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# An experimental study of a new multi-bunch damping mechanism in PETRA

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**Abstract.** A new damping mechanism of multi-bunch oscillations in a storage ring with help of a narrow-band feedback system has been experimentally tested in PETRA. The oscillations of a multi-bunch filling were sucessfully damped. The bandwidth of the active loop was 1.5 kHz instead of 5 MHz needed for standard damper systems.

## 1 Introduction

In an article recently published, a new multi-bunch damping mechanism was described, based on a combination of a narrow-band feedback system and frequency splitting between bunches [1].

Due to this combination the frequency differences between individual bunches are "transformed" into damping rates, so that all states of oscillation in a multi-bunch filling can be damped.

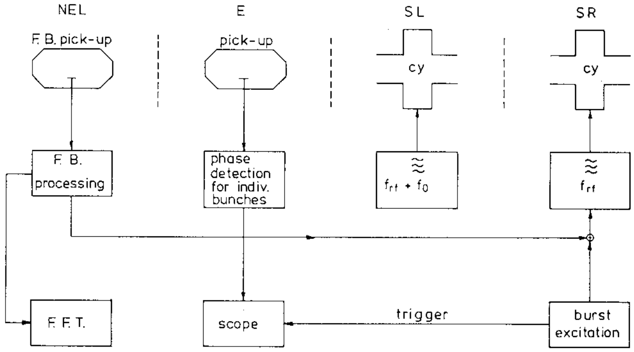
The bandwidth of the feedback system is determined by the tolerable frequency spread within the beam, and this spread also determines the maximum possible damping rates if the open-loop gain of the feedback system is properly adjusted.

In this article we will describe the experiment which has been performed in PETRA in order to demonstrate the existence of the predicted damping mechanism.

## 2 Description of the experimental arrangement

The experiment was performed making use of the existing pick-up and processing system which can be operated in such a way as to produce a signal proportional to the sum of the longitudinal displacements of the single bunches (barycentric mode pick-up system).

After processing, this signal was used to modulate the phase output of the klystron of one of the main transmitters. We detuned another transmitter such that it ran one harmonic above the fundamental frequency of the rf-system, so providing splitting of the synchrotron frequencies between bunches.



cy : cavities
NEL : north east left
E : east
SL : south left
SR : south right
$f_{rf}$ ≙ radio frequency (499.665 MHz)
$f_0$ = revolution frequency ($f_{rf}/3840$)

Fig. 1. Block diagram of the experimental arrangement

The bunches were excited individually by a signal burst on their individual synchrotron frequencies. The decay of the oscillation amplitude could then be observed for the corresponding bunches.

In addition to this, the signal coming from the phase detector of the feedback system was observed on an F.F.T.-analyzer when the bunches were excited by rf-noise only. Fig. 1 shows the block diagram of the experimental arrangement.

## 3 Description of the components

### 3.1 Frequency splitting

The fundamental frequency of the PETRA rf-system is generated from a 60 MHz signal by frequency multiplication (Fig. 2).

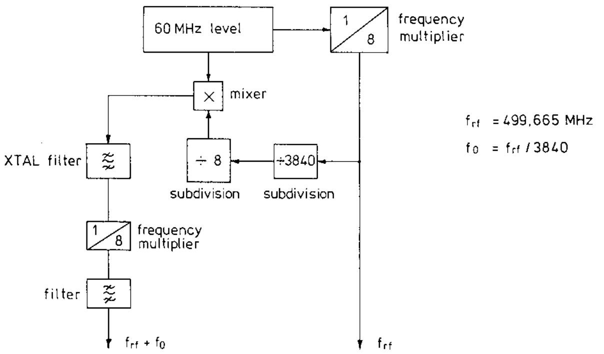


**Fig. 2.** Block diagram for frequency splitting

In order to generate a frequency one harmonic above the fundamental PETRA frequency, the 60 MHz component was mixed with the revolution frequency transformed to the 60 MHz level by frequency subdivision. A crystal filter was to filter out the $(f_{rf} + f_0)/8$-component. Frequency multiplication and subsequent filtering then delivered a signal on $f_{rf} + f_0$ used to control the power output of the transmitter in the south (right) of the PETRA ring.

