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Beam Dynamics Newsletter

No. 27

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1: Forewords

1.1 From the Chairman of the ICFA Beam Dynamics Panel

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Sign-up for the Beam Dynamics Newsletter!

It is now possible to sign-up to an electronic mailing list for the ICFA Beam Dynamics Newsletter. I mention this first and prominently because we would like to encourage **all readers** to visit our Web page

http://wwwslap.cern.ch/icfa/

and sign up immediately. The form is very short and simple and, of course, registration is free. Once you have signed up, you will be notified promptly by email whenever a new issue of the newsletter becomes available on the Web. Please also encourage your colleagues to do the same.

Those who receive the printed edition are **strongly recommended** to sign up to indicate their continuing interest in the newsletter (the distribution lists for the printed edition appear to contain some obsolete entries that we would like to eliminate).

This measure should greatly improve the timeliness of the newsletter distribution and reach more members of the accelerator physics community at minimal cost. The paper version of the newsletter always takes some time to print and distribute.

We promise to practice restraint in our use of this list. Apart from three notifications of newsletters per year, we will only use it for occasional important announcements. And we will not, of course, give anyone else access to the list.

ICFA

I would like to draw readers' attention to the summary of the 43rd meeting of ICFA that was held at SLAC, USA, on 14 and 15 February 2002. You can find the summary of this meeting on ICFA's home page, which you can reach by clicking the big ICFA logo on the Beam Dynamics Panel's home page.

In addition to ICFA members, directors of the world's major particle physics labs were invited. Part of the meeting was devoted to a joint session with the OECD Global Science Forum Consultative Group on High Energy Physics. This body is finalizing a report on the development of high-energy physics over the next two decades, to be published in June 2002. Since this report is founded on the consensus view that the next big project in our field should be a linear collider, ICFA decided to set up the International Steering Committee for the Promotion of the Linear Collider Project together with the continuing activity of the Linear Collider Technical Review Committee. These are significant developments towards the realization of this long-standing dream, which will bring new opportunities and challenges for the beam dynamics community.

Besides changes to the membership of our Panel (see below), ICFA also approved the 28th ICFA Advanced Beam Dynamics Workshop on Quantum Aspects of Beam Physics, to be held in Hiroshima, Japan, in January 2003. This is the third of a series of workshops initiated within the Panel that opened up a new field of research in beam physics and created many fruitful links with other fields. This time it is jointly sponsored by the ICFA Panel on Advanced and Novel Accelerators. Further details can be found later in this newsletter.

Changes in Membership of the Beam Dynamics Panel

Dr J.-L. Laclare of CEA (France), Dr Elcuno A. Perelstein of the Laboratory of Nuclear Reactions, JINR (Russia), Prof. Claudio Pellegrini of UCLA (USA) and Dr Dmitri Pestrikov of the Budker Inst. of Nuclear Physics (Russia) have retired from the Panel. Each of them has drawn on his expertise and dedication to further our mission within ICFA during several years of service. I would like to thank them on behalf of the Panel and trust that their association with Panel activities, particularly our workshops and the newsletter will continue.

At its meeting on 15 February 2002, ICFA approved five new members of the Beam Dynamics Panel: Dr Caterina Biscari (LNF-INFN), Dr Alessandra Lombardi (CERN), Dr Olivier Napoly (DAPNIA-CEA), Dr David Rice (Cornell University) and Prof. Yuri Shatunov (BINP). On behalf of the Panel, I welcome them and look forward to the fruits of their ideas and initiatives.

The list of Panel members on our home page has been updated to facilitate access to the Panel for all members of the beam dynamics community.

New Chief Editor of this Newsletter

After acting for several years as Chief Editor of the Newsletter (as well as Panel Chairman), Dr Kohji Hirata has expressed his wish to stop this activity. In that time, he has done much to establish the newsletter's position as an important organ of our field and I wish to thank him on behalf of the Panel.

Dr Weiren Chou, who has edited a number of especially interesting issues, including the present one, has kindly agreed to take over as the new Chief Editor.

The 28th issue, due out in August 2002, will be edited by Dr Caterina Biscari, who accordingly joins the editorial team. Please send your contributions to her by mid-July.

The Beam Dynamics Panel Web site

New Web pages covering the Panel's activities in the Americas region are now online at Jefferson Lab. Please visit them via the "Americas" link on our home page

http://wwwslap.cern.ch/icfa/

Past Beam Dynamics Newsletters have been consolidated into a new archive, in PDF format within these pages. We have been able to find electronic versions of newsletters going back to 1995. If anyone has electronic or paper versions (especially if willing to make scans) of earlier issues, we would be grateful to hear from them.

The Panel is grateful to Yuhong Zhang of Jefferson Lab for implementing these innovations.

Panel Meeting

The ICFA Beam Dynamics Panel held a meeting during the European Particle Accelerator Conference in Paris, on 4 June 2002. The minutes of this meeting can be found later in issue.

1.2 From the Editor

Weiren Chou (Fermilab)
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This issue of the ICFA Beam Dynamics Newsletter includes a number of summary reports from the ICFA-HB2002 Workshop, held at Fermilab, USA, April 8 – 12, 2002. In addition to a general workshop report, this newsletter also includes reports from three working groups and several parallel sessions. Although the workshop proceedings are to be published, it will take 6 months or longer for them to appear. Furthermore, only the 150 participants at the workshop will receive a copy of the printed proceedings. In contrast, the Newsletter provides a convenient vehicle for rapid communications to the accelerator community on important subjects, such as that of the HB2002. It is the editor's opinion that we should explore this unique feature of the Newsletter in future issues so that reports from important workshops can be disseminated in a timely manner.

This issue also includes the reports from several other important workshops: the 24th ICFA Advanced Beam Dynamics Workshop (ABDW) on Future Light Sources, the Mini-Workshop on Coherent Synchrotron Radiation, and the Ecloud 2002 Mini-Workshop. Mini-workshops appear to be gaining in popularity. This is because they are easy to organize, have a small number of experts meeting together, and are well focused on specific problems. They have been proved to be efficient and productive. We look forward to receiving more mini-workshop reports for publication in this Newsletter.

There are two activity reports in this issue: one on a real time radiation simulator, another on the analogies between light optics and charge particle optics. We hope readers find them interesting. There are a number of announcements of upcoming workshops. The minutes of a recent ICFA Beam Dynamics Panel Meeting are also included.

Because of limited editing resources, it has been decided that Microsoft Word will be the only document type for future publications in this Newsletter. In the past, the newsletter was prepared with LaTeX but some Word contributions were accepted and manually converted. Now there is a clear majority preference of contributors and editors in favor of Word so it makes sense to produce the Newsletter in Word. Word is also better adapted to the Web, which is now our main medium of transmission. But it is time consuming to convert LaTeX contributions to Word, as the editors did for this issue (No. 27) as well as for last issue (No. 26).

Starting with issue No. 28, therefore, only manuscripts written in Word will be accepted. LaTeX files will be returned to the authors for conversion. Articles consisting of simple plain text and requiring only very simple formatting may be accepted at the discretion of the issue editor. Please refer to Section 6.2.3, *"How to Prepare a Manuscript,"* of this issue for further details. We'd like to thank you for your understanding and cooperation.

The editor expresses his sincere gratitude to Ernie Malamud, a retired Fermilab senior physicist for his assistance in editing this newsletter.

2: Workshop and Conference Reports

2.1 The ICFA-HB2002 Workshop

2.1.1 Workshop Summary

Weiren Chou (Fermilab) and Yoshiharu Mori (KEK)
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The 20th ICFA Advanced Beam Dynamics Workshop on High Intensity High Brightness Hadron Beams (ICFA-HB2002) was held April 8-12, 2002 at Fermilab, USA. It was co-sponsored by Fermilab and KEK. There were a total of 151 registrants, 130 presentations and 14 summary talks. The workshop had 4 plenary sessions, 11 parallel sessions and 3 working groups in five days. A guided tour at Fermilab was also provided on the last day.

At the first two plenary sessions, there were three physics talks: JHF physics (J. Imazato, KEK), neutrino physics (D. Michael, CalTech) and muon physics (W. Molzon, UC Irvine). They discussed various physics programs based on high intensity proton machines. They were followed by a series of machine overview talks: introductory remarks (A. Sessler, LBL), JHF machines (Y. Mori, KEK), synchrotron based proton drivers (W. Chou, Fermilab), SNS project (J. Wei, BNL/ORNL), linac based proton drivers (T. Wangler, LANL), and a proposal for an 8 GeV superconducting proton linac (W. Foster, Fermilab). These talks covered the machines under construction (JHF and SNS) as well as those being proposed (various types of proton drivers). It was emphasized at this workshop that the U.S. high-energy physics (HEP) community must prepare a proposal for a mid-size accelerator project (a proton driver) in addition to a big-size one (a linear collider) in order to have a guaranteed future of this community.

The plenary sessions at the last two half-days had three more physics reports: one from the Femilab physics study group (M. Velasco, Northwestern U.), another from the BNL neutrino physics study group (W. Marciano, BNL), the third one on progress on bright ion beams for medicine, industry and fusion (J. Kwan, LBL). The first two were initiated by the directors of the two labs (Fermilab and BNL) and were focused on the applications of neutrino superbeams. The conveners of each working group and parallel session gave summary reports at the final plenary sessions. S. Holmes, on behalf of Fermilab, gave closing remarks.

The three working groups and eleven parallel sessions and their conveners are listed below:

Working Groups	Conveners
WG I - Circular Accelerators	L. Teng (ANL), R. Cappi (CERN)
WG II - Linear Accelerators	J-M. Lagniel (CEA/Saclay), R. Garoby (CERN)
WG III - Beamlines and Targets	C. Moore (Fermilab), K. McDonald (Princeton U.)

Parallel Sessions	Conveners
A. Lattice	A. Thiessen (LANL)
B. Beam Loss, Collimation and Shielding	N. Mokhov (Fermilab)
C and G (Joint) FFAG and Cyclotrons	R. Baartman (Triumf), Y. Mori (KEK), P. Schmelzbach (PSI)
D. New Ideas	K. Takayama (KEK), C. Ankenbrandt (Fermilab)
E. Space Charge Simulations	I. Hofmann (GSI), R. Ryne (LBL)
F. Remote Handling	D. Pushka (Fermilab)
H. Ion Sources	H. Klein (U. of Frankfurt), K-N. Leung (LBL)
I. Space Charge Experiments	S. Machida (KEK)
J. Hadron Beam Cooling	S. Nagaitsev (Fermilab)
K. H^- Stripping	I. Yamane (KEK)
L. Electron Cloud Effects	R. Macek (LANL)

Reports from these working groups and parallel sessions can be found in the following sections.

2.1.2 Working Group I - Circular Accelerators

Lee Teng (ANL) and Roberto Cappi (CERN)
Working Group Co-Conveners
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Working Group I was very well attended by some 60 people at the peak. The two half-day sessions were fully loaded with 16 talks. Since it did not appear possible to have scheduled time dedicated to structured "discussion" or "work," we tried to allow as much time as possible after each talk for comments and discussions. The 15 talks (one withdrawn) are widespread in subject matter and content. They can roughly be grouped into the following categories.

Projects

3-GeV Ring at the JHF	F. Noda (JAERI)
AGS High Power Upgrade Plan	W.T. Weng (BNL)
AHF Project	A. Thiessen (LANL)

Beam Studies and Simulations

High Density and High Intensity Beams at CERN-PS	R. Cappi (CERN)
Impedance Reduction in the SPS	E. Shaposhnikova (CERN)
Emittance Dilution in HERA-p	R. Wanzenberg (DESY)
Investigations of Beam Tune and Stability in IPNS-RCS	J. Dooling (ANL)
Multiparticle Longitudinal Dynamics Code ESME	J. MacLachlan (FNAL)
UAL-Development and First Application	N. Malitsky (BNL)

Hardware (JHF and PD)

Longitudinal Dynamics and RF Hardware in JHF	M. Yoshii (KEK)
JHF Beam Injection and Extraction	I. Sakai (KEK)
High Intensity Proton Beam Profile Monitor	T. Toyama (KEK)
Proton Driver Magnet Design	F. Ostiguy (FNAL)
Dual-Harmonic Resonant Power Supply	C. Jach (FNAL)
Proton Driver Vacuum System	T. Anderson (FNAL)

Since full-length papers from the speakers will follow, in this summary I will only review some interesting features that struck my own fancy and point out some connections and similarities between the various subjects discussed.

Of the three projects reported, the Japan Hadron Facility (JHF) is the only one funded and under construction. The parameters and general features of JHF have already been reported in other sessions at this workshop. Other than aiming for high intensity, the unique feature of the project is that the utilities of the beam at each stage of acceleration (600 MeV, 3 GeV, 50 GeV) have been investigated and planned from the beginning. Thus, it will likely prove to be a very productive facility.

The planned high-power upgrades of the AGS are quite ambitious but straightforward in concept. The two stages of beam power upgrade to 0.47 MW and to 2 MW should be attainable; however, much effort and care are required.

The Advanced Hydrotest Facility (AHF) is actually an elaborate proton radiography facility. It consists of a slow-cycling synchrotron that provides very high per-pulse intensity. The 6×10^{13} protons/pulse in the ring are fast extracted into 12 beamlines that converge onto the target. Each beam consists of 29 bunches with 1×10^{11} protons/bunch (allowing for losses), which is adequate for one "frame" of the radiograph. As expected, this interesting machine requires several innovative design features.

A great deal of effort has been devoted to the study of high-intensity beam behavior (emittance growths, coherent instabilities, transition crossing losses, etc.) in the CERN-PS and SPS. These are difficult measurements. The dynamic behavior of the beam is difficult to measure, and the beam parameters are hard to control. Nevertheless, persistent and meticulous efforts have paid off. They have brought agreement between measurement and computation, thereby establishing a reliable understanding of the phenomena.

In the HERA-p ring there is an observed luminosity decay due to intrabeam scattering and a factor of 6 growth in longitudinal emittance due to the coupled bunch instability. On the other hand, in the Argonne Intense Pulsed Neutron Source — Rapid Cycling Synchrotron (IPNS — RCS) the longitudinal emittance is intentionally blown up using a phase shaker (scrambler) to avoid instability.

Two computing developments were reported. The long available longitudinal dynamics program ESME is now equipped with multiparticle capabilities to simulate high intensity beam motion. Both the space charge and the beam-environment impedances can be input directly. Two interesting movies were shown, which exhibit bucket formation in beams interacting with empty rf cavities. An ambitious Unified Accelerator Library (UAL) composed of some ten programs has been compiled, debugged, and benchmarked at BNL. An initial application on the SNS ring has been successfully run.

Several hardware innovations were advanced for both the JHF and the Proton Driver (PD) projects. In the JHF 50-GeV ring we have the following:

1. Split ferrite rings are used in the rf cavities to control the Q.
2. Bipolar kickers and septa were designed for fast beam extraction and abort towards both the inside and the outside of the ring.
3. A clever gas sheet blasted across the beam is developed to use as the screen for displaying the profile of a very intense beam.

For the 15-Hz PD ring:

1. A dual-harmonic resonant power supply is designed to give a slower rise time and faster fall time.
2. To minimize the ring magnet gap, hence the size and cost of the magnet, the magnet-in-vacuum design is again contemplated. A low-temperature (150°C) bake will hopefully keep outgassing under control. The impedance of the exposed magnet laminations would be reduced by a liner or a cage structure. Thin silicon-steel laminations and multi-small-wire cables with radiation-resistant ceramic insulation and water cooling will be used for the magnets.

It s clear that for high intensity machines, beam loss is a major concern. Therefore, reliable and precise evaluation of the beam behavior based on high intensity beam dynamics is of paramount importance.

2.1.3 Working Group II - Linear Accelerators

Roland Garoby (CERN) and Jean-Michel Lagniel (CEA/Saclay)
Working Group Co-Conveners
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Linear hadron accelerators of high intensity/power/energy are at the core of many contemporary projects in the world. They cover a broad range of applications which reflects in the large span of their characteristics and their very different level of advancement, some of them being already approved and in construction, others being simply contemplated as long term possibilities. Based on an original table by T. Wangler (LANL), the compendium given in Table 1 was elaborated during the workshop with the help of the participants. Issues related to these machines were presented either in plenary talks or during the two sessions of working group 2. They all use superconducting RF structures.

