GSI – Note	**Nr.:** SIS070611070828.HF
First Beam Experiments Concerning Closed 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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Document History:

Version	**Date**	**Authors**	**Comments**
1.0	07/12/2007	M. Mehler,	Reviewed 07/12/2007 by H. Klingbeil, K.-P. Ningel

First Beam Experiments Concerning Closed Loop Damping of Quadrupole Oscillations in SIS12/18

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June 11, 2007 and August 28, 2007

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

1 Introduction and Summary

Two machine development experiments have been accomplished in June and August 2007.
After investigating the physical aspects of exciting or damping quadrupole oscillations [5], the technical closed loop aspects now came to the fore. Therefore the goal of both machine experiments was a first investigation of the closed loop damping system built to damp induced quadrupole oscillations in SIS12/18. The experiment took place with the ion species $^{238}U^{73+}$ at injection energy (E_{kin} = 11.4 MeV/u).
The quadrupole oscillations were induced by an RF voltage amplitude jump (voltage before the jump: U_{RF} = 7.2 kV, voltage after the jump: U_{RF} = 10 kV, harmonic number h = 4). This should excite a beam current amplitude oscillation of about 10% of the mean beam current amplitude (evaluated from formulas in [4]).
The electronic system for the closed loop damping of the quadrupole oscillations was a DSP (Digital Signal Processing) system [1, 2] formerly developed for cavity synchronization at GSI and now adapted for the described task. The data have been recorded with the DSP systems and a LeCroy oscilloscope.
In frequency domain it could be shown that the amplitude of the quadrupole oscillation mode was reduced by the application of the closed loop system. Therefore it could be demonstrated for the first time that quadrupole oscillations were damped by means of a closed loop feedback system.
It is assumed that dipole oscillations were responsible for the impossibility to see any differences in the damping results in time domain. Therefore further investigations and machine experiments should follow. The effect of the closed loop damping system should also be seen in time domain, so that a damping time can be evaluated.

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 a DSP system for data acquisition and closed loop damping (Figure 3 shows the quadrupole damping system).
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 K_I 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 4. At injection energy (E_{kin} = 11.4 MeV/u) $^{238}U^{73+}$ was captured with an isoadiabatic voltage ramp of 100 ms length and a voltage amplitude of U_{RF} = 7.2 kV (f_{RF} = 1639.6 kHz at the harmonic number

h = 4). A short flat top of 30 ms with a constant voltage amplitude of U_{RF} = 7.2 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 = 1932.3 Hz) occurred. The new voltage flat top had a length of 300 ms.
With the help of the function generators 1 and 2 (Figure 3) 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 4). The data acquisition worked over the whole duration of the voltage amplitude ramp.

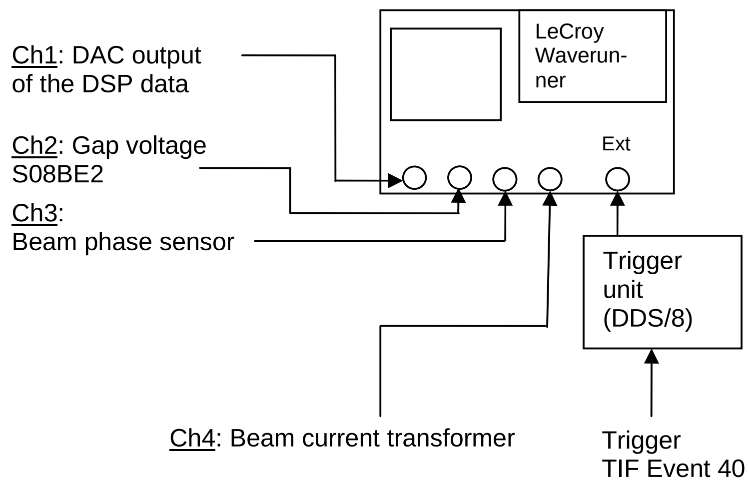

Figure 1: Measuring setup and data acquisition with the LeCroy oscilloscope (waterfall measurements June 11, 2007).

