SUMMARY OF WORKING GROUP A ON "BEAM DYNAMICS IN HIGH-INTENSITY CIRCULAR MACHINES"

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Abstract

In this proceeding we summarize the presentations of the HB2010 Workshop session on "Beam Dynamics in High-Intensity Circular Machines" as well as the outcome of the discussion session.

INTRODUCTION

This working group hosted 23 presentations in total, with 22 excellent talks [1-19;21-23] and a beautiful (revolutionary?) one [20]. Eleven speakers were coming from Europe (5 CERN&EPFL, 4 GSI, 1 FZJ, 1 RAL), eight from USA (1 BNL, 5 FNAL, 1 ORNL, 1 UMD) and four from Asia (1 IHEP Beijing, 1 J-PARC, 2 KEK). We summarize below the session and the discussion.

SUMMARY OF THE WORKING GROUP ACTIVITY

Yoshihiro Shobuda [1]

A 3D (i.e. with finite longitudinal length) theory of a "short" (with respect to the beam pipe radius) resistive insert, sandwiched by perfectly conducting chambers, was presented. It has been benchmarked against ABCI, which was upgraded to handle a resistive material inside a cavity. Nature tries to minimize the beam energy loss: the entire image current runs on the thin insert (i.e. still perfect shielding) except when the skin depth is more than several orders of magnitude larger than the beam pipe thickness. If the insert length is greater than the beam pipe radius, the 2D theory (e.g. Zotter 2005, Burov-Lebedev 2002) can be used. This new theory could be applied for instance in the CERN SPS where all (~ 200) BPMs are electrically isolated by enamel flanges (one in each side). Note that another 3D study was performed by Gluckstern-Zotter 2008 (AB-Note-2008-045).

Nicolas Mounet [2]

A 2D (i.e. with infinite longitudinal length) theory for both cylindrical and flat multi-layer chambers, for both longitudinal and transverse impedances was presented, extending Zotter 2005's formalism under the assumptions of linearity, isotropy and homogeneity, and neglecting both the anomalous skin effect and the magneto-resistance. Matrix formalism was used (already introduced by Ivanyan 2008 and Hahn 2010) where one only needs to multiply N-1 (relatively) simple 4x4 matrices and invert the final result, to get the constants. The number of layers is no longer an issue. A comparison with other formalisms is ongoing, and the codes are available, only the circular case at the moment, but the flat one should come soon. The main results for the cylindrical case are: the use of wall impedance instead of resistive-wall impedance, and the introduction of a new quadrupolar term usually considered only for asymmetric chambers. For the flat case: the transverse quadrupolar terms are in general not opposite in sign and generalized Yokoya factors were obtained, which are material and frequency-dependent.

Alexey Burov [3]

In 1955, N.G. Van Kampen found the eigen-system of Jeans-Vlasov equation for infinite plasma. The Van Kampen modes are the numerical solutions and the spectrum consists of two parts: a continuous and a discrete one (which may not exist). A.N. Lebedev first considered eigen-modes of Jeans-Vlasov equation for bunch longitudinal motion in 1968. This method can be applied for an arbitrary impedance, RF shape, and beam distribution function. It was applied here for the case of the resistive-wall impedance, considering only the dipole azimuthal mode m = 1. Stability areas (intensity - emittance) were found for 3 RF modes (single RF system, BS and BL modes). Two possibilities arise for the loss of Landau damping as results of phase mixing of Van Kampen modes of the continuous spectrum: (1) the discrete mode is inside the bucket and in this case some tails can help; (2) the discrete mode is outside the bucket and there is a radical loss of Landau damping.

Elena Shaposhnikova [4]

The "peak detected Schottky" is a diagnostics tool developed by D. Boussard and T. Linnecar, which is used in the SPS since the late 1970s. The quadrupole line was always believed to represent well the particle distribution in synchrotron frequencies. A detailed analysis revealed that ideally, for the detection of the bunch peak amplitude, it would be very close to the particle distribution in synchrotron frequencies. The spectrum is similar, in revolution frequencies, to that obtained for an un-bunched beam and much closer than that given by the traditional longitudinal bunched-beam Schottky spectrum. In reality, the measured peak detected signal is proportional to an average over the bunch current around its peak value. The difference mainly depends on the phases over which the bunch current averaging is performed.

Stefan Paret [5]

Deformations of the Schottky spectra and of the BTFs were measured in SIS18 vs. intensity. An analytic model with linear space charge for a KV distribution, i.e. a homogeneous beam profile was employed to describe the deformed signals: it was pointed out that linear space charge is different from impedance. The comparison gave very good agreement with Schottky data. A very good agreement with BTF data at low intensity was also reached. However, at high intensity deviations from the model were observed. The stability diagrams obtained from the BTFs are shifted and shaped by space charge as expected (with some noise at high intensity). The small differences observed between measurements and theory does not come from the linear space charge model as PIC simulations confirmed it. This analysis could be done with bunched beams but there is no solid theory at the moment.

