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Very Large Hadron Collider Instability Workshop Summary Report*

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Abstract

The VLHC Instability Workshop was held at SLAC, March 21-23, 2001. The purpose is to review the instability issues facing VLHC, both for the high-field and the low-field stages. The review is considered a snapshot survey of these issues as presently conceived, and serves as input to its current Feasibility Study. The agenda is shown as Appendix. Presentations of the talks are posted on the web site http://www.slac.stanford.edu/ achao/VLHCworkshop.html.

Presented at the Very Large Hadron Collider Instability Workshop
SLAC, Stanford, California
March 21 - 23, 2001

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1 Introduction

The VLHC Instability Workshop was held at SLAC, March 21-23, 2001. The purpose is to review the instability issues facing VLHC, both for the high-field and the low-field stages. The review is considered a snapshot survey of these issues as presently conceived, and serves as input to its current Feasibility Study. The agenda is shown as an Appendix. Presentations of the talks are posted on the web site http://www.slac.stanford.edu/~achao/VLHCworkshop.html.

In this workshop, we have agreed to use the following parameters as the nominal values (values are at injection, unless otherwise specified):

	Stage 1	Stage 2
Circumference (km)	233	233
Revolution frequency (kHz)	1.29	1.29
Energy/beam		
injection (TeV)	0.9	10
top (TeV)	20	87.5
Bunch spacing (m)	5.7	5.7

	Stage 1	Stage 2
Number of bunches	37152	37152
Number of buckets	41280	41280
Protons/bunch (10^{10})	2.5	0.9
Beam current (mA)	190	69
Synch. rad. power/beam (W/m)	0.03	5.6
Pipe/Liner		
aperture radius (mm)	9 x 14	10 x 10
material	1 mm aluminum	1 mm stainless steel
coating	-	50 micron copper
temperature (K)	300	80
Area coverage holes	-	4.0%
Lattice		
betatron tunes	218.3, 218.4	218.19, 212.18
slip factor	2.2×10^{-5}	2.65×10^{-5}
cell length (m)	271	271
beta average (m)	230	230
Rf frequency (MHz)	478	478
Rf voltage (MV)	50	50 (200 at storage)
95% long. emittance (eV-s)	2.0	12.0
Trans. rms emittance (mm-mrad)	1.5	1.5
Rms bunch length (mm)	55	82
Rms energy spread σ_p/p	6×10^{-4}	2.3×10^{-4}
Synchrotron frequency f_s (Hz)	10.6	3.6
Synchrotron tune ν_s	0.0082	0.0028

Summary

- Most instability issues examined in this workshop are not expected to be serious concerns for the VLHC. Two exceptions are the transverse mode-coupling instability (TMCI) and the transverse resistive wall instability, both are most pronounced for Stage 1 at injection. In particular,
  - the design beam current is a factor of 2 higher than the expected TMCI threshold;
  - the resistive wall instability will require an extension of the state-of-the-art feedback system; and
  - a practical way to compensate for the very large incoherent and coherent tune shifts, as well as tune variation along the bunch train, due to resistive wall has yet to be designed.

  Possible ways to deal with these instabilities are suggested in this report, but more R&D will be necessary before a viable VLHC design is reached.

- In this report, we suggest that the following parameters be changed, or consider to be changed, in order to deal with the TMCI and the resistive wall instabilities:
  - Stage 1 beam pipe radius and magnet gap
  - Stage 1 beam pipe thickness
  - Stage 2 liner thickness
  - Stage 2 liner coating thickness

- Stage 2 liner temperature
- Rf voltage
- Rms long. emittance

- A list of R&D items are suggested in Section 11 of this report.

2 Impedance Budget

Machine	$R\,(\mathrm{m})$	$b\,(\mathrm{mm})$	$\frac{Z_\parallel}{n}\,(\Omega)$	$Z_\perp^{BB}(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Broadband	$Z_\perp^{LH}(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Liner holes	$Z_\perp^{RW}(\frac{\mathrm{M}\Omega}{\mathrm{m}})$ Resis. wall
MI	529	25.4	1.6	2.2	-	26
LHC	4243	18.0	0.66	28	1.5	124
SSC	13866	16.5	0.68	54	21	4200
VLHC						
Stage 1	36924	9	0.6	490	-	65000 (?)
Stage 2	36924	10	0.6	390	90	55000

Table 1: Impedance budgets for various hadron rings. The resistive wall transverse impedance is quoted for the lowest frequency mode, at $(n-\nu_\beta)\omega_0$.

