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BEAM-PHASE ADJUSTMENT OF SINGLE-GAP CAVITIES

W. Pirkl

The problem

Adjustment of a cavity phase with respect to the beam passage is a common problem encountered during operation of accelerators. There may be situations where correct phase settings can be directly deduced from beam response, e.g. where beam passage at the zero crossing of the rf wave form can be immediately related to zero energy deviation in a downstream spectrometer; this situation is however the exception.

This note describes a (novel) method to adjust cavity phases from interpretation of the beam-loading pattern, relying entirely on the local beam-cavity interaction without considering any beam effects outside the resonator. The method is therefore well suited for initial adjustments to prescribed beam phases, whereas final optimization may later be performed using non-local beam performance criteria.

The method

The basic idea is to

- create an internal "phantom" beam current that is in quadrature with the cavity voltage.

This phantom beam current is easily created by detuning of the cavity. Its phase is always in quadrature with the cavity voltage, its sign and magnitude proportional to the direction and the amount of the detuning, respectively. Seen from the outside, i.e. at the feeder line, the phantom current thus generated is indistinguishable from an additional particle beam current passing through the gap exactly at zero crossing of the cavity voltage (fig. 1),

- record the rf systems response (called the "profile" in the following) of the rf system to this 90 degree phantom beam current,

- apply external (particle) beam and adjust its phase such that the response of the rf system lies on the "profile" previously established. The external beam is then known to be in quadrature with the cavity voltage. Phases different from 90 degrees may then be set from there using the calibrated input phase shifter.

Implementation at CERN Linac II

As an illustration of the procedure the measurement on the rf system of Debuncher 2 is shown, whose structure is given in fig. 2.

The equipment contained in the box SERVO reconstructs the actual values of amplitude, phase and tuning angle at the cavity, and creates three error signals AMOD, PHIMOD and TUNING.

Closed loop corrective action

- keeps gap voltage constant (via AMOD),
- ties gap phase to phase at servo input (via PHIMOD),
- sets tuning state of the cavity using phase difference between gap and feeder forward wave (fig. 3).

Phase adjustments are therefore performed by phase shifters INPUT PHASE (for system phase) and DETUNING (for tuning state).

System response to the phantom beam is recorded by displaying two signals from within the rf system in the form of an XY-plot, and retained on a storage screen. This is repeated for different amounts of detuning, (without particle beam). The trace thus obtained is the "profile", i.e. the locus of all 90-degree-beams of different sign and intensity.

The two signals should as much as possible be "orthogonal" in the sense that they should reflect two different projections of the two-dimensional beam load (amplitude/phase, real/imaginary, forward/reflected etc.). Servo error signals PHIMOD for the x-axis and AMOD for the y-axis are well suited for the purpose and have the additional advantage of being available in the control room.

The PHIMOD/AMOD-plot can in fact be interpreted as the distorted projection of the conditions at the cavity gap as shown in fig. 4. The profile for 90 degree phase separates the accelerating from decelerating half-plane; points 3 (purely focusing) and 5 (purely defocusing) can be easily identified.

Fig. 5 shows the measured "profile" for the 90 degree (phantom) beam together with the system response to the real beam. Its phase is changed through degrees by variation of the input phase shifter INPUT PHASE in steps of about 9 degrees.

Measurement accuracy

Setting of the phase within an error band of 5 degrees (+-2.5 degrees) is easily achieved even under less than ideal conditions. Fig. 5 was obtained by manual transfer of measurement data into an EXCEL-file and subsequent plotting by the same program. Automated data acquisition and plotting, together with zooming around the crossing point can certainly improve the accuracy.

The response of the rf system to a particle beam depends on its amplitude as well as its phase; intensity variations from pulse to pulse may therefore give the beam response curve a ragged contour (see fig. 4, points 4A and 4B). This does not significantly impair the determination of the crossing point with the "profile" as the latter is smooth (since measured without beam).

