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1: Forewords

1.1 From the Chairman of ICFA Beam Dynamics Panel

Kohji Hirata hirata@post.kek.jp the Chairman

Dear beam dynamics physicists all around the world!

I have been the chairman since 1994. Recently, I have decided to resign because (1) it is not good for the whole society that a single person chairs such an influential panel for a long time, (2) I believe I have done some useful things as the chairman but the efficiency might already begin to saturate: a new chairman can start something new and fresh, and (3) I am less involved in the beam dynamics studies than before so that I might misevaluate the importance of many proposals addressed to me as the chairman.

Dr. John M. Jowett, a member of the panel and a chief editor of this newsletter, has kindly accepted to succeed this important job and he was approved by ICFA. So, there should not be any sudden change. My term will end at the end of this year (2000). I am convinced that, with the help of the other panel members, he can make this panel more useful and attractive for the beam dynamics and accelerator societies.

The leading principle in my chairmanship was to invite all the beam dynamics activities regardless to the projects concerned. Above all, all the accelerators are more or less the same: "a beam dynamics for a particular accelerator" does not exist. The beam dynamics is the physics of the beam, with a lot of application to accelerators. It is a study of the accelerator beam as a special state of the matter, where the practical and immediate usefulness is of secondary value. Thus, I even want to include the beam dynamics studies useless to any existing machines.

It is impossible to divide the beam dynamics into useful and useless parts. This applies to physics itself. Perhaps, some of the knowledge of the present day physics has no useful application to human life but the useful part of the physics is strongly supported by the apparently useless part. If we employ the useful part of the physics only and abandon the "useless" part, the physics will die and only empirical technology will be left, which does not have an ability of evolution hence cannot produce anything new in the end.

I do not mean that the project oriented research should be discouraged. On the contrary, I believe that the real breakthrough in the beam dynamics may come only from a struggle for a project. In such a struggle, however, it is very important to study the problem from a general and physics point of view, not from empirical and technical point of view.

Historically, the major part, or at least a considerable part of the beam dynamics has been developed through the high energy physics projects. The high energy physics has grown up rapidly in the last half of the 20-th century. To meet its requirements, i.e. higher energy, more current, lower emittance, less cost and so on, the accelerator became more and more sophisticated. The beam dynamics was born from this demand and has progressed as a front of the high energy physics in its early stage.

The high energy accelerators have attracted many young and ambitious physicists partly because of its intrinsic interest as a branch of physics. Another but equally essential part of the attraction seems to consist of its role in exploring the fundamental physics. Most of the high energy accelerator physicists feel happy and honored to contribute to the progress in high energy physics.

As the chairman of this panel, I felt many times that there is a tendency to split the high energy physics society into physics part (experiment) and technical part (accelerators). This tendency exists in both sides: ICFA supports three international conferences — the lepton-photon conference, the so-called Rochester conference and the high energy accelerator conference (HEACC). The participants are almost completely different between the first two and HEACC.

This tendency is wrong and dangerous, in particular at this moment when the future of high energy physics is not so clear. At this moment, the high energy accelerator physicists should think of the future of the high energy physics and the high energy physicists should participate in the development of future high energy machines. The high energy accelerator is an essential part of the high energy physics, as well as an important contributor of the beam dynamics.

1.2 From the Editor

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Dear Colleagues!

First, let me take an advantage of my duty as an acting Editor of this Newsletter. As such, I have got the news about Kohji Hirata's resignation from Chairmanship in ICFA Beam Dynamics Panel well in advance of most of you. Therefore, let me thank him here in this paper, on behalf of the entire beam dynamics community and the Panel members, for his enthusiasm, persistent optimism and continuous efforts in running the Panel and revitalizing the BD Newsletter publishing process.

Kohji Hirata asked me to join the editorial team two years ago at the 17th HEACC held in Dubna in September of 1998. I had agreed for I consider such a job as a real contribution to Beam Dynamic Panel activity. Having compiled this issue, I see that it is a real job, and decision to share efforts between a few (six) editors was a very reasonable one.