Table 1 gives a very crude VLHC impedance budget obtained by scaling to other hadron accelerators. The scalings used are:

$$\begin{aligned}
Z_\perp(\text{broadband}) &\sim \frac{R}{b^2}\ \text{(rough)}\\
Z_\perp(\text{liner holes}) &\sim \frac{R}{b^3}\ \text{(exact for same coverage)}\\
Z_\perp(\text{resistive wall}) &\sim \frac{R^2}{b^3}\ \text{(one } R \text{ from 2-layer. Almost exact)}
\end{aligned}$$

- Impedance per circular hole of diameter d:

$$Z_\perp(\text{holes}) = j\frac{Z_0}{24\pi^2}\frac{d^3}{b^4}$$

- Resistive wall impedance:

$$Z_\perp(\text{wall}) = \frac{Z_0 R}{b^3}\delta_s K \simeq \frac{Z_o R}{b^3}\frac{\delta_s^2}{\Delta}$$

where δ_s is the skin depth, Δ is the thickness of the copper layer, and K is the 2-layer multiplicative factor.

- Parameters used here are:

$$\begin{aligned}
\sigma_l(\text{Cu}) &= 3.3\times 10^9\ \Omega^{-1}\text{m}^{-1}\ (\text{RRR} = 50,\ 30 \text{ for SSC}) \\
n - \nu_\beta &= 0.3\ (0.1 \text{ for SSC}) \\
\sigma_l(\text{Al}) &= 0.056\times 10^9\ \Omega^{-1}\text{m}^{-1} \\
\text{hole coverage} &= 4\%
\end{aligned}$$

3 Transverse Mode Coupling Instability

The TMCI threshold for the resistive wall was calculated in A. Burov, et al., “Beam stability issues in very large hadron collider”, NIM Phys. Res. A 450 (2000) 194-206. The formula for the threshold bunch population reads

$$N_{\text{th}} = 1.24\times 10^{10}\sqrt{\frac{\sigma_z}{10\,\text{cm}}}\left(\frac{E}{3\,\text{TeV}}\right)\left(\frac{\nu_s}{0.005}\right)\left(\frac{b}{0.9\,\text{mm}}\right)^3\left(\frac{520\,\text{km}}{C}\right)$$

$$\times \quad \left(\frac{250\,\mathrm{m}}{\langle\beta\rangle}\right)\sqrt{\frac{\sigma_c}{3.5\times 10^7/\Omega-\mathrm{m}}} \tag{1}$$

Where σ_z is the rms longitudinal size, E is the energy, ν_s is the synchrotron tune, C is the circumference, and $\langle\beta\rangle$ is the average beta function. The simplified formulas in Bill Ng's estimation for the threshold give approximately 40% larger threshold than in Eq.(1). The above number was obtained by a matrix approach for 25 modes (five radial and five azimuthal modes included). Particle tracking was also done and the difference between the matrix approach and particle tracking was about 30%. For high field at injection, the simple formula gives a threshold about 30% higher than that given by numerical solution.

One source of discrepancy between Eq.(1) and Ng's formula is related to the fact that the resistive wall wake goes to infinity as the inverse square root of the distance between the source and the test particles, taken for a separation of the rms length of the bunch. Moreover, the divergence of the wake at small distances brings up numerical convergence questions. It is worthwhile checking other approaches. V. Lebedev will perform independent particle tracking. On the other hand, M. Blaskiewicz calculated the threshold using basis expansion for a gaussian bunch, and his result confirmed Eq.(1) to less than 1%.

The problem is very important for the low field VLHC. The threshold number for the bunch population at injection with the nominal set of parameters (from the above formula) is equal to 1.14×10^{10} protons, about half the nominal intensity.

The above estimate assumes a round beam pipe of 9 mm radius. The threshold estimate should be redone for the nominal oval-shaped beam pipe. The high-field machine TMCI threshold is of the same order as the nominal value.