CAVEATS

The method works well for single-gap resonators for which the beam can be considered as a constant current source with unique phase. By contrast, multi-gap structures such as an Alvarez tank have in general different phases and rely on certain energy gains at each gap to maintain synchronism; although a profile can be measured for the overall assembly, the positioning of the beam on the 90 degree line is impossible or ambiguous.

It goes without saying that all rf system parameters have to remain the same for the measurement of the "profile" and the response to the beam, the two data sets should therefore be collected at the shortest possible interval.

Finally, the beam may hit the downstream wall of the cavity and generate secondary electrons which may shift the phase of the overall current seen by the resonator. This possible error mechanism was pointed out by M. Vretenar.

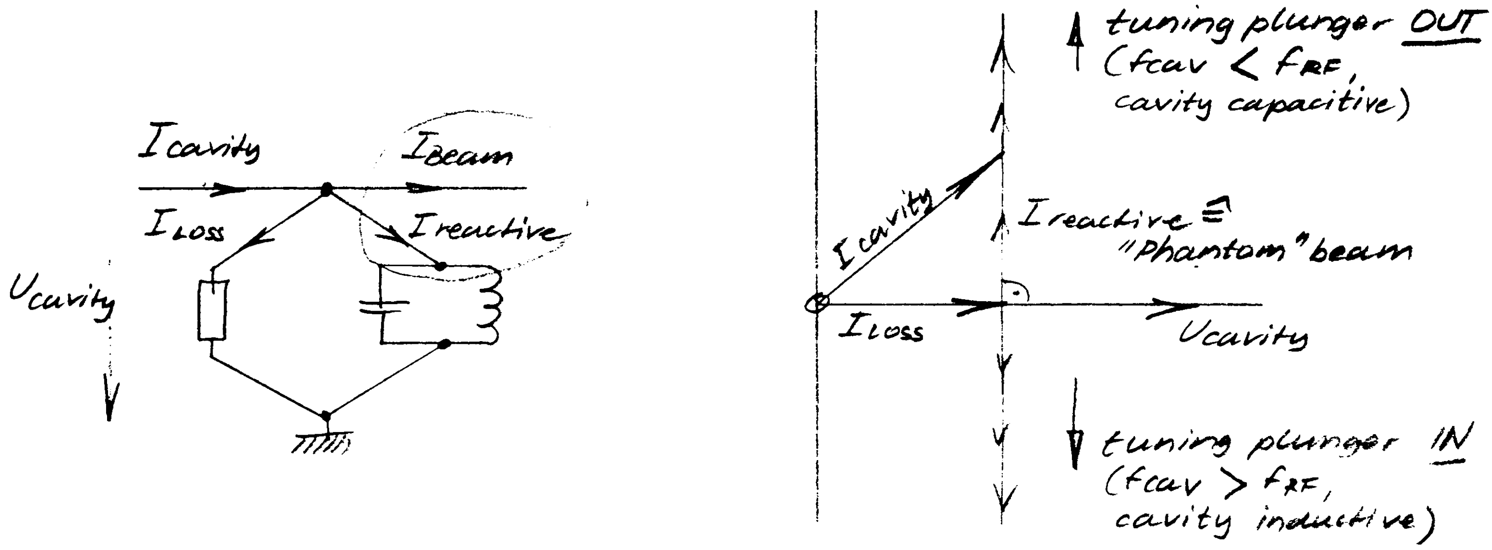


FIG 1: Cavity voltage and currents (at "detuned short" - plane)

