400 MHZ IMPEDANCE - WHERE ARE WE?

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Abstract

In the SPS the impedance of MSE and MST septa were considered as one of the possible sources of instability observed at 400 MHz. All these elements were shielded during the last shutdown, but the instability still can be seen. Measurements done with the beam during 2000 year operation period, both below and above transition, are compared with data from previous years. Their analysis is presented together with results of simulations. Other possible candidates for the 400 MHz impedance source in the SPS ring are discussed.

1 INTRODUCTION

The instability at 400 MHz was first observed in 1996 in the measurements with long ($\sim$ 25 ns) single bunches injected into the SPS with RF off [1]. It was seen as a strong signal growing at frequencies around 400 MHz directly from a spectrum analyzer connected to the wideband pick-up (100 MHz - 4 GHz). Later it was also observed from Fourier analysis of the bunch profile with line density modulation (the same pick-up, each X turns with 4 GHz sampling rate). In these measurements due to small momentum spread the bunches were debunching relatively slowly (debunching time ~ 80 ms) and also were unstable (with instability growth time much less than debunching time).

Recording the maximum mode amplitude of the signal reached during the observation time (50 ms) at different frequencies and using statistics (data from > 10 bunches with similar intensity) led to the global spectral distribution presented in Fig. 1 for the frequency range (100 MHz - 1.7 GHz).

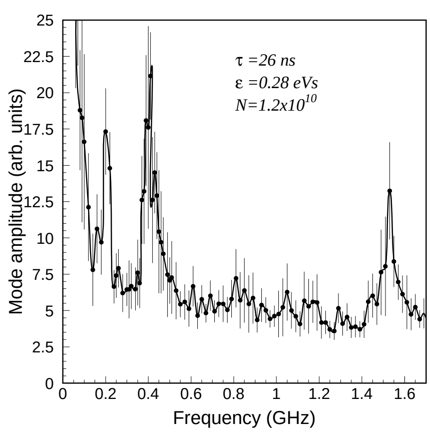

Figure 1: Measured spectral distribution, 1996.

2 POSSIBLE IMPEDANCE SOURCES

Most of the peaks recorded in the measurements, see Fig. 1, were identified [2] with different resonant impedances in the ring (fundamental and HOMs of RF cavities, intermagnet vacuum ports). However the source of impedance at 400 MHz was not obvious. High amplitude of the signal suggested some significant impedance, comparable with the impedance of the 200 MHz TW RF system, also seen well in Fig. 1. Existing impedance at 200 MHz can also generate signals at higher harmonics in this type of measurements, since maximum mode amplitude is reached at the nonlinear stage of instability, when it is saturated. In Fig. 2 the results of simulation with ESME are shown for the ratio of amplitudes of the maximum signal generated at 400 MHz and 200 MHz by TW cavities impedance at 200 MHz. As one can see the ratio is ≤ 0.5 and the results of measurements can be explained only by the presence of some impedance at 400 MHz.

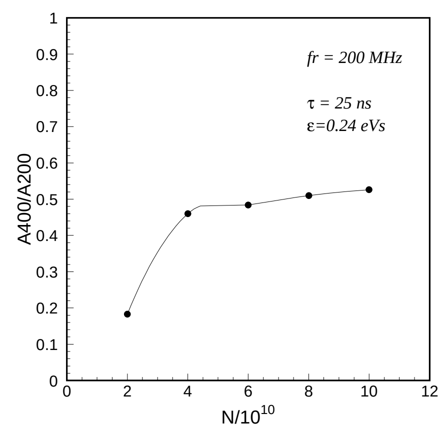

Figure 2: Relative amplitude of the second harmonic obtained in simulations for 200 MHz TW cavities impedance.

Simple estimations show that a cavity-like object with radius around 30 cm is required to have lowest resonant frequency at 400 MHz. The list of these objects found in the ring at that time [2] is presented in Table 1.

The first group in the Table contains elements which are already considered as harmless. The 400 MHz LHC prototype cavity was removed from the ring at the beginning of 1999. MSE and MST extraction septa, which were seriously suspected due to their large number, were shielded during the last, 1999/2000, shutdown. The second group collects together lepton equipment which will be removed from the ring during this, 2000/2001 shutdown. The elements under study (see below) are in the third group.

n	Element	No.
1	400SC, LHC prototype cavity	1
	MSE, extraction septum	10
	MST, extraction septum, thin	6
2	MSL, lepton injection	2
	MKLE electron extraction	1
	MKLP positron extraction	1
	MKA antiproton injection	2
3	MKE extraction	3
	MKP proton injection	3
	ZS electrostatic septum	10
4	MKDH H dump sweep	3
	MKDV V dump sweep	2
	MKQH H q measurement	1
	MKQV V q measurement	1
	TCE extraction collimator	2

Table 1: Possible 400 MHz band sources in the SPS.