Assuming that TMCI will exist in the VLHC, the following measures could be cures:

- Inject low intensity bunches and coalesce them to make high intensity bunches at high field where the TMCI threshold is increased.

- Debunch and rebunch in the Tevatron so that at injection the bunch population is lower while the number of bunches is higher, and rebunch after the beam is sufficiently accelerated in VLHC (Limon).

- Consider using extra-pure aluminum to increase conductivity of the beam pipe (Limon).

- Provide active feedback (resistive damping) at a few low order modes $\ell = \pm 1, \pm 2, \cdots$.

- Introduce an RF quadrupole to provide a tune shift between the head and tail of the bunch.

Some items for further study:

- The TMCI theory for proton beams is technically challenging because the bunches are longer and other forces may be present. Experimental data for comparison would be most useful.

- The TMCI can be studied with the Tevatron Electron Lens (TEL).

4 Resistive Wall Effects

For the low field ring parameter range the various formulae for the resistive wall impedance agree within a factor of two. The e-folding time for the low frequency resistive wall instability is less than 1 turn. Additionally, the very low revolution frequency leads to a variation in the magnetic image Laslett tune shift when the ring is partially filled during the injection process. The variation is due to the fact that the revolution period is comparable to the magnetic diffusion time through the beam pipe.

Initial estimates of the latter effect produce tune shift variations of order 0.3 along the bunch train for a half filled ring. Both of these problems will be reduced by increasing the vacuum pipe thickness and/or radius. Increasing the dipole magnet gap from 20 mm to 28 mm reduces the DC Laslett tune shift from 1.0 to 0.6. The variation in tune along the bunch train could be reduced by quadrupoles running at multiples of the revolution frequency, or by injecting the bunches in such a way to minimize the lower harmonics of the revolution frequency in the beam spectrum. Also, the resistive wall instability needs to be damped. Realistic studies of the feedback system are needed.

Uncertainties are larger for the high field ring and a reliable estimate of the transverse impedance is needed. Worst case estimates lead to resistive wall e-folding times of order 3 turns, significantly slower than in the low field case. Any damper technology required should easily follow from that developed for the low field case. Future studies may indicate that increasing the thickness of the copper layer is beneficial. The effect of dipole magnetic fields on the resistivity of the various materials should be understood.

It is recommended that the copper coating on the liner for stage 2 be increased from 50 microns to 0.5 mm, while maintaining the temperature at 80 K. The stress on the liner pipe during a magnet quench is judged to be acceptable (Foster and Zlobin).

5 Incoherent Tuneshift due to Collective Fields

Multi-bunch fields of the beam in the low field VLHC are so strong that during the accumulation the betatron tune may cross some major resonances with the consequent beam loss. To estimate the fields from the resistive wall we assume the chamber is flat (elliptic with the big axis ratio, e.g. 3 or more). For this vacuum chamber the horizontal detuning wake is equal to the horizontal conventional wake (see the brief explanations in the Danilov's talk). The vertical motion has the opposite sign detuning wake. Thus it gives similar contribution to the incoherent tune as the conventional wake to the coherent tune shift for both transverse degrees of freedom.

The conventional resistive wall wake growth time $N_{\rm rw}$ is about one turn or less. The incoherent tune shift could be estimated as $1/2\pi N_{\rm rw} \sim 0.2$. For chambers with the big asymmetry the tune shift can reach 0.5. More precise estimation should take into account many factors, as the thickness of the vacuum chamber, its particular shape, etc. and could be done numerically later.

This is only the resistive wall contribution and the appropriate choice of the vacuum chamber (namely, the round chamber) eliminates the detuning wake contribution for not very large distances. But there exist one even more strong effect, whose importance was noted by V. Lebedev (see p.14 of his talk). The effect is just the Laslett tune shift due to the dc image currents in the poles of the magnets. The formula for the round chamber tune shift reads (assuming the magnets occupy the whole ring):

$$\Delta\nu_y = -\Delta\nu_x = -\frac{\pi r_0 N R}{24\,\gamma a^2 \nu} \approx -0.32$$

where the average current is $I_b = 190$ mA, the average radius $R = 36.9$ km, $N = 9.2 \times 10^{14}$, $r_0 = 1.5 \times 10^{-18}$ m, $\nu = 214$, $\gamma = 1000$, the gap half height $a = 0.01$ m.

