The CESR Horizontal Separators Impedance Study *

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Abstract

The longitudinal multi-bunch beam instability significantly complicates Cornell Electron Storage Ring (CESR) operation. The observed dependence of the horizontal separator temperature on the space between two bunches circulating in the same direction suggested the presence of long lasting parasitic modes in the separators. The S-parameters measurement confirmed existence of the modes and gave their frequencies and quality factors (Qs). Program URMEL was used to calculate the modes coupling with beam, i.e. parameters R/Q. Using these characteristics the longitudinal instability growth rate and instability threshold current were computed. The calculated threshold is only 35% higher than observed. The conclusion has been made that the parasitic modes in horizontal separators are among the major factors causing longitudinal multi bunch beam instability at CESR. The multi bunch beam stability at CESR will be significantly improved if these modes are damped.

1 INTRODUCTION

The two bunches technique developed in [1] has been used at CESR to search for elements with long lasting wake fields. The technique is based on the following phenomenon. Suppose there are two following bunches circulating in the ring. If the leading bunch left long lasting wake field, the trailing bunch may gain or loose energy depending on the wake field phase at the moment of the trailing bunch arriving. The gain or loss of energy by the following bunch will cause the change in temperature in the location where wake field energy is absorbed.

Analyzing recorded data of the temperature of the CESR elements after a period of time, when two intensive bunches circulating in the same direction with various spacing were used, it was found that the temperature of one of the four of CESR horizontal separators is sensitive to the distance between these bunches [2]. This hinted on the existence of long lasting wake fields in separators and promoted a more detailed study of their impedance. Results are reported in this paper.

2 CALCULATION OF THE PARASITIC MODES CHARACTERISTICS.

Figure 1 gives the schematic view of the CESR horizontal electrostatic separator. There are four high voltage (HV) and two ground electrodes arranged into a cylindrical body as it is shown on the upper left of the picture. Two conic

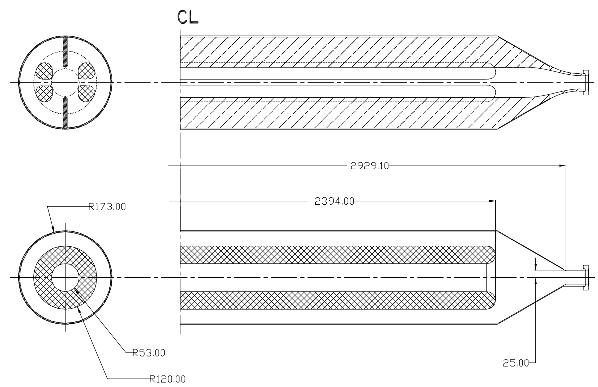

Figure 1: Schematic view of CESR electro-static horizontal separator and it's model used in calculation

tapers at the separator's ends provide smooth transition between regular beam pipe profile and separator's body. The ground electrodes take the full length of the separator and are connected to the tapers as it is shown on upper right side of figure 1. Both, ground electrodes and conic tapers are to provide smooth image current flow through the separators. A more detailed description of CESR horizontal separators can be found in reference [3].

Program URMEL, which was used for calculation of parasitic modes, requires cylindrical symmetry. Thus, the real geometry shown on the upper half of figure 1 were approximated with the cylindrical model shown on the lower part of the picture. HV electrodes were represented by a hollow cylinder with corresponding dimensions. Ground electrodes were omitted. Effects the absence of ground electrodes on result of calculation will be discussed later.

Because we discuss longitudinal beam dynamics, only TM0 type of parasitic modes has been considered. In the model, a series of modes of this type has been found. Characteristics of few of them are listed in table 1. The structure of the lowest frequency mode ($f_1 = 61.04$MHz) is depicted on figure 2.

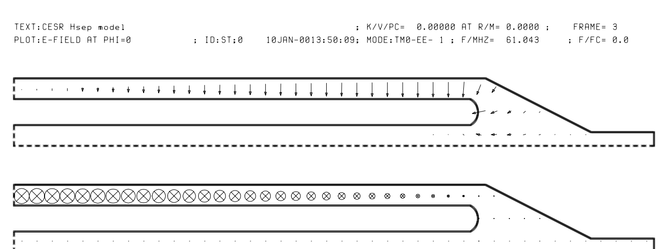

Figure 2: TM0-EE-1 mode structure

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One can see that this is a standing wave with half the wave length equal to HV electrode length. I has maximum voltage on the electrode ends and maximum current in the middle. Other modes in the series have a similar structure and approximately multiple to 61.2MHz frequencies. Interaction between the modes and passing bunches occurs at the separator's ends where the electrical field is parallel to the beam axis. The strength of the interaction is characterized by shunt impedance R/Q.