Still, editing the manuscript is an effort which, on being done, will eventually be done. To attract contributions has proven to be much more difficult than to convert a text, say, from Word to LaTeX. To this end, I would like to ask the people active in the field to respond a bit more promptly and readily to calls of the editorial team. The Beam Dynamics Newsletter cannot be representative without your valuable contributions.

To conclude, during our editorial work on the issue John Jowett of CERN has noticed an instructive and comprehensive preprint FERMILAB–TM–2130 by Roy Rubinstein, the ICFA Secretary, entitled "What, Why, and Who, is ICFA?". This paper exposes the ICFA organization, purposes and a place of our Beam Dynamics Panel in its hierarchy. The paper is of interest to everybody involved in beam physics, and we have decided to announce its Web address. So, here it is

`http://fnalpubs.fnal.gov/archive/2000/tm/TM-2130.html`

as an invitation for further reading.

2: Workshop and Conference Reports

2.1 Workshop on Beam Delivery Systems and Interaction Region Issues for Linear Colliders

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A workshop on Beam Delivery Systems and Interactions Region Issues for Linear Colliders was held at Daresbury Laboratory in the UK, between 3rd and 5th July 2000. Thirty-seven participants attended the workshop, with representation from the major laboratories leading research into electron-positron linear colliders, including CERN, DESY, KEK and SLAC. CEA/Saclay, a number of UK universities and Daresbury Laboratory itself were also represented.

The aims of the workshop were:

- to bring together those people who are either currently active in Beam Delivery System research and development or those who are interested in getting involved;
- to identify the technical challenges of such systems;
- to identify those aspects that are considered either to have technical solutions; to have partial technical solutions and still need some work — or better ideas; or have currently either only a conceptual solution, or no solution at all;
- to identify areas of mutual common ground where collaboration would be beneficial;
- to form a plan for further (collaborative) work beyond the Workshop.

The meeting opened with plenary talks on the status of the beam delivery systems for each of the major projects currently under consideration. Talks were given by Daniel Schulte (CERN) on CLIC, Toshiaki Tauchi (KEK) on JLC, Tom Markiewicz (SLAC) on NLC. Main points of their talks were

- collimation systems;
- luminosity stabilisation and diagnostics;
- backgrounds and other interaction region issues.

Further plenary sessions considered topics of wider interest, including opportunities for closer collaboration and recent advances in the design of final focus systems.

2.1.1 Backgrounds and Interaction Region Issues

Grahame Blair (London University) and Daniel Schulte (CERN) led the working group on Backgrounds and Interaction Region Issues. Pair production (10^4 to 10^5 per bunch crossing) is an important background issue for all linear colliders. Pair particles hit mainly the final quadrupoles inside of the detector, and a mask is required to prevent high background levels from back-scattered particles. Since low-angle tagging of high-energy particles is crucial for a number of measurements, attempts are made to instrument the mask. Possible schemes for JLC and TESLA were presented, with simulation results predicting good performance.

The collision of two photons can also lead to the production of hadrons. Hadronic background can have an important impact on the physics analysis of events. In the framework of the CLIC Physics Study, a publicly available library (HADES) has been written that allows easy addition of hadronic background to events in the main PYTHIA common block. A generic event generator to produce the necessary background files will be provided. It is based on GUINEA-PIG and PYTHIA and uses the Schuler–Sjoestrand parameterisation of the hadronic cross-section. The knowledge of the corresponding cross section is still unsatisfactory, and it is therefore helpful to use more than one parameterisation and the corresponding generator. It is proposed to investigate whether the programs used at TRISTAN, HERA and LEP can be used for this purpose.

Two programs exist to simulate the beam–beam interaction. Their results have been successfully checked for agreement. Each machine study uses at least one of the programs. The detector simulations are based on GEANT, so a common basis for all studies exists. Background coming from the machine is less well understood and realistic scenarios have to be developed. In addition, careful comparisons of programs will be needed.

