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Beam Experiments Concerning Damping of Quadrupole Oscillations in SIS12/18

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1 Introduction and Summary

The goal of the machine development experiment was to investigate the closed loop damping of induced quadrupole oscillations in SIS18 with the ion species $^{40}Ar^{18+}$ at injection energy (E_{kin} = 11.4 MeV/u).
The quadrupole oscillation was induced by an RF voltage amplitude jump (voltage before the jump: U_{RF} = 5 kV, voltage after the jump: U_{RF} = 10 kV, harmonic number h = 8). The electronic system for the closed loop damping of the oscillations was a DSP (Digital Signal Processing) system [1, 3] formerly developed for cavity synchronization at GSI and now adapted for the described task. A second system has been used to damp undesired dipole oscillations [2] also induced by the voltage jump to isolate the desired quadrupole oscillations. Therefore also the co-operation of the two closed loop damping systems was examined.
The data have been recorded with the DSP systems and a LeCroy oscilloscope.
In time domain was shown that the closed loop damping leads to a damping time that is about two times faster than the Landau damping time.
In frequency domain it was shown that the amplitude of the quadrupole oscillation mode was reduced by the application of the closed loop systems. This is the verification of the result that could be seen in time domain.
As a conclusion the machine experiment was a success concerning the operability of the electronic system.
The following topics are still open and will be addressed in further machine experiments:

- optimization of the electronic setup (reduction of delays).
- thorough investigation of the closed loop parameters.
- different ion species and energies.
- extension to ramped operation (automatic adaptation of parameters).
- more detailed analysis of interactions between dipole and quadrupole damping systems.

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, secondly two DSP systems for data acquisition and closed loop damping (Figure 2 shows the quadrupole damping system).
One of the two DSP systems was used to get phase information of the beam compared to the phase of the gap voltage. Former experiments and analytical estimations allowed to determine the best settings for the closed loop damping of dipole oscillations with the coupled bunch instability mode n = 0 (coherent oscillation of all bunches). These settings were used for this experiment.

The other DSP system was used to get the amplitude information of the beam current in real time and it was used for the closed loop damping of quadrupole oscillations also with the coupled bunch instability mode n = 0. This system and its interaction with the closed loop dipole oscillation damping system were tested. The control loop algorithm is based on a digital filter with an integral element and a proportional factor as a gain. The filter centre frequency and the gain are the parameters which determine the closed loop behavior.
The voltage ramp for the excitation of the quadrupole oscillations has been created by an arbitrary waveform generator. This ramp is shown in Figure 3. At injection energy (E_{kin} = 11.4 MeV/u) $^{40}Ar^{18+}$ was captured with an isoadiabatic voltage ramp of 100 ms length and a voltage amplitude of U_{RF} = 5 kV (f_{RF} = 1713.17 kHz at the harmonic number h = 8). A short flat top of 30 ms with a constant voltage amplitude of U_{RF} = 5 kV followed for the damping of disturbances induced to the beam by this capturing process. Afterwards the voltage jump up to
U_{RF} = 10 kV (f_S = 3312.31 Hz) occurred. The new voltage flat top had a length of 300 ms.
With the help of function generators 1 and 2 (Figure 2) it was possible to gate the operation of the closed loop control. The closed loop control system started to work 2 ms before the voltage jump occurred (Figure 3). The working time of the closed loop control system for damping quadrupole oscillations was limited to about 29 ms (50000 periods) by the abilities of the function generators.
The data acquisition worked over the whole duration of the voltage amplitude ramp.

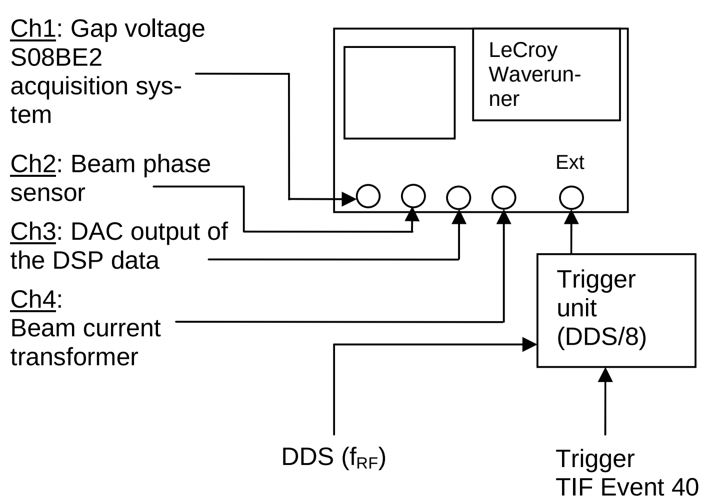

Figure 1: Measuring setup and data acquisition with the LeCroy oscilloscope (waterfall measurements).