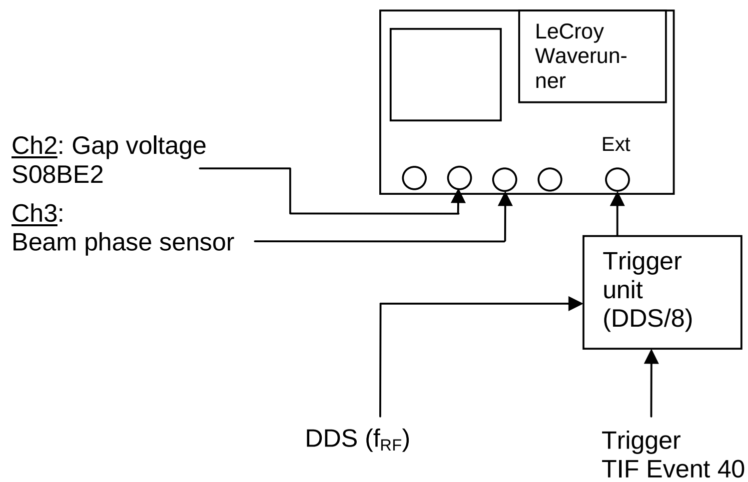

Figure 2: Measuring setup and data acquisition with the LeCroy oscilloscope (waterfall measurements August 28, 2007).

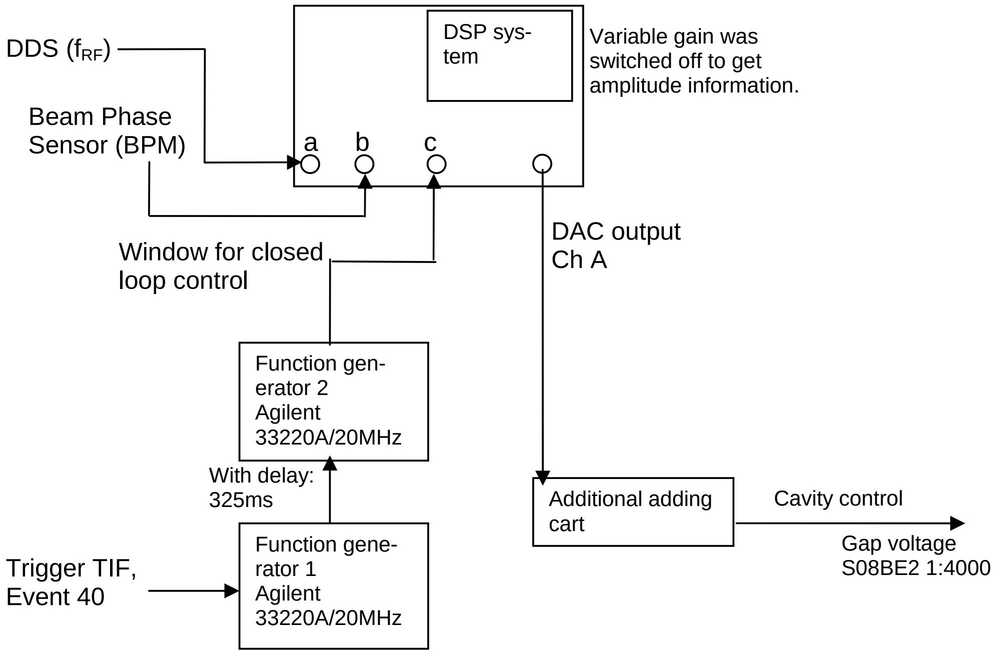

Figure 3: Data acquisition with the DSP system and closed loop damping setup of quadrupole oscillation modes.
The RF signal feeding the cavity is routed to the offset local oscillator (LO) via input (a). Input (b) is the measuring input. During this experiment CH A of the DSP system has been used. Input (c) was used to define the window during which the control loop was closed as 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).

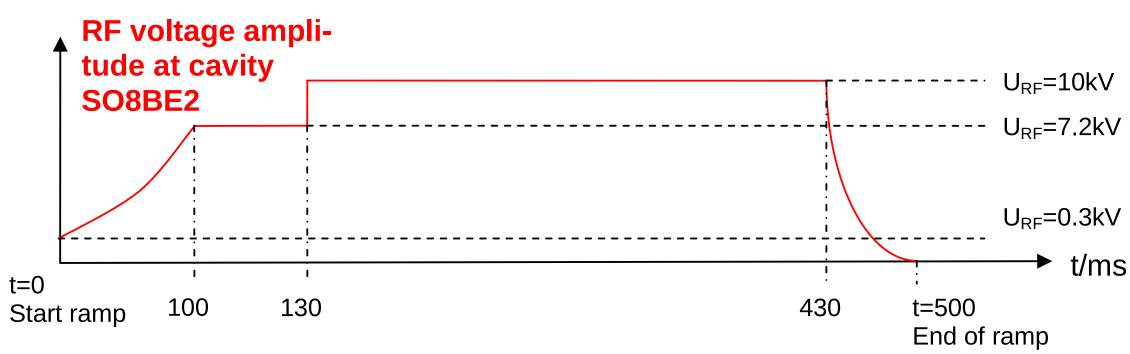

Figure 4: Voltage ramp for the excitation of quadrupole oscillations.