Estimation of the beam tails that are to be expected in a future linear collider is crucial. However, experience at SLC shows that it is very difficult to draw conclusions on the tail size. Predictions of the conditions under which one has to expect synchrotron radiation background in SLD and the corresponding measurements agree. The background levels could however be explained with different tail models.

2.1.2 Collimation System Design

Mike Seidel (DESY) and Peter Tenenbaum (SLAC) led the working group on Collimation System Design. The designs currently under study for NLC and TESLA are similar in concept. Both consist of an energy collimation system with bending magnets to sweep off-energy particles into the collimators, followed by a system of horizontal and vertical collimators to remove particles with large betatron amplitudes. Both systems also rely on a combination of spoilers and absorbers, the former being required primarily to protect the latter from catastrophic hits by the tightly focused high-power beam. The principal differences in the systems are a result of the very different time structures of the two bunch trains. The TESLA bunch train is long enough (almost 1 ms) to allow the beam to be steered safely out of the BDS down an extraction line, in the event of a large oscillation in the linac, thus reducing the amount of beam power likely to hit a collimator. The NLC bunch train, however, is only 300 ns long, and the assumption must be made that the entire bunch train could hit a collimator at a single point.

The open questions on collimation systems can be summarised as follows:

- what fraction of the beam power will be in the halo outside of the collimation envelope?
- how severe are the wakefields from the collimators likely to be?

- what ideas are there (e.g., nonlinear optics, engineering) for reducing the risks to the collimators?

On the question of halo, Reinhard Brinkmann (DESY) presented estimates for TESLA indicating that only a few thousand particles per bunch train will need to be collimated. Similar calculations for NLC have yielded estimates as large as 10^7 particles per bunch train, but this included the effects of dramatic mistuning of the linac. Some interest was expressed in a quantitative beam halo experiment at SLAC.

Addressing the wakefields question, Peter Tenenbaum and Tor Raubenheimer (SLAC) presented measurements and MAFIA simulations of the wakefields from tapered collimators. The measurements and simulations agree approximately with one another, but they are both an order of magnitude smaller than the predictions of the analytic model. Future experiments at SLAC will include graphite collimators being constructed at DESY for this purpose. Graphite is an excellent collimator material from point of view of beam damage, since it can tolerate an impact from a very small beam spot size without fracturing or melting. However, it has a high resistivity and poor vacuum performance, although it is believed that the vacuum performance can be improved by appropriate treatment. All linear colliders would prefer to use graphite for at least some of their collimators.

Reinhard Brinkmann and Nick Walker presented techniques using nonlinear optics to improve the performance of various systems. Brinkmann showed a scheme using an octupole doublet to reduce the amplitude of halo particles. The scheme requires that the halo first be collimated to lie entirely within a fixed amplitude, but that amplitude can be reduced by the octupoles. Walker presented a system that dilutes the energy density of an electron beam entering the collimation system off-energy, thus reducing the damage from such a beam hitting the collimators. Josef Frisch (SLAC) presented initial designs for “consumable” and “renewable” collimators, which in principle, could permit damaged collimators to continue to function without needing to be replaced.

2.1.3 Luminosity Stabilisation and Diagnostic Systems

Joe Frisch (SLAC) and Ingrid Reyzl (DESY) led the working group on Luminosity Stabilisation and Diagnostic Systems. To achieve the required high luminosity, the colliding beam sizes are typically a few nanometers vertically, and a few hundred nanometers horizontally. This results in very tight magnet tolerance and stability requirements: precision monitoring and feedback systems are needed to maintain vertical beam position at the level of 0.5 nm (TESLA and CLIC) to 1.5 nm (NLC/JLC).