### *3.2 Modulation of the klystron*

Since damping for all bunches is necessary, one has to keep the feedback loop "resistive" over a frequency range determined by the frequency spread within the beam.

Therefore, the overall phase response of the rf-system was measured. As a result of this measurement, the amplifier controlling the phase modulation at the klystron input was replaced, so that the phase response was limited only by cable length, wave guide length and the frequency response of the cavities.

### *3.3 The feedback loop*

The feedback loop is divided into three sections (Fig. 3):
- pick-up and rf-section
- IF-section
- low frequency section (including devices for feedback adjustment and control)

The technique processing phase oscillations is double conversion technique.

As a pick-up one of the four plates of a normal PETRA position monitor was used. The pick-up was tuned to the 3840 th harmonic of PETRA's revolution frequency (about 500 MHz) with the help of a $\lambda/2$-resonator type transformer matching the subsequent 50 $\Omega$-system. The transformer was directly connected to the pick-up.

The rf-section included a 500 MHz bandpass filter, the first mixer with an associated 470 MHz local oscillator, and a 50 dB gain IF-amplifier. The band-width of this section was about 10 MHz. The total rf-section was mounted next to the pick-up in the north-east of the PETRA ring tunnel.

The IF signal was transferred by a 200 m long coaxial cable to the NE experimental hall, where the IF detector was installed. This detector included:
- a 30 MHz bandpass filter
- the second mixer with LO of 19.3 MHz

