DEVELOPMENT OF THE FAST FEEDBACK SYSTEM FOR THE GSI SIS CAVITIES

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Abstract

The longitudinal impedance seen by the beam is about 3 kOhms per SIS cavity. For the planned high current operation, cooled beam experiments, bunch length compression studies etc., reduction of the gap impedance below 1 kOhm is necessary. The paper summarizes various possibilities for cavity impedance reduction that were taken into consideration. Installation of a fast feedback system has been chosen as the most adequate solution. Simulation calculations with PSPICE show the limitations and promise impedance reduction factors in the order of 5 to 8 at the low frequency end. For development and adaptation of the feedback system, a test accelerating station has been set up on the base of the old SIS prototype cavity.

1 GENERAL

The impedance seen by the ion beam passing through a cavity is usually described by the equivalent circuit given in Fig.1. Ri is the inner resistance of the generator, Rc the impedance of the cavity at resonance, N is the voltage transformation ratio from the generator to the cavity. Any of these quantities can be used to influence the resulting gap impedance Rg seen by the beam.

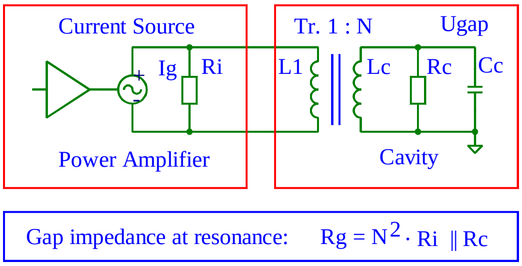

Fig.1: Equivalent circuit used for the description of the gap impedance seen by the an ion beam

1 REVIEW OF PASSIVE SOLUTIONS

1.1 Additional Resistive Loading of the cavity

By connecting a water-cooled loading resistor in parallel with the cavity gap, Rg can be reduced to about 1 kOhm very easily. The presently available anode current would limit the gap voltage to about 50% of the maximum of 16 kV in this case, however. The simplicity, broadband nature and stability of this solution look very attractive (cf. Fig.4). Low gap impedances are mainly necessary during low voltage operation. Use of a resistive load in the low voltage range, and disconnecting it for higher voltages by a vacuum relay may still be interesting for certain applications. With regard to the reduced gap voltage and increase of wasted energy the solution is not being followed any further.

1.2 Installation of a second power Stage

Installation of a second power tube for the push-pull arrangement of the SIS cavities has been prepared in the mechanical design of the accelerating stations since the very beginning. The high costs of installing additional power stages seem not justified for the possible reduction of Rg by a factor of two in this case.

1.3 Cavity Input Transformation Ratio

In the actual geometry, the rf power is coupled into one half of the SIS cavities (see Fig.2). The input transformation ratio is N=2, and the resistance Ri of the tube is transformed into Rg by the factor of four. In the ESR cavities a transformation ratio N=1 has been realized. As shown in Fig.2, in principle, the transformation ratio of N=1 can be realized in the SIS cavities also. In this case, gap impedances of about 1 kOhm should be possible (see Fig.3). With the actually available anode voltage, the gap voltage would be limited to 12 kV, however. This solution and the possible high voltage and resonance problems will be looked in more closely in the SIS test station described below.

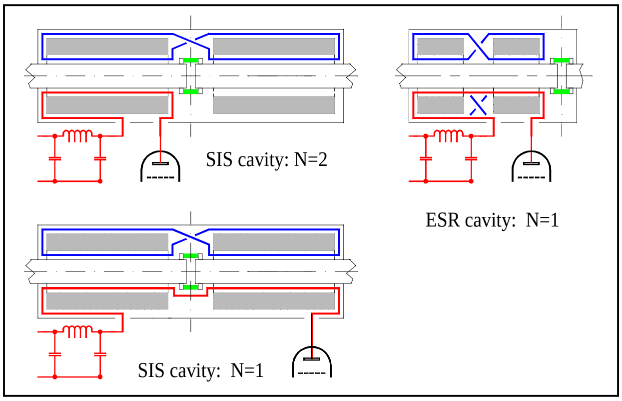

Fig.2: Principle of rf coupling from the power tube into the SIS and ESR cavities. Possible modification of the SIS coupling to a 1:1 input transformation ratio .

