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Machine Development Experiment Concerning Excitation and Open Loop Damping of Longitudinal Quadrupole Oscillations in SIS12/18	**Name:** M. Mehler, H. Klingbeil, U. Laier, K.-P. Ningel, G. Schreiber, B. Zipfel

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Machine Development Experiment Concerning Excitation and Open Loop Damping of Quadrupole Oscillations in SIS12/18

M. Mehler

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Participants: H. Klingbeil, U. Laier, M. Mehler, K.-P. Ningel, G. Schreiber, B. Zipfel

1 Introduction

One of the machine experiments dated December 19/20, 2006 was to empirically investigate induced quadrupole oscillations in SIS12/18 with the ion species $^{40}\mathrm{Ar}^{18+}$ and a flat top energy of 80 MeV. The goal was to verify that a modulation of the RF voltage amplitude with a rectangular voltage at twice the synchrotron frequency $2f_S$ = 4205 Hz can excite or damp quadrupole oscillations depending on its phase compared to the RF voltage and its amplitude. This confirmed the physical theory [1, 2] and the results of the ESME simulations [3] done before.

2 Measurement Setup and Voltage Ramps

Two data acquisition setups were used. Firstly the LeCroy oscilloscope to get data in time domain (Figure 1), e.g. waterfall plots, to verify the DSP data which is the secondly used data acquisition system (Figure 2). The used oscilloscope has a sequential triggering that makes it possible to get 10000 short measurements for a good resolution in time domain. The DSP system made it possible to get the beam current amplitude information in real-time and with a higher resolution.

The acceleration from injection energy (11.4 MeV/u) up to E_{kin} = 80 MeV/u was done by the main control room. Afterwards their voltage ramp was switched off. The RF voltage ramp for the modulations was produced by arbitrary waveform generators. These ramps are shown in Figure 3, Figure 4 and Figure 5.

The ramps created by the arbitrary waveform generator started with the adiabatic capturing of the ions. The minimal necessary time for adiabatic processes has been calculated with $\alpha_{ad} = \left| \frac{1}{\omega_S^2} \frac{d\omega_S}{dt} \right|$ [1]. Then a safety margin of a few ms has been added. At the first flat-top at U_1 = 3 kV Landau damping should damp all oscillations induced by the capturing process. Then the voltage jump up to U_2 = 10 kV induces a big mismatch so that it was easy to detect the quadrupole oscillations and to get a bigger distance between the separatrix and the bunch. This made it possible to use bigger voltage modulation amplitudes before losing ions from the bucket.

For excitation and damping of quadrupole oscillations, the modulation of the RF voltage amplitude started synchronously with the voltage jump (Figure 3 and Figure 4).

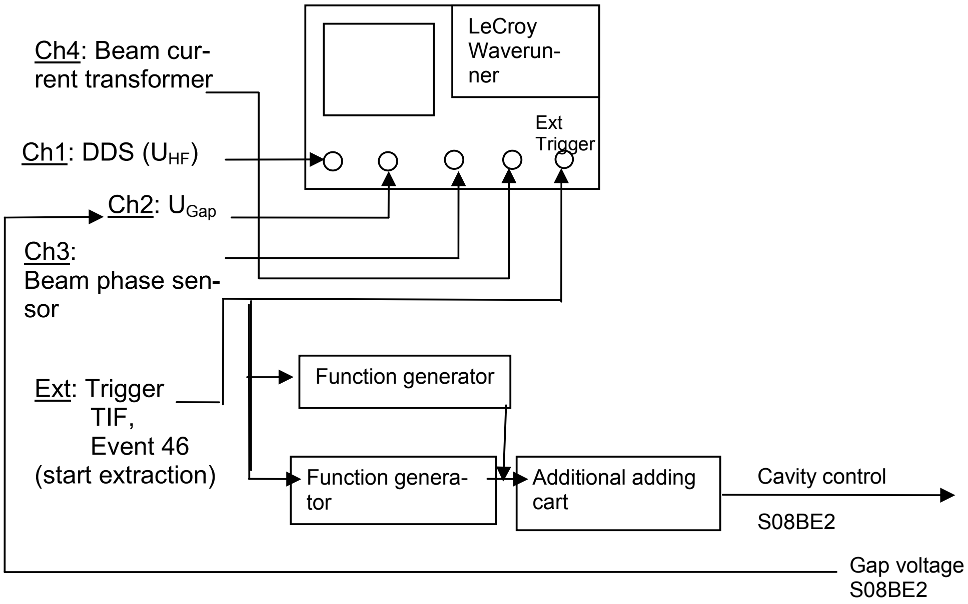

Figure 1: Measuring setup and data acquisition with LeCroy (waterfall measurements)