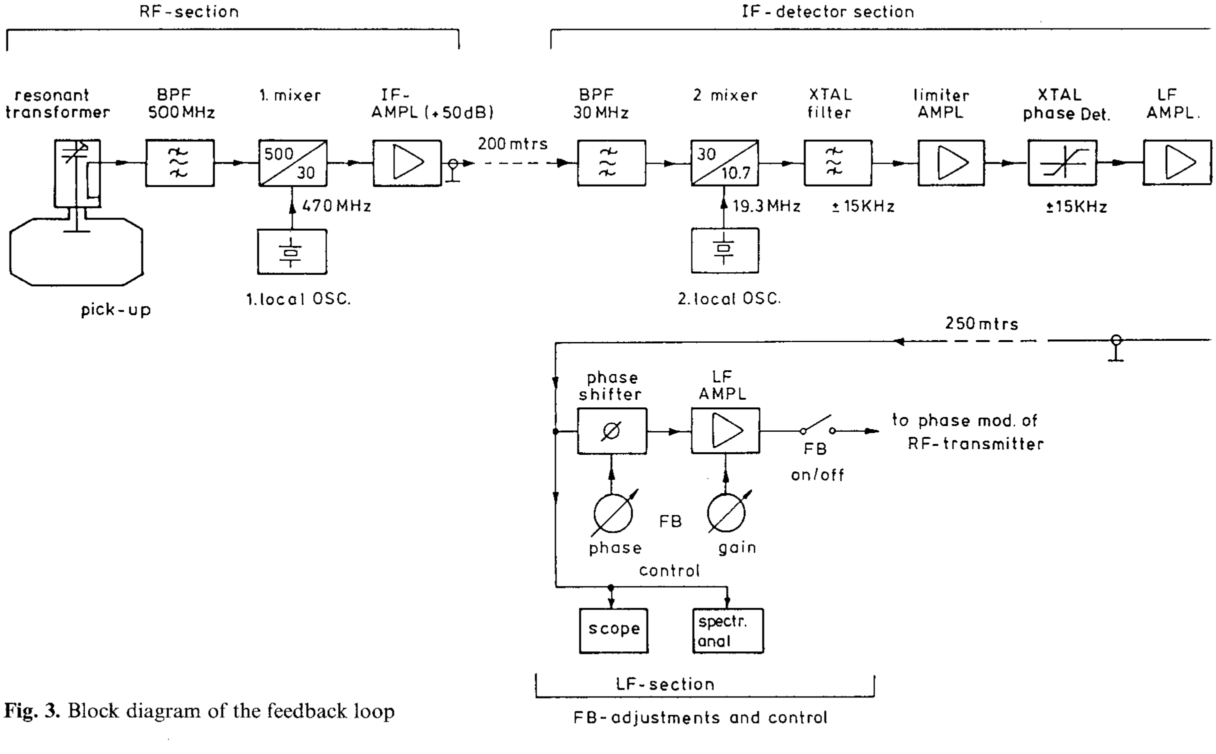


**Fig. 3.** Block diagram of the feedback loop

- a narrow-band crystal IF-filter (frequency: 10.7 MHz, bandwidth: 30 kHz)
- two associated limiter amplifiers
- a crystal phase detector
- a low frequency amplifier.

After the detection of phase oscillations the low frequency signal was transferred to the main control room by a 250 m long coaxial cable. There the phase and the gain of the feedback loop could be adjusted observing the damping time of a single bunch phase oscillation.

The frequency dependence of the phase shifting device was minimized around 8 kHz. However, since the feedback loop was originally developed for the longitudinal 8-channel narrow-band feedback system where the phases could be adjusted individually for each channel, the overall phase response due to the application of narrow-band devices was measured to be 25°/kHz.

The system was proved to be very sensitive at small oscillation amplitudes and small bunch currents, so that the experiments could be carried out even at single bunch currents lower than 60 μA. In this range the experiments do not conflict with instabilities, not even in the multi-bunch case.

### *3.4 The detection system*

In order to observe the phase oscillations of a single bunch within a group of adjacent bunches a combined phase detection/sampling scheme was used (Fig. 4).

The bunch signal was derived from a capacitive pick-up electrode installed in the East of the PETRA ring. This signal was transferred to the main control room by a 300 m long broad band cable. There it passed a 500 MHz bandpass filter with a 10 MHz bandwidth.

After 20 dB of amplification the narrow-band spectrum signal was applied to the rf part of a double balanced mixer. The LO part was fed with a phase adjustable 500 MHz reference from the PETRA master oscillator.

When triggered on the occupied buckets, the IF output of the mixer showed about ten oscillations at 500 MHz which were amplitude modulated at the synchrotron frequency [2].

The connected sampling scope (Tektronix 7904 + 7912 + 94) takes an amplitude sample and holds it during one revolution time of PETRA for further processing. The sampler was triggered from a conventional rf driven bunch trigger generator which allows the trigger to be adjusted to the single PETRA buckets.

The bunch related phase oscillation signal was then amplified in an adjustable lf bandpass filter, providing sufficiently high bandwidth and could be observed and documented on a digital storage scope.

In addition, the signal coming from the feedback pick-up was observed and documented on a FFT spectrum analyzer.