If the vacuum chamber is elliptical, the electric field contribution will give roughly half of that number. Therefore the effect of zero harmonic current is even larger than the resistive wall contribution.

One possible solution to this problem is to adjust the betatron tune by a variable quadrupole in order to avoid resonances. In this case two problems are seen. The first problem is related to the nonlinear fields of the image currents. They could be so large that the dynamic aperture shrinks below 5-6 transverse rms. The other problem is that the coherent tunes of the multi-bunch modes may cross resonances in case of big reference betatron tune shift. Both problems need to be studied in detail.

Another solution to this problem could be the following. Let's take the round vacuum chamber. Let's assume it has the constant current, opposite to the average current of the beam. In this case the total average current of the vacuum chamber is equal to zero and the image currents in the iron poles of the magnets disappear. Moreover, for nonzero harmonics the round shape vacuum chamber the detuning wake is equal to zero (neglecting some leakage of the magnetic field through the vacuum chamber for the very low frequencies). Therefore the incoherent tune shift disappear almost completely in principle. However, there remains the possible problem of coherent tunes shifting across major resonances. Whether a sufficiently strong feedback system can suppress this problem needs to be evaluated.

6 Intrabeam Scattering

Intrabeam scattering is not a significant effect for Stage 1, because of the comparatively large beam emittance. For nominal parameters the amplitude growth rates are about 5 and 25 days for the horizontal and longitudinal degrees of freedom. At top energy, the transverse growth rate is about 22 days while the longitudinal rate stays approximately the same.

IBS is expected to be significant in Stage 2. The horizontal growth rate is by far the strongest, with growth times becoming comparable with the synchrotron radiation damping time when the vertical emittance shrinks to make the beam flat. The minimum growth time is controlled by heating in the longitudinal plane.

IBS growth rates calculated currently vary by about 50%, depending on the model used. An understanding of this apparent discrepancy is needed.

7 Electron Cloud Instability

The electron cloud in the Stage 1 VLHC has started to be investigated. The LBNL electron-cloud simulation code POSINST has been run, taking into account the actual beam parameters and an elliptic vacuum chamber design with uncoated aluminum (secondary electron yield at peak $\sim$2.75). Electron multiplication has been observed as expected, since the nominal bunch spacing and current satisfy the multipacting condition. The power deposited at the wall by the electrons is 0.5 W/m in the dipole magnet section, in the worse case. The electron-cloud wake field is such that the vertical growth rate in the dipole sections is on the order of $\gtrsim 0.25$ sec. The electron energy spectrum and the electron cloud dynamic have been also investigated. Thus, we have a preliminary understanding of the electron cloud issue in the Stage 1 VLHC, although more studies are necessary to:

- complete the instability studies, looking at the electron-cloud wake field in other sections of the machine;
- study the head-tail instability;
- introduce the rediffused and the elastic components in the secondary electron energy spectrum.

The electron cloud instability does not seem a serious problem for stage 1. It will need to be studied for stage 2.

8 Impedance Reduction

It has long been realized that a large circular accelerator would have a large transverse impedance. The large circumference is a major factor, but the transverse size of the beam pipe is very important. The transverse beam size at high energies is very small - less than a few mm - and the imperative to design an affordable machine argues for a small aperture. The transverse impedance scales as $Z_\perp \propto C/b^3$, where C is the circumference and b is the transverse beam pipe dimension. This combination of effects increases the magnitudes of many coherent effects beyond what is normally encountered. It is critical to understand these phenomena in enough detail to determine whether the machine will produce the desired luminosity.

Given the large size of these effects, it is natural to consider methods that can be used to reduce impedance. The two main drivers, the circumference and transverse beam pipe size, are set by magnet technology and costs. We take these parameters to be fixed.

Cooling the beam pipe to cryogenic temperatures will result in a lower impedance for beam pipe materials (high purity copper and aluminum) although the effect is small for stainless steel. In addition to the cost of cooling the beam pipe, the synchroton radiation load should also be considered. The Stage 1 beam pipe is at 300 K, and the Stage 2 liner is at 80 K.