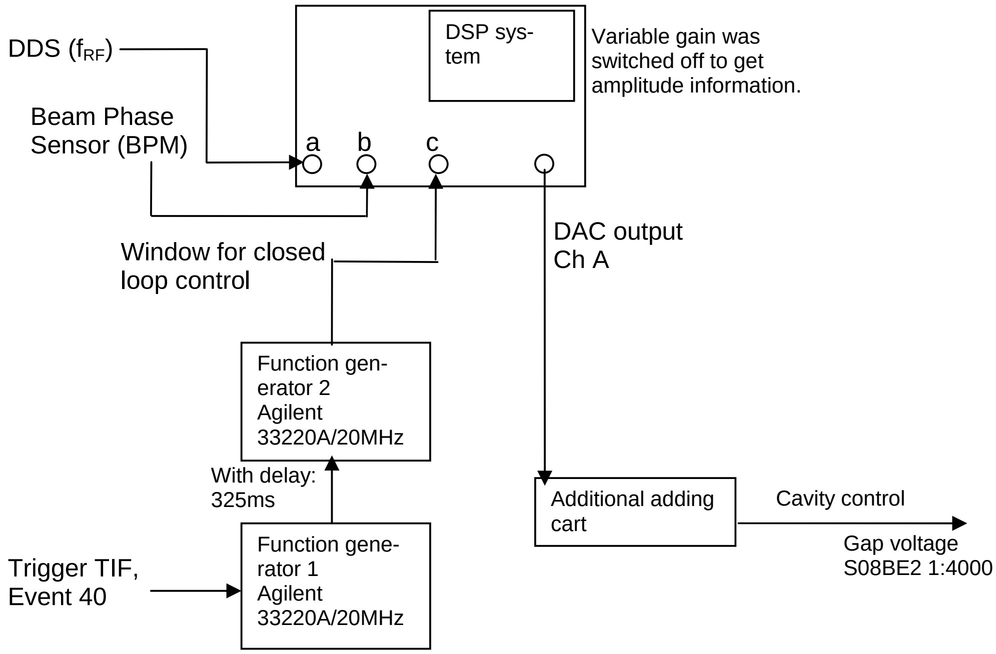

Figure 2: Data acquisition with the DSP system and closed loop damping setup of quadrupole oscillation modes.
The RF signal feeding the cavity is routed to the offset local oscillator (LO) via input (a). Input (b) is the measuring input. During this experiment CH A of the electronic system has been used. Input (c) was used to define the window during which the control loop was closed as is described above. Function generator 2 was responsible for the signal to be fed into input (c). Function generator 1 was responsible for the delay after TIF event 40 (start injection from UNILAC, delay time: 325 ms).

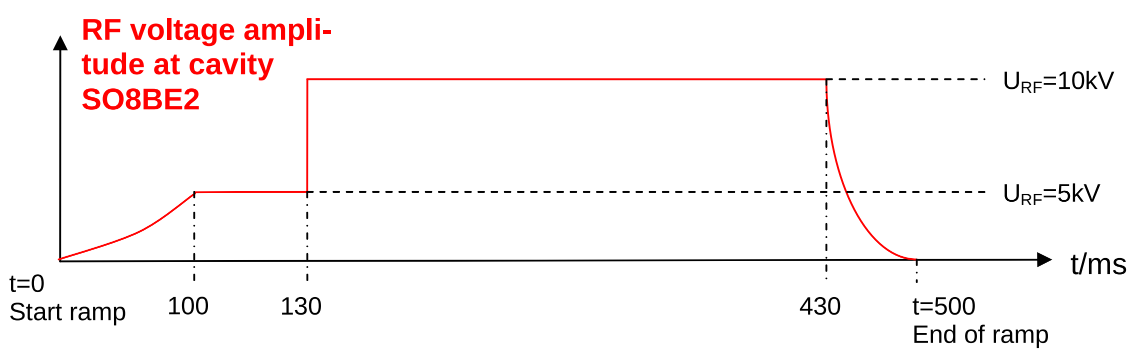

Figure 3: Voltage ramp for the excitation of quadrupole oscillations.