3 REFERENCE MEASUREMENTS

3.1 Thresholds and growth rates

Beam measurements done in 2000 showed that in spite of the shielding of possible candidates (MSE and MST) for the impedance source at 400 MHz, the instability is still there. As was discussed above the signal at 400 MHz will be always seen due to the presence of the 200 MHz RF system and nonlinearity of the proccess. To have an idea about its amplitude relative measurements were used. The maximum amplitude of the signal at 200 MHz was used for "calibration" of the 400 MHz signal. It was also noticed earlier that the relative amplitude of these two signals is changing with intensity. Reference measurements started in 1999, before shielding the septa, are presented for comparison in Fig. 3 together with measurements from 1996 and 2000.

One can see that the bunch intensity at which the 200 and 400 MHz mode amplitudes become comparable increased in 2000. This can be interpreted as the result of shielding the septa. However more detailed studies of the dependence of mode amplitude on bunch parameters showed that the increase of the instability threshold at 400 MHz can be attributed, at least partially, to the slightly different bunch lengths used in measurements.

Measurements of e-folding time of this instability do not need any calibration, but they are difficult due to the impure exponentional character of signal growth. Growth rates of the signal at 200 MHz and 400 MHz, measured in 2000 as a function of bunch intensity assuming exponential growth, are shown in Fig. 4. Every symbol corresponds to one shot. As one can see the 400 MHz signal is much faster and the dependence on bunch intensity N is also very different. Fit to the data shows that for 200 MHz the growth rate Im$\Omega \propto N^{1.16}$ and for 400 MHz Im$\Omega \propto N^{0.67}$.

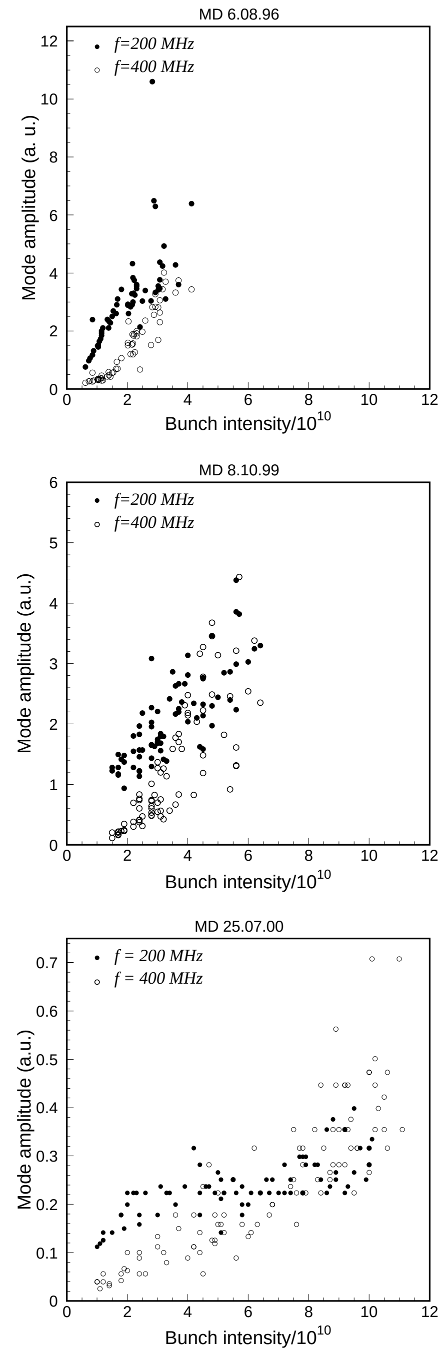

Figure 3: Mode amplitude at 200 MHz and 400 MHz as a function of bunch intensity measured at 26 GeV in 1996 ($\tau = 25$ ns, $\varepsilon = 0.25$ eVs), 1999 ($\tau = 26$ ns, $\varepsilon = 0.24$ eVs) and 2000 ($\tau = 21$ ns, $\varepsilon = 0.24$ eVs).

3.2 Dependence on bunch length

To check the sensitivity of the reference measurements to changes in bunch parameters, a series of measurements, above and below transition, as well as numerical simulations were made.