The thickness of the beam pipe can be increased. Assuming that the magnet gap were left constant, this would reduce the beam aperture slightly. For example, if the norminal wall thickness were increased from 1 mm to 2 mm, the aperture would decrease from 9 mm to 8 mm. However, transverse growth rates would decrease by about a factor of 2, and the dynamic Laslett tune shift would also decrease.

The concept for the high field machine beam pipe is a stainless steel pipe coated with copper. The nominal thickness of the liner coating is 50 μm. Increasing this thickness is desirable as also mentioned in Section 4.

Wake fields depend on the shape of the beam pipe. Asymmetric beam pipes may have some advantages, but this question needs to be studied in more detail, considering all coherent effects before making a specific recommendation.

There is a real need for an impedance estimate and budget for both the high field and low field rings. The impedance of the bellows has been estimated to be a major contributor to the broad-band impedance of the high field ring. Techniques of reducing the bellows impedance or of eliminating their impedance completely should be developed.

An idea for a "superpipe" was presented. The superpipe relies on a feed-forward system to create currents that cancel the wakefields caused by the beam currents. The concept should be studied further to understand more clearly the wakefield cancellation mechanism and the technical requirements. It would be fairly easy and inexpensive to perform bench tests of the concept.

9 Feedback Systems

It is generally agreed that at least two transverse feedback systems are required for stage 1. (Only one feedback system is needed if copper coating on the liner can be increased to 0.5 mm.) The first is a high-gain, low bandwidth (perhaps 100 kHz) feedback system where the pickup signal arrives at the kicker slightly behind the beam bunch that produced the signal. The second is a conventional one turn delay system with a 26 MHz bandwidth. A high frequency system or perhaps a few systems may be useful to increase the TMCI threshold.

Low frequency, high gain transverse feedback A model was presented in which the single turn gain was limited to about 1 by unstable loop behaviour, independent of the number of systems used. The gain limitations need to be explored further to see if this limitation is fundamental.

Closed orbit and common mode motion need to be controlled at each pickup to the level of 100 μm. How this might be achieved is a subject for future study. In particular, injection transients create special difficulties.

Damper emittance growth due to broad-band damper noise can be calculated as

$$\frac{d\epsilon}{dt} = 24\pi\beta_k f_0 \frac{Z_0 S^2 \ell^2 P}{g^2 (E/e)^2}$$

where β_k is the beta function at the kicker, f_0 is the revolution frequency, Z_0 is the system impedance, S is the kicker sensitivity ($S < 1$), ℓ is the kicker length, P is the power input to the kicker, g is the kicker gap, and E/e is the beam energy. We conclude that the emittance growth for the VLHC feedback

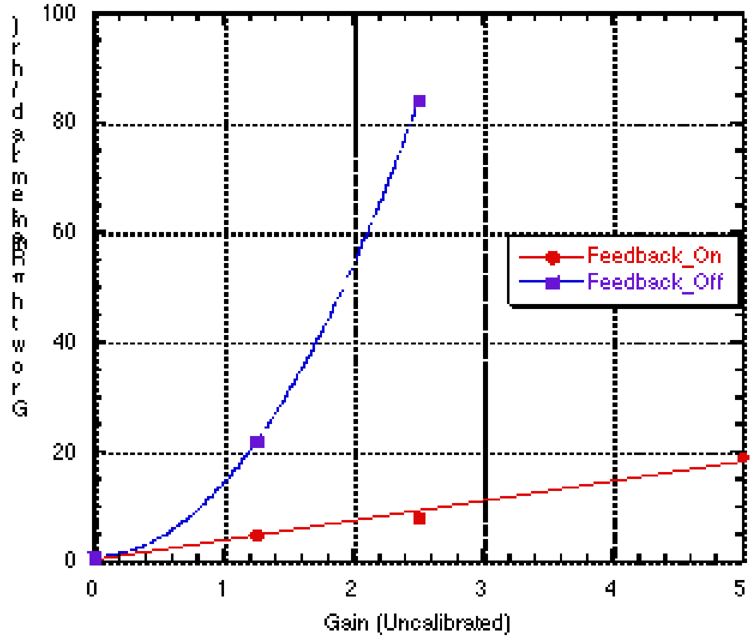

Figure 1: The power amplifier noise is applied to a beam in the Tevatron and the emittance growth is measured. The Feedback-On curve represents normal operation of the damper system and Feedback-Off is the same except that the feedback is turned off by unplugging the damper pickup signal. The damper feedback greatly suppressed the emittance growth caused by damper noise.

system will be small provided the noise can be held to the theoretical minimum “Johnson” noise.