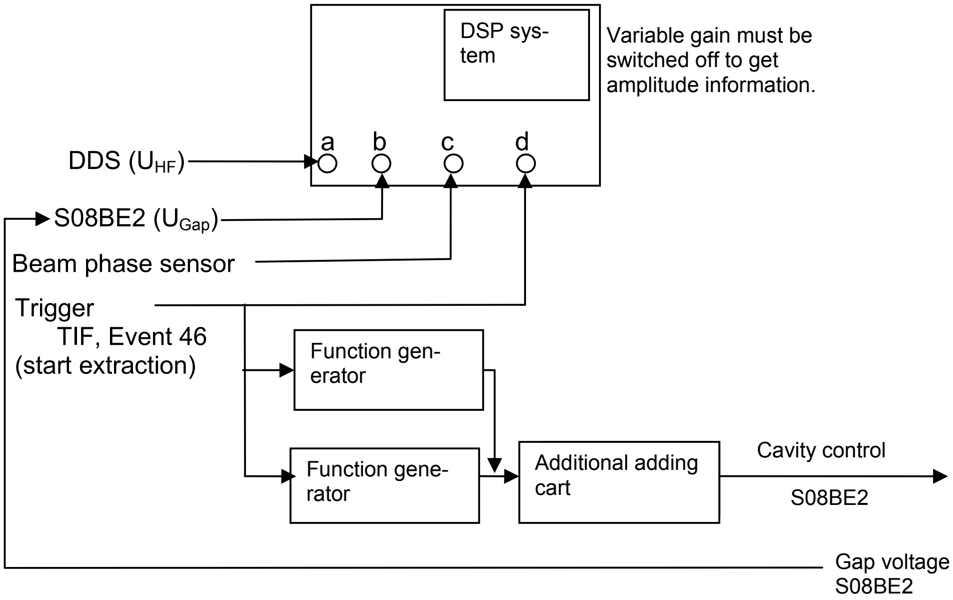

Figure 2: Measuring setup and data acquisition with DSP system

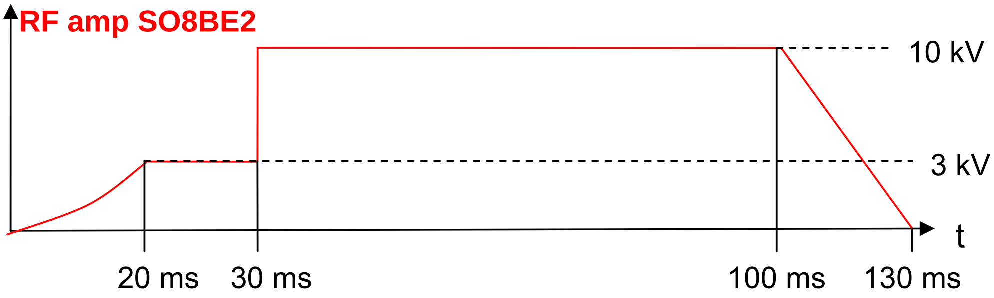

Figure 3: Voltage ramp for the data acquisition to get the Landau damping time.

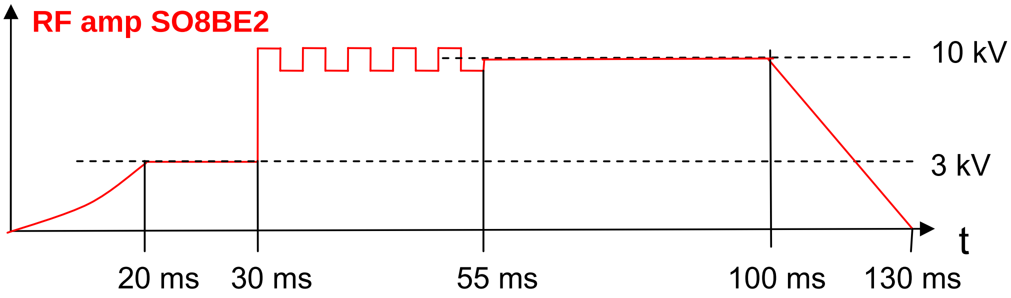

Figure 4: Voltage ramp for exciting quadrupole oscillations.