2 ACTIVE SOLUTIONS

2.1 *Fast Feedback,*

Fast feedback has been worked out as state of the art in most of the CERN [1-5] and Brookhaven [6] cavities and has been chosen as the final solution for the SIS cavities also. By means of the closed loop feedback system, the source impedance of the power stage can practically be reduced by the open loop gain factor Aol of the system.

One has the standard problem of any closed loop control system: realization of a maximum gain factor Aol and keeping the system from becoming instable due to the phase shifts at the high frequency end. Due to the high operating frequency and the large dimensions of the usual cavities, the time delays and phase shifts produced by the cables, filters and amplifiers are so large that the practically useable gain factors are realtively small. In the existing fast feedback / cavity systems the impedance reduction factors are in the order of ≤10. With the larger frequency swing and larger dimensions of the SIS cavities (0.8 to 5.4 MHz, length 3.20 m) practical impedance reductions in the order of 5 to 8 are expected.

2.2 *Electrical Design of the Feedback System*

The principle and the main characteristics of the SIS feedback system are described in the simplified schematic given in Fig.3. Details are discussed with with the PSPICE simulations described in the next section.

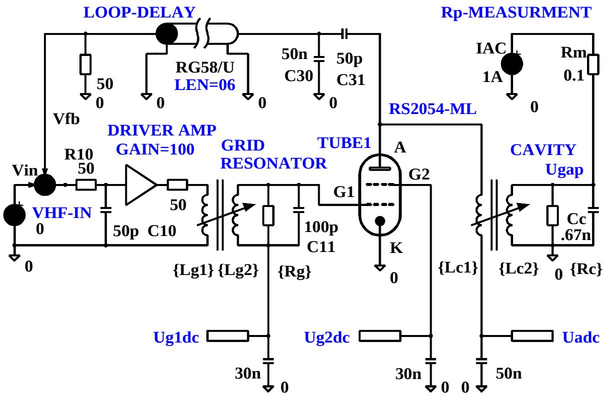

Fig.3: Principal arrangement of the feedback system Shown is a simplified part of the schematic used for the PSPICE simulations described in the text

The feedback signal is derived from the gap or the anode rf voltage by means of a capacitive voltage devider. A power combiner produces the difference of the rf input minus the feedback signal. The difference signal is amplified by the driver amplifier, and passed through a tuned resonant circuit to grid 1 of the final power tube.

Realistic values of the delay time are td=30...50 ns. The frequency fc where one has 120 degrees of phase shift within the loop, (fc≈1/(3·td)), can comes very close to the maximum operating frequency fmax=5.4 MHz. The conditions of a loop gain Aol<1 for f>fc, necessary for preventing self-oscillation, and Aol>>1 for f<fc, for a useful feedback effect, cannot be realized well enough when the usual lowpass filter is used at the input of the power tube. These problems are faciliated considerably by means of a ferrite-tuned parallel resonant circuit at the tube input. A further advantage of the grid resonator is the possibility of up-transformation of the driver voltage and corresponding reduction of the driver output power.

2.2 *PSPICE Simulations*

The design of the SIS fast feedback system has been studied extensively by means of PSPICE simulation calculations on the base of the schematic given in Fig.3.

The power tube model uses a simple fit of the relation [7]

$$Ik=F0*(F1*Ug1+F2*Ug2+Ua)^{3/2}$$

which delivers a relatively good approximation in the vicinity of the normally used operating point. The load Rc of the cavity is roughly matched to the impedance measured / calculated at lower gap voltages. The driver amplifier within the feedback loop is simulated by an ideal amplifier with about 100 MHz bandwidth. The total delay time of the external loop is represented by a certain length of coaxial cable. The additional delay produced by the tube is simulated by the tube model. The resonant frequency of the cavity, the tuning and detuning of the grid resonator, the time delay of the feedback loop and driver amplifier gain can be controlled during simulation by variable parameters. The gap impedance at the various operating conditions is “measured” by feeding a known current into the cavity gap. The passive as well as the active solutions for impedance reduction have been studied in this way.

The gap impedances calculated for two of the passive solutions discussed above are shown in Fig.4.