The damper can suppress noise from other sources such as fluctuations in the magnetic field and ground motion. Figure 1 shows the suppression of emittance growth in the Tevatron damper.

Noise suppression in the strong damping regime should be studied in more detail.

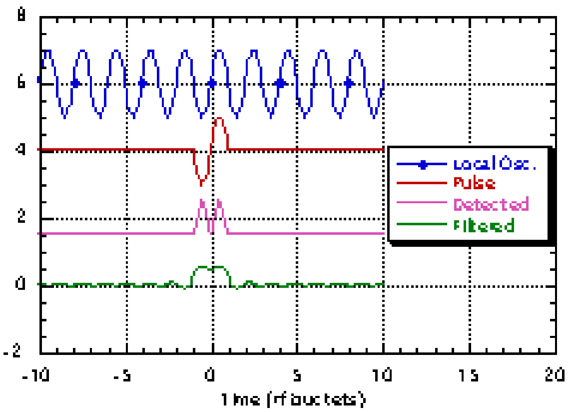

Figure 2: A cartoon of the TMCI pulse processing to develop a $l = \pm 1$ signal that can be digitized.

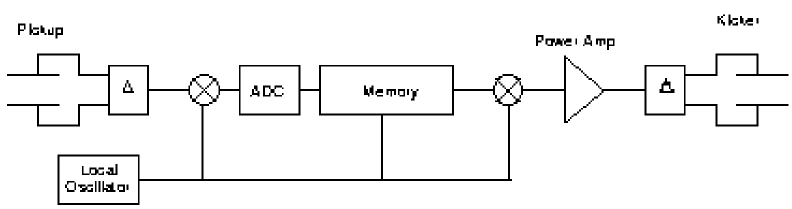

Figure 3: A damper schematic. The ADC and memory clock speed is equal to the bunch spacing (system requires a 27 MHz bandwidth for the VLHC).

One turn delay system The one-turn delay system is conventional in design and system gain and should not present any unusual difficulties.

TMCI System A concept for a TMCI damping system was presented. A mode $l = \pm 1$ signal is detected at a frequency appropriate for the bunch length. The signal is then mixed down to baseband and digitized by a conventional digitizer (one digitization per bunch). See Fig.2. A rough idea of the signal processing and system block diagram are given in Fig.3.

Orbit, Tune, & Chromaticity Feedback Orbit feedback will be desired to control the damper system orbit to 100 μm. Global closed orbit may be useful in stabilizing machine behavior and reducing the time spent tuning the machine, for example up the energy ramp. It should also be possible to provide feedback for the tune and chromaticity.

10 VLLC, the e^+e^- Option

We heard a presentation on the VLLC, the e^+e^- option in the VLHC tunnel. This is a 184-GeV ring with a luminosity of 10^{32} cm^{-2} s^{-1}.We did not discuss in detail its instability issues due to time limitations, but noted the following:

- The high value of the beam-beam parameter, at 0.1, is in unfamiliar territory. Justification has been attributed to the exceptionally large radiation damping decrement.
- Lowering the RF Frequency from 400 MHz to 350 MHz should help to slightly relieve some of the instability considerations.
- TMCI at injection is identified to be by far the most dangerous instability mechanism if impedance is scaled from that of LEP (threshold current due to bellows alone is 10 times lower than design current). A combination of cures must be found. Possible cures include:
  - raising injection energy (perhaps to 45 GeV – the injector can then be used as a Z_0-factory)

- a TMCI feedback system (see Section 9)
- coalescing at top energy
- eliminating bellows altogether
- optimizing rf voltage, synchrotron tune, and momentum compaction factor.