Slava Danilov [6]

The recipe for e-p instability mitigation: (1) electron collection near stripper foil; (2) coating of all pieces of VC with TiN; (3) use solenoids near the regions with high loss; (4) clearing electrode near the stripper foil; (5) use of electron detectors for electron accumulation study. The 1st observation of instability was done with ~ 1E14 p few years ago and it was found that it was dominated by the e-p instability. A strong dependence on the RF configuration was revealed. A possible explanation is that the e-accumulation depends on the longitudinal distribution of the p bunch. Two new parameters were introduced to study better the mechanism: (1) trailing edge steepness, and (2) integrated SEY as a function of the trailing edge duration. The most promising case for e-p mitigation is the sharp edge, created by the high-voltage barrier cavity. In this case, the e- accelerated by the protons have a much higher energy (few keV) where the SEY is smaller than 1.

Valeri Balbekov [7]

The effect of space charge on transverse instabilities was studied under the assumptions of space charge dominated regime (vs. the impedance of the machine) and below mode coupling. The cases of a boxcar (Sacherer 1972, i.e. a bunch with constant linear density), parabolic and Gaussian distributions were discussed. Space charge almost completely controls the intra-bunch oscillations (head-tail modes): frequency, shape, and threshold of the possible instability, but it cannot cause the beam instability itself. The wake field is directly responsible for this and even if it is relatively small, it controls the beam collective modes including the instability growth rate. There is a rigid mode, which is not sensitive to space charge and synchrotron oscillations for any distribution: therefore no Landau damping takes place and it should be avoided by chromaticity control. Landau damping suppresses almost all intra-bunch modes if the space charge tune shift is smaller than about the synchrotron tune.

Vladimir Kornilov [8]

The head-tail bunch dynamics under space charge was studied for a single-bunch, below mode coupling, in the case of SIS100 on the injection plateau with a space charge tune shift of ~ -0.25. The non-realistic "airbag" bunch of Blaskiewicz 1998 is a very useful model, as a very good agreement with PIC codes (PATRIC and HEADTAIL) was found using a Gaussian bunch. The bunch form is therefore not so important, as it was also the case without space charge (e.g. Laclare 1987). The predictions of Landau damping by pure space charge (Burov 2009, Balbekov 2009) are confirmed by simulations. The Eigen-functions from simulations and theories with Gaussian or water-bag bunches are very similar. It seems to be the same as without space charge (Sacherer). Above a certain space charge, the instability growth rate saturates to a value close to the case without space charge. This could perhaps explain why the mode $|m| = 6$ was observed in the past at the CERN PS with a very large space charge (~ -0.25). It is also seen from simulations that increasing the intensity (i.e. space charge), a head-tail instability can change its mode.

Sheng Wang [9]

The characteristics of RCS/CSNS are reminded: 228 m circumference, 4 super-periods and a maximum space charge tune shift of ~ -0.28. The injection is performed within a long drift space and anti-correlated painting was adopted. It was mentioned that a correlated painting is sometimes better for high intensity to produce a beam with constant density (as a significant beam halo could be produced). Design benefits from the commissioning of existing spallation neutron sources: trim Q design, chromaticity correction, transverse collimation, momentum collimation, etc. Several space charge effects were studied (including the Montague resonance) with ORBIT and SIMPSONS. In the discussion it was warned on the artifacts introduced by the use of KV distributions. The combined effects of space charge and sextupoles were in particular studied, as the conclusion is important for the chromaticity correction design.

Kazuhito Ohmi [10]

The target for J-PARC is 1 MW in the RCS and 750 kW in the MR. A new code (SCTR) was developed to perform long-term simulations: 20 ms for the RCS and 1 s for the MR. The main results for the RCS are: the KV distribution is broken at an early stage of the simulation; the realistic painting process will be done in the simulation. For the MR: 750 kW is very hard already with the ideal lattice. There is a higher probability for 0.75Hz (instead of 0.45 Hz) repetition rate.

Alexander Molodozhentsev [11]

Resonance-induced beam losses for the Main Ring were studied (maximum power lost 450 W). The computational model was made as realistic as possible: all magnet nonlinear components and field leakage from injection septum were included. The initial beam distribution is fully 6D. Two studies were performed for the MR at low and moderate power. At low power single particle issues are explored: experimental and numerical tune scans were made to indentify the main resonances. The most critical was the sum resonance $Q_x + Q_y = 43$.