3 Main results

First measurements had shown that a DAC gain of -0.6 at a filter frequency f_{pass} = 9000 Hz (analytically evaluated $2f_S$ = 6624.62 Hz) showed the best damping results in time domain. Therefore several samples were taken for these parameters:

- 5 measurements for data with Landau damping as the only point responsible for the damping of the quadrupole oscillations.
- 5 measurements for only using the closed loop quadrupole damping system.
- 5 measurements with both closed loop damping systems working.

The most important results can be seen in Figure 4 to Figure 8.

The measurement results were highly reproducible which allowed to use averaging methods to reduce the noise in the analysis.
The beam current amplitude curves that can be seen in Figure 4 show the mean amplitude values of 5 data sets measured with the same settings (filter frequency: 9000 Hz, DAC gain: -0.6 for the red and blue curve, DAC gain: 0 for the black curve). The difference between the blue and the red curve is that the blue curve shows the data without using an additional closed loop dipole damping system and the red curve shows the data where both closed loop damping systems were working. The black curve shows the data for Landau damping only. About 2.2 ms beginning since the voltage jump inducing the quadrupole oscillations are displayed in Figure 4 (it is the important part of the data).
Without control loops (only Landau damping) 4 oscillation periods can clearly be identified. In comparison with the closed loop quadrupole damping system working only 2 periods can be identified before the oscillation amplitude corresponds in height to the oscillation amplitude shown in the black curve (Landau damping). The result when using both damping systems (red curve in time domain) looks similar to the case mentioned before. The damping time in closed loop operation is about twice as fast as Landau damping.
For producing spectra the curves shown in Figure 4 were cut into halves (Figure 5, Figure 7) and convolved with a Hamming window. Then a Fourier transformation was carried out. The resulting spectra can be seen in Figure 6 and Figure 8. The height of the spectral line of the quadrupole oscillation modes is only 30% of the height without an electronic system (Figure 6).
The spectral line of quadrupole oscillation of the persistent noise (1.1 ms after the oscillation inducing voltage jump) shows only half of the height of the one visible only with Landau damping if the closed control loop systems are used (Figure 8).