3 Main results

This section shortly describes the result of the machine development experiments done for the testing of the closed loop electronic system for damping quadrupole oscillations. Section 3.1 gives a short summary of the experiment done on June 11, 2007. Section 3.2 gives the short summary of the experiment done on August 28, 2007.

3.1 Machine Development Experiment on June 11, 2007

Figure 5 shows a part of the determined data at certain gains K_I of the feedback loop of which the spectra are taken which can be seen in Figure 6 (more detailed description in [3]). For every gain one data set is available. As can be seen there is a quadrupole oscillation band around 2700 Hz. This is in the region of the double of the synchrotron frequency of the outer part of the bunch that fills the bucket about 75%. It can be observed that with growing negative gain K_I the frequency band around 2700 Hz is decreasing except the frequency band near 3000 Hz which was the center frequency of the filter. This one is increasing with increasing negative gains K_I. This might lead to the conclusion that there is a connection between the filter frequency and the growth of the spectral line. This has to be analyzed in further machine experiments.
As a conclusion it was demonstrated for the first time in SIS18 that quadrupole oscillations were damped by means of the digital feedback loop.

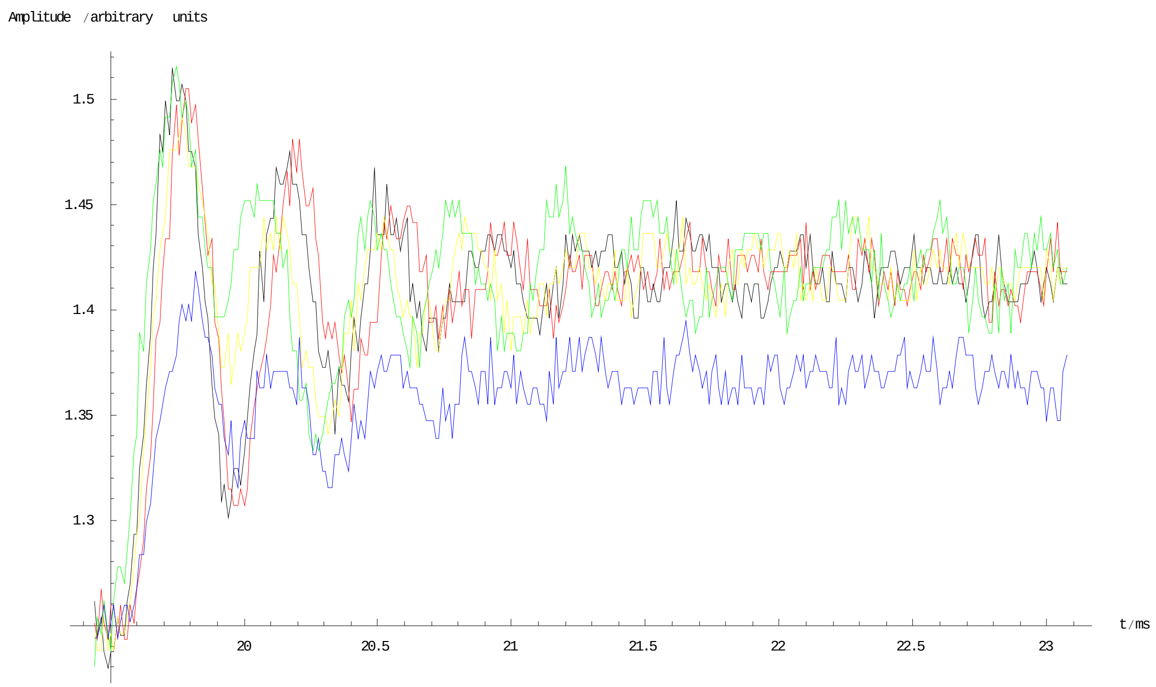

Figure 5: Part of the development of the beam current amplitude data over the revolutions of some damping results recorded by the oscilloscope (Figure 1) in time domain of which the spectra of Figure 6 are taken. Black: gain of the feedback loop $K_I = 0.0$, red: $K_I = 0.15$, yellow: $K_I = -0.5$, green: $K_I = -0.75$, blue: $K_I = -1.0$.

