the z-alignment and scaling of the 4 quadrants data sets. For H field measurements, a finite impulse response (FIR) filter is used to estimate the positions of specific objects (end plate, tuner,…) within the curve (Fig. 6). On E-field curves we detect small local variation of ϕ caused by mechanical obstacles hit by the bead when it crosses the ending plates. A max. jitter of 1 or 2 samples ($\overline{dz} \approx$0,6 mm / sample) is quite easily reached.

The raw voltage U_i of the *i-th* quadrant is then computed in arbitrary units as $U_i = \sqrt{\left|\phi_P(z) - \phi_0(z)\right|}$.

A systematic study of noise and uncertainties reduction has led to a clearly enhanced signal to noise ratio (S/N). The standard deviation of arg(s21) in the rfq cold-model (Q≈2500) is as low as σ_{rms}=0,03°. The S/N is also improved by signal processing of the numerical data. In particular we apply a FIR low-pass filter associated with a side-lobe reduction function.

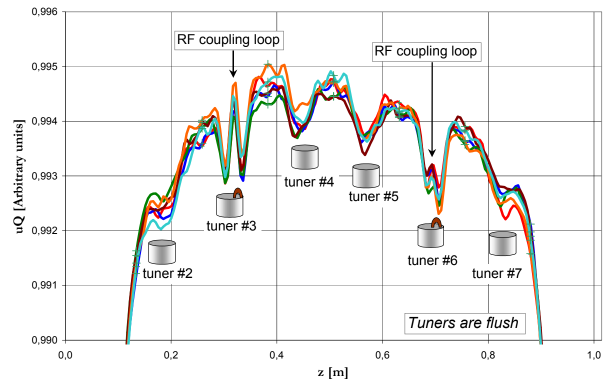

Fig. 7: six aligned and scaled modal voltage profiles

The excellent reproducibility is illustrated superposing six measurements acquired within 3 days with different bead motion directions on the bisector of the same cavity (Fig. 7). Maximum dispersion is of the order of 7.10^{-4}. The sensitivity is so high that even when the tuners are flush, their small positioning errors make the H-field lines perturbation visible on this zoomed measurement. Even the RF coupling loop can be distinguished.

5 CONCLUSION

The automation, the reproducibility and the high sensitivity of the bead-pull bench have turned out to be very important for the development of our tuning formalism through tests in the cold-model. In particular the low signal to noise ratio of the raw data is a key point for a high precision tuning of the voltage profile, i.e. with relative errors as small as 7.10^{-4} [4].

The possibility of perturbing fields in 3 different positions is useful to check the validity of a RFQ tuning procedure deduced from H-field towards E-field [3]. Il has also led to the choice guiding the bead on the bisector for real RFQ tests.

The complete system is easily transportable: it has been applied in the factory site to the mechanical default estimation of the first IPHI RFQ segment.

This field profile bead-pull test-bench can be easily adapted to the characterization of any other resonant structures. It will be used for measurement in superconducting cavities.

6 REFERENCES

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