The FNAL 8 GeV linac (W. Foster) stands out as the highest energy project, relying on TESLA technology to keep cost acceptable, using a high RF frequency (1.2 GHz) and a very high gradient (≤ 23 MV/m). On the opposite , the 2.2 GeV CERN SPL proposal (R. Garoby) makes use of existing cavities recuperated from LEP, with a low RF frequency (352 MHz) and a modest gradient (≤ 9 MV/m). The other projects assume the construction of accelerating structures optimised for their own use, with intermediate RF frequencies (600-800 MHz) and gradients (≤ 16 MV/m).

Considerations about RF adjustment and losses in the SNS linac were presented by S. Nath (LANL). M. Ikegami described the status of the linac accelerator for the JKJ project in Japan. The plans and studies for ESS and IFMIF (R. Ferdinand), CERN SPL and TRASCO (C. Pagani) were the subject of talks. A. Takagi showed the results obtained with a fast beam chopper modulating energy in front of an RFQ.

Table 1: High Power Linacs Survey

Name	Ion	Pulse Length (ms)	F_{Rep} (Hz)	Duty Factor (%)	I_{Bunch} (mA)	$I_{Average}$ (mA)	Kinetic Energy (GeV)	$P_{Average}$ (MW)	Start date
LANSCE	H^+/H^-	0.625	100/20	6.2/1.2	16/9.1	1.0/0.1	0.8	0.8/0.08	On
SNS	H^-	1.0	60	6.0	38	1.4	1.0	1.4	2006
CERN SPL	H^-	2.8	50	14	22	1.8	2.2	4.0	?
ESS Short Pulse ESS Long Pulse	H^- H^-or H^+	1.2 2/2.5	50 16.67	6.0 4.2	114 114/90	3.75 + 3.75	1.33	5 + 5	2010
FNAL 8 GeV	$H^+/H^-/e$	1.0	10	1.0	25	0.25	8.0	2.0	?
JKJ 400 MeV JKJ 600 MeV	H^-	0.5	50/25 25	2.5 1.25	50	0.7 0.35	0.4 0.6	0.28/0.14 0.21	2006 ?
TRASCO	H^+	∝	0	100	30	30	≥1.0	≥30	?
IFMIF	D^+	∝	0	100	2x125	2x125	0.04	10.0	2010

These presentations and the active discussions they triggered clearly demonstrate that high performance hadron linacs is nowadays a very active field where significant progress can be expected in the coming years.

2.1.4 Working Group III - Beam Lines and Targets

Craig Moore, Alberto Marchionni (Fermilab) and Kirk McDonald (Princeton U.)
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Introduction

How to handle intense beams safely and how to target them safely were the main foci of this working group. The talks were evenly divided between the two subjects.

High Intensity Beamlines

Beam transfer lines for the SNS
D. Raparia (BNL)

The SNS talk was concerned with the physics and diagnostic capability of the beamlines into and out of the Main Ring. The injection line (HEBT) is more than a transfer line with very good diagnostic capability in both longitudinal and transverse dimensions. The line also has the capability of cleaning the beam in both longitudinal and transverse dimensions. The line to the target (RTBT) is noteworthy for its immunity to kicker failure; for one or even two failures the beam motion on target is minimal.

Sophisticated beam permit system
R. Ducar Fermilab
Radiation protection utilizing electronic berms

John Anderson (Fermilab)
Automatic beam line tuning (AUTOTUNE)
T. Kobilarcik (Fermilab)

At Fermilab the upcoming neutrino experiments will deliver more intensity in a single year than was delivered in the seventeen years of running the Fixed Target Program. In MiniBooNE's case the beam will be almost continuous (18,000 pulses/hour). The intensity and nature of these beams have led to the development of control mechanisms for the care and handling of these high intensity beams. To begin with a "Sophisticated Beam Permit System" will check a large number of status bits and analogue information before permitting a pulse of beam. Then an automate intensity checking system will determine how much beam was lost from the beginning of the line to the end of the line (electronic berm system). Finally an automated tuning program (Autotune) will find and correct minor beam wandering before there are sufficient losses that the electronic berm system would stop operation.

Tails of beam distribution
A. Marchionni (Fermilab)

The NuMI project is designed to handle an intensity of up to 4×10^{13} protons delivered in 8 μs pulses every 1.9 s, corresponding to a beam power of 0.4 MW.

For the NuMI beam line the normal concern about ground water activation is exacerbated due to the fact that the sloping beamline traverses the aquifer. . Groundwater protection considerations severely constrain the allowable continuous proton losses. Fractional proton losses below 10^{-4} are required in the sloped transport region, with a tighter limit of about 10^{-6} in a limited 140 ft region at the interface between two geological formations. The primary proton beamline has been carefully designed to take into account these constraints, with input from recent measurements of transverse and longitudinal emittances of the Main Injector beam. A measurement program of beam tails is presently ongoing.

Hign Intensity Targets

Mercury target
K. McDonald (Princeton U.)

Neutrino factories demand targets capable of at least a few MW beam power, optimized for the production of soft pions (50 - 500 MeV/c). A free mercury jet target located inside a solenoidal magnetic field, with a field adiabatically falling off along the axis to provide focusing of the produced pions, is a promising design for 4 MW of beam power. The goal of BNL experiment E951 is to test key components of this design in realistic single pulse beam conditions. In particular the viability of a liquid metal jet target in intense, short proton pulses and in strong magnetic fields has to be investigated.

Simulations of jet distortions due to beam energy deposition and/or eddy currents have been performed. Experimental studies with 2×10^{12} protons on a Hg jet target of 1 cm diameter show no destructive effects. Combined tests of a Hg jet in a proton beam and in a 20 T pulsed magnet are being planned.

Target development for the SINQ high-power neutron spallation source
W. Wagner (PSI)
Carbon and beryllium targets and beam windows at PSI
Gerd Heidenreich (PSI)

PSI has an ongoing program of neutron spallation operation and a target development program for higher power. The SINQ facility has a layout for vertical targeting. This is used for the present Target Irradiation Program but in fact was set up for the proposed liquid metal spallation targets in order to utilize gravity for flow enhancement purposes. The MEGAPIE target is predicted to have a greatly enhanced neutron flux. The present solid targeting arrangement allows many different samples to be irradiated at the same time.

The beamline from Target-E to SINQ (or the dump) is very cleverly designed from a maintenance point of view. The vertical access and in particular the inflatable seal assembly are very important concepts. The rotating targets are well designed to handle the pattern of power deposition.

NuMI target
James Hylen (Fermilab)

The NuMI target has been designed for reliable operation for at least 1 year (~ 10^7 beam pulses) and optimized for neutrino event rate. It has to withstand a 0.4 MW primary proton beam with a spot size of $\sigma_x\ \sigma_y = 0.7 \times 1.4\ mm^2$ and must be capable of handling dynamic thermal stresses due to single-turn extraction. Graphite grade ZXF-5Q from Poco Graphite, Inc. is the chosen target material. A prototype target has been exposed to an accumulated dose of about 2×10^{18} protons/mm^2, corresponding to about 5% of the expected dose for the NuMI target in a year. During the test higher stresses than those expected in the NuMI operation have been induced in the prototype target by the use of a higher flux beam, with 10^{13} protons/pulse over a spot size of $\sigma_x \times \sigma_y = 0.2 \times 0.2\ mm^2$. No visible damage to the target segments was detectable after this irradiation test.

Targetry issues for the Fermilab 2 MW Neutrino superbeam
M. Kostin (Fermilab)

A study was presented for a solid target suitable for a neutrino "superbeam", with a primary proton beam power of 2 MW (5 times the NuMI intensity) and optimized for neutrino energies of about 3 GeV, that is pions around 7 GeV. . A beam spot size of $\sigma_x\ \sigma_y = 3 \times 3\ mm^2$ on a graphite target, with a radius of about 2.5 σ, would give an acceptable energy deposition of 300 J/g and still provide a good yield of ~ 0.3 pions/proton.

2.1.5 Lattice

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Abstract. We discuss here the status of dynamic aperture calculations for the various machines discussed at this workshop. We recommend that these calculations be extended to include all magnet field errors and alignment errors as quickly as possible.

The Convenor's View

At this meeting, we saw many new, innovative lattices proposed for machines either in design phase or in construction. These lattices have many essential features for operation at high current with low losses including explicit collimation schemes, avoiding transition, and intentional eta function manipulation to allow production of short pulses, etc. Most of these lattices have larger acceptance than their predecessors. Dynamic aperture is an important issue to be considered before committing to a final design of any of these machines.

We saw numerous studies of the dynamic aperture of the intrinsic lattices, *i*.e., in the absence of magnet field and alignment errors. Tune issues, placement of chromaticity sextupoles, and nearby structural resonances all play important roles in limiting the dynamic aperture seen. Most of the dynamic aperture studies shown at this workshop did not include magnet errors, although all participants acknowledged that such calculations were planned for the future.

However, there was a general trend. The more magnet imperfections that were included, the smaller was the dynamic aperture. Indeed, the Fermilab Proton Driver talks showed that the differences in dynamic aperture among the various lattice designs tended to disappear when systematic errors of quadrupoles were included in the tracking.

The Los Alamos team found that the dynamic aperture of their lattices was marginal when all magnet errors - random, systematic, and alignment - were included in the tracking[1]. The solution needed at Los Alamos is to build better quadrupole magnets[2].

This reminds us of the early years of operation of the original Fermilab Main Ring. For this machine, the dynamic aperture was found to be very small at injection time, due to unexpected and unanalyzed remnant sextupole and decapole components in the dipole fields. The heroic efforts of many people and on the order of a year's time was needed to correct the dynamic aperture of the Main Ring. We do not want to repeat this exercise.

In contrast, the Fermilab Main Injector dynamic aperture was studied in advance of construction with all errors included. A decision was made to build better dipoles than in the Main Ring, and to operate these dipoles at a higher injection field. Many of the quadrupoles were reused. Tracking with worst-case errors showed that the dynamic aperture at injection time exceeded the physical aperture. Turnon of the Main Injector was rapid and uneventful, as we wish for future machines.

The message is clear – do a dynamic aperture study with all errors in advance of construction. Either provide sufficient quality magnets, or a suitably designed correction scheme such that the dynamic aperture can be made larger than the required aperture. In most cases, the critical time in the accelerator cycle is near injection time, when the required aperture is largest and magnet field errors may be largest.

References

[1] Filippo Neri, Martin Schulze, Dave Johnson, Peter Schwandt, "Transverse Tracking of the AHF Rings", in this workshop proceedings.

[2] Martin Schulze, David E. Johnson and Ben Prichard, Filippo Neri and Arch Thiessen, "Magnets that Meet Tracking Requirements for AHF", in this workshop proceedings.

[3] “The Fermilab Main Injector Technical Design Handbook” 1995, private communication.

2.1.6 Beam Loss, Collimation and Shielding

Nikolai V. Mokhov and R.C. Webber (Fermilab)
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Presentation Overview

This group heard about beam loss, collimation, and shielding issues from a wide range of perspectives including design, simulation, and test and operational experience. The applications covered machines, systems, and processes as diverse as megawatt spallation sources, proton driver machines, high energy beam slow extraction, multi-megawatt spallation targets, colliding 340-MJ beams, and an operational rapid cycling synchrotron.

R. Webber (FNAL) provided a status report on Fermilab Booster operations. Difficulties and efforts to achieve Booster 8 GeV beam operation at 40 kW with acceptable losses were described. Measurement data on current residual radiation levels in the Booster was shown.

S. Cousineau (SNS) presented an efficient two-stage collimator design with performance simulation data for the SNS ring. A necessary design compromise was described in which a secondary collimator needed to be placed at a position of “less than ideal” phase advance in order to reduce the radiation load on a pair of quadrupole doublet magnets in a particularly sensitive location. A moderately complex scheme to clean beam out of the extraction kicker gap prior to extraction to reduce energy deposition on extraction components was described. The beam-cleaning scheme is complicated by the large tune spread in the intense SNS circulating beam. It was noted that a similar “beam in gap” problem exists in high energy collider rings where even a small amount of beam that has escaped RF bucket containment can be sufficient to quench superconducting magnets or damage sensitive particle detectors if partially kicker during the rise time of an abort or extraction kicker magnet. This has been a recent problem in the Tevatron.

C. Warsop (RAL) described collimator designs for the ESS ring. The importance of collimation in achieving acceptable performance at high beam powers was dramatically shown in a picture depicting 25% of the ESS accumulator ring circumference devoted to the collimation system. Another picture showed attention in early design stages paid to critical handling and maintenance issues including quick disconnect services and vacuum seals, modular component design, remote handling mechanisms, and importantly adequate working space in the vicinity of highly activated collimators.

M. Tomizawa (JHF) presented collimator design considerations for a slow extraction system to handle a 50-GeV 750-kW beam. Detailed modeling of collimator performance and interaction of beam with the electrostatic septum wires has been done with the MARS code.

A. Drozhdin (FNAL) informed the group of collimation system designs related to Fermilab Proton Driver proposal efforts. A comprehensive design philosophy for shielding and beam loss control was described. The impact of machine design parameters on collimation system design constraints and options was made apparent by comparison of the designs for an 8-GeV ring and for a 16-GeV ring. In one case, the collimation system could be placed almost completely within one straight section; in the other, it needed to be located in the arc of the ring. Sensitivities of collimation system performance to parameters like closed orbit deviation and betatron tune were shown.

J. Johnson (ORNL) described the impressive code library available at Oak Ridge for radiation shielding design and residual activity predictions. Examples of coupling between codes to take advantage of the best aspects of each while minimizing computing time were shown.

T. Gabriel (ORNL) impressed the group with some of the difficulties of developing and shielding a multi-megawatt neutron spallation target. Actual beam tests have been done at Los Alamos to understand target issues and tackle material deterioration problems caused by hydrodynamic cavitation of the liquid mercury target. The reality of the SNS project situation was “brought home” by pictures he showed of actual site construction. Any remaining SNS design issues must be resolved in a timely manner before they shift from being paper problems to being real problems. The second part of his talk was devoted to targetry and radiation issues of the muon collider and neutrino factory projects, studied in great detail with the MARS code at Fermilab.

J.B. Jeanneret (CERN) steered the session focus from high average power beam to extremely high peak power beams. He talked of the design issues associated with control of colliding 340-MJ beams in the LHC. The stored energy in each of the beams at 7 TeV is sufficient to melt 800 kg of copper in a single pulse. Yet this tremendous stored energy must be contained in a superconducting magnet ring. The LHC collimation system must protect against unavoidable particle losses that are 2 to 3 orders of magnitude above magnet quench limits. In addition, the LHC must survive a dump kicker failure that can spray 7-TeV particles in an uncontrolled manner — the process studied in detail at Fermilab with corresponding protective measures designed.

Summary Observations and Ideas

There is much consensus and are many similarities in approaches to beam loss control, collimation, and radiation shielding on a worldwide basis despite the wide range of machines and initial perspectives:

- Two-stage collimation system designs are nearly universal. These typically utilize a thin primary collimator (scatterer) in each plane followed by one or more absorbers (collimators). The ESS design is an exception, proposing a two-stage system with a thick primary collimator.

- Uncontrolled losses limits at the level of 1 part in 10,000 of the total beam are typical objectives in new machine designs.

- Hands-on maintenance through the bulk of a machine is a goal in all cases with residual dose rates of 10 to 100 mrem/hr (at contact for 30 days irradiation and 1 day cool-down, or at 30 cm from the components for 100 days irradiation and 1 day cool-down) corresponding to about 1 Watt per meter uncontrolled beam loss.

Some concerns were expressed about SNS and ESS modeling approximations that treat normal components in collimator regions as “black absorbers.” Scattered particles, ignored in this approximation, may play a significant role in the beam loss distribution, energy deposition, and residual radiation in collimators and other components.