The simulation results for several fast feedback configurations are shown in Fig.5. Curve D30-G050-LP describes feedback with a low-pass filter at the power tube input. With a delay of only 30ns, (amplifier) gain of 50, the impedance exceeds the value without any feedback and the system becomes instable above 4.5 MHz. With a grid resonator tuned to exactly to the cavity resonant frequency the result is identical (curve D50-G050-F10). By tuning the grid resonator to 1.4 times the cavity frequency, the margin to instability is improved considerably and higher gain factors can be applied.

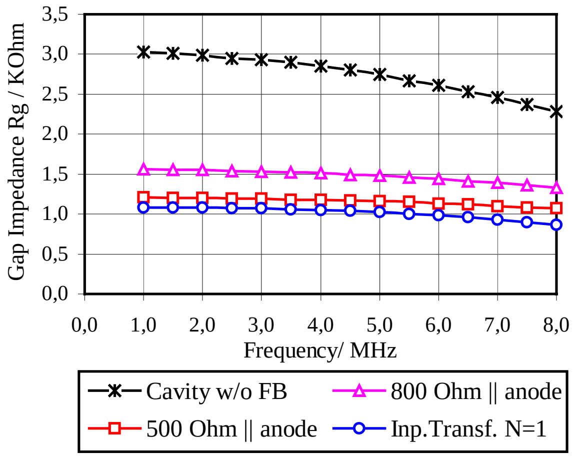

Fig.4: Passive solutions. Gap impedances with loading resistors in parallel to the anode, resp. transformation ratio N=1 between tube and cavity

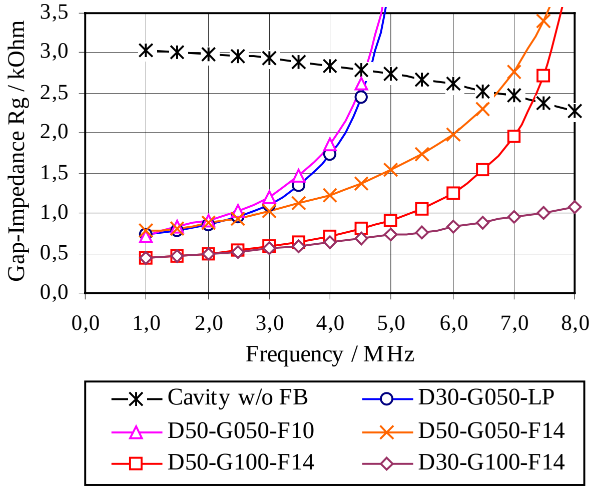

Fig.5: Active feedback with various feedback parameters
Parameter D50: total loop delay is 50 ns
Parameter G050: gain factor of driver amplifier
Parameter F14: tuning of grid resonator to fres*1.4

An increase of the gain beyond 150 leads to unacceptable distortions of the cavity resonant curves. According to the simulations, gap impedance reductions below 1 kOhms are possible over the whole SIS frequency range if and only if total loop delay times below 50 ns can be realized. This is difficult to fulfil with commercially available amplifiers. The feasability has been shown in [6] with a dedicated amplifier development.

In spite of the simplifications of the PSPICE model used, the results give a very good insight into the overall behaviour of the circuit and the influences of component and parameter variations. As long as the rf system is run in the linear operating range, the quantitative results are regarded as relatively reliable.

2.3 Setup of a SIS Test Accelerating Station

Considerable experimental work is expected to adapt the needs of the fast feedback system to the existing SIS accelerating stations. To be independent of the SIS shut-down periods, a complete SIS test accelerating station is being set up for these developments in the laboratory. By using the old SIS prototype cavity, the reserve SIS power amplifier modules, and sharing the power supplies with one of the ESR cavities, the costs of this test facility are kept moderate. The slight differences between the test cavity and the original cavities seem negligible for the electrical developments.

The test station will be ready for operation in summer 2000. First studies will be run for optimization of the existing filters, input circuits, control circuits, measurment of impedances, possible resonances, etc. The tuned grid resonator development has been completed and will be integrated next. Among others, also passive methods for impedance reduction like the 1:1-coupling, will be investigated. Before purchasing or developing new driver amplifiers, modification and use of the existing driver amplifiers for the feedback system will be studied.

ACKNOWLEDGEMENTS

The overall design of the feedback system is closely based on the techniques worked out for the CERN PS and booster cavities. Many helpful personal discussions with R. Garoby, F. Pedersen, D. Grier, M. Paoluzzi of the PS RF group have to be mentioned and acknowledged here.

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