Recent results from studies at SLAC suggest that ground motion may be represented by slow systematic drifts (on the time scale of a year or more), diffusive motion following the ATL law, and high frequency (> 1 Hz) wave propagation. Plans for developing a standard model of ground motion for use in different linear collider projects were discussed. Fast feedback systems will be required to correct beam offsets and angles on a bunch-to-bunch basis. In TESLA, where there is a long bunch train with approximately 300 ns bunch separation, studies suggest that luminosity loss from these effects can be limited to 10%. In the NLC, bunch separation is only 3 ns, and simulations suggest an upper limit on luminosity loss from currently proposed systems of 30%. There are proposals to test fast intra-train feedback components (BPMs and kickers) in the ASSET test area at SLAC. Of particular interest is the performance of the BPMs in the presence of electron showers from the interaction point. System performance could also be affected by bunch shape deformations, induced by wakefields, and simulations will be carried out to investigate this.

Optical and inertial mechanical stabilisation methods can be applied to the final focus quadrupoles, and systems will be tested at SLAC and at UBC. The JLC has found in simulations that a rigid support tube connecting the final focus quadrupoles significantly reduces vibration. This will be tested at KEK.

Progress is being made at DESY in the mechanical and electrical design of BPMs for TESLA. Both direct digital and analogue (amplitude to time conversion) systems were discussed at the workshop, and resolution is expected to be at the sub-micron level. There is a proposal from Saclay for a non-resonant cavity BPM with high mechanical rigidity suitable for use in a cryogenic system. Bunch length measurements may be performed using streak cameras in the case of TESLA, while NLC/JLC and CLIC can use transverse deflection cavity monitoring.

The luminosity is highly sensitive to the vertical beam size at the interaction point. Beam–beam deflection measurements and luminosity signals can provide some data, and TESLA is considering an optical fringe monitor. However, it is unclear that the required 5 nm resolution can be reached, or that the system is mechanically compatible with installation at the interaction point. There are proposals for various diagnostics in the extraction lines, though the large backgrounds and energy spread make this particularly challenging. More work needs to be done here for all the machines.

2.1.4 New Concepts for Beam Delivery System Design

Nan Phinney of SLAC gave a presentation on a new design for the NLC final focus system, proposed by Pantaleo Raimondi (SLAC). The design is based on combining the chromatic correction with the final telescope. This is an attractive idea in principle, since the large chromaticity generated by the final doublet is then corrected more locally, and the overall length of the beam delivery system can be significantly reduced. In the case of the NLC, the length of the combined chromatic correction and final focus section are reduced from nearly 2 km to around 300 m. While the idea is not new, this is the first time that such a system has been achieved with the necessary momentum bandwidth and cancellation of higher-order aberrations. Studies show that the new design meets present specifications, and has potentially a much better performance than the previous (conventional) designs.

2.1.5 Opportunities for Future Collaboration

A dedicated session on opportunities for collaboration on linear collider research and development was held at the workshop, chaired by Phil Burrows (Oxford University). There are presently several facilities at laboratories around the world, principally TTF at DESY, the CTF at CERN, NLCTA at SLAC and the ATF at KEK. To exploit fully the potential of these facilities, more people are needed to work on them.

Growing areas of co-operation between the major projects include studies of ground motion and stabilisation, interaction point feedback, collimator wakefields, background simulations, and diagnostic systems including BPMs and laser wires. A rich programme of studies could be developed at the FFTB at SLAC. This facility would be an ideal test bed for vibration control and beam size diagnostics, studies of the new NLC final focus system, collimation system investigations and halo measurements etc. However, recommissioning of the FFTB would be a significant undertaking, and would require a great deal of work. Further discussions on this issue are planned for the autumn of 2000.

It was agreed that further mini-workshops on specific topics could be highly productive, the first of which, on ground motion, is already scheduled to take place at SLAC in October. Possible future topics include machine protection and reliability, halo generation and collimation, instrumentation, etc. A small international steering committee will be formed to help co-ordinate these workshops.