Important code benchmarking work remains to be done for beam loss, collimation, and residual radiation prediction codes. Some open issues include energy dependence, beam tail modeling, and correlation between particle tracking codes and radiation codes. N. Mokhov suggests definition and development of a “toy model” accelerator, a generally accepted simple but realistic machine model, on which all codes can be run for benchmarking.

R. Webber concluded the summary stating, “Personally, I am anxious for SNS startup as a true test of the validity and appropriateness of the predictions generated by the heroic efforts that have gone into machine performance and beam loss simulations and collimation system design on a worldwide basis”.

2.1.7 FFAG and Cyclotrons

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There were about 25 attendees in this session. Papers presented were as follows:

PSI Cyclotron	P. Schmelzbach
High Intensity Cyclotrons at IBA	Y. Jongen
Isochronous and Scaling FFAGs	R. Baartman
FFAG Development at KEK	Y. Mori
Beam Dynamics in the FFAG	M. Aiba
Non-Scaling FFAGs for Muon Acceleration	C. Johnstone and S. Koscielniak
Longitudinal Motion in Nearly-Isochronous FFAGs	J.S. Berg
Stochastic Cooling in FFAGs	M. Wakasugi

The first 2 speakers emphasized that cyclotrons are indeed high intensity accelerators. Many of the "Cyclone" series of cyclotrons built and commercially available from IBA routinely deliver 10mA of protons for isotope production. The PSI cyclotron (Villigen, Switzerland) routinely delivers >1 MW of beam power (2mA at 590MeV). The TRIUMF cyclotron (Vancouver, Canada) routinely delivers 0.2 MW beam power.

New developments include "self-extraction" and use of molecular hydrogen. A non-intuitive aspect for synchrotron physicists is that at high space charge fields, such as occur in the PSI injector cyclotron, the space charge force in an isochronous machine "curls" up the bunches, reducing their length to equal their width.

With sufficient rf voltage, extraction from machines such as those at PSI can be very clean, with loss on the order of $1{:}10^4$. Machines of the PSI type have been studied to reach yet higher power and energy. An extrapolation to 1GeV and 10mA (10 MW) is considered feasible.

In fact, it is believed that up to this amount of beam power, cyclotrons are a more economic choice than linacs. Energies higher than 1GeV become expensive because isochronism demands that the radial tune be equal to γ (Baartman). This means that for large energy, many low-order resonances are crossed. To avoid low-order intrinsic resonances, requires the cyclotron be composed of many sectors. Intensity larger than 10mA becomes expensive because space charge fattens the turns, making clean extraction only possible for very large energy gain per turn. At some point the rf becomes sufficiently expensive that one might as well save the cost of the magnet and go with a linac.

Between the regimes of the cyclotron and the sychrotron, there is the synchrocyclotron. With the addition of strong focusing, this has come to be known as the FFAG. Strictly speaking however, cyclotrons with sector focusing (this includes practically all modern cyclotrons) are FFAGs, since they use strong focusing and are "fixed field". So there are two types: isochronous FFAGs on the one hand, and pulsed beam FFAGs on the other. If we release the isochronism requirement, the optics can scale from inner radii to outer and the radial tune can be made constant. This allows for extremely large acceptance (Aiba). On the other hand, if the machine is isochronous, beam intensity is large because it is cw, but acceptance is small because of the resonances crossed, as noted above.

As Mori pointed out, pulsed FFAGs have an advantage over synchrotrons besides their large acceptance: Since the magnetic field is fixed, the ramp rate and therefore intensity is limited only by the ability of the rf to ramp quickly. A major development in this regard is the magnetic alloy (MA) rf cavity. The MA of choice (FINEMET) has good μQf up to very high rf excitation, and has a high Curie temperature. Both these features make possible much higher ramp rates and rf voltage as compared with conventional ferrite core cavities. The Mori group has built and commissioned a 0.5MeV "proof of principle" proton FFAG. This machine has demonstrated both high ramping rates and large acceptance.

Both of these features make such machines ideal for accelerating secondary particles such as muons. For the particular application of the ν-factory, a goal is to reach about 20GeV in a short time of about 1ms. FFAGs seem a more natural choice than linacs (recirculating or otherwise) because they have such large acceptance. This has the potential of reducing the very difficult beam cooling requirements. Ideas were presented by Koscielniak, Johnstone and Berg on how to achieve the acceleration in the required time. The extremely short acceleration time implies need for very large rf voltage, which may only be possible with high Q cavities. Since this makes ramping difficult, an idea is to make the machine close enough to isochronous that phase slip over a few turns can be tolerated. The 20GeV FFAG would have a circumference of 2km and to avoid excessive phase slip, acceleration would need to be complete in the order of 10 turns.

Wakasugi presented RIKEN's ideas on using an FFAG and in particular, stochastic cooling inside the FFAG. The application here is to radioactive isotope beams (RIBs). A novel feature of the design is the use of the ASTOR scheme to convert the cw RIB to a pulsed beam before transfer to the FFAG.

2.1.8 New Ideas

Ken Takayama (KEK) and Charles Ankenbrandt (Fermilab)
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In Session D, nine papers were presented. Their subjects are in a wide range of accelerator physics and technology. Their outlines are briefly summarized here. These papers may be classified under 5 topics.

Griffin has reviewed a historic "New Idea" on passive compensation of longitudinal space charge effects by insertion of inductors initiated by Sessler and Vaccaro and related works. In addition, he described milestone experiments that have been performed in the KEK 12 GeV PS and LANL PSR with great success. He addressed the merits and demerits of this technique such as the inherent resonance leading to self-bunching instability at high intensity.

Ongoing plans for RF gymnastics in the Fermilab accelerator complex and a new idea, demonstration of which is expected in near future, have been covered by three papers. Bhat presented experimental results of beam handing with barrier buckets and pbar/proton beams in the Fermilab Recycler Ring. Most important features of longitudinal beam handling such as capture, stacking, and debunching were introduced. These experimentally obtained results will provide guidance for various succeeding applications. Ng presented results of simulations of a method for doubling the beam intensity in the Main Injector with the aid of barrier buckets. Koba discussed slip stacking that had been proposed in order to increase the primary proton-beam intensity for pbar production. A size of sufficient frequency separation to avoid undesired interference between two adjacent booster batches has been experimentally confirmed. Stacking with low intensity beams has been successfully demonstrated. She addressed the importance of beam loading compensation in a practical case at high intensity.

Use of beam echo as a means of beam diagnostics was discussed from both theoretical and experimental perspectives. Stupakov, one of the pioneers developing beam echo since early 90's, presented an instructive view of the theory. Colestock reviewed typical results experimentally obtained in the Fermilab Antiproton Accumulator Ring, CERN SPS, Fermilab Tevatron, and DESY-HERA. Both presentations have emphasized the importance of its application to measurement of small diffusion rates.

A novel concept of super-bunch acceleration, which is expected to be realized in Induction Synchrotrons, was explained by Kishiro, and the R&D status at KEK for required induction accelerating devices was introduced. He asserts that a crucial point of super-bunch acceleration is acceleration by long step-voltages induced in the induction gaps. A proof-of-principle experiment in the KEK 12GeV PS is anticipated to justify reliance on this type of device, because it will replace a conventional RF device.

An ambitious plan, where a post-linac accelerating section called "Linac Afterburner" is installed in the Fermilab 8GeV Booster tunnel, is presented by Popovic. He claims that increasing the injection energy by 200 MeV by means of additional 805 MHz side-coupled cavities could be helpful to mitigate transverse space-charge effects. The plan in near future seems to be quite practical with existing infrastructures and R&D work as well as a reasonable cost estimate.

2.1.9 Space Charge Simulations

Ingo Hofmann (GSI) and Robert Ryne (LBL)
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This session included the following 7 presentations:

"ORBIT: A Code for Collective Beam Dynamics in High Intensity Rings," by S. Cousineau and J. Holmes (ORNL)

"Behavior of Intense Beams with Simpsons," by S. Machida (KEK)

"Coherent Transverse Resonance Effects," by I. Hofmann (GSI)

"Space-Charge Calculation with the code ORBIT," by A. Luccio (BNL)

"Simulation Studies with PATRASH," by Y. Shimosaki (KEK)

"Space-Charge Effects on Beam Loss due to Resonance Overlap," by G. Francetti (GSI)

"Status of the IMPACT Parallel Beam Dynamics Code," by J. Qiang and R. Ryne (LBNL)

The main topic was space-charge simulation in rings. There was a general consensus that linac modeling was well in hand, if compared with ring simulation challenges. The presentations and discussions focused on simulation tools, new phenomena and issues of concern, and future tasks and challenges in space-charge simulations.

As is evident from the list of talks, several simulation tools were presented (ORBIT, Simpsons, PATRASH, IMPACT, Micromap, and others.) Some talks presented comparisons of the various codes, e.g. a comparison of simulation results for ORBIT, Simpsons, and PATRASH. Most of the ring modeling results that were presented used 2D or 2.5D space-charge solvers, in simulations of up to 1000 turns. There were also some reports of 3D simulations (e.g. using IMPACT).

In the area of new phenomena, an important issue was that of the coherent versus incoherent resonance condition. The main point is that the single particle (incoherent) resonance condition needs to be modified if coherent motion occurs. The shift of the resonance provides what I. Hofmann has called the "coherent advantage," meaning that it appears to be possible to propagate beams with higher intensity than would be predicted on the basis of the incoherent condition simply adjusted for space-charge tune spread. This leads to a 30% advantage in the PSR and SNS rings. It was pointed out that this is not a new idea (it was originally due to Sacherer), but it has now been confirmed by simulation in realistic lattices. A related issue that was discussed was the question of whether or not the coherent advantage still applies if resonance crossing occurs over many synchrotron oscillations? It is possible that the synchrotron oscillation might "wash out" the coherent response. This is a question that will be explored in future simulations. Another phenomena discussed were the possibility that space charge might have a beneficial effect on the beam dynamics. This is because space charge detuning in nonlinear resonances (e.g. 3rd and 4th order) leads to self-limitation, making the resonances less serious. In fact, it was mentioned during the discussions that an ideal barrier bucket might be an attractive option from a resonance point of view.

In addition to self-consistent multi-particle simulations, there were also presentations involving analytical and semi-analytical work. It was shown that, in very long (~1 million turn) simulations using an analytical space-charge model, repeated sweeping over resonances could lead to beam blow-up and particle loss. Given the numerical inaccuracies in self-consistent solvers, the question arose as to whether analytical models might provide a higher degree of confidence than self-consistent models over time spans involving hundreds of thousands or millions of turns. One advantage of the analytical models is that it is possible to gain insight from them due to the ability to make "clean" Poincare plots.

During the discussion period following the presentations there was much discussion devoted to the accuracy of Particle-In-Cell (PIC) codes and what they could be reliably predicted by PIC codes. Clearly one needs to pay attention to convergence of the results with respect to grid size, number of simulation particles, step size, number of space-charge kicks, etc. Furthermore, when testing such codes, one test is not enough to cover all problems and range of phenomena (i.e. all resonances, all intensity regimes, etc.). Numerical diffusion is an issue in long-time simulations, particularly given that it may obscure physical diffusion associated with the true dynamics. Numerical diffusion occurs at some level in all simulations, and has been shown to lead to a linearly growing emittance. This is a major issue for long-term simulations, since, e.g., a 1% emittance growth in a 1000-turn simulation would not be acceptable if one was interested in performing longer simulations of 100,000 or more turns. A related issue involves the smoothness of the forces in PIC simulations. If one is very interested in long-time simulations, it may be necessary to use models in which high derivatives of the self-force are continuous across grid boundaries.

In regard to the future, it was felt that the biggest challenges lie in the real of long-term ring simulations. We have reached the point where the current capability of 2D or 2.5D models over ~1000 turns need to be extended to 3D models for 0.1 to 1 million turns. This will require the use of massively parallel computers, and such work is already underway -- Examples include the DOE/HENP SciDAC accelerator-modeling project, the parallelization of ORBIT, and the WARP suite of codes used in the heavy ion fusion community. Finally, the validation of such computer simulations will require sufficient diagnostics in dedicated experiments and sufficient characterization of the machine nonlinearities so that modelers and experiments have an adequate description to quantitatively compare simulations and experiments.

2.1.10 Ion Sources

Horst Klein (Univ. of Frankfurt) and Ka-Ngo Leung (LBL)
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In the ion source session, a total of 9 talks had been given, all of them were very interesting, and presenting new results and generated a lot of lively discussions. It can be considered as a very successful session in this Workshop, putting together the scientists of the leading labs in ion source physics and technology all over the world.

It is remarkable, that most of the talks (7 out of 9) were devoted to the production of H^--ion beams, thus reflecting the increasing importance of such high current sources for many ongoing projects and proposed facilites like spallation neutron sources, accelerator for neutrino production, for high energy physics etc. All these accelerator-based facilities need intense H^--beams from the linacs for the non-Liouvillian injection by charge exchange into synchrotrons or accumulator rings. The requirements for the ion source become more and more stringent: beam currents up to 100 mA, high duty cycles up to 10 % or even 100 %, long pulse lengths (several msec), low noise and beam current fluctuations (1%), good beam quality, low transverse and longitudinal emittance. In addition: The lifetime, reliability, and the availability of the ion source must be very high. It is clear, that in most cases the use of cesium is inevitable. And all these call for more and intensify research work, since so far no H^--ion source worldwide can satisfy all the requirements.

The production of positive ions is much simpler than the prediction of negative ions, but even for them the requirements for many applications (e.g. transmutation, IFMIF, RIA, energy amplification) become difficult. So Richard Pardo, ANL showed that the ion source – it is the ECRIS of course, which is the proper and best choice – had no difficulty to produce the required beam current for the lighter ions (e.g. 600 pμA for mass 1, 29 pμA for mass 40). But for heavier ions, the ECR has to be improved (for example using higher frequencies), since for mass 209 only 5 pμA instead of 11 pμA have been achieved, and for mass 238 only 2 instead of 8 pμA have been obtained.

The ECR is unbeatable for heavy ions, but it can produce also protons in the range of 100 mA continuously, with higher reliability and long lifetime. This has been demonstrated by Robin Ferdinand, CEA Saclay: In long operations, the availability was measured up to 98 % and currents up to 175 mA in pulsed mode have been achieved for deuterons (necessary for IFMIF). In addition to these remarkable experimental results, the Saclay group also develops nondestructive diagnostics, which is essential for the high intensity beams. Especially interesting is the use of the Doppler shift to get the beam profiles from the light produced by the interaction with the residual gas.

Now lets go to H^--sources. Alain Girard, CEA Grenoble, discussed the possibility to use the reliable ECR source for H^--production also. In first tests in Saclay low current H^--beams could be extracted from a modified ECR, but the work has just started, and more optimization, especially in the magnetic field configurations have to be done.

Working horses for pulsed H^--beam production at low duty cycle are the magnetron sources. V. Dudnikov, Fermilab, gave a nice overview on the history and the experiences at Fermilab, and J. Alessi, BNL, presented the results achieved in Brookhaven. In both cases the magnetron sources are working very reliably, but the extrapolation to higher current and high duty cycle seems to be somewhat problematic; V. Dudnikov is more optimistic, recommending the Semiplanotron, whereas J. Alessi sees some difficulties regarding noise and stability.

B. Ellingboe, Dublin City University, comes from the plasma physics side. He showed among others an experiment where the influence of added noble gas on the H^--production is measured. Some surprising results need to be explained, and he pointed out, that the theory of the H^--sources in general has to be improved including the role of the cesium.

J. D. Sherman, LANL, gave an review of the Penning-H^--source. This type of source is very successfully working at ISIS, RAL, for many years. It is based on a Penning source operated in Los Alamos. A scaled Penning source produced later on in 1984 a 250 mA H^- beam, but at low duty cylce. J. Sherman is convinced that using the applied scaling rule further the Penning source can achieve all the properties required by the new accelerator facilities including the high duty cycle.