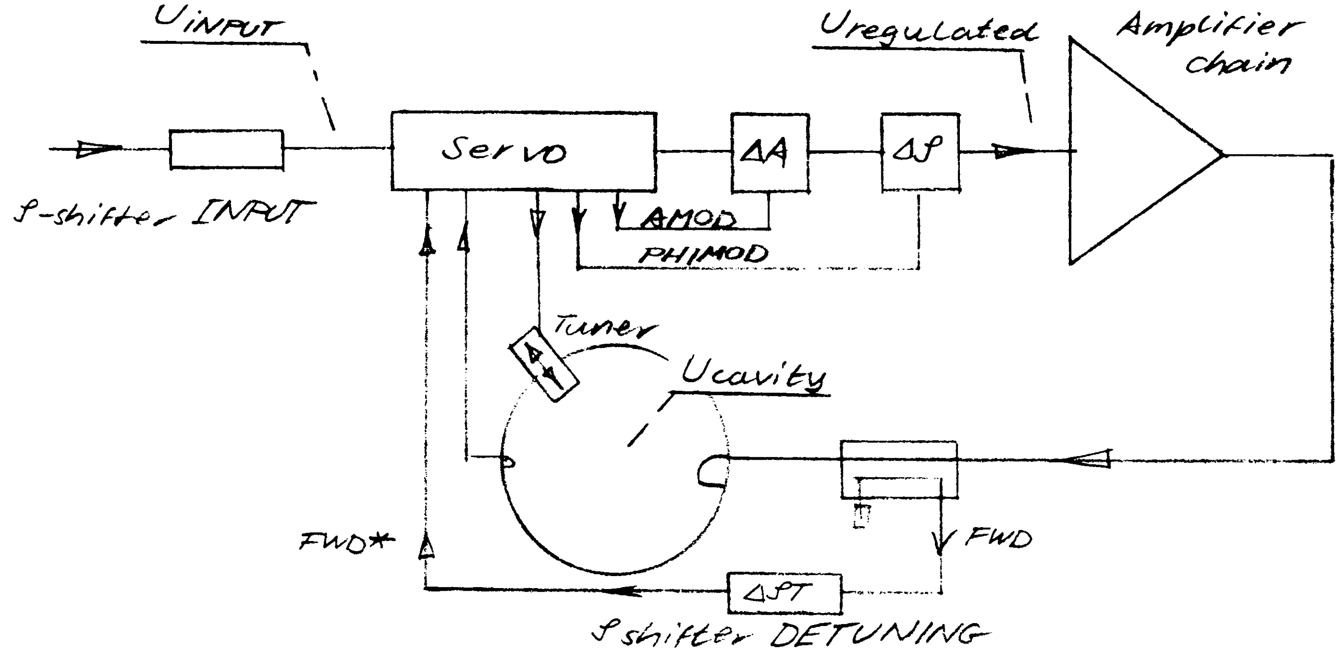
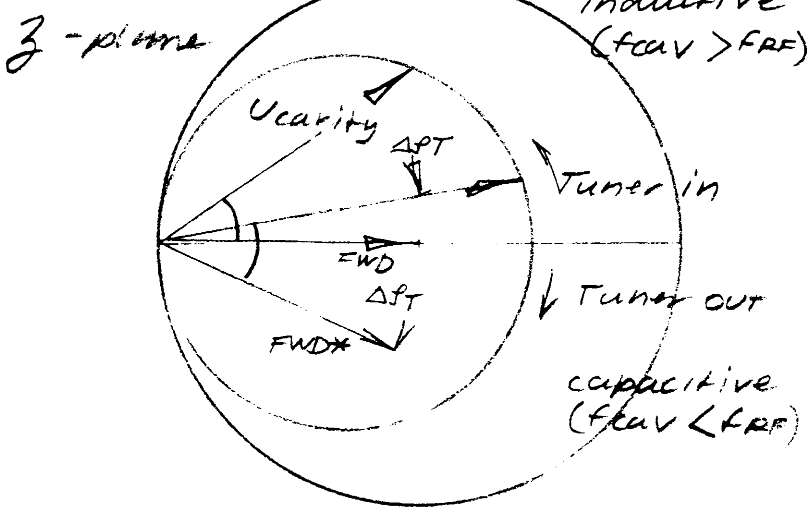
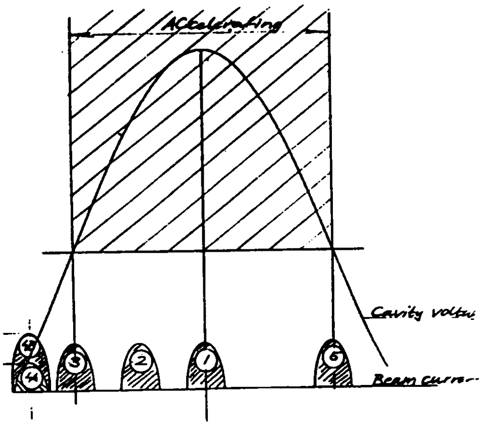