Proceedings from the workshop are available on the Web, at

`http://accelerator.dl.ac.uk/ap/bdir2000/`

2.2 Workshop on the Physics of, and the Science with, X-Ray Free-Electron Lasers

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The 19th Advanced ICFA Beam Dynamics Workshop on “The Physics of, and the Science with, X-Ray Free-Electron Lasers” took place in Arcidosso (Italy) from the 10th to the 15th of September, 2000. The Workshop was sponsored by the International Committee for Future Accelerators, the US Department of Energy, the University of California at Los Angeles, the Stanford Linear Accelerator Center, the Deutsches Elektronen-Synchrotron and the Lawrence Berkeley National Laboratory, together with local authorities of the Tuscany, Grosseto and Arcidosso areas. The Workshop’s chairmen were M. Cornacchia (SLAC), I. Lindau (SLAC/Lund. Un.) and C. Pellegrini (UCLA). Seventy-five scientists, of which 50 are involved in the physics and technology of accelerators, free-electron lasers and X-ray optics, and 25 in the scientific applications, attended the workshop. There were plenary and parallel sessions and many lively discussions, during and after the regular workshop schedule.

Arcidosso is a medieval town in southern Tuscany, close to the city of Sienna. The meeting took place in the historically evocative scenario of an 11th century castle atop a hill dominating the nearby valley. The castle was restored in 1989, and preserves the atmosphere and raggedness of medieval times.

There were two invited lectures on Monday, September 11, to open the subjects and two summary talks in the afternoon of Friday, September 15. All the other presentations were either informal or in the form of posters.

The Group on “Physics and Technology of the XFEL” with introductory talks by Kwang-Je Kim (ANL) and Jamie Rosenzweig (UCLA), was coordinated by Alberto Renieri (ENEA-Frascati).

The Group on ”Science with the XFEL” was coordinated by Mark Sutton (McGill University) with introductory talks by Andreas Freund (ESRF) and Ingolf Lindau (SLAC/Lund. Un.).

These notes reflect the summary talks of the coordinators and the impressions and recollections of the organizers. The American Institute of Physics will publish the proceedings of the Workshop.

2.2.1 Summary of discussions and conclusions of Group 1: Physics and Technology of the XFEL

The main issues that were discussed by the 50 participants in this group were the photo-injector, the production of ultra-short pulses, the effects of wake-fields induced by the electron bunch, the operation at lower charge and emittance, the possibility of harmonic generation and the diagnostics in the undulator. The following is a short summary of the discussions and their conclusions.

It is important to measure the *electron bunch emittance*, length and energy spread as a function of charge and not focus exclusively on the standard photo-injector parameters (1 nC charge, 1 π mm·mrad emittance). The low charge (about 0.2 nC charge, 0.6 π mm·mrad emittance) option appears as feasible as the standard case used in the LCLS design, and offers the clear advantage of being less vulnerable to the effects of wake-fields. It has not been studied as much as the standard case and requires more work.

One should follow the progress with the new guns currently under study, like the pulsed gun being developed at BNL and Eindhoven, and the Van der Wiel plasma gun.

The studies of the feasibility of *electron bunch compression* and/or *X-ray pulse slicing and compression* must be continued, given the importance of this option for the experimental program. In particular one should study the possibility of bunch compression when operating at low charge, and the effect of wake-fields in the two-undulator (seeding) scheme.

Much attention was given to the *wake fields* in the undulator vacuum pipe. Comparative estimates were made using different models proposed by A. Agafonov (Levedev Physical Institute, Moscow), A. Novokatsky (Darmstadt Un.), L. Palumbo (Rome University) and G. Stupakov (SLAC). The effects have been calculated for the following situation: 15 GeV, undulator length of 100 m, a pipe radius of 2.5 mm, 1 nC charge, 230 fs long bunch. The maximum energy changes along the undulator length, according to different models and regimes are:

Agafonov model:	2×10^{-6}	(roughness height: 100 nm, roughness period: $100\ \mu$m)
Novokatsky:	2×10^{-3}	(roughness height: 100 nm, roughness period: $0.1\ \mu$m)
Palumbo:	3×10^{-6}	(roughness height: 500 nm, roughness period: $<10\ \mu$m)
Stupakov:	10^{-4}	(roughness height: 500 nm, roughness period: $100\ \mu$m)

In addition, the contribution of the resistive wall effect is about 1.5×10^{-4}.