Another powerful type of ion source is being used for the SNS, the volume source. Roderich Keller, LBNL, reported on the newest achievements. This volume source uses the rf (2 MHZ) for the plasma generation and is based on the developments of K.-N. Leung. The source now produces 50 mA with a duty factor of 6 % and normalized emittance between 0.2 and 0.3 πmm mrad rms. The reliability has substantially improved, especially by a new coating of the antenna. Moreover, the electrostatic LEBT system worked as expected, and the operation with the full RFQ could be done, resulting in very good transmission of more than 90 %. So the crew of R. Keller did an excellent job, achieving all the SNS requirements –congratulations.

J. W. Thomason, RAL, had a difficult task. He had to report on three different H^--sources at DESY, IAP Frankfurt and at Rutherford Laboratory and he did it in a fair and convincing way. In the volume source at DESY, the plasma is produced by rf also, but – in contrast to the Berkeley source – the antenna is now outside of the plasma volume, so the plasma can not damage the coating of the antenna. The source is operating at HERA, therefore the duty cycle is low (0.15 %, τ = 0.15 msec), but it produces 40 mA in pulse mode without cesium! The Frankfurt volume source is working with filaments. It fullfills nearly all the requirement of ESS: 120 mA at 6 % duty cycle, 50 Hz rep. rate, τ = 1.2 msec. The beam quality is excellent. But it has not been operated with an accelerator, only at a test stand so far, and the question of realiability and lifetime has not been addressed yet. The ISIS source is a Penning source, which delivers the beam routinely to the synchrotron. The beam current is 35 mA with the normalized emittance of 2 π mm mrad, pulse length 0.25 msec, rep. rate 50 Hz, and duty factor ~ 1 %. The source is very reliable and can operate about 1 month between services.

The ion sources, and especially the H^--sources, are still somewhat a black magic. Therefore intense theoretical and experimental work has to be performed in different labs to achieve the new requirements. In Europe the NIS-network, supported by the EU, with its 8 partners will help to reach the goal. But also such a meeting as we have had in Fermilab is very helpful and intensifies the worldwide collaboration. Concerning the different types of ion sources, I think the most promising candidates for H^- are the Penning ion source and the volume source.The ECR source may be a hope for the future.

2.1.11 Space Charge Experiments

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There were 7 talks in the Space Charge Experiments Session:

1. Experiment at the KEK PS main ring by S. Igarashi.
Beam profiles were measured at different vertical bare tunes and clear broadening is observed when the bare tune is approaching integer 7. As a function of time, the profile is also measured 3 ms after injection and compared with the ACCSIM simulation. Both agree each other quite nicely when the horizontal bare tune is 7.05. The ACCSIM simulation clearly identifies the octupole resonance that produces the broadening.

2. Experiment at the KEK PS booster by I. Sakai.
Since the bare tune of the booster is (2.17, 2.32), just above the coupling resonance of 2nx – 2ny = 0, space charge forces may induce emittance exchange. Experimentally, that was observed when the beam intensity is increased. Emittance evolution in the first 1 ms is measured and compared with Simpsons that confirms space charge is the source of the exchange, at least qualitatively.

3. Experiments at PSR by S. Cousineau.
Beam broadening has been observed both in experiment and ORBIT. That is analyzed with coherent resonance theory. As a function of several parameters such as longitudinal charge distribution and vertical bare tune, RMS emittance is observed. The results are indeed consistent with the theory and simulation.

4. Measurement of ferrite material characteristics installed as a inductive insert at PSR by B. Ng.
Although the first attempt of the inductive insert at PSR indicated the cancellation of longitudinal space charge force, longitudinal microwave instabilities were observed when

the bunch length is shortened. The real and imaginary part of the ferrite impedance is measured and the reduction of those impedances at high temperature such as 130^{o} C is confirmed. In this way, the microwave instabilities were suppressed.

5. Flattening of bunch shape with longitudinal hallow distribution at CERN PSB by C. Carli.
First, they utilized RF gymnastics with complicated control of phase and amplitude of first and second harmonics. In simulation, a hollow bunch is created as expected, but it may not be easy in reality. During the study, an idea of creating the hollow beam easily comes out. That keeps the first harmonic RF voltage constant and less RF gymnastics of the other parameters. In the experiment, the second way is employed and the resulting distribution is measured using the tomographic method. Hollow bunch created by redistribution of phase space surfaces are confirmed.

6. Measurement of the PSI beam by A. Adelmann.
Transverse beam profiles are measured in the beam line and in the cyclotron. At the same time, simulation with space charge by MAD9P is performed. Agreement is good in general, but at some points, the measurement results are slight different from simulation. One of the reasons may be neutralization, which is not constant in reality but assumed constant in simulation.

7. Current status of beam experiment at University of Maryland including electron ring and 5-beamlet experiment by R. Kishek.
The electron ring is under construction, which is named UMER and aiming research platform for intense beam physics. They intend to study the beam in HIF density regime. The ring should be completed in a year or so. Recently, energy analyzer with 10^{-4} resolution is developed.

2.1.12 H^- stripping

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Outlook of the session

At the beginning of the session, the convener of the session announced that the motivation of this session was to find out a break through, or at least any hint leading it, to the present uneasy situation with the stripping media, and therefore, the session was concentrated upon stripping media. At present, solid foils don't seem enough durable against MW proton beams, but nevertheless we had not yet found out a realistic way of the laser stripping.

The session was composed of two parts; Laser stripping and Foil stripping part, and four and three presentations were given in the respective part.

Laser stripping (chaired by Y. Y. Lee)

In the laser stripping part, three stripping schemes were proposed and an advanced technique on Fabry-Perot resonator was reported.

Of these three laser stripping schemes, two were three-step scenarios; $H^- \rightarrow H^0$, $H^0_{gs} \rightarrow H^{0*}$, $H^{0*} \rightarrow p+e$. Another one was two-step scenario; $H^- \rightarrow H^0$, $H^0_{gs} \rightarrow H^{0*} \rightarrow p+e$. In both scenarios, the first step, $H^- \rightarrow H^0$, is commonly done by Lorentz stripping in a magnetic field. Difference is in following two processes; excitation of H^0 atom from the ground state to a higher excited state and decay of the excited H^0 atom to proton and electron. In the three-step scenario, these processes are done separately. In the two-step scenario, these are inseparable neither spatially nor temporally.

In the three-step scenario, H^0 atoms are excited in the second step by collision with a laser beam in a free space or in a slight magnetic field. Then excited H^0 atoms are stripped by Lorentz stripping in the third step. In this case, following problems take place with the second step. 1) Doppler broadening of the transition frequency distribution occurs due to the momentum spread of H^0 beam. 2) Population of the upper state is saturated to one half by competition of pumping up and down by the laser beam. As a result, if any special measure like the Rabi-oscillation is not taken, stripping efficiency is limited to one half at most.

The scheme proposed by U. Gastaldi is a three-step scenario, and as a measure to the problem 1), scanning of the transition frequency in a slight gradient of magnetic field is adopted. Because no special measure is taken for the problem 2), four or five systems are necessary to achieve a stripping efficiency near to 100%. But such a scheme is considered to be useful when many users must share H0 beams. This scheme is planned to adopt a Favbry-Perot resonator that contains a 10kW/cm^2.

In the other three-step scenario proposed by S. Danilov, the measure to the problem 1) is cancellation of Doppler shift by adjusting dispersion derivative and colliding angle between H^0 and laser beam. As a measure to the problem 2), a Froissart-Stora solution is adopted. In order to obtain necessary high power of the laserbeam, recycling of laser beam is considered at the first stage.

The two-step scenario proposed by I. Yamane is a resonant photo-ionization via a broad Stark state. It utilizes a broad Stark state to cover the Doppler broadening due to the momentum spread of H^0 beams. Since the lifetime of the state is very short, population of the upper state cannot be increased and therefore pumping down of excited H^0 atoms to the ground state is negligible. Thus the ionization efficiency reaches to 100%. Necessary laser power density is supplied by a Fabry-Perot resonator which contains a several kW/cm^2 light beam.

In the report on the development of Fabry-Perot resonator for the PVLAS experiment, G. Cantatore showed that a very powerful Fabry-Perot resonator, which is 6m long and contains a 10kW/cm^2 light beam with a diameter of 10mm, was available by existing technique. Introduction of such an advanced technique of another field of science is expected to bring an important step-up to the accelerator technology.

Foil stripping (chaired by I. Yamane)

M. Borden presented a review on the precious experience of stripping foils at LANL-PSR.

I. Sugai talked on the present status of development of long-lived foils, and indicated that "cluster foil" is a promising candidate. He suggested that temperature control of foils to keep at about 750°C under bombardment might help to elongate the lifetime of foils.

Y. Y. Lee showed the "Diamond foil" was the most long-lived foils. But it needs a frame of Si substrate and the frame may introduce some problems when it is used in a high intensity proton ring. In order to overcome the problems, he proposed a new type of stripping foil; "Diamond foil cylinder".

Summary

It is impressive that patient and steady efforts are continued to develop long-lived foils. These efforts should be encouraged.

Development of lasers stripping showed a spread and three schemes are reported. Introduction of a powerful Fabry-Perot resonator is expected to encourage and accelerate the development of the laser stripping. A demonstration to show that the laser stripping works well is desired to be performed as soon as possible.

2.1.13 Electron Cloud Effects

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Abstract. This is a brief summary of the Electron Cloud Session L at the 20th ICFA Workshop, HB2002. Co-conveners were Robert Macek, LANL and Hitoshi Fukuma, KEK. The session was devoted to a review of the status, recent progress and impact of Electron Cloud Effects (ECE) on circular machines. Observations at both positron and proton machines were presented along with theory and simulations plus the impact of ECE on the joint KEK-JARI project.

Introduction

As noted in the SNOWMASS 2001 workshop report, electron cloud effects (ECEs) are now recognized as a serious problem for many existing and future high intensity accelerators and one that calls for a concerted R&D effort. ECEs have limited the performance and restricted the operating range of several modern storage rings around the world and are a major concern for future, high-intensity accelerators. Possible adverse effects include emittance dilution, single- and coupled- bunch instabilities, particle losses, vacuum degradation, excess power deposition on the chamber walls, and interference with certain diagnostics instrumentation. For these reasons, ECE is a very important and timely topic in the accelerator community and of particular importance to high intensity, high brightness rings, hence its inclusion in this workshop.

1 Agenda

This session was organized to cover a broad range of topics in this field and review the considerable progress that has been made experimentally, on theory and simulations and in dealing with ECE in the operation of existing machines. The list of presentations included:

1. Kathy Harkay (ANL) - *ECE at e+/e- machines and electron cloud diagnostics*.
2. Hitoshi Fukuma (KEK) - *Observations of ECE at KEKB*.
3. Robert Macek (LANL) - *Observations of ECE at the Los Alamos PSR*.
4. Kazuhito Ohmi (KEK) - *Theory and Simulations of the Electron Cloud Instability.*
5. Mauro Pivi (LBNL) - *Simulations of electron cloud generation in the PSR and SNS*.
6. Hong Qin (PPPL) - *Nonlinear delta-f simulations of e-p two-stream instabilities in High-Intensity Beams*.
7. Takeshi Toyama (KEK) - *ECE in the KEK-PS and KEK-JAERI joint project*.

2 Observations of ECE

A reasonably comprehensive list of electron cloud effects and the machines that are affected by ECE or, in the case of proposed machines, are at risk from the ECE includes:

- Beam induced multipacting
    - Resonant (APS, KEKB, PS, SPS), [LHC]
    - Trailing-edge multipactor (PSR), [SNS, JHF]
- Vacuum degradation i.e., electron-stimulated gas desorption, is the most common indication of beam induced multipactor
- Two-stream e-p instability (ISR, PSR, AGSB), [SNS, JHF]
- Transverse coupled bunch instability from EC wake (B factories, PS, SPS), [LHC]
- Single bunch (head-tail) instability; emittance blowup (B factories, PS, SPS)
- Tune shifts (KEKB, AGS Booster)
- Heat load on cryogenic wall [LHC]
- Cloud-induced noise or spurious signals in beam diagnostics (e.g., wire scanners, electrostatic pickups, ionization profile monitors) (PSR, PS, SPS)
- Electrons trapped in distributed ion pump leakage field (CESR)

Harkay reviewed various electron cloud diagnostics, in particular, the elegant retarding field analyzer (RFA) developed at ANL and the electron-sweeping detector developed at LANL. The RFA is a well-characterized device that measures the electron flux, energy spectra and time structure (when augmented with fast electronics) of electrons striking the wall. Since electrons enter the RFA through small slots in the wall and an outer, grounded grid, the collector and bias grid are shielded, and there is very little perturbation of the electron cloud or the beam/wall environment as compared with biased collection plates or buttons. The electron sweeper extends the RFA concept by using a pulsed electrode to sweep low energy electrons from the beam pipe into the RFA. These devices have been key elements for the observation of electron cloud characteristics at APS and PSR. RFA-like devices are now in use or planned at most machines that have encountered ECE. Harkay also discussed the information provided by the RFA to characterize the ECE buildup at the APS and comparisons with simulations by Furman and Pivi at LBNL.

Fukuma reviewed experience with ECE at the KEKB low energy ring (LER), which included observations of emittance growth, instability mode spectra and growth times, tune shifts and luminosity degradation both with and without solenoids. In the absence of mitigation, emittance growth and luminosity degradation greatly limited facility performance. Solenoids, which now cover 95% of the straight sections (~70% of the ring circumference), were most beneficial in suppressing the electron cloud effects and have resulted in a good improvement in the KEKB luminosity.

Beam blowup in the LER at KEKB was eliminated after the last (5th) installment of solenoids. The tune shift along the train (from the electron cloud), which seems to be a good measure of the cloud density, was reduced by at least 40% after the 4th installment of solenoids. Growth rate of the coupled bunch instability was reduced by a factor of two after the 4th installment of solenoids. Mode spectra from simulations of the electron cloud induced coupled bunch instability (solenoids off) are in general agreement with observations for the vertical plane but not for the horizontal plane if the photoelectrons are produced mainly at an illumination point of the synchrotron radiation. However, if the photoelectrons are produced uniformly over the surface of the vacuum chamber, then the simulated mode spectra are consistent with observations for both planes.

Macek discussed the extensive observations and experience with ECE at the Los Alamos PSR. It is now reasonably certain that trailing edge multipactoring causes a good fraction of the prompt electron signal emerging at the end of the beam pulse and striking the chamber wall. The energy spectrum of the prompt component extends to ~400 eV and simulations of this spectrum by the LBNL code POSINST are in reasonable agreement with measurements. Measurements of the electrons surviving the beam-free gap between successive passages of the bunch were made with the electron-sweeping detector. These data provide a lower limit of 1-2% on the beam neutralization, which is sufficient to explain the e-p instability thresholds observed at PSR. Measurements with the electron sweeper also revealed a surprising slow decay (170 ns decay constant) of electrons after the beam was extracted. These data imply a high secondary emission coefficient for the low energy electrons lingering in the gap.

Tests and demonstrations of potential remedies for the e-p instability at PSR included Landau damping by increased rf buncher voltage, transverse coupling, multipoles and inductive inserts. These, along with a conditioning effect, have enabled stable storage of 6.3×10^{13} protons per pulse, which is 60% more than was previously possible without these measures.

Toyama presented data obtained from electrostatic pickups and exciter, which indicated ECE in the KEK-PS (12 GeV main ring). The indication was suppressed with bias voltage or solenoidal fields. Dedicated electrons detectors will soon be installed. Toyama also presented data from KEK on measurements of SEY as a function of primary electron energy for a variety of chamber materials both as received and after sputter cleaning. Most interesting was the improvement in SEY with sputtering. TiN had a peak SEY of ~0.8 and stainless steel a peak SEY of ~ 1.2 after the sputtering treatment.