FIG 2: Structure of the RF chain (CERN Linac II, Buncher2)



NOTE: Ucavity is shown relative to Uregulated. Absolute position with respect to Uinput is constant due to servo action.

FIG 3: Action of the "DETUNING" phase shifter



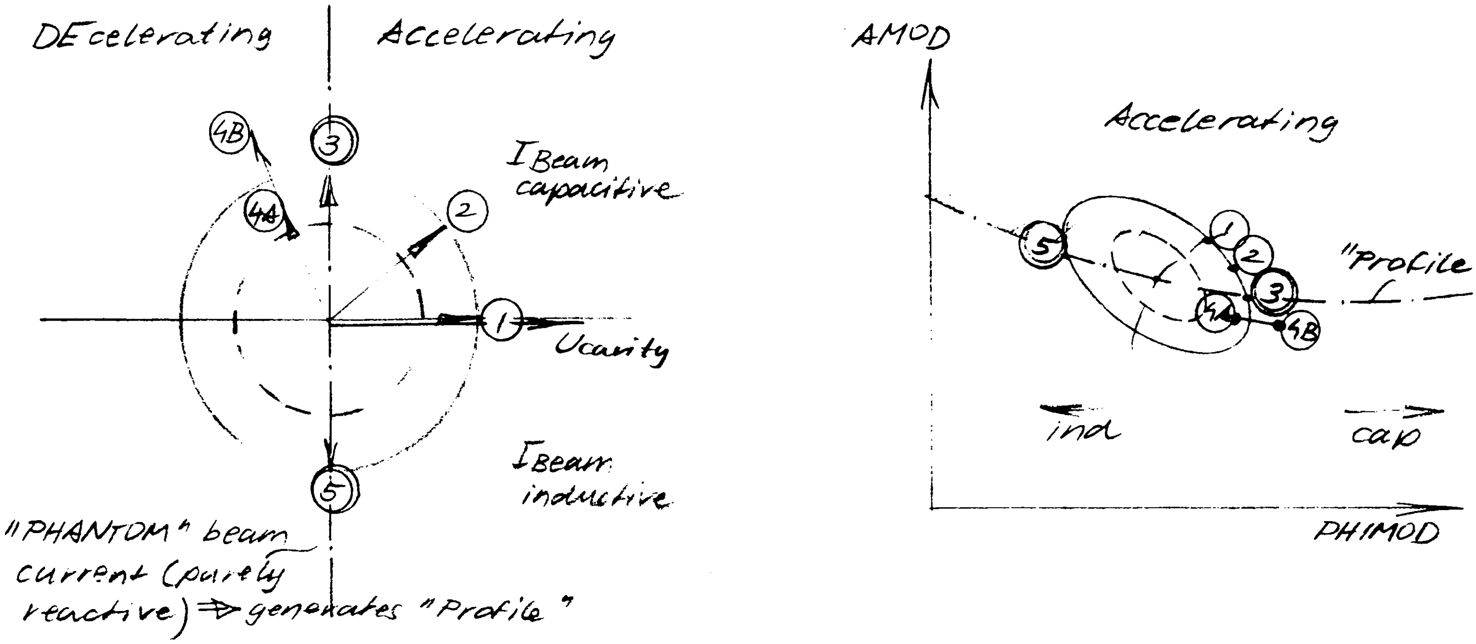


FIG 4: Mapping of beam current (complex quantity) into the PHIMOD/AMOD plane

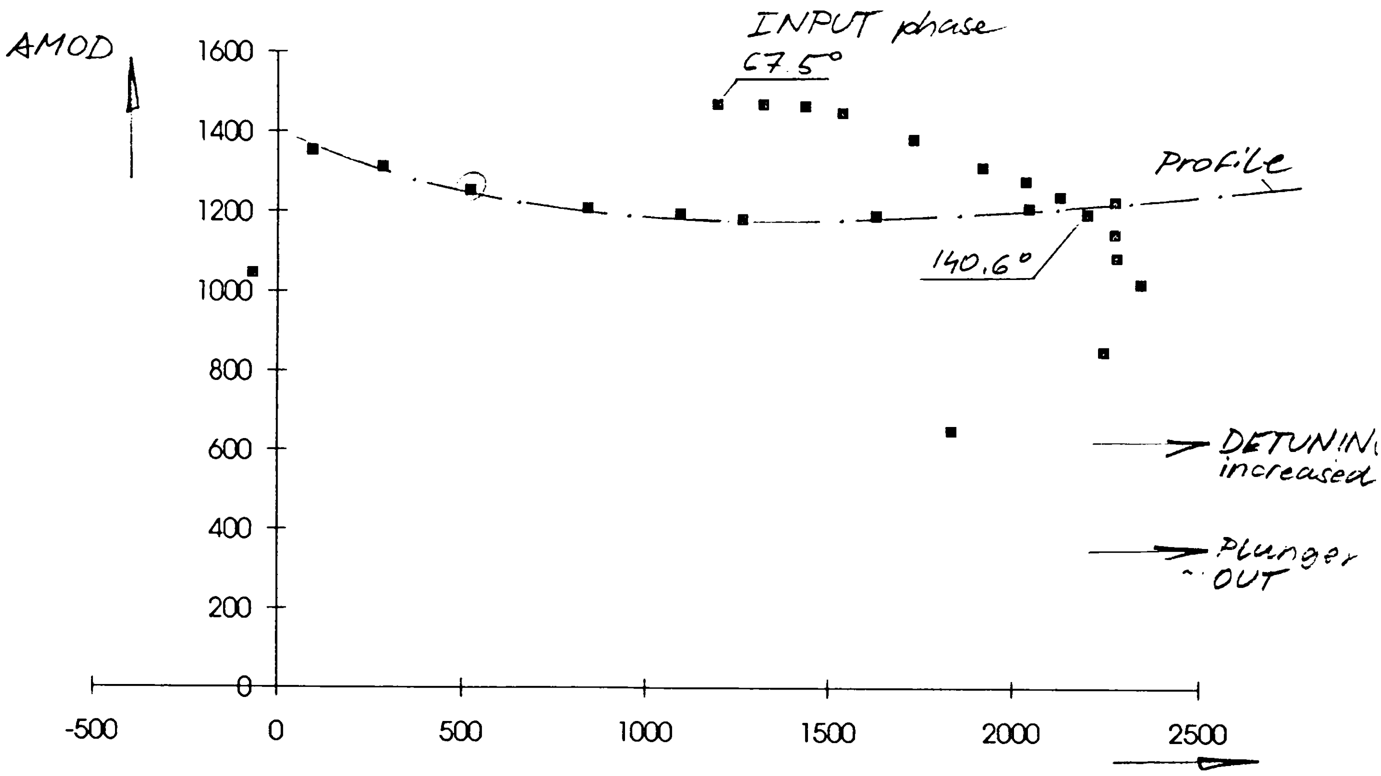


FIG 5: Measurement of Buncher 2 - phase