Measurements of mode amplitude at 200 MHz and 400 MHz as a function of bunch length for constant emit-

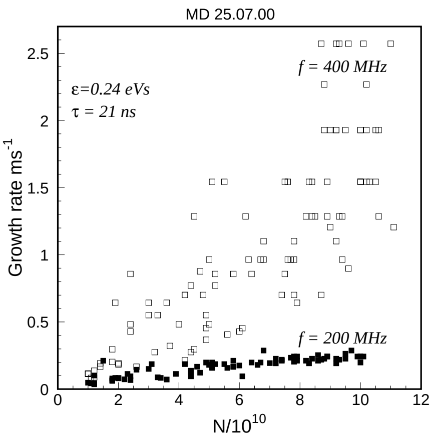

Figure 4: Growth rate at 200 MHz and 400 MHz measured at 26 GeV in 2000 as a function of bunch intensity.

tance and intensity are shown in Fig. 5. At this intensity the two amplitudes are practically equal for 25 ns bunches, but become very different for smaller bunch length. This is even more visible when the ratio of two amplitudes measured for the same bunch is plotted versus bunch intensity as shown in Fig. 5 (bottom).

Similar measurements, but with different bunch emittance, were also done below transition, at 20 GeV, see Fig. 6. In all the measurements described $\gamma_t = 23.3$.

3.3 Results of simulation

For a known impedance, simulations reproduce sufficiently well the results of measurements. As an example, the growth rate of the signal at 200 MHz obtained in simulations (ESME) with the TW cavities impedance ($R/Q =$ 26 kOhm, $Q = 134$) is shown in Fig. 7 (compare with Fig. 4).

For an unknown 400 MHz impedance, the parameters ($R/Q, Q$) which satisfy the experimental fact $A_{200} = A_{400}$ at intensity $N = 6 \times 10^{10}$, were found in simulations with ESME and are shown in Fig. 8.

The behaviour of mode amplitudes for bunch lengths around 30 ns in measurements above transition can be also reproduced in the simulations, see Fig. 9. For 400 MHz impedance we used parameters $R/Q = 20$ kOhm and $Q = 20$ from Fig. 8. Comparing also the two cases studied in simulations - with and without 400 MHz impedance, one can see that, being much faster, the growth of the signal at 400 MHz seems to be able to suppress the development of instability at 200 MHz.

4 NEW CANDIDATES FOR IMPEDANCE SOURCE

Numerical simulations suggest that a 400 MHz impedance with Q in the range (10-100) should have a minimum R/Q of the order of 15 kOhm. The impedance of shielded septa,

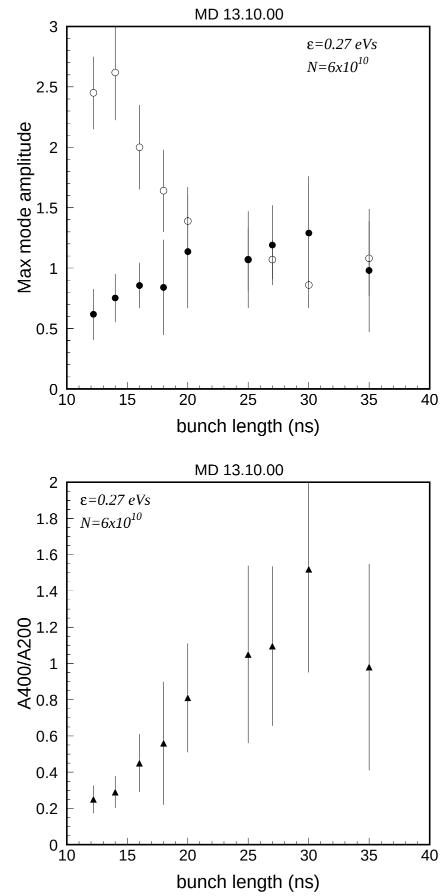

Figure 5: Mode amplitude at 200 MHz and 400 MHz (top) and their ratio (bottom) measured above transition (26 GeV) as a function of bunch length for constant emittance (0.27 eVs) and intensity (6×10^{10}).

MSE and MST, was smaller by an order of magnitude. Bench measurements of MKE tank with one module inside, [3], showed significant impedance around 400 MHz, $R_{sh} \simeq 6$ kOhm, see Fig. 10. There were 4 of these tanks in the ring during the last two years of operation giving a total MKE impedance at 400 MHz around 25 kOhm.