3 Theory and Simulation of ECE

Ohmi discussed several approaches that he has used to model electron cloud buildup and the resulting instabilities for both positron and proton rings. The electron cloud buildup is calculated in a simulation model, which incorporates a rigid beam, and dynamical electrons that interact with the Coulomb field of the beam and the space charge of the other electrons. Primary electron yields are input to the simulations. In the case of positron rings, the primaries are the well understood photo electrons while for proton rings the source strength from losses and even residual gas ionization is much more uncertain. Instability dynamics were studied using both the wake field approach and direct tracking of both species (beam and cloud macro particles). Coupled bunch instabilities, which were observed at KEK-PF, BEPC and KEKB, are consistent with the simulations. The single bunch instability, which was observed at KEKB, is consistent with simulations for the threshold behavior and the effect of solenoids.

Toyama presented additional results on simulations of ECE for proton rings (JHF 3 GeV RCS, JHF 50 GeV MR, PSR, ISIS and AGS) using the codes and methods developed by Ohmi. He also discussed the implications of ECE for the KEK-JAERI joint project. The electron cloud buildup was presented as a source-independent amplification factor, which multiplies the primary electron yield to give the total electron yield along the beam bunch. PSR had the highest amplification followed by JHF rings and ISIS. The estimates of stability (coasting beam model) showed that PSR would be unstable while ISIS should be stable, which is in qualitative agreement with observations, and that the JHF rings are close to instability. A decision has been taken to use TiN coatings on the 3 GeV RCS while the use of coatings for 50 GeV Main Ring is still being evaluated.

Pivi described the main features of the LBNL code, POSINST, as modified and adapted to simulate electron cloud generation in PSR and SNS. The code employs a rigid proton beam using measured or calculated beam profiles. Electrons move in 3-dimensions subject to 2-dimensional forces from the proton beam and electron cloud space charge. Perfect conductor boundary conditions are imposed at the round or elliptical chamber walls. Primary electrons originate from proton beam losses (4×10^{-6} lost protons/stored proton/turn for PSR) and/or residual gas ionization. For LHC, photoelectron emission is the dominant source of primary electrons. A very detailed model of the secondary emission process at the wall is a hallmark of their code. Their simulations reproduce the general features of the RFA signals and cumulative energy spectra at PSR. For SNS they predict a large neutralization, which is reduced significantly by conditioned TiN coatings. As noted by both Pivi and Ohmi, primary electron source terms and SEY are key input parameters that must be determined by experiment or other analyses.

Hong Qin outlined the key features of the PPPL code (BEST) and discussed the main results to date. They employ self-consistent methods based on the Vlasov-Maxwell equations and use an assumed electron cloud distribution. The code has been parallelized but is still somewhat limited by available computing power. Simulation noise is reduced significantly by the delta-f method. This code does provide a self-consistent description of mode structures, instability thresholds and growth rates. To date, only coasting beams have been studied. Theory and simulations of the e-p instability in bunched beams are under development.

In general, the PPPL results confirm the main results of the centroid model for thresholds and mode structure. Landau damping emerges naturally. Mode structure, thresholds and growth times for the linear phase agree reasonably well with experimental observations. Both theory and simulations predict a saturation level that is probably below the experimental sensitivity and then a growing nonlinear phase. More computing time is needed to follow the nonlinear phase to large amplitude motion.

4 Conclusions

The study of ECE and their mitigation is a very active topic of investigation for both positron and proton machines for the simple reason that ECE is a limiting factor for a number of existing machines and a major concern for future high intensity accelerator facilities. This workshop provided a good overview and highlighted the impact of ECE on high intensity rings and high brightness beams. Significant progress has been made both to understand ECE at a fundamental level and to mitigate the adverse impact on accelerator design and operation. While there has been good progress, the problem is far from resolved. The quantitative agreement between simulated results and measurements remains uneven, and the predictive power of the available tools is insufficient to extrapolate with high confidence the present results to future machines with higher beam intensity. A significant part of the problem for proton machines is the level of uncertainty and ambiguity on the input parameters associated with the primary electrons and the SEY, which must be determined experimentally or by other analyses. More work is clearly needed.

2.2 The 24th ICFA Advanced Beam Dynamics Workshop on Future Light Sources

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The 24th ICFA Advanced Beam Dynamics Workshop was held May 1-4 at SPring-8 in Harima, Japan. With 140 participants representing 37 laboratories from 11 countries, the workshop on Future Light Sources provided a forum for discussions to explore the future of the LINAC-based light sources, particularly FELs and ERLs (Energy Recovery LINACs) in the photon energy region from the vacuum ultraviolet to hard X-ray. The first day was kicked off by K-J. Kim with a plenary talk on Summary of the 17th ICFA Advanced Beam Dynamics Workshop held at APS. Then followed T. Moeller who demonstrated the first scientific result on multi-photon process in molecules and clusters using SASE in the VUV region at the TESLA Test Facility.

The latter half of the morning of Day 1 featured sessions on a general view of future light source developments with three plenary talks. B. Faatz presented the status of SASE developments at TTF, the performances of the hardware (photo-cathode rf-gun, superconducting cavities, undulators, photon diagnostics), CSR effects in the bunch compressor, the results of the characterization of SASE performances in comparison with those derived from the theory, and the plan for TTF phase II aiming at SASE in the soft X-ray region around 10 nm with a 1-GeV Linac. S. Milton presented an overview of the LEUTL and other SASE experiments including optics and scientific applications. C. Sinclair presented an overview of ERLs including the principle, technical challenges and survey of ERL projects in the world.

The first half of the afternoon of Day 1 was dedicated to plans or ideas to utilize SASE for optical experiments. J. Hastings gave a plenary talk on scientific opportunities with LCLS and introduced the first experiments covering various fields such as Femto-chemistry, Nanoscale Dynamics in Condensed Matter, Atomic Physics, Plasma & Warm Dense Matter, Structural Studies in Single Particles and Biomolecules. T. Tschentscher presented an outline of TTF Phase-II for VUV/SX region and also the design for the XFEL laboratory based on 20-GeV Linac. The proposal for BESSY Soft X-ray SASE FEL project based on 2.25-GeV linac, presented by E. Jaeschke, is thought to be complementary with that of the XFEL laboratory at DESY. J. Arthur gave a talk on Synchronization in XFEL Pump-Probe Experiments with less than 1 ps of jitter.

The latter half of the afternoon of Day 1 featured focus sessions on theoretical aspect of SASE. S. Reiche made a plenary talk on Free-Electron Simulation at Short Wavelenghs and showed various vital points in the simulation at short wavelength together with results of start-end simulations applied to VISA –FEL, LEUTL-FEL and TTF-FEL. Z. Huang presented a talk on Recent Progress in the High-Gain FEL theory analyzing SASE properties at various stages of SASE, the start-up, exponential gain, and saturation. E. Saldin showed a theoretical limit of high gain harmonic generation where noise degradation is proportional at least to the square of the frequency multiplication factor. T. Tanaka's talk on undulator segmentation, in particular the result that accurate alignment between segments is unnecessary if the length of segment is longer than two gain lengths, generated much discussion.

The morning of Day 2 was dedicated to accelerator technologies for future light sources; the first half to Linacs for SASE and the latter to ERLs. M. Cornacchia gave a plenary talk on Linacs for SASE including an overview of LCLS project. Then followed T. Shintake, Y. Kim and H. Matsumoto who reported the status of SCSS (SPring-8 Compact SASE Source), an overview (Shintake), bunch compressor (Kim) and C-band linac (Matsumoto). G. Krafft made a plenary talk on "Work on ERLs at Jefferson Lab." where he showed the performance of ERLs in comparison with other sources based on rings or Linacs with high-gradient acceleration, the CEBAF results, and proposal of ERL project in the X-ray region in collaboration with Cornell University. R. Hajima presented the project to reconstruct the existing 15-MeV super-conducting Linac to ERL type. The next three talks described proposals of ERL facilities; 3-GeV X-ray facility at BNL (J. Murphy), 2.5-GeV ultrafast X-ray facility at LBNL (D. Li), 0.6-GeV soft X-ray facility at Daresbury Lab. (M. Poole).

The first half of the afternoon of Day 2 featured focus sessions on insertion device technology and other essential technology such as beam diagnostics. E. Gluskin made a plenary talk on "Undulator Line for SASE FEL" where he described a survey of undulators for different SASE projects (TESLA, LEUTL and LCLS), magnetic & mechanic tolerance in relation to effective saturation length, and beam & photon diagnostics. The demagnetization of undulator magnets irradiated by high-energy electrons was presented by T. Bizen. He showed that Sm2Co17 is superior to NdFe in resistance against irradiation, but the magnetic degradation of even this material cannot be neglected. E. Noelle gave an overview of the electron beam diagnostics for SASE and emphasized the importance of single-shot diagnostic system capable to resolve structures within a bunch. M. Tischer proposed a photon diagnostic system for TESLA XFEL project.

The latter half of the afternoon of Day 2 featured focus sessions on the technology of injector for main linac. C. Sinclair made a plenary talk on photoemission injectors, particularly for ERLs where high average current electron beams are necessary, and concluded that the development of ERLs will require aggressive development in the gun accelerating structure, photoemission cathode technology and unique laser systems matched to the chosen cathode. The next three talks described present status of the development of photo-injectors by F. Sakai (Sumitomo Heavy Industries), F. Stephan (TTF) and L. Serafini (INFN). However, T. Kazuaki showed a different approach based on traditional thermionic gun with very high voltage cathode of 500 kV.

The first half of the morning of Day 3 featured focus sessions on coherent synchrotron radiation (CSR) effects. T. Limberg gave a plenary talk on "Coherent Synchrotron Radiation Effects" where he gave a tutorial talk on CSR, merits and demerits of various codes, dependence on energy spread or emittance, and comparison with experimental results. S. Krinsky presented a theoretical analysis of the CSR instability in a bunch compressor and revealed a mechanism of amplification of density modulation due to CSR fields. M. Borland stressed the importance of Start-to-END (S2E) simulation composed of various codes; PARMERA for injectors, elegant for bunch compressor and GENESIS for SASE simulation.

Starting from the latter half of the morning of Day 3, working group meetings were held to address expert items. There were five groups; WG-I (Optics and Applications, Leader: T. Ishikawa, Co-leader: M. Yabashi), WG-IIa (Linacs for SASE, Leader: J. Rossbach, Co-leader: T. Shintake), WG-IIb (ERLs, Leader: I. Ben-Zvi, Co-leader: R. Hajima), WG-III (FELs, Leader: K-J. Kim, Co-leader: T. Nakamura) and WG-IV (Insertion devices & others, Leader: P. Elleaume, Co-leader: T. Hara). Since there were many common items between WG-IIa and -IIb, joint meeting was held to discuss such items.

The three plenary talks in the first half of the morning of Day 4 were dedicated to the sources based on other than Linac-based FELs and ERLs. Y. Kato presented the status of soft x-ray laser development with short-pulse laser pumping of 100TW power and 20 fs pulse length. A. Ropert gave an ultimate ring source design based on the extension of 3rd generation source concept. The ring proposed here has a circumference of 2 km with a very low emittance less than 0.2 nmrad giving rise to brilliance of 1E23 from spontaneous undulator sources. M.E. Couprie gave an overview on storage ring FEL sources and concluded that the ultimate performance of ring based FELs have not been reached so far. In the latter half of the morning, the summary of each working group meeting was reported. The details will appear in the Proceedings of 24th ICFA Workshop, which will be distributed in August 2002.

2.3 The Future Light Source Mini-Workshop on Coherent Synchrotron Radiation

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An ICFA Beam Dynamics Mini-Workshop on “Coherent Synchrotron Radiation and Its Impact on Beam Dynamics of High Brightness Electron Beams” was held at DESY-Zeuthen, 10-14 January 2002. The workshop was co-chaired by J. Galayda and J. Rossbach and jointly organized by SLAC and DESY, under the auspices of the ICFA Future Light Sources Subpanel. Information on the workshop, including all presentation materials, may be found at the workshop website

http://www.desy.de/csr/

The purpose of the workshop was to assess and compare numerical and analytic predictions of beam dynamics phenomena driven by coherent synchrotron radiation

(CSR). Thirty-five people responded to the workshop invitation. Prior to the workshop, researchers actively developing predictive tools were encouraged to perform calculations of the CSR effects for two "benchmark" problems. The benchmark problems were simple four-magnet chicane bunch compressors, chosen for their relevance to the TESLA and Linac Coherent Light Source free-electron lasers. A summary of numerical results for the benchmarks may be found at:

http://www.desy.de/csr/csr_workshop_2002/csr_workshop_2002_index.html

Numerical benchmark calculations were performed by

- M. Borland, using the 1D code **`elegant`**
- P. Emma, using his 1D code
- M. Dohlus using his 1D code
- P. Piot et al., using the 3D code **TraFiC4**
- L. Giannessi and M. Quattromini, using the 3D code **TREDI**
- R. Li using her 2D code

The results showed good agreement in computation of average energy loss to CSR, reasonable agreement in predicted emittance growth, and some variation in computed energy spread. Variations in results are attributable to several sources, including simplifying approximations for the transverse dependence of the CSR forces and the treatment of space-charge forces (which must be disentangled from forces associated exclusively with CSR). The codes differed in their treatment of transverse dependence of the CSR wake, the inclusion or neglect of transverse forces, and the propagation of CSR forces in conditions where the bunch length and hence the spectral content of the CSR force is evolving rapidly due to the bunch compression process.

It became evident that one of the most important differences between the various results was the handling of the high-frequency cutoff of CSR forces. Most codes applied some smoothing algorithm to the charge distributions used to compute the CSR forces. The CSR wake has a sharp peak at very short (sub-micron) wavelengths, capable of inducing microwave instability during the bunch compression process. Too little or too much smoothing of the charge distribution used in the computation could exaggerate or hide this microwave instability.

The microwave instability mechanism itself received much attention at the workshop. In past years, CSR effects in bunch compressors for colliders and free-electron lasers were thought to be dominated by the envelope of the high-current pulses required in these facilities. Though theory predicted the possibility of a microwave CSR instability in a coasting beam[i], the potential impact of this instability on the performance of free-electron lasers was brought to light in simulations of LCLS performance carried out by Borland[ii], Emma and Stupakov[iii]. The Zeuthen workshop prompted significant progress in theoretical understanding of the CSR microwave instability. Analytical results were presented by Stupakov, Huang, and Schneidmiller that confirmed key characteristics of the phenomena observed in numerical simulations. It became clear that CSR effects can amplify minute current variations in a bunch to produce an energy modulation. The energy modulation is transformed to a larger current variation in the bunch compression process. In this way, the effects of magnets in a bunch compressor chicane, and indeed the effects of subsequent chicanes, can accumulate to degrade the energy spread and also the emittance of the electron beam in the bend plane of the compressors. The CSR microwave instability can be viewed as a broadband amplifier of current fluctuations in an electron bunch, with bandwidth extending into the submicron range for the high currents and small energy spreads of beams for free-electron lasers. The workshop inspired several participants to continue theoretical investigations of the instability[iv].

Experimental results from The CERN CLIC Test Facility (CTF), TESLA Test Facility (TTF), the Argonne Low Energy Undulator Test Line (LEUTL), and the Brookhaven Source Development Lab were also presented. Some showed microbunching effects at high current. Comparison to numerical simulations for CTF, TTF and LEUTL were also presented. Agreement between experiments and simulations was good, though it must be kept in mind that the simulations incorporate many assumptions about input beam properties, which were not completely constrained by the experimental data.

The workshop participants resolved to continue their benchmarking efforts and to meet again at the ICFA Advanced Accelerator and Beam Dynamics Workshop to be held at Chia Laguna, Sardinia 1-6 July 2002. At this workshop it should be possible to do a meaningful comparison of theoretical and numerical predictions of the CSR microwave instability. Information on the Sardinia Workshop may be found at:

http://www.physics.ucla.edu/AABD/index.html

The organization of the workshop was excellent, a credit to the Program Committee (P. Emma, A. Kabel and T. Limberg), the Organizing Committee (Ph. Piot, T. Limberg, D. Lipka and F. Stulle) and the Workshop secretary (C. Oevermann).