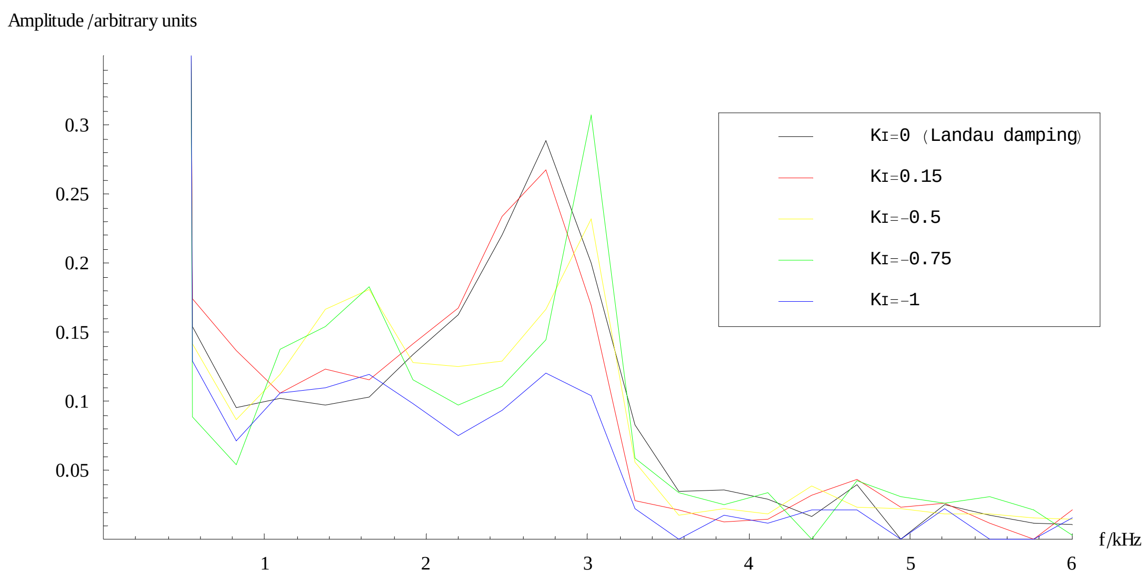

Figure 6: Spectra of some damping results recorded by the oscilloscope. The variable K_I denotes the gain of the feedback loop. The spectra are taken from the data displayed in Figure 5.

3.2 Machine Development Experiment on August 28, 2007

During this machine experiment the goal was to verify and improve the one described in section 3.1. A cross scan of the feedback loop gains K_I and the filter frequencies was done to identify the best values. From these data a stability diagram was made that can be seen in Figure 9. For every gain and filter frequency one data set is available. The lower the amplitudes of the spectral line of the quadrupole oscillation are the better is the damping efficiency.
As described above (section 3.1) from the interesting part concerning the quadrupole oscillations of the data in time domain a spectrum was made. The amplitudes of the spectral lines of the quadrupole oscillation of all measured gains K_I and filter frequencies were identified. The result can be seen in Figure 9. The most effective region of the closed loop damping system was found for gains K_I = -5…-13 and filter frequencies
$f_{pass} \cong$ 2500 Hz …7000 Hz ($2f_S$ = 3865 Hz, f_S: synchrotron frequency).
In general the damping results are not as good as expected. Two reasons are possible:

- The gain is too large to operate in the stable region. This is unlikely because the simulations showed a better performance.
- The hardware setup has a saturation which prevents higher gains from taking effect. This has to be analyzed in future experiments prepared by thorough simulations.