Consider the effect of the ground electrodes on the mode characteristics. The mode frequencies are defined by the length of the HV electrodes and can not be affected by the ground electrodes. Their main effect is the reduction of R/Q parameters.

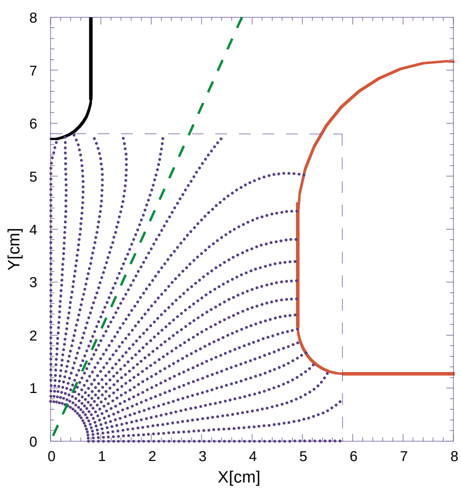

Figure 3: Transfer structure of electrical field generated by moving bunch in the middle of separator. Because of symmetry only one quarter of the cross section is shown. Calculation is made with program POISSON in region 5.8cm x 5.8 cm. Ground and HV electrodes are on the left upper and on the right side of picture, respectively. Electrical field lines which start from the beam on the left side from dashed straight line end on the ground electrod. Those on the right side end on HV electrod.

Figure 3 shows a picture of transverse electrical field, generated by the relativistic bunch moving along the beam axis in the middle of the separator. 28% of the electrical field lines started from the beam end on the ground electrode, which has smooth transition from one separator's end to another. The rest 72% of the lines end on HV electrodes. One can suggest that coupling between modes and beam calculated in the cylindrical symmetry model should be reduced by 28%. The shunt impedances given table 1 are parameters R/Q calculated for cylindical model and reduced by this factor.

	Calculated		Measured	
Mode	$F[MHz]$	$R/Q\,[\Omega]$	$F[MHz]$	Q
EE-6	657.22	0.353	613.2	1576
ME-6	713.3	0.815	671.9	937
EE-7	767.15	1.894	724.5	840
ME-7	819.88	3.458	795	163
EE-8	870.52	5.340	851.2	459
ME-8	921.1	6.090	903	790
EE-9	971.24	5.582	965.6	1263
ME-9	1022.8	4.149	1022.2	870
EE-10	1074.5	2.876	1069.2	1570
ME-10	1127.1	1.958	1115.7	1459
EE-11	1178.6	1.570	1164.1	1248
ME-11	1229.4	.601	1215.4	665
EE-12	1277.7	2.294	1266.9	470
ME-12	1324.8	3.526	1316.9	1550

Table 1: Calculated and measured characteristics of few parasitic modes

3 MEASUREMENT OF THE PARASITIC MODES CHARACTERISTICS.

Effect of parasitic modes on beam stability depends on its frequencies and quality factors. Because of a variety of uncertain factors, usually these parameters is difficult to calculated. For estimation below we used the measured parasitic mode frequencies and Qs.

The measurement has been made on a spare separator identical to the operating units. Two short antennas, electrically coupled to the studied modes, were implemented on the beam axis on both ends of the separator, and transient function $|S21|$ has been measured with the network analyzer *HP 85047A*. There was seen the series of approximately equidistant peaks. The frequency spacing between the peaks was approximately 61 MHz. This indicates that the peaks were caused by the modes found in model calculation in the previous section.

The measured frequencies and Q parameters of the modes are listed in table 1. One can see that some of the modes have Q as high as 1500, see for example modes TM0-EE-10 and TM0-ME-12. Their lasting time estimated as $\tau = 2Q/(2\pi f_m)$ should be $465\,nsec$ and $376\,nsec$, respectively. Comparing this with the time between bunche trains at CESR, which is approximately $280\,nsec$, one can conclude that these modes can easily couple longitudinal motion of bunches from different trains creating condition for multi bunch beam instability.