2.4 The Ecloud 2002 Mini-Workshop

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A Mini-Workshop, “Electron-Cloud Simulations for Proton and Positron Beams” (ECLOUD'02), was held at CERN from April 15 - 18, 2002. The workshop received an enthusiastic response from the international accelerator physics community as reflected by more than 60 participants from 17 different institutes. This underlines the growing consensus among machine scientists that the electron cloud will likely become a performance limit for many next generation high-intensity rings. ECLOUD'02 was organized by members of the Accelerator Physics group in the CERN SL Division (F. Ruggiero, G. Rumolo, J. Thomashausen, F. Zimmermann). Participants from CERN included many members of the SL Operation group, the PS Experimental Areas group and the LHC Vacuum group.

Beam induced multipacting, instabilities and beam blow-up driven by the accumulated electrons have been observed at many accelerators around the world, for example at CERN with the LHC proton beam in the SPS and in the PS, at the SLAC and KEK B factories, at the Los Alamos PSR, at the Bejing Electron Positron Collider, etc. The pressure increase caused by the electron cloud, its impact on beam diagnostics and, for the LHC, the heat load on the beam screen and cold bore are further primary concerns. Simulations for future linear colliders and intense proton drivers suggest that in these machines electrons in the vacuum chamber may reach densities higher by up to a factor 10 — 100 than in existing machines.

The electron cloud induces betatron tune shifts, tune spread, and transverse single- and multi-bunch instabilities. A variety of theoretical and simulation approaches have addressed these possibilities. A number of simulation codes have also been developed, using different approximations and including different physics. ECLOUD'02 has reviewed the present analytical, simulation and modeling approaches to the electron-cloud problem, determined the important outstanding questions, and developed a strategy for further R&D. Reports on the current status of experimental observations worldwide served as a motivation and benchmark for the simulation studies.

Experimental work carried out at many different laboratories (KEK, SLAC, CERN, LANL, BNL, LBNL, IHEP, ANL) was reported in the two opening sessions of the workshop (Monday 15 April). This session also included results from laboratory measurements of secondary emission and of electron energy spectra, which are an invaluable input for the electron-cloud modeling. Tuesday's sessions were entirely devoted to the simulations of the electron cloud build up and of the associated beam instabilities. They included presentations of the physics models, which form the basis of the existing simulations codes, discussions of simulation results and comparisons of simulations and observations. In particular, several reports on the simulation of single-bunch instabilities driven by the electron cloud, e.g., by K. Ohmi (KEK), G. Rumolo (CERN), Y. Cai (SLAC), and J. Xing (IHEP), and on theoretical studies by S. Heifets (SLAC), E. Metral (CERN) and E.Perevedentsev (BINP) demonstrated the recent fast progress in the field.

Wednesday's two sessions concentrated on plasma physics approaches and on future research and development as well as possible remedies to the electron cloud problems, respectively. A highlight was the presentation by T. Katsouleas (University of Southern California) who applied the sophisticated and well-benchmarked plasma simulation codes which were developed at USC/UCLA to the electron cloud in the CERN SPS, and who also pointed out the importance of cloud image forces. A further intensified collaboration with the USC group is foreseen. Another interesting simulation result is the surprising strength of the horizontal wake field in a combined function magnet, presented by G. Rumolo (CERN).

F. Caspers (CERN) drew attention to the possible interaction of microwaves with the electrons. He proposed an experimental study of trapped modes near the PEP-II collimators and their effect on the electron cloud, which is now imminent. He stressed that rf waves could also be intentionally fed into the vacuum chamber as a possible means to suppress the cloud.

The workshop sessions were summarized on Thursday morning by R. Macek (LANL), O. Gröbner (CERN), M. Furman (LBNL), A. Wolski (LBNL), R. Assmann (CERN), and W. Chou (FNAL), who highlighted the necessity of strengthening the international collaboration on electron-cloud effects. With this goal in mind, a few key contact persons were selected from different institutions, who agreed to coordinate future worldwide activities related to laboratory measurements (F.-J. Decker, SLAC; F. Ruggiero, CERN; S. Kato, KEK), theoretical approaches (A. Chao, SLAC; M. Furman, LBNL; S. Heifets, SLAC), and simulation-code comparisons (F. Zimmermann, CERN).

The ECLOUD'02 program, presentations, and papers are posted on the workshop web site (http://wwwslap.cern.ch/collective/ecloud02}. The proceedings will be published as a CERN report. Workshop participants were encouraged to submit their contributions to a special ECLOUD'02 conference edition of Physical Review Special Topics - Accelerators and Beams.

3: Activity Reports

3.1 Real Time Radiation Simulator

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The best way to study radiation mechanism from a moving charge will be firstly to see dynamic picture of the radiation field. "Radiation2D" computes the electromagnetic field in real time and shows animation of the field lines on a PC computer. Using this software, one can see how the deformation of electric field line (this is the origin or the radiation) is generated with the motion of charge, and how the radiation propagates along the field lines. Once we understand the radiation process in graphically, it becomes much easier to follow the complicated math process to describe the synchrotron and the undulator radiations. It is also useful to study a new type of phenomena such as the coherent synchrotron radiation in a bending magnet.

Now, how does it work? It does not solve the retarded potential, and it is not the finite difference solver of the Maxwell's equation. It directly solves the motion of the electric field lines and the wave fronts. As like the conformal mapping technique, the code treats the 2D grid space consists of the field lines and wave fronts. It should be noted that they are not orthogonal in this case. This is due to the light aberration effect. Any trajectory of electron motion can be separated into a series of linear segments. Within this short segment, the electric field lines uniformly spread from the center on the electron rest frame. Because of the relativistic effect, from the laboratory frame the observed electric field lines concentrate towards the electron motion. This is so called “light aberration”. It defines the initial condition of the field lines at the origin (electron position).

Once the wave is emitted from a moving electron in free space, the spherical wave front propagates outward with speed of the light. It does not change its direction and speed in free space. This is known as Huygens theorem. The code simply expands the wave fronts with same amount in each time step.

Although the software is simple, it correctly illustrates a beautiful nature of radiations as the synchrotron radiation (Fig.1), or the undulator radiation (Fig.2). The software can be downloaded from http://www-xfel.spring8.or.jp as a freeware. For more detail, please refer Ref.[1]

References

[1] T. Shintake, “New Mathematical Method for Radiation Field of Moving Charge”, contributed to EPAC2002, Paris, June 2002, PDF file is available from http://www-xfel.spring8.or.jp.

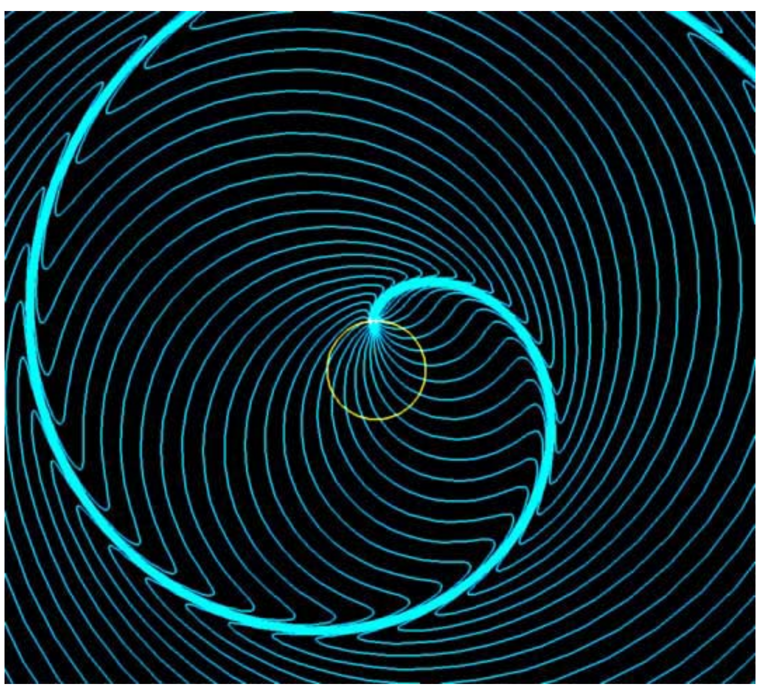

Figure 1. Synchrotron radiation at v = 0.9c.

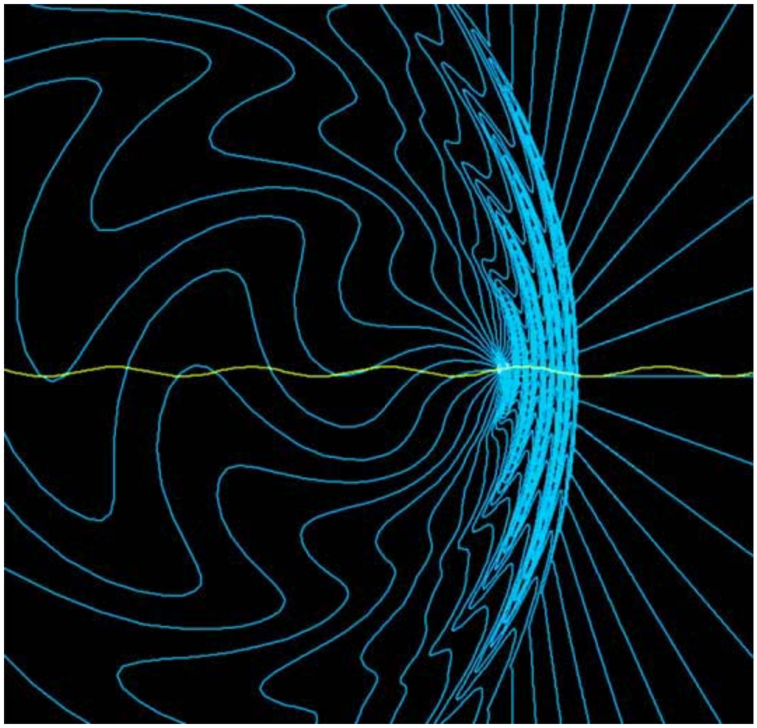

Figure 2. Undulator radiation at v = 0.9c and K=1.

3.2 Analogies between Light Optics and Charged Particle Optics

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1. Introduction

Historically, variational principles have played a fundamental role in the evolution of mathematical models in classical physics, and many equations can be derived by using them. Here the relevant examples are Fermat's principle in optics and Maupertuis' principle in mechanics. The beginning of the analogy between geometrical optics and mechanics is usually attributed to Descartes (1637), but actually it can traced back to Ibn Al-Haitham Alhazen (0965-1037) [1]. The analogy between the trajectory of material particles in potential fields and the path of light rays in media with continuously variable refractive index was formalized by Hamilton in 1833. The Hamiltonian analogy lead to the development of electron optics in 1920s, when Busch derived the focusing action and a lens-like action of the axially symmetric magnetic field using the methodology of geometrical optics. Around the same time Louis de Broglie associated his now famous wavelength to moving particles. Schrödinger extended the analogy by passing from geometrical optics to wave optics through his wave equation incorporating the de Broglie wavelength. This analogy played a fundamental role in the early development of quantum mechanics. The analogy, on the other hand, lead to the development of practical electron optics and one of the early inventions was the electron microscope by Ernst Ruska. A detailed account of Hamilton's analogy is available in [2]-[4].

Until very recently, it was possible to see this analogy only between the geometrical-optic and classical prescriptions of electron optics. The reasons being that, the quantum theories of charged particle beam optics have been under development only for about a decade [5]-[7] with the very expected feature of wavelength-dependent effects, which have no analogue in the traditional descriptions of light beam optics. With the current development of the non-traditional prescriptions of Helmholtz optics [8] and the matrix formulation of Maxwell optics [9], accompanied with wavelength-dependent effects, it is seen that the analogy between the two systems persists. The non-traditional prescription of Helmholtz optics is in close analogy with the quantum theory of charged-particle beam optics based on the Klein-Gordon equation. The matrix formulation of Maxwell optics is in close analogy with the quantum theory of charged-particle beam optics based on the Dirac equation. This analogy is summarized in the table of Hamiltonians. In this short note it is difficult to present the derivation of the various Hamiltonians, which are available in the references. We shall briefly consider an outline of the quantum prescriptions and the non-traditional prescriptions respectively. A complete coverage to the new field of *Quantum Aspects of Beam Physics* (**QABP**), can be found in the proceedings of the series of meetings under the same name [10].

2. Quantum Formalism

The classical treatment of charged-particle beam optics has been extremely successful in the designing and working of numerous optical devices, from electron microscopes to very large particle accelerators. It is natural, however to look for a prescription based on the quantum theory, since any physical system is quantum mechanical at the fundamental level! Such a prescription is sure to explain the grand success of the classical theories and may also help get a deeper understanding and to lead to better designing of charged-particle beam devices. The starting point to obtain a quantum prescription of charged particle beam optics is to build a theory based on the basic equations (Schrödinger, Klein-Gordon, Dirac) of quantum mechanics appropriate to the situation under study. In order to analyze the evolution of the beam parameters of the various individual beam optical elements (quadrupoles, bending magnets,…) along the optic axis of the system, the first step is to start with the basic time-dependent equations of quantum mechanics and then obtain an equation of the form

$$i\eta \frac{\partial}{\partial s}\psi(x,y;s) = \hat{H}(x,y;s)\psi(x,y;s) \qquad (1)$$

where (*x,y;s*) constitute a curvilinear coordinate system, adapted to the geometry of the system. Eq. 1 is the basic equation in the quantum formalism, called as the *beam-optical equation*; H and ψ as the *beam-optical Hamiltonian* and the *beam wavefunction* respectively. The second step requires obtaining a relationship between any relevant observable $\{\langle O\rangle(s)\}$ at the transverse-plane at s and the observable $\{\langle O\rangle(s_{\rm in})\}$ at the transverse plane at $s_{\rm in,}$ where $s_{\rm in}$ is some input reference point. This is achieved by the integration of the beam-optical equation in (1)

$$\psi(x,y;s) = \hat{U}(s,s_{in})\psi(x,y;s_{in}) \qquad (2)$$

which gives the required transfer maps

$$\langle O(s_{in})\rangle \longrightarrow \langle O(s)\rangle = \langle \psi(x,y;s)|O|\psi(x,y;s)\rangle\,,$$
$$= \langle \psi(x,y;s_{in})|\hat{U}^{\uparrow} O \hat{U}|\psi(x,y;s_{in})\rangle\,. \qquad (3)$$

The two-step algorithm stated above gives an over-simplified picture of the quantum formalism. There are several crucial points to be noted. The first-step in the algorithm of obtaining the beam-optical equation is not to be treated as a mere transformation, which eliminates t in preference to a variable s along the optic axis. A clever set of transforms are required which not only eliminate the variable t in preference to s but also give us the s-dependent equation which has a close physical and mathematical analogy with the original t-dependent equation of standard time-dependent quantum mechanics. The imposition of this stringent requirement on the construction of the beam-optical equation ensures the execution of the second-step of the algorithm. The beam-optical equation is such that all the required rich machinery of quantum mechanics becomes applicable to the computation of the transfer maps that characterize the optical system. This describes the essential scheme of obtaining the quantum formalism. The rest is mostly mathematical detail, which is inbuilt in the powerful algebraic machinery of the algorithm, accompanied with some reasonable assumptions and approximations dictated by the physical considerations. The nature of these approximations can be best summarized in the optical terminology as a systematic procedure of expanding the beam optical Hamiltonian in a power series of $\left|\hat{\boldsymbol{\pi}}_{\perp}/p_o\right|$, where p_0 is the design (or average) momentum of beam particles moving predominantly along the direction of the optic axis and $\hat{\boldsymbol{\pi}}_{\perp}$ is the small transverse kinetic momentum. The leading order approximation along with $\left|\hat{\boldsymbol{\pi}}_{\perp}/p_o\right| << 1$, constitutes the paraxial or ideal behaviour and higher order terms in the expansion give rise to the nonlinear or aberrating behaviour. It is seen that the paraxial and aberrating behaviour get modified by the quantum contributions which are in powers of the de Broglie wavelength $\bar{\lambda}_0 = \eta/p_0$. The classical limit of the quantum formalism reproduces the well-known Lie algebraic formalism [11] of charged-particle beam optics.