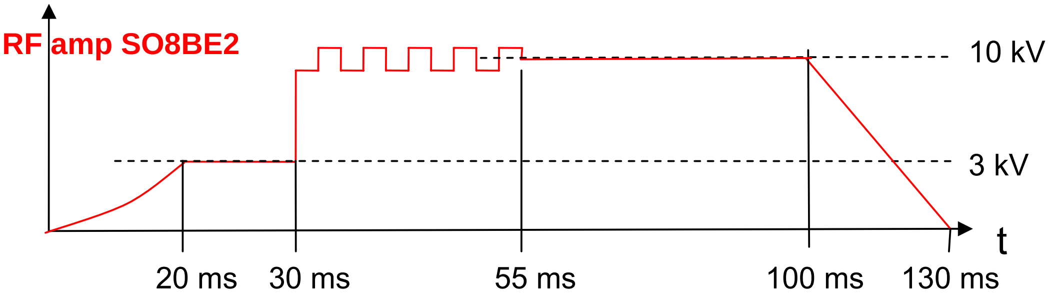

Figure 5: Voltage ramp for damping quadrupole oscillations.

3 Main results

The result for the Landau damping time was t_{Landau} = (1.08 ± 0.01) ms.
As can be seen in Figure 6 and Figure 8, the measured maxima in both figures are cut.
There are two explanations:

- An off-center phase shift at the beginning of the modulation. This was measured with the DSP system and could be verified with ESME simulations. The bunch furls during rotation and this cuts the maxima.
- Saturation effect of the measurement system which could neither be excluded nor verified.

Also a combination of the two possibilities is possible because neither can be excluded based on the data.

Therefore a statement about the effect of exciting and damping can currently be made only by analyzing the minima.
The results in time domain for the excitation of quadrupole oscillations can be seen in Figure 6 and the results for the open loop damping of quadrupole oscillations can be seen in Figure 8. These curves are normalized to the arbitrary mean amplitude of the beam signal before the amplitude jump of the RF voltage occurs and the time when the RF voltage jump occurs is normalized to 1s to establish the comparability of the measured data curves.

3.1 Excitation

The first case is the one of the excitation of quadrupole oscillations (Figure 6). In this case the bunch becomes longer in Θ direction and smaller in ΔE direction in phase space (emittance conservation). Therefore the minima are going to lower values with increasing excitation voltage amplitude. This can be seen by comparing the measurement results in time domain.
The development of the first minimum in Figure 6 shows a run to smaller values as expected (Figure 7).
The yellow curve (according to U_{Mod} = 250 V, this is 2.5 % of the RF voltage) in Figure 6 shows roughly constant minima over time. From this it can be deduced that the growth rate created by the modulating voltage is nearly equal to the damping rate of Landau damping ($[926^{+8.7}_{-8.5}]$ s^{-1}). Therefore if Landau damping shall be compensated in new experiments with similar parameters to increase the time for tests, a voltage around this value can be used.

3.2 Damping

The second case is the one of the open loop damping of quadrupole oscillations whose results can be seen in Figure 8. During damping the bunch becomes shorter in Θ direction and bigger in ΔE direction. Therefore the minima are growing to higher values with increasing damping voltage amplitude. This can be seen by comparing the measurement results in time domain at the first minimum of the curves (Figure 9).
The evolution of the minima for the curves over time shows a growth to lower amplitude values after some damping time (Figure 8). The turning point is where the modulation signal is out of phase. If the damping voltage modulation is continuing, a new quadrupole oscillation will be induced with phase shift to the one before. The reason is that ΔE now exceeds its value for a matched bunch and Φ (length of the bunch) becomes smaller than its value for a matched bunch (for remembrance: The starting point for the damping of quadrupole oscillations was that Θ was bigger than the value for a matched bunch and ΔE was smaller than the value for a matched bunch).
The development of the first minimum in Figure 9 shows a run to higher values as expected.
The linearity that can be seen in Figure 7 and Figure 9 shows that 10 % RF voltage modulation are necessary to cope with 10 % bunch length deviation in Θ direction. This is in agreement with ESME simulations.