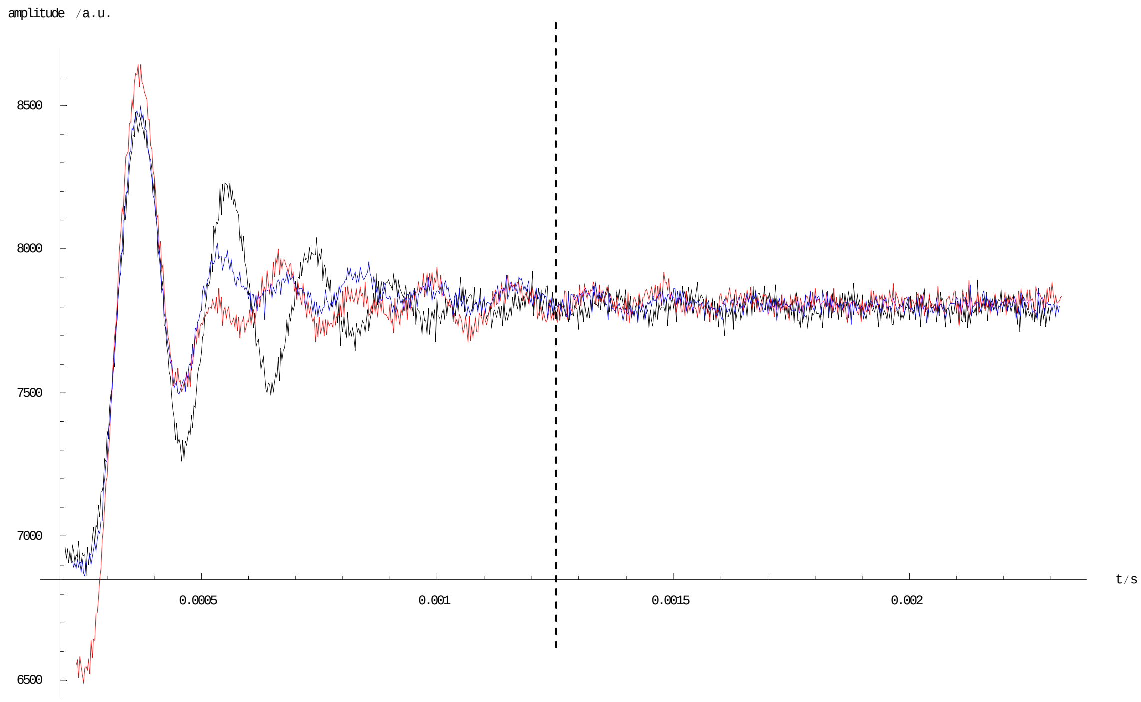

Figure 4: Measured amplitude data of the DSP acquisition system (Figure 2) in time domain. The left part separated by the dashed line is equivalent to Figure 5 and the right part is equivalent to Figure 7.
Black: Landau damping of the quadrupole oscillation, blue: closed loop quadrupole oscillation damping without using the closed loop dipole damping system, red: closed loop quadrupole oscillation damping with additional closed loop dipole oscillation damping.

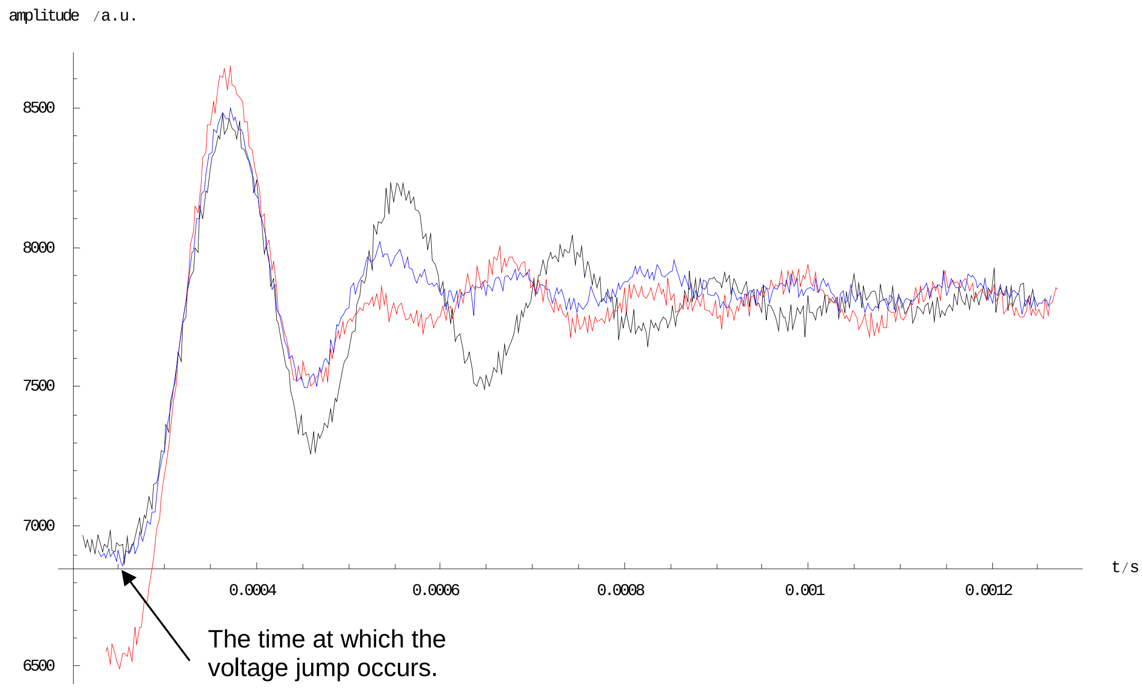

Figure 5: Measured amplitude data of the DSP acquisition system (Figure 2) in time domain. Displayed are the first 1.1 ms after the voltage amplitude jump.
Black: Landau damping of the quadrupole oscillation, blue: closed loop quadrupole oscillation damping without using the closed loop dipole damping system, red: closed loop quadrupole oscillation damping with additional closed loop dipole oscillation damping.