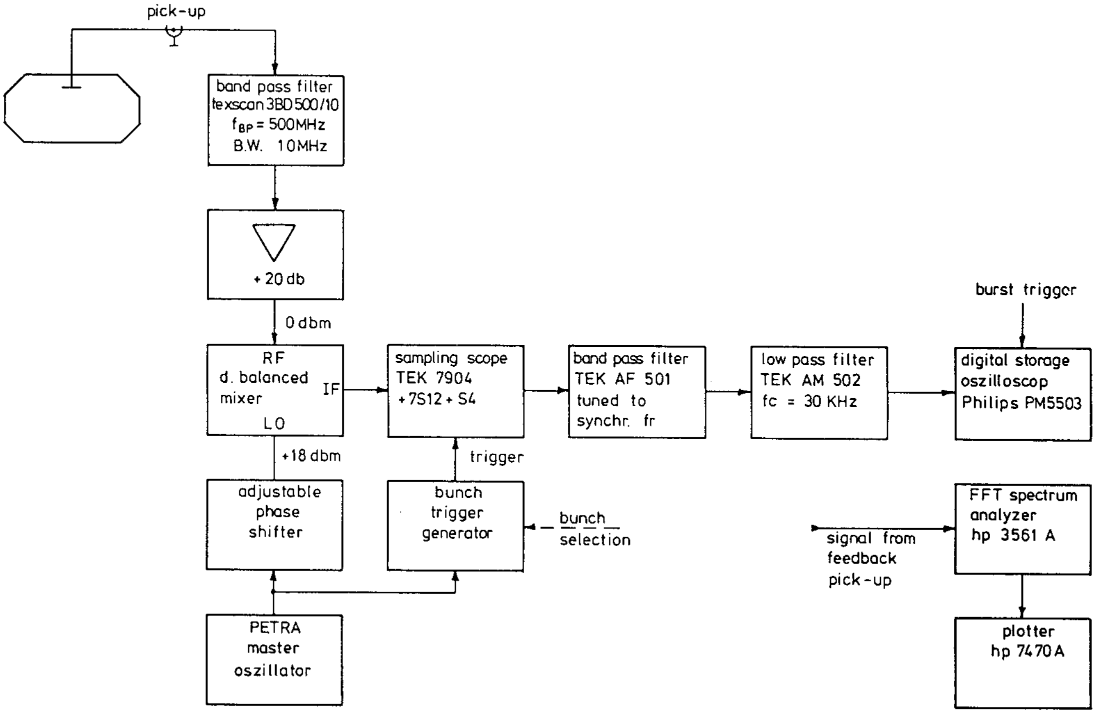


**Fig. 4.** Block diagram of the phase detection system

## 4 Experimental procedure and results

After the frequency splitting transmitter was brought into operation, three bunches were filled into that part of the ring, where the sinusoidal modulation of the synchrotron frequency is nearly linear (see [1]). The time interval between adjacent bunches in the ring was 0.5 $\mu$s. The current was 0.4 mA/bunch which is below the threshold of all collective effects.

In Fig. 5 we have plotted the spectrum of the signal coming from the feedback pick-up. The beam was excited by rf-noise only.

With the feedback loop *open,* the three observable synchrotron frequencies correspond to the three different single bunch frequencies.

The beam is mainly damped by Landau-damping. Since the excitation amplitude is very small, the Landau-damping is determined by the "static" Landau-damping which can be calculated from the bunch distribution and the non-linear rf-potential. The "sidebands" on each side of the main peaks are due to the small low frequency components (50 Hz) modulating the rf-voltage.

With the feedback loop *closed,* the signal is strongly damped.

However, still one observes three different frequencies, corresponding to three different (linearly independent) states.

The width of the frequency bands has increased due to the increase of damping. Therefore, all states are damped, so that Fig. 5 immediately proves the existence of the predicted effect.

It should be mentioned that the reduction of the measured oscillation amplitude in Fig. 5 is also influenced by the linearity properties of the phase detection system within the observed range of about 30 dB.

In Fig. 6 the result of burst excitation for individual bunches is documented.

Figure 6a shows the decay of phase oscillations of bunch no. 1 (first bunch on the left in Fig. 5) when the feedback loop if open.

The decay is determined by the "dynamic" Landau-damping which is much higher than the "static" one since the excitation amplitude is at least 10 times higher than in the case of noise excitation. The detection sensitivity is also much lower compared to the sensitivity applied in the case of the FFT spectrum.

Figure 6b shows the phase oscillations of bunch no. 2 while bunch no. 1 is excited. It proves that bunch no. 2 is not significantly affected by the excitation on bunch no. 1. The same was observed to be true for bunch no. 3, which establishes the method of single bunch excitation.

Figure 6c shows the phase oscillations of bunch no. 1 when the feedback loop is closed. The damping effect can clearly be seen.

