Synchro-Betatron Resonances in LEP

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Abstract

During LEP operation in 1995 studies have continued on the subject of synchro-betatron resonances; their strength and their effect on the beam in terms of emittance blow-up. Specifically data is presented on the effect of beam energy on the strength of such resonances.

1 MOTIVATION

The single bunch intensity in LEP is limited by the Transverse Mode Coupling Instability (TMCI) [1]. In order to achieve highest possible bunch currents a high synchrotron tune q_s is needed. At one moment during the energy ramp the high synchrotron tune has to be lowered and hence the beams will cross amongst others the synchro-betatron resonance $2q_s = q_v$. At 20 GeV beam energy this resonance has found to be very strong resulting in beam blowup and intensity losses. As a result many ramping schemes have been proposed and discussed. During 1995 an experimental program was carried out in order to find at which beam energy this resonance can safely been crossed.

2 ENERGY DEPENDENCE

2.1 Measurement Procedure

In order to measure the strength of a synchro-betatron resonance the beamsizes and the beam lifetimes have to be recordered as a function of the betatron tunes. This is one application of a measurement procedure in LEP called ”tune scans”. During a tune scan the betatron tunes of LEP are changed by acting on the main quadrupole strings via a measurement sequencer [2]. The available trim range is $\Delta q_h = \Delta q_v = \pm 0.15$ with a resolution of 0.001. The maximum number of trim steps is 400 and the time interval between tune changes is 2 seconds, hence a complete scan takes about 12 minutes measurement time. Synchronous to the tune variations several beam parameters are recorded. The tunes themselves are tracked by the LEP q-meter in PLL mode [3]. The transverse beam dimensions are recorded from the UV-monitors and beam lifetimes from the bunch current transformers.

Fig. 1 shows as example the data obtained at 45.6 GeV beam energy.

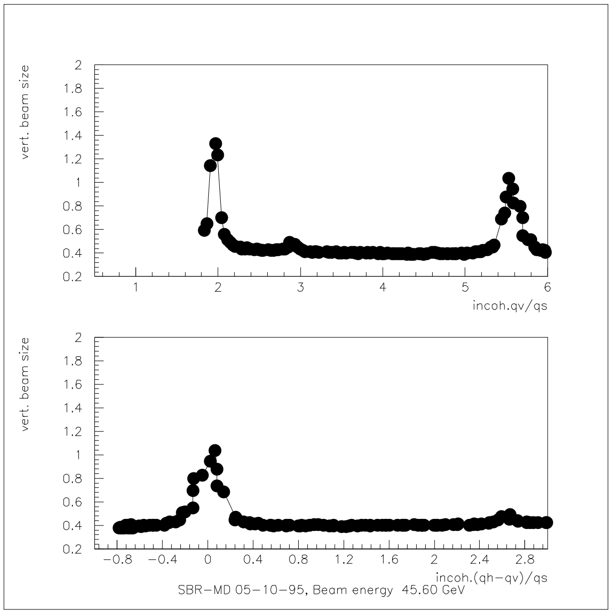

Figure 1: Measurement example of a tune scan. The vertical beam size is measured as a function of the vertical tune. In the top diagram the data is presented as a function of the vertical tune divided by the synchrotron tune. Vertical SBRs show up at integer values in x. In the bottom trace the same data is displayed as a function of the difference between the horizontal and vertical tune normalized to the synchrotron tune. In this form the coupling resonance and its synchrotron side bands show up at integer x-values.

2.2 Previous Experimental Results

During machine studies in 1993 and 1994 we have studied the dependence of the vertical synchro-betatron resonances on the following machine parameters:

- mean residual vertical dispersion $< D_y >$
- offsets in the Rf-cavities
- chromaticity
- bunch intensity

Two measurement result, which have already been published in [4] are recalled, because they are relevant for the discussion of the energy dependence in the next chapter.

Figure 2 shows the strength of the vertical synchro-betatron resonances for different values of the average vertical dispersion $< D_y >$ and figure 3 for two bump amplitude in the region of the Rf-cavities (sundelin bumps).

