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Summary Report of Session II: Dual Harmonics, Blow-up and Instabilities

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Summary Report of Session II: Dual Harmonics, Blow-up and Instabilities

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1 Introduction

There are 6 presentations in this session:

1. F. Pedersen, Dual harmonic rf operation in the CERN PSB.
2. E. Shaposhnikova, Using multi-harmonic rf system in the SPS.
3. F. Blas, Blow-up methods tested in the CPS.
4. A. Burov, Broad-band impedance for long bunches.
5. T. Bohl, Single-bunch instability below transition energy.
6. P. Baudrenghien, Reducing the impedance of the 200 MHz travelling wave cavities.

They can be found on the web (*http://nicewww.cern.ch/PSdata/www/icfa9/Program.html*). We will select several topics to summarize the work reported in these talks.

2 Dual harmonic rf and longitudinal emittance blow-up

2.1 Mike's question

Mike Brennan (BNL) posed an interesting question for discussion: If there is a cavity available, which can be used either for dual harmonic or for blow-up, what would be the choice? The following table summarizes the benefits and concerns of either choice:

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                   Dual Harmonic                    Blow-up
                   =============                    =======

Benefits  * Reducing space charge tune      * Increasing instability
--------    shift in transverse plane         threshold in both longitudinal
            (e.g., PSB, n=2, in bunch         and transverse planes (due to
            lengthening mode).                larger dp/p).

          * Improving rf capture efficiency * Reducing intrabeam scattering.
            during injection from the linac.

          * Landau cavity (e.g., SPS, n=4).
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Concerns  * Loss of Landau damping when      * Need enough momentum acceptance
--------    bunch length exceeds certain       in the machine.
            critical length due to zero
            synchrotron tune spread.         * Not allowed in machines requiring
                                               high longitudinal brightness
          * Mismatch problem during beam       beam (e.g., the proton driver).
            transfer from one ring to another.
            (What is the matching condition?)
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2.2 How to blow-up?

Three methods for longitudinal emittance blow-up were discussed:

1. Phase modulation of a high harmonic rf;
2. Frequency offset of a high harmonic rf;
3. Two-step method:
   (a) phase modulation of the fundamental rf;
   (b) frequency offset of a high harmonic rf.

The following table summarizes the test results of these methods at three CERN machines: (Yes: working well, No: not working or working but having problems, –: not tried.)

	CPS	PSB	SPS
Method 1	Yes	Yes	Yes
Method 2	No	Yes	-
Method 3	Yes	No	-

3 Instability and impedance

3.1 Instability

There are two outstanding instability questions in proton synchrotron design, namely:

1. Is there any microwave instability below transition?
2. Is there any transverse mode coupling instability (TMCI) in a proton machine?

Both questions are closely related to the space charge effects:

1. When $\gamma > \gamma_t$, the space charge would cause negative mass instability, which has been observed in many proton machines. When $\gamma < \gamma_t$, however, the capacitive space charge impedance would stabilize the beam.

2. The TMCI observed in electron machines is in most cases caused by the coupling between $m = 0$ and $m = -1$ modes. In a low or medium energy proton machine, the transverse space charge impedance would shift the $m = -1$ mode downward, which makes the mode coupling between $m = 0$ and $m = -1$ difficult.

Despite these arguments, however, it was reported at this workshop that the answer to both questions 1 and 2 is: YES.

- SPS microwave instability experiment:
  The experimental conditions were as follows: single bunch, length = 25 ns, emittance = 0.25 eV-s, intensity = 1 - 6 $\times 10^{10}$, $\gamma_t = 23.2$. The experiment was carried out for both above ($\gamma = 27.7$) and below ($\gamma = 21.3$) transition. In both cases, when the rf was turned off and the beam began to debunch, it was seen that:

  - bunch was lengthened;
  - momentum spread was increased by a factor of 3;
  - microstructure in the beam appeared;
  - beam signal covered a wide range up to 4 GHz.

  These indicated that the microwave instability occurred in both cases. However, several issues remain to be studied:

  - This experiment demonstrated that, below transition, microwave instability can occur in a coasting beam. But how about a bunched beam? If one keeps rf on while lowering the rf voltage (so that dp/p would become smaller), would the instability still occur? (During the discussion, SPS people said this would be hard to do because the rf bucket will be too short to contain the debunching beam.)
  - In this experiment, space charge impedance is negligible. How about if space charge impedance is significant? This would be the case for a number of high intensity proton machines (*e.g.*, the SNS, ESS, JHF, proton driver, *etc.*), in which the injection energy will be about 1 GeV or below.
  - The SPS has an impedance model. Can this model explain the microwave instability as observed (*e.g.*, the threshold and growth rate)?

- CERN Antiproton Decelerator (AD) observation of TMCI:
  It was reported that TMCI was seen at the AD when too much electron cooling was applied. The reason is that this machine has large transverse impedance. But no data was presented at this workshop.

3.2 Impedance

3.2.1 Tevatron measurement

At the Fermilab Tevatron, the transverse impedance was obtained by measuring the betatron tune spread ΔQ_β in the beam signal spectrum. The measured spread is indeed the summation of $\Delta Q_\beta + \Delta Q_s$. But the synchrotron tune spread ΔQ_s is negligible. From the measured value of $\Delta Q_\beta = 4 \times 10^{-5}$, one calculated the transverse impedance $Z_\perp/Q = 1$ MΩ/m, which is in agreement with a previous theoretical estimate.

3.2.2 SPS 200 MHz cavity impedance reduction

Two systems were built and tested for reducing the 200 MHz cavity impedance. One is feed-forward, another 1-turn feedback. When the two systems were combined, it gave an impedance reduction of about 30 dB within $\pm$ 1 MHz range.

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