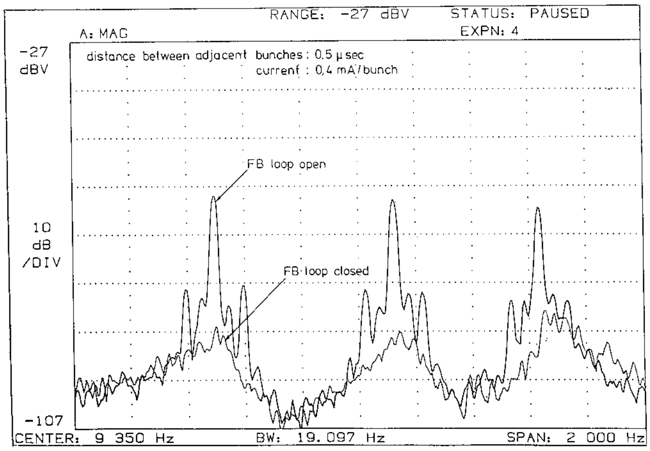


**Fig. 5.** FFT-spectrum of phase oscillations, three bunches injected

In Fig. 6d the phase oscillations of bunch no. 2 are shown in that case. We observe no significant oscillation amplitude also in the case of the acting feedback loop. This is due to the fact that the feedback gain was kept small during these experiments, so that the coupling between bunches also remained small.

In Fig. 6e, 6f we can see the phase oscillations of bunch no. 2 with the feedback loop open and closed respectively. Also for this bunch the acting feedback loop leads to an increase of the damping rate. The same was observed for bunch no. 3.

Since the "burst excitation" on an individual bunch frequency in the case of small feedback gain leads to a state, where mainly one bunch has a significant oscillation amplitude, the observed increase of damping for "single" bunches also proves the existence of the predicted damping mechanism. The total bandwidth of the feedback system used in these experiments was about 1.5 kHz instead of 2 MHz necessary to control adjacent bunches separated by 0.5 $\mu$s with help of a "conventional" feedback system.

Figure 7 shows the FFT spectrum when five bunches were filled with a time interval between adjacent bunches of 200 ns. The frequency difference between adjacent bunches is limited by the number of bunches and the usable bandwidth of the feedback loop (1.5 kHz). Again the action of the feedback loop leads to a considerable increase of damping for all independent states. A "conventional" feedback system in this case needs a bandwidth of about 5 MHz.

In Fig. 8 we plotted the spectrum when the feedback gain was increased. Although the different frequency bands start to overlap one can still detect five different frequencies.

At this point we reached the maximum possible damping of multi-bunch oscillations (see [1]). The