3. Light Beam Optics: Non-Traditional Prescriptions

The traditional scalar wave theory of optics (including aberrations to all orders) is based on the beam-optical Hamiltonian derived by using Fermat's principle. This approach is purely geometrical and works adequately in the scalar regime. The other approach is based on the *square-root* of the Helmholtz operator, which is derived from the Maxwell equations [11]. This approach works to all orders and the resulting expansion is no different from the one obtained using the geometrical approach of Fermat's principle. As for the polarization: a systematic procedure for the passage from scalar to vector wave optics to handle paraxial beam propagation problems, completely taking into account the way in which the Maxwell equations couple the spatial variation and polarization of light waves, has been formulated by analyzing the basic Poincaré invariance of the system, and this procedure has been successfully used to clarify several issues in Maxwell optics [12].

In the above approaches, the beam-optics and the polarization are studied separately, using very different machineries. The derivation of the Helmholtz equation from the Maxwell equations is an approximation as one neglects the spatial and temporal derivatives of the permittivity and permeability of the medium. Any prescription based on the Helmholtz equation is bound to be an approximation, irrespective of how good it may be in certain situations. It is very natural to look for a prescription based fully on the Maxwell equations, which is sure to provide a deeper understanding of beam-optics and light polarization in a unified manner.

The two-step algorithm used in the construction of the quantum theories of charged-particle beam optics is very much applicable in light optics! But there are some very significant conceptual differences to be born in mind. When going beyond Fermat's principle the whole of optics is completely governed by the Maxwell equations, and there are no other equations, unlike in quantum mechanics, where there are separate equations for, spin -1/2, spin -1, etc.

Maxwell's equations are linear (in time and space derivatives) but coupled in the fields. The decoupling leads to the Helmholtz equation, which is quadratic in derivatives. In the specific context of beam optics, purely from a calculational point of view, the starting equations are the Helmholtz equation governing scalar optics and for a more accurate prescription one uses the full set of Maxwell equations, leading to vector optics. In the context of the two-step algorithm, the Helmholtz equation and the Maxwell equations in a matrix representation can be treated as the `basic' equations, analogue of the basic equations of quantum mechanics. This works perfectly fine from a calculational point of view in the scheme of the algorithm we have.

Exploiting the similarity between the Helmholtz wave equation and the Klein-Gordon equation, the former is linearized using the Feshbach-Villars procedure used for the linearization of the Klein-Gordon equation. Then the Foldy-Wouthuysen iterative diagonalization technique is applied to obtain a Hamiltonian description for a system with varying refractive index. This technique is an alternative to the conventional method of series expansion of the radical. Besides reproducing all the traditional quasiparaxial terms, this method leads to additional terms, which are dependent on the wavelength, in the optical Hamiltonian. This is the non-traditional prescription of scalar optics.

The Maxwell equations are cast into an exact matrix form taking into account the spatial and temporal variations of the permittivity and permeability. The derived representation using 8 x 8 matrices has a close algebraic analogy with the Dirac equation, enabling the use of the rich machinery of the Dirac electron theory. The beam optical Hamiltonian derived from this representation reproduces the Hamiltonians obtained in the traditional prescription along with wavelength-dependent matrix terms, which we have named as the *polarization terms*. These polarization terms are very similar to the spin terms in the Dirac electron theory and the spin-precession terms in the beam-optical version of the Thomas-BMT equation. The matrix formulation provides a unified treatment of beam optics and light polarization. Some well-known results of light polarization are obtained as a paraxial limit of the matrix formulation [12]. The traditional beam optics is completely obtained from our approach in the limit of small wavelength, $\bar{\lambda}_0 \longrightarrow 0$, which we call as the traditional limit of our formalisms. This is analogous to the classical limit obtained by taking $\eta \longrightarrow 0$, in the quantum prescriptions.

From the Hamiltonians in the Table we make the following observations: The classical/traditional Hamiltonians of particle/light optics are modified by wavelength-dependent contributions in the quantum/non-traditional prescriptions respectively. The algebraic forms of these modifications in each row is very similar. This should not come as a big surprise. The starting equations have one-to-one algebraic correspondence: Helmholtz ↔ Klein-Gordon; Matrix form of Maxwell ↔ Dirac equation. Lastly, the de Broglie wavelength $\bar{\lambda}_0$, and $\bar{\lambda}$ have an analogous status, and the classical/traditional limit is obtained by taking $\bar{\lambda}_0 \longrightarrow 0$ and $\bar{\lambda} \longrightarrow 0$, respectively. The parallel of the analogies between the two systems is sure to provide us with more insights.

4. Hamiltonians in Different Prescriptions

The following are the Hamiltonians, in the different prescriptions of light beam optics and charged-particle beam optics for magnetic systems. $\hat{H}_{o,p}$ are the paraxial Hamiltonians, with lowest order wavelength-dependent contributions.

Table 1

Light Beam Optics	Charged Particle Beam Optics
Fermat's Principle	**Maupertuis' Principle**
$H = -\{ n^2(\boldsymbol{r}) - \boldsymbol{p}_\perp^2 \}^{1/2}$	$H = -\{ p_0^2 - \pi_\perp^2 \}^{1/2} - qA_z$
Non-traditional Helmholtz	**Klein-Gordon Formalism**
$\hat{H}_{o,p} = -n(\boldsymbol{r}) + \frac{1}{2n_o}\hat{\boldsymbol{p}}_\perp^2 - \frac{i\bar{\lambda}}{16n_0^3}[\hat{\boldsymbol{p}}_\perp^2, \frac{\partial}{\partial z}n(\boldsymbol{r})]$	$\hat{H}_{o,p} = -p_0 - qA_z + \frac{1}{2p_o}\hat{\pi}_\perp^2 + \frac{i\eta}{16p_0^4}[\hat{\pi}_\perp^2, \frac{\partial}{\partial z}\hat{\pi}_\perp^2]$
Maxwell, Matrix	**Dirac Formalism**
$\hat{H}_{o,p} = -n(\boldsymbol{r}) + \frac{1}{2n_o}\hat{\boldsymbol{p}}_\perp^2 - i\bar{\lambda}\beta\Sigma.\boldsymbol{u} + \frac{1}{2n_0}\bar{\lambda}^2\omega^2\beta$	$\hat{H}_{o,p} = -p_0 - qA_z + \frac{1}{2p_o}\hat{\pi}_\perp^2 - \frac{\eta}{2p_0}\{\mu\gamma\boldsymbol{\Sigma}_\perp.\boldsymbol{B}_\perp + (q+\mu)\Sigma_z B_z\} + i\frac{\eta}{m_0 c}\varepsilon B_z$

Notations

Refractive index, $n(\boldsymbol{r}) = c\sqrt{\varepsilon(\boldsymbol{r})\mu(\boldsymbol{r})}$

Resistance, $h(r) = \sqrt{\mu(\boldsymbol{r})/\varepsilon(\boldsymbol{r})}$

$\boldsymbol{u}(\boldsymbol{r}) = -\frac{1}{2n(\boldsymbol{r})}\nabla n(\boldsymbol{r})$

$\boldsymbol{\omega}(\boldsymbol{r}) = \frac{1}{2h(\boldsymbol{r})}\nabla h(\boldsymbol{r})$

$\boldsymbol{\Sigma}$ and β are the Dirac matrices.

$\hat{\boldsymbol{\pi}}_\perp = \hat{\boldsymbol{p}}_\perp - q\boldsymbol{A}_\perp$

$\mu_{\rm a}$ anomalous magnetic moment.

$\varepsilon_{\rm a}$ anomalous electric moment.

$\mu = 2m_0\mu_a/\eta, \quad \varepsilon = 2m_0\varepsilon_a/\eta$

$\gamma = E/m_0c^2$

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4: Recent Doctoral Theses

4.1 Design and testing of a high gradient radio frequency cavity for the muon collider

Author: Vincent Wu
Institution: University of Cincinnati
Title: Design and testing of a high gradient radio frequency cavity for the muon collider
Date: May 2002
Supervisors: Norbert Holtkamp, Randy Johnson, and Alfred Moretti
Reference: (1) Proceedings of the XX International Linac Conference, August 2000
(2) MUC-NOTE-COOL-exp-0235, May 2002, Fermilab
Keywords: high gradient cavity, muon collider

Abstract:
This thesis describes the design and testing of a high gradient RF cavity for the muon cooling channel of the muon collider. The 805 MHz multi-cell open iris cavity was high power tested with a 12 MW klystron in a superconducting solenoid environment. The cavity reached 21 MV/m for peak klystron power in the absence of the solenoidal field. During magnetic field operation, the cavity suffered serious surface damage and RF breakdown. Dark current in excess of 400 mA was observed. Present R&D results imply that the cavity is not suitable for the muon collider.

5: Forthcoming Beam Dynamics Events

5.1 ICFA Advanced Beam Dynamics Workshop

5.1.1 26$^{th:}$ NANOBEAM2002

The 26th Advanced Beam Dynamics Workshop on Nanometre-Size Colliding Beams (NANOBEAM2002) will be held at Lausanne, Switzerland on 2-6 September 2002. The registration deadline is 15 July. A workshop bank account has been set up, posters have been ordered and will be distributed shortly. Registrations and abstracts are coming in. A draft schedule exists. Satellite meetings during EPAC will finalise the programme and invited speakers. Lausanne University has applied for student grants from Swiss funding agencies (Japan 3, UK 2, US 1, Germany 1). The latest information is posted on the workshop web site:

http://icfa-nanobeam.web.cern.ch/icfa-nanobeam/

5.1.2 27th: High Brightness Electron Beams

The 27th Advanced Beam Dynamics Workshop on the Physics and Applications of High Brightness Electron Beams will be held on 1-6 July 2002, near Cagliari, Sardinia. The Beam Dynamics Panel and the Panel on Advanced and Novel Accelerators jointly sponsor this workshop. Information is available at

http://www.physics.ucla.edu/AABD/index.html

5.1.3 28th: Quantum Aspects of Beam Dynamics 2003

1. Introduction

The frontiers of beam research point to increasing high energy, greater brightness and lower emittance beams with ever-increasing particle species. These demands in turn have triggered a rapidly growing number of beam phenomena that involve quantum effects. In addition, the knowledge on advanced accelerator concepts may help to shed lights on astrophysical phenomena such as the production of ultra high energy cosmic rays.

Based on the success of the first two workshops under the same title (Monterey 1998 and Capri 2000), we are organizing the 3rd workshop in this series to further propagate this rapidly developing new subject.

2. Time and Place

Time: January 7-11, 2003
Place: Faculty Club, Hiroshima University, Higashi-Hiroshima, Japan

3. Sponsorship

Jointly sponsored by ICFA Panel on Beam Dynamics and Panel on Advanced and Novel Accelerators, Japanese Beam Physics Club, Hiroshima University, and the US Department of Energy.

4. International Advisory Committee*

J. Dorfan (SLAC), E. Picasso (Pisa), A. Sessler (LBL), A. Skrinsky (BINP), H. Sugawara (KEK), D. Sutter (USDOE), S. Tazzari (Rome), A. Wagner (DESY), T. Wilson (CERN), M. Witherell (Fermilab),
ICFA Beam Dynamics Panel and Advanced Accelerator Research Panel members
*To be confirmed

5. Program Committee

D. Barber (DESY), S. Chattopadhyay (LBL), P. Chen (SLAC) (Chairman), A. Dragt (U. Maryland), K. J. Kim (Argonne), K. McDonald (Princeton), C. Pellegrini (UCLA), M. Pusterla (Padova), F. Ruggiero (CERN), R. Ruth (SLAC), T. Tajima (JAERI), V. Telnov (BINP), E. Uggerhoj (Aarhus), K. Yokoya (KEK)

6. Organizing Committee

P. Chen (SLAC), A. Ogata (Hiroshima Univ.) (Chair), K. Hirata (Graduate University for Advanced Studies, Japan), I. Endo (Hiroshima Univ.), H. Okamoto (Hiroshima Univ.), T. Takahashi (Hiroshima Univ.), M. Uesaka (Univ. of Tokyo), K. Nakajima (KEK/GUAS/JAERI)

7. Conference Topics

a) Quantum Fluctuations in Beam Dynamics:
Synchrotron radiation and spin polarization in storage rings, spontaneous/stimulated emissions in FELs, radiation reaction in focusing systems, etc.

b) Photon-Electron Interaction in Beam Production, Cooling, Monitoring:
Laser cooling, Compton backscattering, laser beam slicing, laser wire, quantum efficiency in photocathodes, laser-plasma electron source, quantum effects in SASE FEL, quantum effects in muon cooling, etc.

c) Physics of Condensed Beams:
Production and handling of Bose-Einstein Condensate atomic beams, crystallization / Fermi-liquidation of ion, proton, and electron beams, ultimate limit of low emittance photon beams, etc.

d) Beam Phenomena under Strong EM Fields:
Beamstrahlung, coherent pair creation, minijets, crystal channeling, nonlinear QED in heavy ion collisions, etc.

e) Astro-Beam Physics and Laboratory Astrophysics:
High energy, high intensity astrophysical phenomena, acceleration mechanisms for ultra-high energy cosmic rays, mechanisms for cosmic magnetic field generation, nature and dynamics of black hole accretion disks and jets, event horizon in violent acceleration, laboratory studies of astrophysics using intense lasers and charge particle beams, etc.

f) Quantum Methodologies in Beam Physics:
Uses of renormalization theory, supersymmetry, Wigner function, Schrodinger equation, Dirac equation, etc., in beam physics.

5.2 ICFA Mini-Workshops on High Intensity High Brightness Hadron Beams

5.2.1 10th: Slow Extraction

We are pleased to announce that the 10th ICFA mini-workshop on slow extraction will be held during the week of October 14 - 18, 2002 at Brookhaven National Laboratory (BNL), in Upton NY on Long Island. The workshop will focus on topics related to slow extraction of beams from particle accelerators. Topics will include low loss extraction techniques, slow extraction of bunched beams, fast-slow extraction, collective effects, spill structure correction systems, as well as technological innovations in extraction devices and instrumentation.

The program for this workshop will be broken up into talks and discussion groups. There will be no parallel sessions. Our goal is to establish an atmosphere in which experts and students can become immersed in stimulating discussions and focus on the many interesting problems associated with slow extraction of particle beams.

This workshop is intended to be a small very focused meeting. Participants will be able to stay on site at BNL. Brookhaven National Laboratory is nestled in the pristine eastern part of Long Islands pine barrens, close to ocean beaches and parks. It is located close to Long Island wineries to the east and New York City to the west. There will be a tour of the RHIC facility and experiments, and the AGS. The meeting will also include a reception and a banquet dinner on site at BNL.

We invite researchers and slow extraction practitioners who would like to give a presentation of their work at this workshop to send a short abstract to us. We are currently compiling abstracts and organizing the program. Please send abstracts to kbrown@bnl.gov on or before August 31, 2002.

For more details on the workshop please visit:

http://www.agsrhichome.bnl.gov/ICFA2002/

Local Organizing Committee:

Kevin Brown (Chair)	kbrown@bnl.gov
Nick Tsoupas	tsoupas@bnl.gov
Ray Fliller	rfliller@bnl.gov

Workshop Secretary:

Mary Campbell	maryc@bnl.gov

5.2.2 11th: Diagnostics for High Intensity Hadron Machines

This workshop will be held at the Spallation Neutron Source project in Oak Ridge TN, USA for 2-½ days, from October 21-23, 2002.

An initial session is aimed at presenting the accelerator physicists' point of view on desired diagnostic capabilities for future high intensity devices. This will be followed by several sessions surveying present diagnostic capabilities as well as new diagnostic R&D efforts. As an outcome of the workshop, a goal is set to identify recommended diagnostic development paths towards realizing the needs of future high intensity hadron accelerators. All aspects of high intensity hadron accelerators will be considered, including linear accelerators, synchrotrons, storage rings, and transport lines.