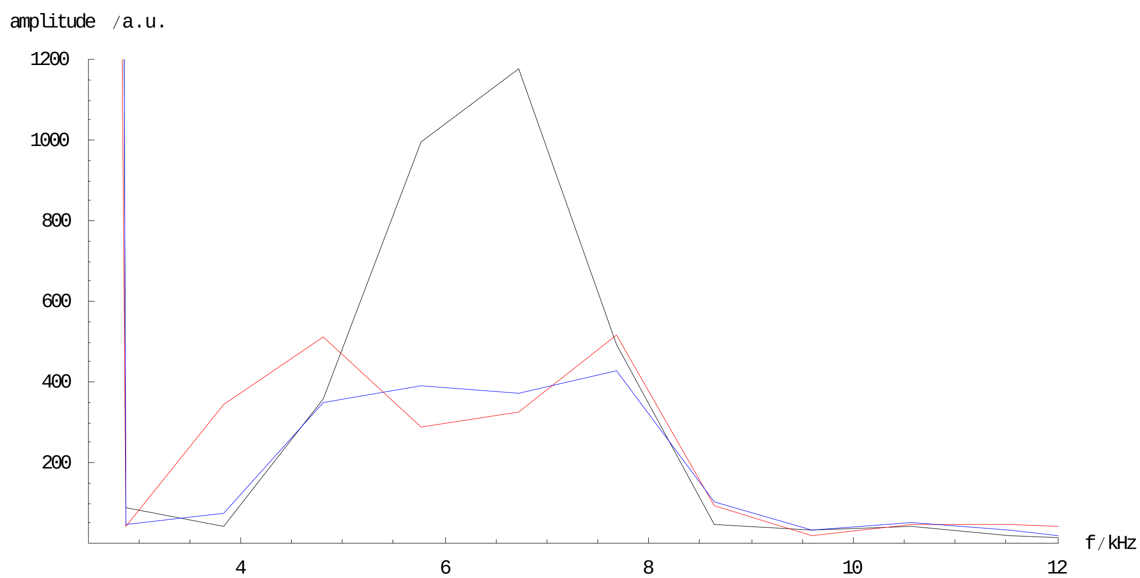

Figure 6: Measured amplitude data of the DSP acquisition system in frequency domain.
Black: Landau damping of the quadrupole oscillation, blue: closed loop quadrupole oscillation damping without using the closed loop dipole damping system, red: closed loop quadrupole oscillation damping with additional closed loop dipole oscillation damping.
To create the spectra the area pictured in Figure 5 has been used (about 1.1 ms from voltage jump to the end of the picture).