The driving term of this resonance is from the feed-down on sextupoles by deformed orbit. As an exercise, some linear coupling was introduced by a controlled deformation of the closed orbit in sextupoles to compensate the machine linear coupling. At moderate power, it was tried to find the best working point and a good agreement between simulations and measurements was reached.

Giuliano Franchetti [12]

Detailed simulations of emittance evolution and beam survival of several beam conditions present a reasonable agreement with the correspondent measurement in SIS18. The results from these measurements are consistent with previous findings in the CERN PS (2002-2003). It is worth mentioning that in the CERN PS the beam dynamics under the effect of the 4th order resonance was studied while in SIS18 the 3rd order resonance was used for studying the periodic resonance crossing. Numerical analyses of the resonance-crossing regime suggest that a scattering is most likely the process-taking place, which is consistent with the experimental data, although the latter do not give direct evidence of the mechanism, but only on global observables. Could such mechanisms play an important role in beam-beam?

Christopher Warsop [13]

Measurements and experiments on the ISIS ring were performed in view of an ISIS injector upgrade. Concerning the transverse dynamics, the working point was studied and the space charge limit was simulated. Studies of the half integer resonance in vertical plane were made. Also the 3rd order structure resonance, maybe due to the image charge was investigated. As concerns the longitudinal dynamics, the evolution of the Hofmann-Pedersen distribution was simulated. Instability measurements in ISIS revealed that the lifetime decreases with intensity. Storage ring mode experiments: half integer studies. For a fixed tune the intensity was increased and beam loss have been measured.

Tobias Baer [14]

On June 27th, 2008, a hole was made in the SPS after the impact of a high-intensity beam (~ 3E13 p @ 400 GeV/c, corresponding to ~ 2 MJ). Tune-resonance dependence was then studied in detail. By a linear decrease of the transverse tune, a complete beam loss can be achieved in 3 turns (i.e. ~ 70 micros), due to a diverging closed orbit. Note that the intensity is measured with BPMs, as the BCT is too slow. Going faster it is possible to cross Q = 26 with almost no loss, but with huge oscillations. With the fastest speed it was in fact possible to reach the super-periodic resonance Q = 24, which is much larger than the others. For the machine protection, a new fast position interlock is in commissioning using 6 BPMs with new HW using logarithmic amplifiers (large dynamic range) and turn-by-turn interlock processing via FPGA.

Brian Beaudoin [15]

The presentation reported on the status of the UMER electron ring. The control of the ring allowed an increase of the beam lifetime from ~ 100 turns (HB2008) to ~ 1000 turns at the time of HB2010. An experimental study of the systematic transverse resonances and beam survival was done. Longitudinal dynamics studies revealed the need for confinement (otherwise the beam structure disappears after ~ 100 turns). The next steps will consist in optimizing the longitudinal confinement to continue other studies, such as improvement of the injection matching etc.

Alexei Fedotov [16]

For the search of QCD phase transition critical point, a low-Energy RHIC requires the use of e- cooling for luminosity upgrade. Hence space charge and beam-beam are therefore simultaneously present for a long time enhancing the role of high order resonances, which are well known to be very important in colliders. The new issue of the interplay between space charge and beam-beam (usually on both sides of the injector chain) is largely unexplored. What is the acceptable space-charge tune shift for a long beam lifetime with collision? First observations during APEX campaigns in 2009-2010 with several combinations of space charge and beam-beam strengths need to be interpreted on numerical and theoretical bases.

K.Y. Ng [17]

A very small bunch at ALPHA (20 m e- storage ring, under construction at Indiana University) is to be extended to 40 ns, and a RF barrier bucket is too costly. An alternative method is proposed: create an RF phase modulation to generate a large chaotic region at the center of the RF bucket. The tiny bunch is immersed into a stochastic layer. The method requires a large modulation amplitude so to form a large chaotic area, and that the initial position of the tiny bunch is inside part of this chaotic region. This is obtained by offsetting the relative phases of 2 RF systems. The analytical-numerical method allows finding all the parameters to reach a uniform density bounded in phase space.

Valeri Lebedev [18]

The Tevatron average luminosity is limited by the IBS: larger beam brightness results in faster luminosity decay. It is impossible to make a significant improvement (~ 2 times) without beam cooling in Tevatron: 10-20% may be still possible (with new tunes and larger intensity beams). The Optical Stochastic Cooling (OSC) was reviewed as a scheme to prevent luminosity decay in the Tevatron. Zolotorev, Zholents and Mikhailichenko (1994) suggested this idea, but it was never tested experimentally. The principle of functioning is similar to the normal stochastic cooling except the much larger bandwidth (~ 200 GHz): undulators replace the PU and Kicker. The theory was extended and it was found that the sum of the cooling rates is proportional to the kicker-to-pickup M_{56}

coefficient. OSC cannot be introduced in 2-3 years, but looks feasible in 5-6 years. For the moment an extension of Tevatron to 2014 is discussed. Note that it should not be useful in the LHC, which is not IBS driven (SR is already present).