Contacts:

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John Galambos	jdg@sns.gov

6: Announcements of the Beam Dynamics Panel

6.1 Minutes of the ICFA Beam Dynamics Panel Meeting

John M. Jowett (CERN)
Chairman, ICFA Beam Dynamics Panel
John.Jowett@cern.ch

Present:
C. Biscari (LNF-INFN),
A. Ropert (ESRF) (replacing K.-J. Kim,),
D. Rice (Cornell University),
J. Gao (LAL/CNRS, replacing O. Napoly),
J.M. Jowett (CERN, Chairman),
L. Merminga (JLAB, replacing S. Chattopadhyay),
Y. Shatunov (BINP),
J. Wei (BNL).

Introduction

There was an ICFA Beam Dynamics Panel Meeting during EPAC02. It was held on June 4, 2002 at Cite des Sciences et de l'Industrie, La Villette Cenference Center in Paris, France. The Chairman welcomed the new members of the Beam Dynamics Panel and recalled the mission given to the Panel by ICFA:

To encourage and promote international collaboration on beam dynamics studies for present and future accelerators.

The Panel's main activities in pursuit of this mission are the organisation of workshops; specialised working groups and the publication of the Beam Dynamics Newsletter but new ideas or improvements are always welcomed. The Chairman of the Panel reports to ICFA once a year. ICFA approved five new members of the Panel at its 43rd Meeting at SLAC in February 2002. (See http://www.fnal.gov/directorate/icfa/icfa_home.html).

ICFA Beam Dynamics Newsletter

J.M. Jowett reported that the newsletter is available mainly from Beam Dynamics Panel Home Page

http://wwwslap.cern.ch/icfa/

Although 1300 paper copies of the three issues per year are still distributed from four distribution centres around the world.

Publication is coordinated by two Chief Editors. K. Hirata has asked to be relieved of this position and W. Chou has agreed to replace him. J.M. Jowett has also been a chief editor for some time and would like to step down, probably sometime next year.

The editing work for a given newsletters is done by an issue editor drawn from a rotating pool, consisting of several Panel members. The issue editor may choose to give the issue a special theme. Editors of recent and future issues are given in the following table. Following some discussion in the meeting, J. Wei agreed to be responsible issue editor for the April 2003 issue and would prepare it in collaboration with L. Merminga, S. Chattopadhyay and others. This will follow a workshop at BNL on the theme of electron-ion colliders in February 2003.

D. Rice expressed an interest in editing the August 2003 issue.

Issue	Date	Editor	Printed	Special Theme
21	April 2000	Wei	BNL	Next-Generation High-Intensity Applications
22	Aug 2000	Zhang	KEK	Accelerators in Asia
23	Dec 2000	Ivanov	CERN	
24	Apr 2001	Mais	DESY	
25	Aug 2001	Jowett	CERN	
26	Dec 2001	Chattopadhyay	JLAB	Recirculating linac light sources
27	June 2002	Chou	Fermilab	Detailed Workshop Summary
28	Aug 2002	Biscari	LNF	(TBA)
29	Dec 2002	Lombardi	CERN	(TBA)
30	Apr 2003	Wei		Electron-ion colliders

Articles are welcomed from everyone in the beam dynamics community. Articles types are letters, opinions, workshop and conference reports, activity reports, announcements or reports on beam dynamics events, announcements of Ph.D. theses in beam dynamics. However the newsletter does *not* publish scientific papers that belong in the usual journals and conferences. Articles should be written in a quite different style. Panel members contribute regularly and encourage contributions from their contacts.

In response to a question from J. Gao concerning who could contribute, the Chairman explained that the pages of the newsletter were open to anyone in the community. Although the editors reserve the right to refuse uninvited or inappropriate contributions, the publication policy is rather liberal. Activity reports from an institution should normally be agreed with the appropriate management.

There was some discussion about the usefulness of a printed edition given universal availability of the Web. Since the Panel has no budget for the purpose, printing the newsletter relies on the support of one or other of the laboratories and can be time-consuming for the editors. Usually the Web edition is available much earlier. J.M. Jowett pointed out that he had proposed dropping the paper edition some years earlier but that this proposal was not popular at the time.

Beam Dynamics Panel Web site

The Chairman reviewed the status of the Panel's home page http://wwwslap.cern.ch/icfa, the central source of information on all the Panel's activities, and the distributed Web site behind it. The Web pages for the European and Asian regions need renewal and volunteers prepared to maintain these parts of the site are invited to come forward.
L. Merminga presented the new Web pages built largely by Yuhong Zhang at JLAB. As well as a new set of pages for the Americas region, this part of the site also contains the new sign-up list for notification about the Beam Dynamics Newsletter and a permanent archive of past newsletters.

The sign-up list has not yet collected many entries, apparently because not many people know about it. Efforts have and will be made to remedy this, including a prominent link on the home page, a poster on the EPAC2002 notice board, etc. Panel members and others can help by encouraging their colleagues to sign up and by downloading the poster from the home page and displaying it in their own institutions. Another idea is to make a one-off mailing to a list of addresses. Once the mailing list is built-up, it should provide much more rapid dissemination of the information in the newsletter.

The JLAB site could also hold an archive of proceedings of ICFA Advanced Beam Dynamics Workshops. It was agreed that this could be useful in cases where an original Web site set up by the workshop organisers could no longer be maintained. While the organisers were able to maintain the site and ensure its availability, it seemed better to leave it in its original location.

Status of Advanced Beam Dynamics Workshops (ABDWs)

The Chairman pointed out that, although the recent average rate of ABDWs is about three per year (four in 2002), there are no new proposals at present and only one workshop foreseen for 2003. Since a lead-time of about a year is required for the process of organising a workshop and seeking the approval of ICFA (normally only at ICFA meetings), any further workshop proposals for 2003 should emerge soon.
It is also important for Panel members to encourage participation in workshops that are already planned to ensure their success.

The workshops held since the last Panel meeting were all held within the framework of one or another of the Panel's Working Groups and are reported on in the following section.

26th ABDW, NANOBEAM2002

On behalf of the organisers, J.M. Jowett reported on the status of preparations for this workshop, on Nanometre-Size Colliding Beams, to be held in Lausanne, Switzerland on 2-6 September 2002. The registration deadline is 15 July. A workshop bank account has been set up, posters have been ordered and will be distributed shortly. Registrations and abstracts are coming in. A draft schedule exists. Satellite meetings during EPAC will finalise the programme and invited speakers. Lausanne University has applied for student grants from Swiss funding agencies (Japan 3, UK 2, US 1, Germany 1). The latest information is posted on the workshop web site:

http://icfa-nanobeam.web.cern.ch/icfa-nanobeam/

27th ABDW, High Brightness Electron Beams

This workshop on the Physics and Applications of High Brightness Electron Beams is to be held on 1-6 July 2002, near Cagliari, Sardinia Although no one was available to report on the status of preparations, it is understood that they are going well and participants are registering. The Beam Dynamics Panel and the Panel on Advanced and Novel Accelerators jointly sponsor this workshop. Information is available at

http://www.physics.ucla.edu/AABD/index.html

28th ABDW, QABP03, 7-11 January 2003

Transmitting information from the organisers, J.M. Jowett reported on the status of preparations for this workshop. Based on the success of the first two workshops under the same title, this is the 3rd workshop in the series on Quantum Aspects of Beam Physics. Printing of the proceedings of the previous QABP2000 (Capri) workshop is well under way. According to the publisher, World Scientific, it should be done by the end of May.

The QABP03 workshop will be held at the Hiroshima University. The details can be found in the attached document. The organisers have secured funding from the Japan

Atomic Energy Society and are continuing their efforts in getting support from other agencies in Japan. As for the previous meeting, Pisin Chen will request DOE's support for the cost of publication.

This time, the workshop is jointly sponsored by the Beam Dynamics Panel and the Panel on Advanced and Novel Accelerators, Japanese Beam Physics Club, Hiroshima University, and the US Department of Energy.

The Programme, Organizing and International Advisory Committees have been appointed.

Reports from Working Groups

The meeting heard reports on the activities of the Panel's three Working Groups (or Sub-Panels). The Chairman recalled the distinction between the "ICFA Advanced Beam Dynamics Workshops", which must meet a number of conditions including formal approval by ICFA, and the "ICFA Beam Dynamics Panel Mini-Workshops" that can be organised informally at the initiative of one of the Working Groups. The latter may be held at short notice with minimal organisation and need not publish proceedings or be widely publicised.

High Intensity, High Brightness Hadron Beams

The Chairman transmitted information received from W. Chou, Chairman of this Working Group:

The 20th ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams (ICFA-HB2002) was held from 8-12April, 2002, at Fermilab. This was a large workshop with 151 registrants, 130 presentations, 14 summary talks, 4 plenary sessions, 11 parallel sessions and three working groups.

For the proceedings, 3 pages are allowed for parallel session/working group talks, 5 pages for plenary session talks and 1-2 pages for summary talks. Manuscripts are due on 31 May.

The next workshop is tentatively proposed as ICFA-HB2004 (2005) in Europe and will be organised by Ingo Hofmann (GSI) and Jean-Michel Lagniel (Saclay).

The group also plans some ICFA Beam Dynamics Panel Mini-Workshops:

- 10th: "Slow Extraction," October 14-18, 2002, BNL, USA. Contacts: Kevin Brown and Thomas Roser.
- 11th: "Diagnostics," October 21-23, 2002, ORNL, USA. Contacts: John Galambos and Tom Shea.
- 12th: "Space Charge Simulations," April 2-4, 2003, RAL, England. Contact: Chris Prior

Future Light Sources

On behalf of the Working Group, A. Ropert reported on the activities of the Future Light Sources Working Group since the last Panel meeting.

The group has organised two significant Advanced Beam Dynamics Workshops and one Beam Dynamics Panel Mini-Workshop:

- 25th ABDW: Symposium on Intermediate Energy Light Sources, Shanghai, China, 24-26 September 2001; around 100 participants.
- 24th ICFA Advanced Beam Dynamics Workshop on Future Light Sources, Spring-8 site, Kouto, Japan, 1-4 May 2002 with140 participants representing 37 laboratories from 11 countries.
- Mini-workshop organised by the Working Group on Future Light Sources: Coherent Synchrotron Radiation (CSR) and its impact on the beam dynamics of high brightness electron beams, 14-18 January 2002, DESY-Zeuthen, Berlin, Germany. http://www.desy.de/csr/

All of these workshops were very successful and further details can be found in the 26th and 27th Beam Dynamics Newsletters.

Some of the topics raised in the Mini-Workshop on Coherent Synchrotron Radiation will be further discussed at the 27th ABDW of High Brightness Electron Beams in September.

The Sub-Panel held a meeting on 2 May 2002 during the workshop at Spring-8 during which its membership was discussed. The Sub-Panel envisages having another ABDW on Future Light Sources at DESY in 2005. Recognising the usefulness of the Mini-Workshop format, A. Wrulich proposed a Mini-Workshop on RF guns and G. Krafft a Mini-Workshop on RF regulation and control. The Subpanel supported the proposals and is looking forward to concrete plans.

High Luminosity Colliders

D. Rice reported on the 23rd ABDW on High Luminosity e^+e^- Colliders, held on 15-20 October 2001, at Cornell University, Ithaca, USA (see also his report in the 26th Beam Dynamics Newsletter). The workshop had been a success despite reduced participation due to the events of 11 September. Working groups were consolidated to compensate for this. Papers are still coming in but the proceedings are expected to come out within the next couple of months. The CD-ROM Version will include the proceedings of the 14th ABDW in Frascati and another workshop held at KEK on similar themes.

This is the newest of the Panel's three working groups and, apart from this workshop has not attained a level of activity commensurate with the other two. Its purpose is to encourage worldwide effort to achieve luminosity at least 10 times larger than the present limit in e^+e^- colliders. Following some discussion, the meeting agreed with the view transmitted by the Working Group Chairman, Y. Funakoshi, that this was a highly worthwhile aim that could be served by the Working Group. Measures will be taken to increase the level of activity.

6.2 ICFA Beam Dynamics Newsletter

6.2.1 Aim of the Newsletter

The ICFA Beam Dynamics Newsletter is intended as a channel for describing unsolved problems and highlighting important ongoing works, and not as a substitute for journal articles and conference proceedings which usually describe completed work. It is published by the ICFA Beam Dynamics Panel, one of whose missions is to encourage international collaboration in beam dynamics.

Normally it is published every April, August and December. The deadlines are 15 March, 15 July and 15 November, respectively.

6.2.2 Categories of Articles

The categories of articles in the newsletter are the following:

1. Announcements from the panel.
2. Reports of Beam Dynamics Activity of a group.
3. Reports on workshops, meetings and other events related to Beam Dynamics.
4. Announcements of future Beam Dynamics-related international workshops and meetings.
   Those who want to use newsletter to announce their workshops are welcome to do so. Articles should typically fit within half a page and include descriptions of the subject, date, place, Web site and other contact information.
5. Review of Beam Dynamics Problems: this is a place to bring attention to unsolved problems and should not be used to report completed work. Clear and short highlights on the problem are encouraged.
6. Letters to the editor: a forum open to everyone. Anybody can express his/her opinion on the beam dynamics and related activities, by sending it to one of the editors. The editors reserve the right to reject contributions they judge to be inappropriate, although they have rarely had cause to do so.
7. Editorial

The editors may request an article following a recommendation by panel members. However anyone who wishes to submit an article is strongly encouraged to contact any Beam Dynamics Panel member before starting to write.

6.2.3 How to Prepare a Manuscript

Before starting to write, authors should download *the latest* model article file, in Microsoft Word format, from the Beam Dynamics Panel home page http://wwwslap.cern.ch/icfa/

It will be much easier to guarantee acceptance of the article if the latest model is used and the instructions included in it are respected. These model files and instructions are expected to evolve with time so please make sure always to use the latest versions.

The final Microsoft Word file should be sent to one of the editors, preferably the issue editor, by email.

The editors regret that LaTeX files can no longer be accepted: a majority of contributors now prefer Word and we simply do not have the resources to make the conversions that would be needed. Contributions received in LaTeX will now be returned to the authors for re-formatting.

In cases where an article is composed entirely of straightforward prose (no equations, figures, tables, special symbols, etc.) contributions received in the form of plain text files may be accepted at the discretion of the issue editor.

Each article should include the title, authors' names, affiliations and e-mail addresses.

6.2.4 Distribution

A complete archive of issues of this newsletter from 1995 to the latest issue is available at

http://wwwslap.cern.ch/icfa/

This is now intended as the primary method of distribution of the newsletter.

Readers are encouraged to sign-up for to electronic mailing list to ensure that they will hear immediately when a new issue is published.

The Panel's Web site provides access to the Newsletters, information about Future and Past Workshops, and other information useful to accelerator physicists. There are links to pages of information of local interest for each of the three ICFA areas.

Printed copies of the ICFA Beam Dynamics Newsletters are also distributed (generally some time after the Web edition appears) through the following distributors:

Weiren Chou	chou@fnal.gov	North and South Americas
Helmut Mais	mais@mail.desy.de	Europe* and Africa
Susumu Kamada	Susumu.Kamada@kek.jp	Asia** and Pacific

* Including former Soviet Union.

** For Mainland China, Chuang Zhang (zhangc@bepc3.ihep.ac.cn) takes care of the distribution with Ms. Su Ping, Secretariat of PASC, P.O.Box 918, Beijing 100039, China.

To keep costs down (remember that the Panel has no budget of its own) readers are encouraged to use the Web as much as possible. In particular, if you receive a paper copy that you no longer require, please inform the appropriate distributor.

6.2.5 Regular Correspondents

The Beam Dynamics Newsletter particularly encourages contributions from smaller institutions and countries where the accelerator physics community is small. Since it is impossible for the editors and panel members to survey all beam dynamics activity world-wide, we have some *Regular Correspondents*. They are expected to find interesting activities and appropriate persons to report them and/or report them by themselves. We hope that we will have a "compact and complete" list covering all over the world eventually. The present *Regular Correspondents* are as follows

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We are calling for more volunteers as *Regular Correspondents*.

6.3 ICFA Beam Dynamics Panel Members

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