Bench measurements done for MKP kickers, [4], also showed resonant peaks around 400 MHz with $R_{sh} \sim$ 3 kOhm. However the operational kickers installed in the ring are different from the one used for measurement since they have 4 modules inside the tank. This makes an estimation of total contribution of MKP impedance difficult. It seems that the value of resonant impedance at 400 MHz coming from MKE and MKP kickers is still below the 15 kOhm expected from numerical simulations. The programme of shielding these elements has been launched. Their position in the ring [5] is presented in Table 2.

Another possible candidate for impedance at 400 MHz is the electrostatic septa ZS. There are 10 of them in the ring, see Table 1. First measurements in the laboratory with probes indicated a strong signal in the region of interest. However bench measurements with the wire method did

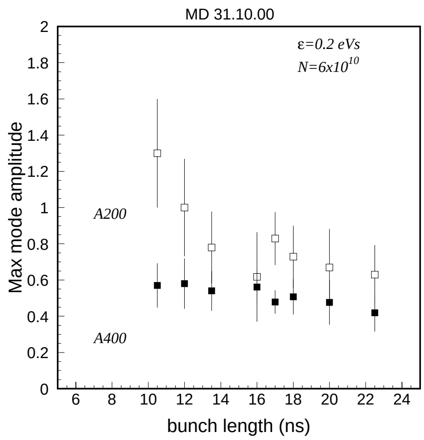

Figure 6: Mode amplitude at 200 MHz and 400 MHz measured below transition (20 GeV) as a function of bunch length for constant emittance and intensity.

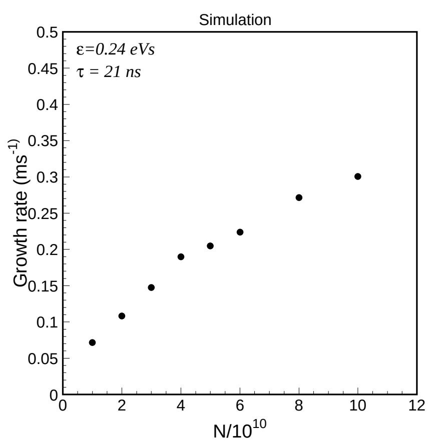

Figure 7: Growth rate of signal at 200 MHz as a function of bunch intensity. Only impedance of 200 MHz TW cavities is present. Results of numerical simulations.

not show any significant impedance around 400 MHz. The raw data obtained using the network analyzer are presented in Fig. 11.

Treatment of these raw data corrected for electrical delay (11.721ns) was done using the improved log formula by F. Caspers and A. Mostacci. Real and imaginary parts of the coupling impedance measured in the frequency range 0 - 1 GHz are shown in Fig. 12.

5 SUMMARY

The single bunch instability at 400 MHz has been observed in measurements with RF off since 1996. This instability is observed both below and above transition. There is also an indication that this impedance can be a cause of single bunch instability observed at 26 GeV with RF on, [6].

The signal at 400 MHz will always be seen in such measurements as a second harmonic due to the presence

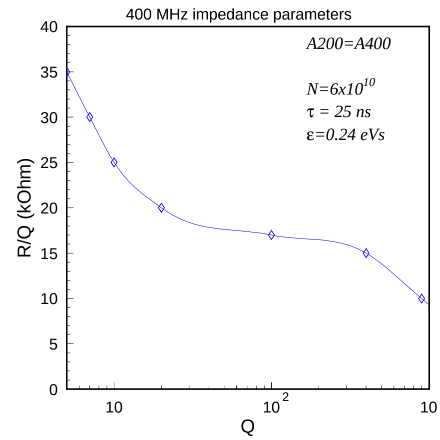

Figure 8: Impedance parameters at 400 MHz from numerical simulations.

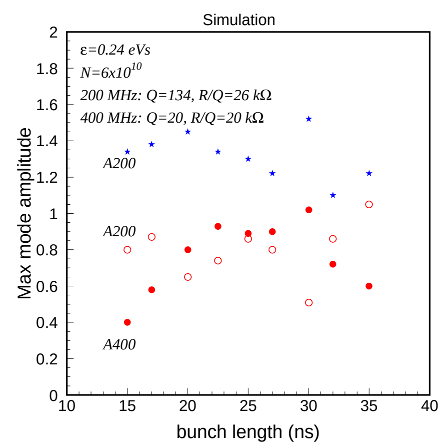

Figure 9: Mode amplitude at 200 MHz and 400 MHz as a function of bunch length for constant emittance (0.24 eVs) and intensity (6×10^{10}). Stars - only impedance of 200 MHz TW cavities is present. Circles show the results when impedance at 400 MHz with $R/Q = 20$ kOhm and $Q = 20$ is also included. Results of simulations with ESME.

of the 200 MHz TW RF system. However to explain its amplitude one needs significant impedance. Simulations give a range of parameters (R/Q, Q) for 400 MHz impedance, which satisfy experimental results, with a minimum $R/Q \sim 15$ kOhm.