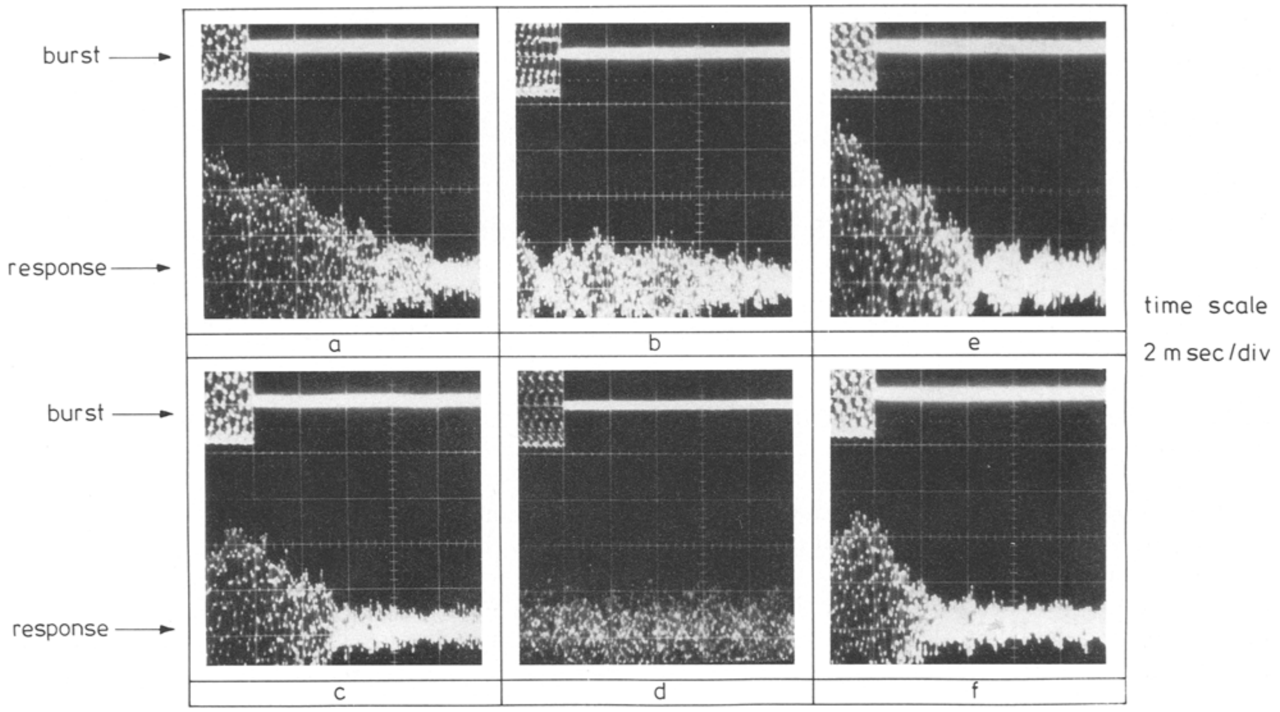


Fig. 6. Decay of phase oscillations observed for individual bunches

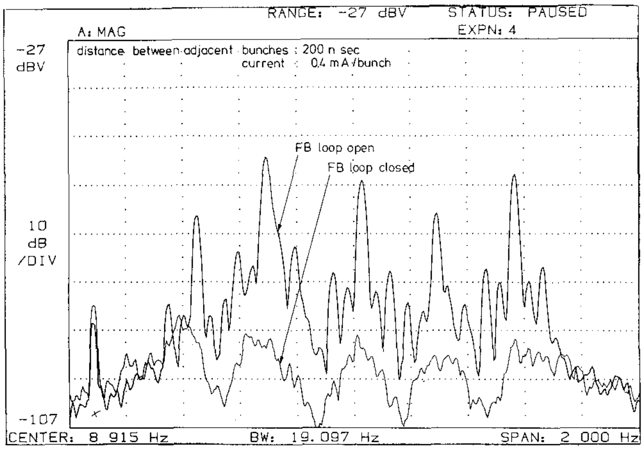


Fig. 7. FFT-spectrum of phase oscillations, five bunches injected

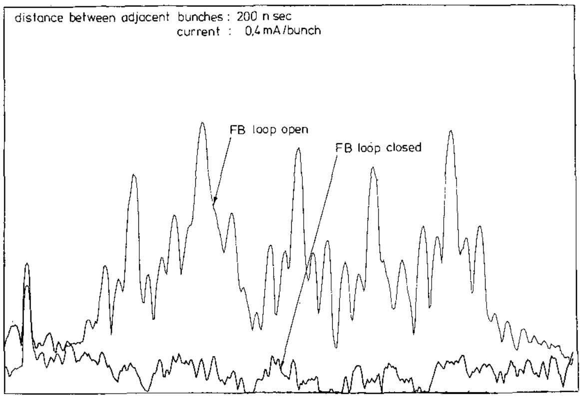


Fig. 8. FFT-spectrum of phase oscillations, five bunches injected, maximum usable feedback gain

damping times with the feedback loop closed were observed to be in the range between 2 ms and 5 ms, in good agreement with the numerical estimates in [1].

## 5 Conclusion and outlook

The damping of multi-bunch oscillations by a narrow-band damper system proposed in [1] was experimentally studied in PETRA. The existence of the damping mechanism was successfully established, and the observed damping rates were in agreement with those values expected from the theoretical considerations.

Due to the drastically reduced bandwidth of the multi-bunch feedback loop and the experience in constructing and operating frequency splitting devices the proposed damper system is an attractive scheme to fight multi-bunch instabilities in PETRA and HERA and especially in DORIS II operated as a synchrotron light source.

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## References

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2. M. Allen et al.: PEP-Note 340, 1980