4 CALCULATION OF LONGITUDINAL INSTABILITY GROWTH RATE AND THRESHOLD BEAM CURRENT.

The longitudinal instability growth rate (R) has been calculated with program MBI [4]. As input were used the measured Qs and mode frequencies and calculated shunt

Beam conf. t x b x s	Model conf.	R_{inst} $s^{-1}mA^{-1}$	I_{thr} mA
9 x 5 x 14ns	$\delta f_{1,2,3,4} = 0$	0.582	313
9 x 5 x 14ns	$\delta f_{1,2} = 0$ $\delta f_{3,4} = 2 \times 10^{-4} f_m$	0.598	304
9 x 5 x 14ns	$\delta f_{1,2} = 0$ $\delta f_{3,4} = \pm 2 \cdot 10^{-4} f_m$	0.560	325
9 x 4 x 14ns	$\delta f_{1,2,3,4} = 0$	0.606	300
9 x 3 x 14ns	$\delta f_{1,2,3,4} = 0$	0.581	313
9 x 3 x 28ns	$\delta f_{1,2,3,4} = 0$	0.578	315

Table 2: Calculated longitudinal instability growth rate (R_{inst}) and instability threshold beam current (I_{thr}).

impedances R/Q of 18 parasitic modes.

The calculated instability growth rate and the threshold beam current for different beam and model configurations are given in table 2. For beam configuration indexes "t", "b" and "s" mean the number of trains circulating in the ring, the number of bunches per train, and space between the bunches. To simulate the effect of the difference between mode frequencies among separators we used different model configuration. The estimated possible variation $\delta l = \pm 0.5$mm in length of the separators' high voltage electrodes, $l = 2.5$m, leads to a $\delta fm/fm = \mp 2 \times 10^{-4}$ variation in the frequencies. In the first case, $\delta fm_{1,2,3,4} = 0$, all four separators had identical parasitic mode frequencies (indexes $_{1,2,3,4}$ refer to the four CESR horizontal separators). Second case represented configuration when separators 1 and 2 had identical mode frequencies, and separators 3 and 4 had frequencies 2×10^{-4} times higher. The calculated instability growth rate (R_{inst}) and the threshold beam current I_{thr} are given in two last columns. I_{thr} was calculated assuming that the instability occurs when the growth rate exceeds the damping rate. For the longitudinal damping rate we used $182 sec^{-1}$ measured by M.Billing and by the author and reported in [5].

Let's analyze the results shown in table 2. First, there is no significant difference in the instability growth rates and subsequently in instability threshold currents for various models. The explanation suggested by S. Belomestnykh [6] is that the instability occurs due to interaction between the beam and many parasitic modes. For any given beam configuration the frequency shift of some modes will increase the instability growth rate, while the shift of others will decrease it. In result, the net effect is small. Taking into account the fact that the model configuration practically does not effect on the instability growth rate, in the next calculation we assumed that all four separators have identical spectrum of parasitic modes. Calculation for the different beam configurations gives $0.588 sec^{-1} mA^{-1}$ of instability growth rate with small, $\pm 2\%$, variation over different configurations. The weak dependence of the instability growth rate on beam configuration is not surprising because the instability is caused by many wide enough parasitic modes with frequencies not correlated with multi-bunch beam spectrum.

An important conclusion may be derived from the comparison between calculated and measured longitudinal instability thresholds. The recent measurement reported in [7], shows the beam current threshold at 205mA and at 195mA for beam configurations "9 x 4 x 14ns" and "9 x 5 x 14ns' respectively. Assuming that the damping rate at the moment of the measurement was $182 sec^{-1}$, the same as it was reported in [5], the estimated instability growth rate will be $0.89 sec^{-1} mA^{-1}$ and $0.93 sec^{-1} mA^{-1}$. For these beam configurations the calculated contribution of parasitic modes in horizontal separators is $0.61 sec^{-1} mA^{-1}$ and $0.58 sec^{-1} mA^{-1}$. It is more than 60% in both cases. Thus one can conclud that the parasitic modes in horizontal separators are among major factors causing the observed longitudinal multi bunch instability at CESR.

5 CONCLUSION

Following the observation of the horizontal separator's temperature dependence on the space between two circulation bunches, there were found parasitic modes excited by the beam. The calculated beam instability threshold due to these parasitic modes appeared to be only 35% higher than observed. It suggests that the parasitic modes in horizontal separators are among the major factors causing longitudinal multi bunch instability at CESR. Their damping will lead to significant improvement of multi bunch beam stability.

6 ACKNOWLEDGEMENTS

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