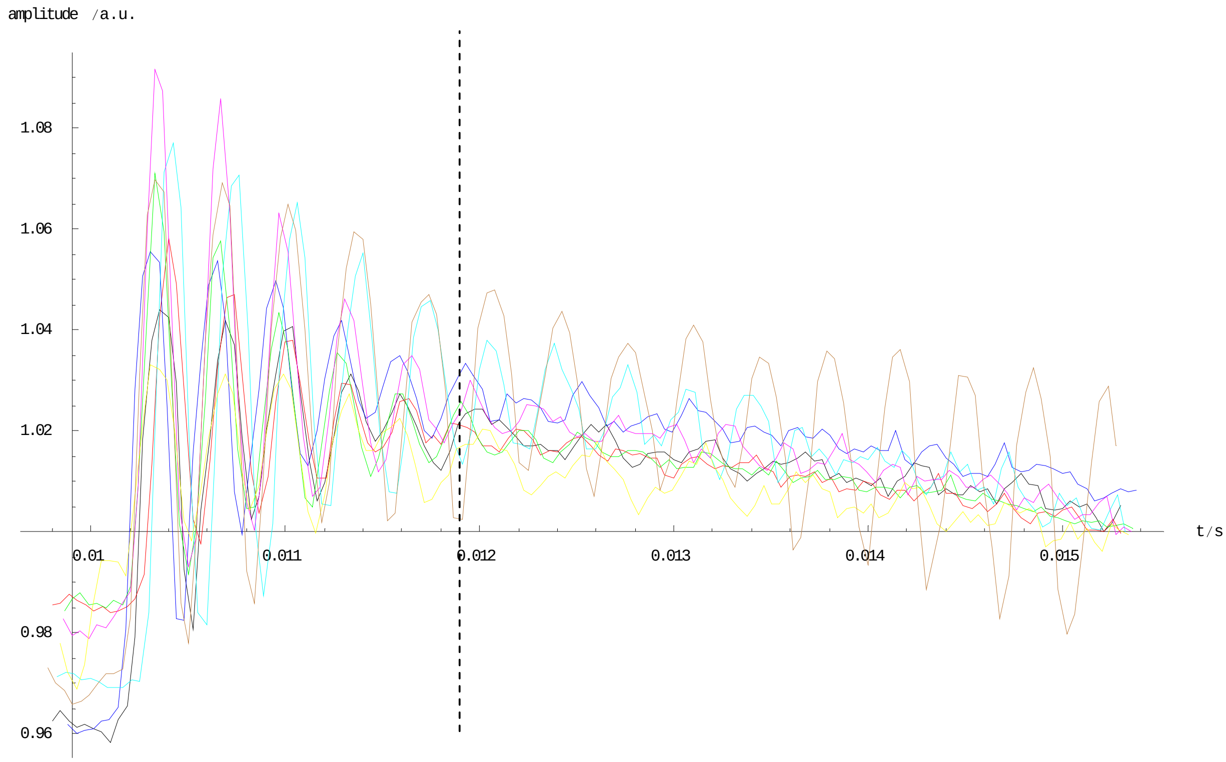

Figure 7: Part of the beam current amplitude data of some damping results recorded by the DSP system (Figure 3) in time domain of which the spectra of Figure 8 are taken. As an example the data for the following gains K_I were displayed: black K_I = -10, red K_I = -11, blue K_I = -12, green K_I = -13, light blue K_I = -14, mauve K_I = -15, yellow K_I = -20, brown K_I = -30.