Possible sources of resonant impedance at this frequency were the MSE and MST septa. They were shielded during the last shutdown 1999/2000, and the SC 400 MHz RF cavity was removed from the ring in 1998, but the instability is still there. Small increase of the threshold measured in 2000 can be due to shielding of septa, however might also be attributed to the strong dependence of mode amplitude on bunch length. Recent bench measurements of the impedance of the electrostatic septa ZS showed small impedance at 400 MHz. Similar measurements done on

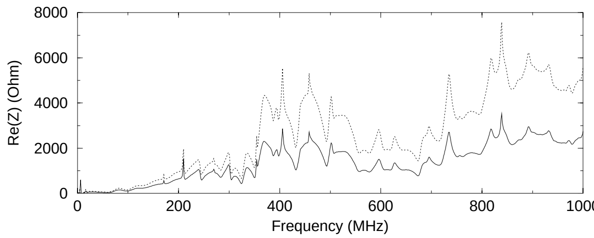

Figure 10: Real part of MKE impedance measured in the laboratory with wire method. Solid and dotted lines: standard and improved log formula, [3].

year	MKE		MKP	
	without screen	with screen	without screen	with screen
1998	3x1	0	3x4	0
1999	3x1+1x1*	0	3x4	0
2000	3x1+1x1*	0	3x4+1x2*	0
2001	1x1	0	1x4	2x5
2002	1x1	0	0	2x5+1x4
2003	0	8	0	2x5+1x4

Table 2: Number of tanks x modules in the SPS ring by years. Symbol “*” means non-operational, installed for temperature measurements.

MKE and MKP kickers suggest significant impedance, answer with beam will be known soon.

The method of beam measurements used allows us to follow up the impedance reduction programme in detail by inspecting it at certain frequencies.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

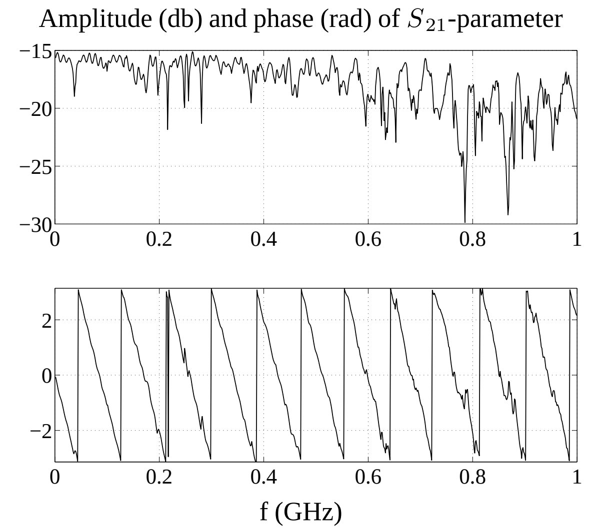

Figure 11: Raw data for amplitude (top) and phase (bottom) of S_{21} parameter from a network analyzer.

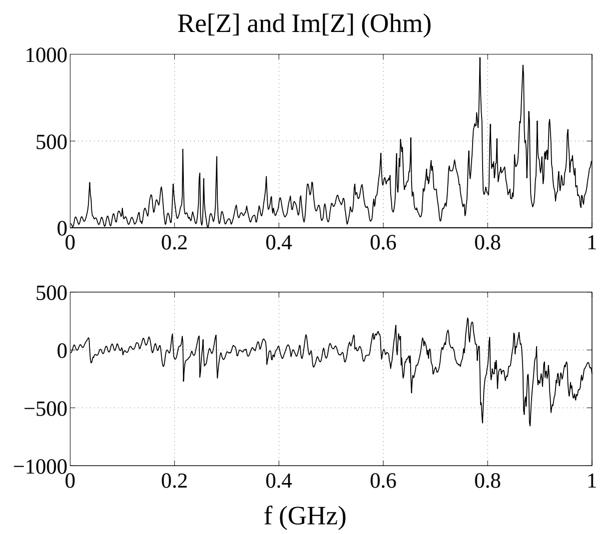

Figure 12: Real (top) and imaginary (bottom) parts of ZS impedance evaluated from the corrected values of amplitude and phase of S_{21} parameter.

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