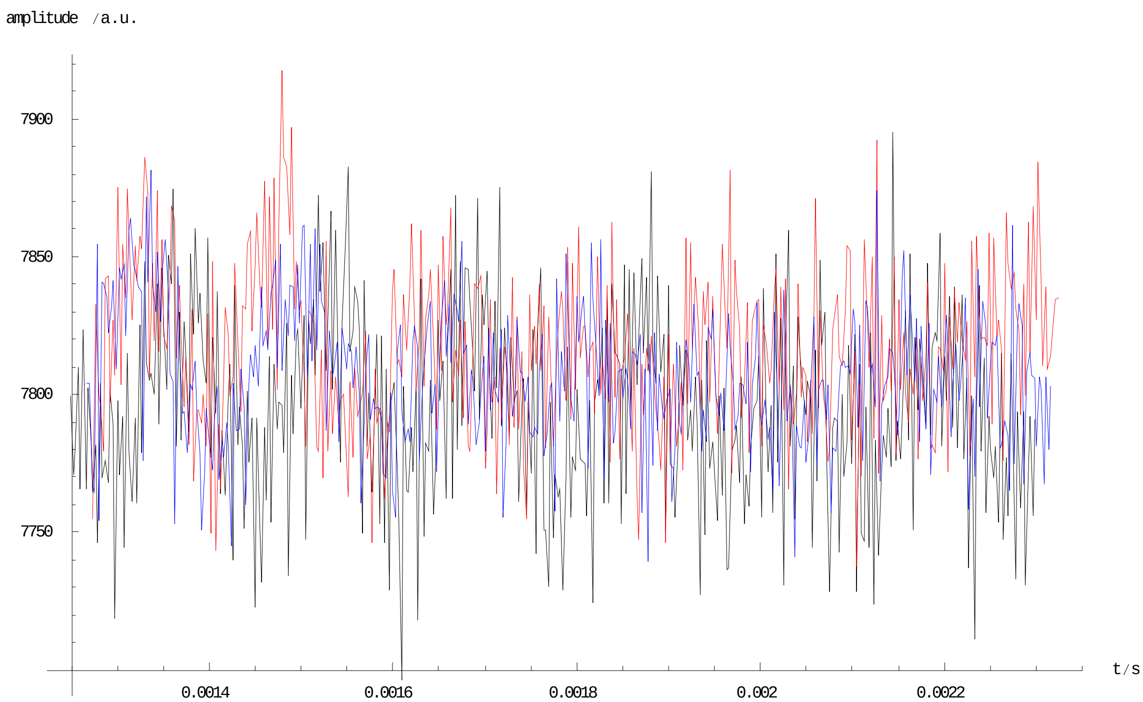

Figure 7: Measured amplitude data of the DSP acquisition system (Figure 2) in time domain.
Black: Landau damping of the quadrupole oscillation, blue: closed loop quadrupole oscillation damping without using the closed loop dipole damping system, red: closed loop quadrupole oscillation damping with additional closed loop dipole oscillation damping.

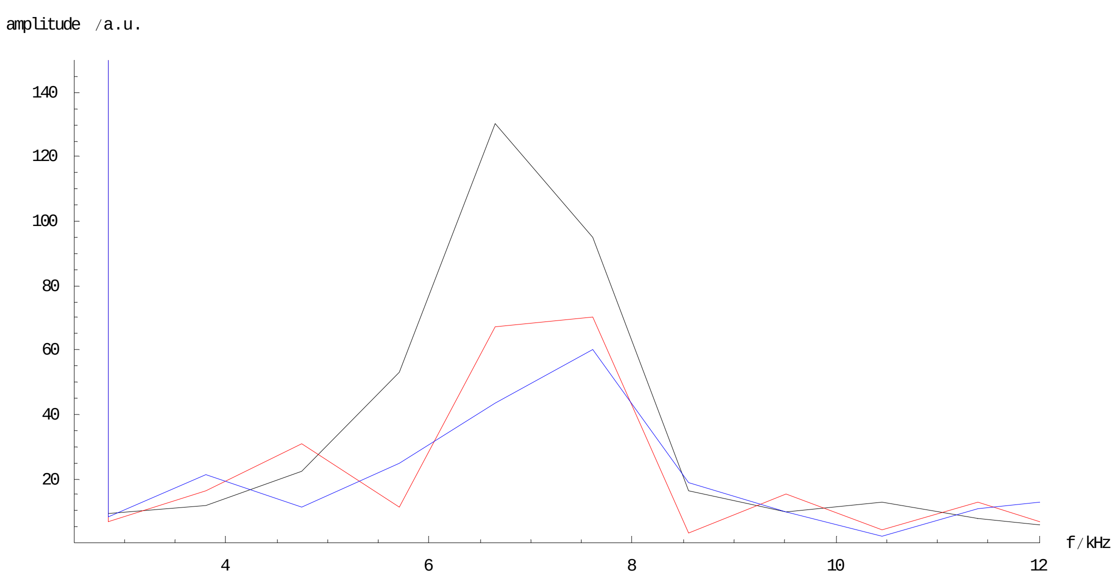

Figure 8: Measured amplitude data of the DSP acquisition system in frequency domain.
Black: Landau damping of the quadrupole oscillation, blue: closed loop quadrupole oscillation damping without using the closed loop dipole damping system, red: closed loop quadrupole oscillation damping with additional closed loop dipole oscillation damping.
To create the spectra the area pictured in Figure 7 has been used (starting about 1.1 ms since voltage jump up to 2.2 ms at the end of the picture).

4 Acknoledgement

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5 References

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