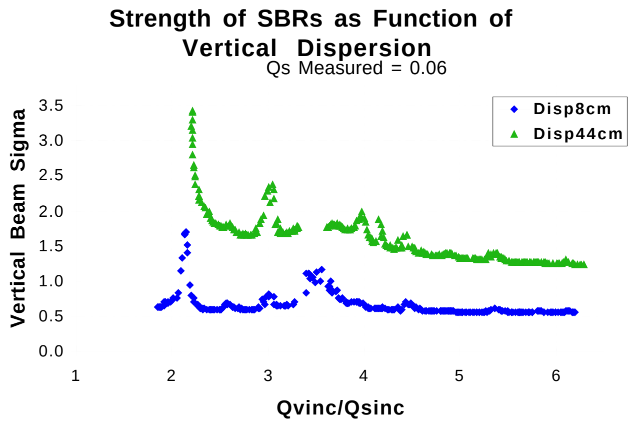

Figure 2: Tunescans across vertical synchro-betatron resonances for 2 different values of the average vertical dispersion $< D_y >$. The base line of the second curve has been shifted upwards in order to make a better distinction of the curves.

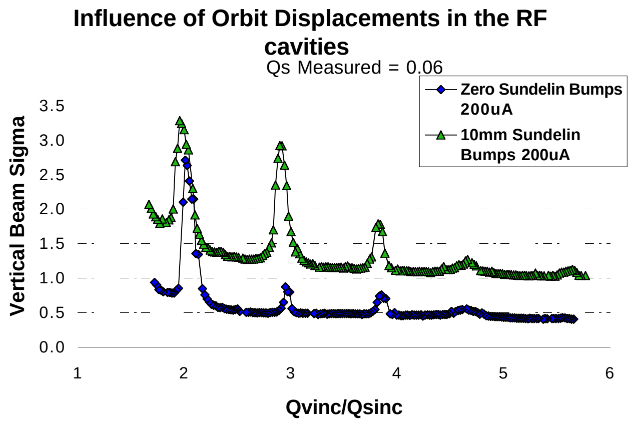

Figure 3: Tunescans across vertical synchro-betatron resonances for 2 different orbit bumps (called sundelin bumps) in the region of the LEP Rf-cavities. The base line of the second curve has been shifted upwards in order to make a better distinction of the curves.

2.3 *Driving Mechanisms*

The driving mechanism for the excitation of synchro-betatron resonances are discussed for example in [5]. From [5] we recall the formulae describing the growth rate of the resonance for the following two driving mechanisms:

1. For the case of dispersion (D_y) at the accelerating cavities one can write:

$$< \frac{d\epsilon}{dt} > = \frac{\pi q_s f_{rev} D_y \hat{y} \frac{\Delta \hat{E}}{E}}{\beta} \qquad (1)$$

   as $\frac{\Delta \hat{E}}{E}$ increases with beam energy one would expect the strength of the synchro-betatron resonances to increase with energy

2. For the case of transverse deflecting fields which vary with longitudinal position, such as misaligned Rf-cavities or orbit offsets in the Rf-cavities one can write:

$$< \frac{d\epsilon}{dt} > = \frac{\beta e c^2}{2\pi E \gamma_t^2 Q_s} \cdot \int \frac{\delta E_y}{\delta s} dt \hat{y'} \frac{\Delta \hat{E}}{E} \qquad (2)$$

   In this case the strength of the resonance will decrease with beam energy due to the term EQ_s in the denominator.

The question which are the relevant driving mechanism for LEP is answered by the measurements described in the next chapter.

2.4 *Measurements on the $q_v = 2 \cdot q_s$ satelite*

In order to measure the energy dependence of a synchro-betatron resonance each other parameter affecting their strength (see above) had to be kept constant while the energy of the beams was variied.

The following experiment was carried out: 200 μA bunch current was accumulated into a single positron bunch. By means of closed orbit corrections $< D_y >$ was adjusted to about 10 cm and the horizontal and vertical chromaticties were set to +2 units.

In all cases the strength of the vertical SBR $q_v = 2 \cdot q_s$ was measured by tune scans.

The 200 μA bunch was ramped from 20 GeV to the following beam energies: 28.5 GeV, 37.1 GeV and 45.6 GeV. At each energy the orbit was corrected towards the reference orbit establised at 20 GeV. This way the residual vertical dispersion $< D_y >$ was controlled and reproduced within values of 7 to 11 cm. The chromaticities were adjusted in each case to +2 units. The data points just arround the vertical SBR $2q_s = q_v$ were extracted and a resonance curve was fitted to the data.