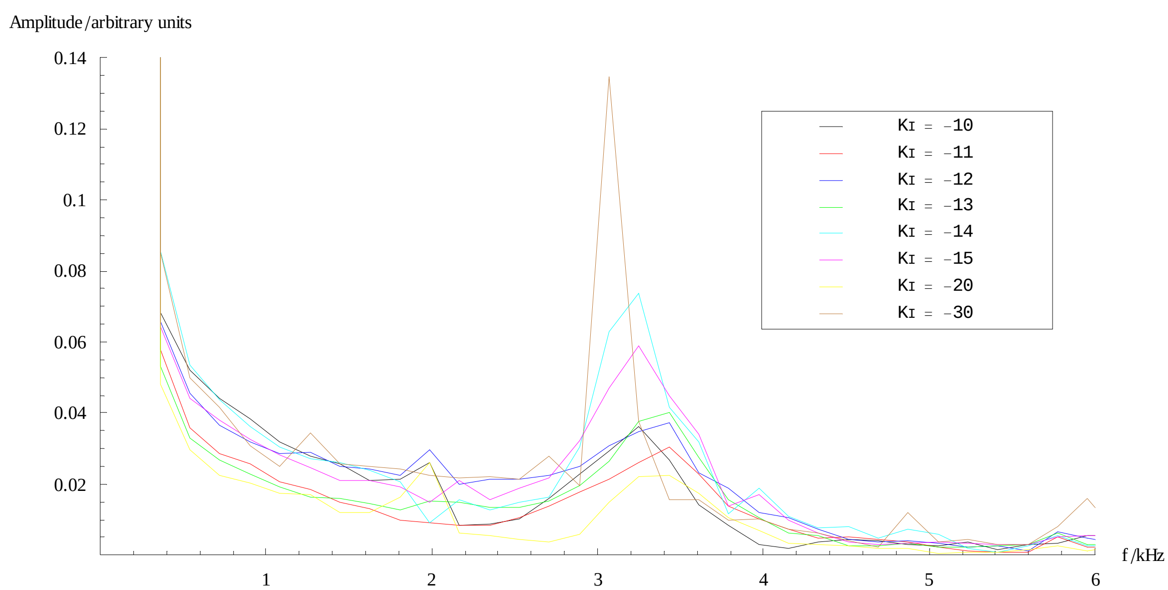

Figure 8: Spectra of the damping results recorded by the DSP system. The variable K_I denotes the gain of the feedback loop. The spectra are taken from the data displayed in Figure 7.

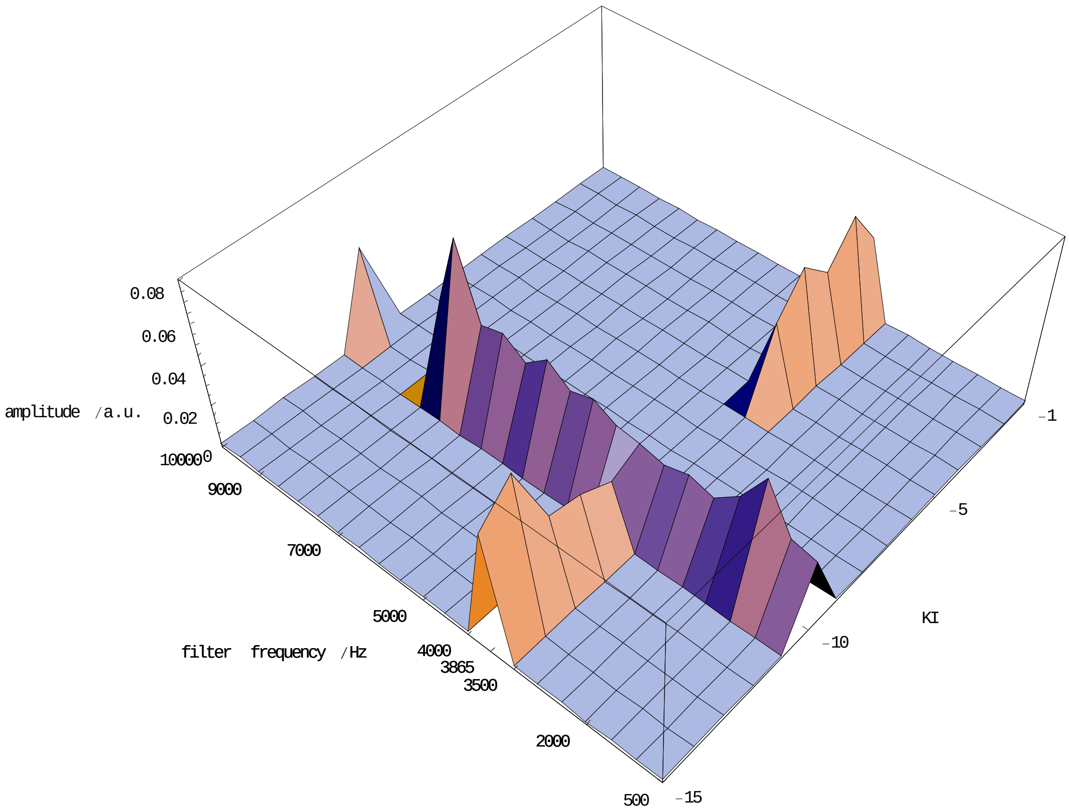

Figure 9: Stability plot of the closed loop feedback system obtained through a cross scan over the feedback loop gains K_I and the filter frequencies with a constant gain of $K_I = -10$. The lower the amplitude of the spectral line of the quadrupole oscillation is the better the efficiency of the closed loop feedback system.

4 Acknowledgement

The author would like to thank the participants and H. G. König, H. Damerau and P. Hülsmann for their help during the preparation of the experiments.

5 References

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