Additional contribution will come from vacuum ports, instrumentation, discontinuities.

Since this energy change is of the order of the FEL parameter, it can have a serious and deleterious effect on the LCLS performance. The message from the workshop is that one should be aware of these effects, in particular for the LCLS small gap undulator. Notice that the minimum undulator gap considered for the TESLA X-ray FEL is 12 mm, compared to the present 6 mm of the LCLS.

Possible strategies to reduce the undulator wake-fields effects include reducing the bunch charge, increasing the undulator gap and reducing the undulator length.

The list of recommendations from the workshop on the *surface roughness* problem include the enhancement of the analytical models to predict realistic surface roughness conditions and of the numerical simulations to model realistic randomly distributed surfaces roughness. Experiments should be performed to measure the effect under controlled conditions of surface roughness.

The possibility of operation at a *charge different and lower than 1 nC* should be studied in all its implications. Different modes of controlling the bunch charge and emittance should also be investigated.

Once the wake-fields and the injector operation at different charges are understood, the system should be re-optimized, including considerations of various types of undulators, planar or helical, and with a gap chosen to minimize the wake-fields to an acceptable level.

The sub-group on *undulator diagnostics* reviewed the issues related to the electron and photon beams. The centroid of the electron beam can be measured to mm resolution with rf Beam Position Monitors (BPMs) or Optical Transition Radiators (OTR). One of the issues is whether the latter can survive the intense electron beam and how the surface quality of the OTR might affect the emitted light. Both questions should be soon be answered by experiments. On the measurements of the beam profile, there was consensus that saturation makes the scintillators not usable, while OTRs might be useful. It is also important to measure the longitudinal characteristics (bunch length and momentum spread) and the time-resolved slice measurements of emittance and momentum spread. A very promising technique for measuring very short bunch lengths uses an rf deflector that rotates the beam onto a screen. It was suggested that it might be possible to measure photon pulses down to 10 fs using grating Michelson interferometers.

One of the outstanding questions concerning the measurements of the X-ray beam is whether one can separate the spontaneous from the FEL radiation and whether the diagnostics can survive the X-ray and electron fluxes. It was recommended to estimate the damage mechanism with ionization as the dominant mechanism.

Crystalline materials directly impacted by the electron beam may see the space charge field and be subject to damage. It was suggested that an experiment be done at SLAC using the FFTB beam to create a high field gradient on a crystal similar to that that would occur in the LCLS.

It is very important to have a diagnostic system capable of measuring low charge beams in the linac and undulator.

More detailed studies of the survivability of the detectors and the information they provide are needed.

Some other noteworthy discussions included the following:

1. The wake fields in the undulator could have a strong effect on the harmonics; we need more experimental and simulation work to investigate this possibility.

2. The same wake-fields could limit the possibility of reducing the line width or the pulse length.

3. The X-ray FEL must be optimized including collective effects.

4. A proof of principle of a seeded scheme using High Gain Harmonic Generation has been done at Brookhaven; the studies of an X-ray FEL using this approach should be continued.

2.2.2 Summary of discussions and conclusions of Group 2: Science with the XFEL

About 25 people attended sessions to discuss the possible scientific applications of a X-ray FEL. Because of the recent focus on the first experiments with the proposed Linac Coherent Light Source at Stanford, the discussions were mainly focussed on these proposals. The extension of the characteristics beyond the initial stage and the further developments of the source were also part of the program.

Six scientific areas were discussed: Atomic Physics, Warm Dense Matter, Femtosecond Chemistry, Imaging/Holography, Bio-molecular Structures and X-Ray Fluctuations Spectroscopy.

New phenomena can be studied in *atomic physics*. Hollow atoms, where inner core electrons have been removed with outer valence electrons still in place, appear especially interesting. Non-linear X-ray interactions are of interest, i.e. parametric down-conversion, two-photon absorption and two-photon mixing. Even with an unfocussed LCLS-type beam it is possible to achieve saturation for photo-ionization. With a focussed beam the Compton scattering will saturate.