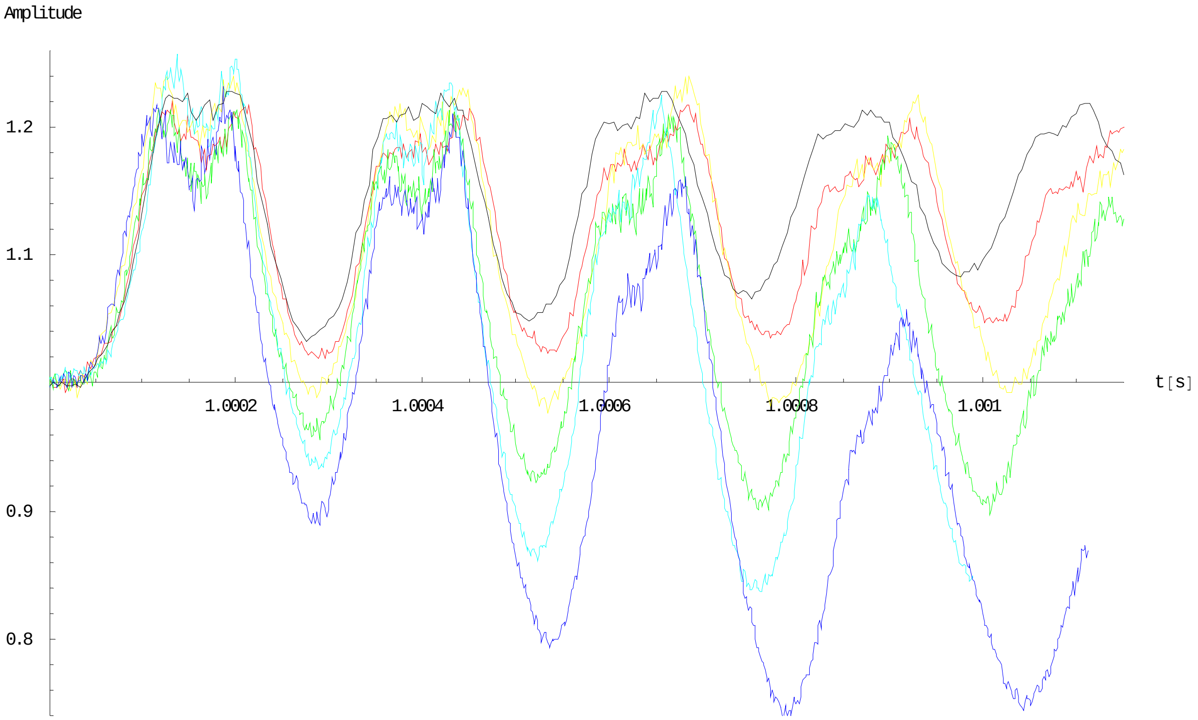

Figure 6: Amplitudes from the DSP data acquisition system for the excitation of quadrupole modes. Black: curve only with Landau damping, red: curve for an exciting amplitude of U_{Mod}=125V, yellow: U_{Mod}=250V, green: U_{Mod}=500V, light blue: U_{Mod}=750V and blue: U_{Mod}=1kV.

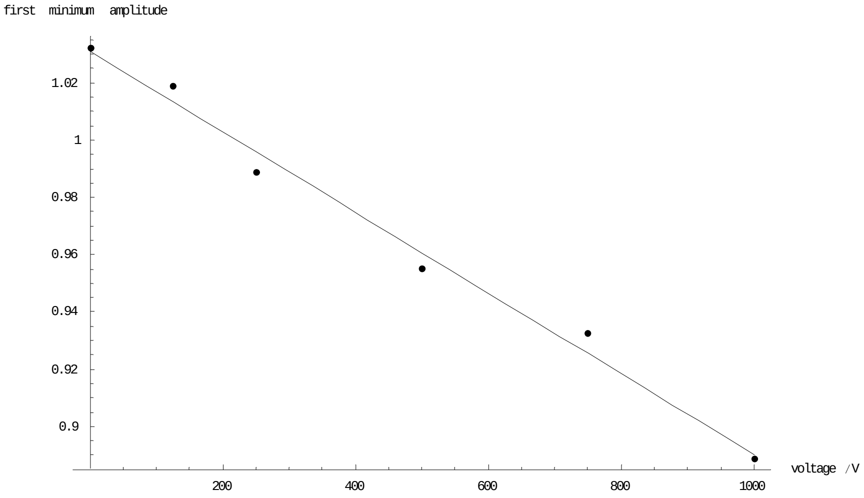

Figure 7: Evolution of the first minimum amplitude over the quadrupole oscillation excitation amplitude U_{Mod}.