11 R&D Items

The proposed low frequency feedback system is novel in that it operates at very high gain. A number of issues need to be considered.

- Can a stable feedback system be designed?
- Can a practical, low-noise design be implemented?
- How effective is the system at reducing noise from magnet ripple, ground motion, or other sources?
- Would a hardware test of the key concepts be possible?

The TMCI stability needs to be studied in more detail as well. Some of the key questions are

- Are there differences in behavior of proton and electron beams (either because proton beams typically operate in a different parameter range or because of the difference in mass)?
- Can the effect be excited with the Tevatron Electron Lens?

In addition, it would be valuable to directly measure the relevant tune shifts in the Tevatron, RHIC, and possibly other machines. If TMCI continues to be a problem at VLHC bunch intensities, cures should be considered including the use of an rf quadrupole to introduce a tune shift between the head and tail of the bunch and direct feedback on the higher order modes. Scenarios that finesse the instability (like bunch coalescing at higher energies), could also be considered.

Recent work decomposes the beam wakefield into deflecting and detuning wakes. The detuning wake depends on the shape of the beam pipe. The detuning wake, particular that due to resistive wall, should be studied to determine:

- The low-frequncy behavior of the resistive wall, taking into consideration of the complex vacuum chamber environment and the field leakage through the chamber (this is especially needed for Stage 2)
- Ways to control the incoherent and coherent tune shifts and avoid their crossing major resonances
- Ways to control tune variation along the bunch train during injection
- The theoretically optimum shape for the beam pipe
- Bench tests of new types of beam pipes

A concept for a "superpipe" was presented. The basic idea is to force currents through the beam pipe in a way that will compensate the beam wakefields. The idea should be further studied to understand what cancellation of wakefields could be achieved.

Additional topics for R&D are listed below:

- Measure intrabeam scattering at RHIC (this will probably be done as a part of the RHIC program, anyway). Understand the apparent discrepancy among the existing IBS theories.

- Study feedback control of orbits, tunes, and chromaticity (LHC is working on this).

- Analyze the electron cloud instability. Complete the study for Stage 2. (SPS is doing a lot of work on this subject, and a collaboration would seem to be desirable).

- Continue $\Delta B/B$ noise measurements in superconducting magnets.

- Study emittance growth in the Tevatron near integer tune. In this mode the Tevatron is sensitive to ground motion and other low frequency noise.

- Study in a parametric way instabilities in proton accelerators. There was some suspicion that instability thresholds were not as well understood in proton machines as they are in other machines and that existing theories are not well supported by experimental data.

- Study ways to eliminate the contribution of bellows to the impedance (either by better shielding or using fewer bellows).

Appendix

Agenda

VLHC Instability Workshop
SLAC, March 21-23, 2001

March 21, Wednesday

starting 9:00 a.m., ending 6:00 p.m.

Business – Chao

Overview – Blaskiewicz

Beam instabilities in VLHC: from 1999 to now – Shiltsev

Collective field effects: TMCI, tune shift, and emittance growth – Danilov

Stability issues for the high field VLHC – Blaskiewicz

Stability issues of the VLHC rings – Ng

Workshop on an e^+e^- ring at VLHC – Wienands

Vacuum system and synchrotron radiation – Pivi and Turner

Longitudinal parameters – Marriner

Feedback system requirements – Corlett

No-host dinner at Capriccio's

March 22, Thursday

starting 9:00 a.m., ending 6:00 p.m.

Control of transverse multibunch instabilities in Stage 1 – Lebedev

Formulation of issues to be addressed – Peggs

Impedance budget – Chou

Electron cloud in Stage 1 – Pivi

Feedback against transverse coupled-bunch from resistive wall – Lambertson

Approximate resistivity of thin wall – Lambertson

Noise issues – Marriner

TMCI Damper issues – Marriner

Intrabeam scattering – Lebedev

TMCI calculations – Ng

Writing assignments

March 23, Friday

starting 8:30 a.m., ending 1:00 p.m.

R & D issues – Marriner

Longitudinal head-tail instability – Ng

Continued discussions

Unfinished homework

Writing

Reports on written drafts