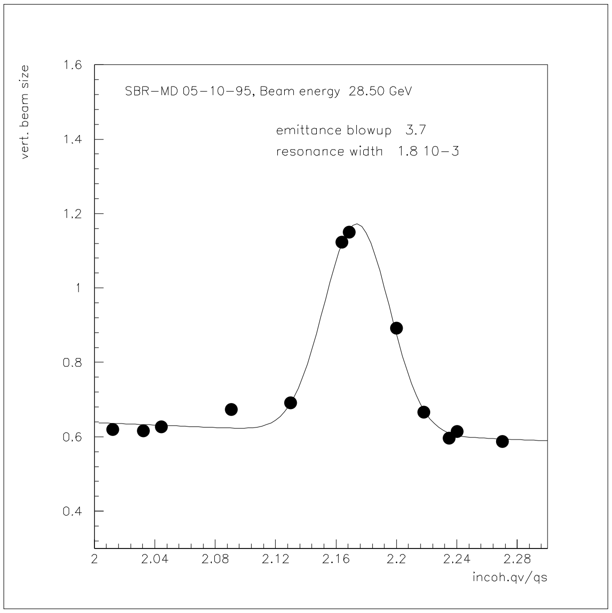

Figure 4: Beam blow up as measured on the vertical SBR $q_v = 2 \cdot q_s$ at 28.5 GeV beam energy. The solid curve is a resonance curve fit to the data.

Fig. 4 shows the result at 28.5 GeV beam energy. The data obtained at the four beam energies is summarized in fig. 5. The top graph shows the measured emittance blowup calculated as the square of the measured blowup in beam size and the bottom graph shows the width of the resonance (in units of tune). The data indicates clearly that the strength of the satelite $q_v = 2 \cdot q_s$ grows with energy.

3 CONCLUSION

The measurements have shown that the strength of the synchro-betatron resonances in LEP increases with beam energy, in terms of emittance blowup as well as in resonance width. From this we have to conclude that residual dispersion at the Rf-cavities is the dominant driving term at LEP.

For running LEP at beam energies around 90 GeV this leaves less space for the working point of the machine as not to affect the small vertical emittance due to the increased width of the synchro-betatron resonances.

If the observed beam blowup was strictly linked to intensity losses the consequence for the acceleration scheme of LEP would be to cross synchro-betatron resonances at energies as low as possible. But the effect of lifetime reduction could not been included in the above tune scan measurements and has been treated in different measurements [6]. Here the result was that at 20 GeV beam energy the resonance $q_v = 2 \cdot q_s$ causes significant intensity losses, but above 35 GeV beam energy the resonance could be crossed safely with 500 μA bunch currents.

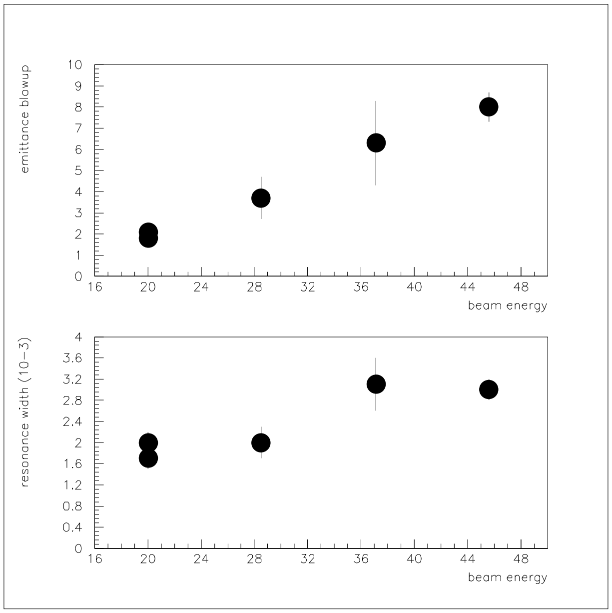

Figure 5: Emittance blowup at the vertical SBR $2q_s = q_v$ as a function of beam energy (top diagram) and width of this resonance (bottom diagram)

4 REFERENCES

[1] K. Cornelis, **How can we get 1 mA per Bunch at 20 GeV** Proceedings of the 5th Chamonix Workshop on LEP Performance, Jan. 13-18, 1995, p 71.

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[6] H. Schmickler, **Can we finally stop talking about crossing Synchro-Betatron resonances during the Ramp?** Proceedings of the 6th Chamonix Workshop on LEP Performance, Jan. 15-19, 1996, p 58.