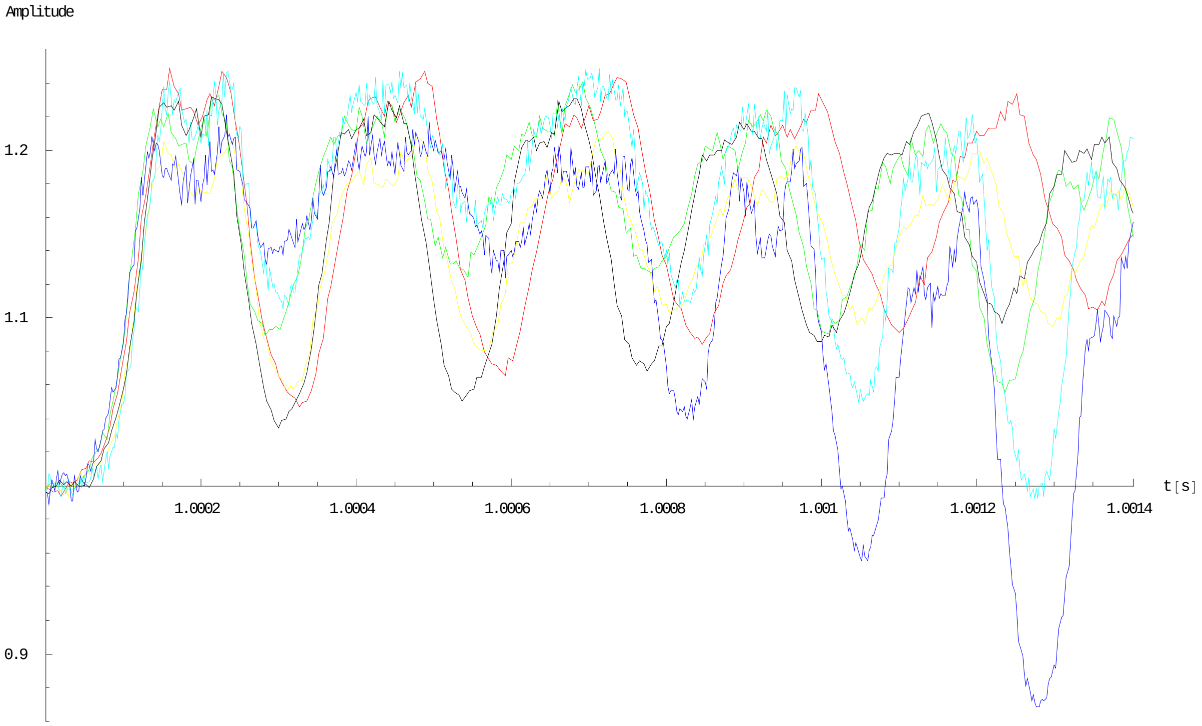

Figure 8: Amplitudes from the DSP data acquisition system for the damping of quadrupole modes. Black: curve only with Landau damping, red: curve for damping amplitude of U_{Mod}=125V, yellow: U_{Mod}=250V, green: U_{Mod}=500V, light blue: U_{Mod}=750V and blue: U_{Mod}=1kV.

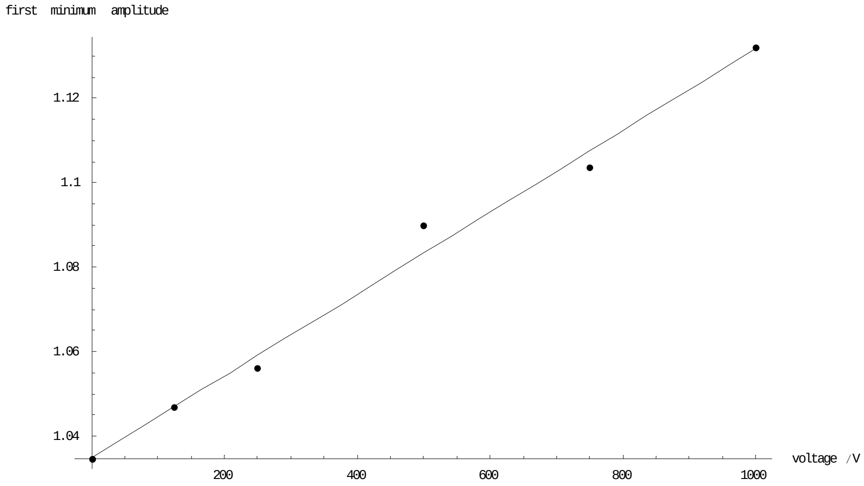

Figure 9: Evolution of the first minimum amplitude over the quadrupole oscillation damping amplitude U_{Mod}.

4 Acknowledgement

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5 References

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[2] P. Hülsmann, H. Klingbeil, M. Mehler, B. Zipfel, 'Analytical Estimations Concerning the Damping of Quadrupole Oscillations', GSI, (oncoming soon)
[3] M. Mehler, U. Laier, 'Longitudinal Feedback System for FAIR', version 2.01, Sept. 07 (section 5.2)