Yurij Senichev [19]

The COSY ring is operating for medium energy experiments in the energy range 45-2500 MeV. Two different methods were used to measure the acceptance of the COSY ring bringing to lower acceptance. There are two reason for that: (1) either the machine acceptance was overestimated in the beam lifetime calculation, and the actual machine acceptance for a cooled beam is significantly lower; (2) the e- beam affect the p beam stability. This last issue has been investigated in detail especially because an e- beam can not only cool an ion beam, but also heats it up (Reistad 1993). With a modelization based on nonlinear e-lenses, a polynomial approximation of the e- force is proposed. This model was used to make the systematic study of the Dynamic Aperture (DA) for several p beams: (1) monochromatic p beam, (2) p beam with momentum spread and also it was investigated the case of an e- beam off center. The conclusion is that the e- beam is the main reason of decreased DA in COSY.

Sergei Nagaitsev [20]

The 1st mention of using an octupole for Landau Damping (LD) was made by Richter in 1965: in fact a "linear" accelerator has a "non steep" Hamiltonian, subject to instability. Presently, most accelerators rely on both LD and feedbacks and there is always a trade-off between LD (nonlinearities) and DA. However, another design using "steep" Hamiltonians (i.e. very stable system) can provide "infinite" LD (in transverse planes). The 1st paper on the subject comes from Nikolay Nekhoroshev in 1971. Non-linear 2D "steep" Hamiltonians (i.e. very stable) to be implemented in an accelerator is proposed (1st examples of completely integrable non-linear optics!). The main issue in this scheme is that in 2D the fields of non-linear elements are coupled by the Laplace equation. The potentials should satisfy Laplace equation in addition to Darboux1901's one. There is a current proposal to build a machine at Fermilab (POP experiment).

Sandra Aumon [21]

The motivations of the study were: (1) to understand the dynamics of the fast instability at transition (with ~ no synchrotron motion) with/without gamma transition jump; (2) improve the stability of high-intensity beams with gamma transition jump without compromising the longitudinal density (which is done at the moment); (3) predict also the transverse stability of the ultimate LHC beam. Measurements without gamma transition jump revealed a vertical instability, which appears ~ 2 ms after transition, with a high-frequency (~ 700 MHz) traveling wave. HEADTAIL simulations revealed a good agreement with a Broad-Band model with a transverse shunt impedance of ~ 1.4 MΩ/m. Note that in 1989 coherent tune shifts measurements revealed an impedance of ~ 3 MΩ/m, but it was the sum of the dipolar and quadrupolar contributions. The next step will consist in improving the impedance model. Concerning them measurements with gamma transition jump, the instability appears after transition, which still needs to be understood. The next step will consist in implementing the gamma transition jump in the HEADTAIL simulation code.

Oleksander Chorniy [22]

Simulations have been recently benchmarked with measurements in SIS18. Bunch compression (performed at top energy with 2 new ferrite cavities) and phase space reconstruction by tomography revealed that the bunch compression could be improved. Furthermore, it was found that space charge does not produce longitudinal emittance growth during the RF capture at injection energy.

Heiko Damerau [23]

Some intensity and beam quality limitations were not fully understood yet and improvements are required for the ultimate beam for LHC. In the CERN PS machine, there are 24 RF cavities from 2.8 to 200 MHz, i.e. many potential impedance sources. The following machine (SPS) imposes to accelerate with a fixed longitudinal density. Coupled-bunch mode spectra during acceleration remain the same. However, a top energy it becomes very different. The driving impedance sources (10 MHz RF cavities) are time dependent. The possible cures are: (1) detuning of unused cavities; (2) add a second gap relay to close both cavity gaps of 10 MHz cavities and feedbacks. New coupled-bunch instabilities with a new beam requested by the LHC (150 ns bunch spacing) are due to the 40/80 MHz RF cavities.

DISCUSSION SESSION

How can we extract the Van Kampen modes from Schottky measurements?

In coasting-beams one can have clear Schottky signals, as in simulations for both coasting and bunched beams. However, in machines with bunched beams it is almost always impossible (as there is always some coherence).

Why/how does a head-tail mode change with intensity (space charge)?

Some analytical formulae exist to predict instability thresholds for particular types of impedances (narrow-band or wide-band resonators for instance), but a theory is missing when both are taken into account. The new (semi-analytical) approach from A. Burov seems to be the best way to go.

Instabilities should be also discussed with the associated electronic feedbacks. There is a need to discuss more closely with the feedback experts (noise issues etc. responsible for emittance growth). Including a realistic model for the different feedbacks in simulation codes is an interesting and challenging subject.

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