Warm dense matter (WDM) is a new form of matter, between highly ionized plasma and condensed matter. Though WDM is of great importance in many fields, i.e. laser plasma production, inertial fusion and astrophysics, its basic properties are still basically unknown. With a X-ray FEL beam, WDM can both be created and probed.

In *femtosecond chemistry* it is of great interest to study bond changes on the time scale characteristic for breaking and forming bonds. This would involve pump-probe experiments where the system is excited with a conventional laser and the structure changes are probed dynamically with the X-ray FEL beam.

The workshop addressed the possibility of *imaging and holography of non-crystalline samples and small nano-structures*. Bio-fragments and bio-molecules are also an extension of this work. The radiation damage and the amount of structural information that can be extracted before the molecules fly apart are key issues. For small structures, great advances have been made in computer modeling. It would be desirable to extend the models to bulk samples.

X-ray intensity fluctuation spectroscopy is already being pioneered at third generation light sources and its extension to x-ray FELs, in terms of the time-scales and length-scales, were discussed, together with the possibility of studying a broad range of materials.

There were intense discussions trying to define the most important radiation characteristics. This will of course in many cases depend on the specific experiments, but in general terms the following order was established, in de-creasing order of importance:

1. Beam position stability
2. Beam focusing
3. Synchronization for pump-probe
4. Shorter pulses
5. Smoother pulses
6. Reduced pulse to pulse intensity fluctuations

2.3 Workshop on Ground Motion in Future Accelerators

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The 22nd Advanced ICFA Beam Dynamics Workshop on Ground Motion in Future Accelerators was held at Stanford Linear Accelerator Center (SLAC) from November 6 to 9, 2000. The widespread interest in this topic was evident in the 58 participants from 20 laboratories worldwide, as well as universities and companies.

A next-generation linear collider will have tight tolerances on alignment and position jitter, so tight that ground motion and vibration can be limiting factors in the performance. Ground motion and vibration are also important in other areas such as synchrotron light sources, large circular colliders, some fields of industry and non-accelerator experiments requiring high precision such as gravitational wave detection. Teams from many different projects are working on these problems and, in many cases, converging on similar solutions.

The Ground Motion Workshop provided a venue to collect and compare the data, resolve outstanding issues, sharpen the contradictions, outline further studies and, most importantly, unify the worldwide efforts to prepare for the challenges of future machines. Topics discussed included:

- Theoretical considerations of the influence of ground motion on accelerators including proper methods to represent and model the ground motion
- Measurement, interpretation and classification of ground motion
- Fast motion, cultural noise and their correlation properties
- Slow motion and the relation between diffusive and systematic components
- Girder design and tunnel construction techniques and their contribution to vibration and ground motion

- Beam independent methods to ameliorate ground motion effects, including passive damping and active methods of stabilization

The Workshop started with a review of the ground motion and vibration problems in various accelerators, such as large hadron colliders (SSC, VLHC and LHC), linear colliders and synchrotron light sources. Ground motion causes different problems in these machines. For example, the primary effect of fast (second – millisecond time scale) ground motion and vibration in large circular machines is to produce emittance growth, while for light sources the beam stability is an issue, and for linear colliders a bigger concern is beam separation at the interaction point.

In large colliders, for example, when the beam passes through a quadrupole which is moving, it undergoes betatron oscillations which grow in amplitude. Beam decoherence due to the tune spread slowly translates the betatron oscillations into emittance dilution. Detailed analysis has shown that the frequency which contributes most to the dilution is the fractional betatron tune times the revolution frequency which, for large colliders, can be several hundred Hertz. Though the ground motion is quite small at those frequencies, the resulting emittance growth may be noticeable over a typical beam lifetime, and beam orbit feedback may be required to cure the effect.

In the example described above, the motion of neighboring quadrupoles in a large collider can be assumed to be reasonably independent, and therefore uncorrelated. For a linear collider, on the other hand, one typically cannot assume that the motion is uncorrelated. In order to correctly evaluate the effect on the beam, the spectral response function of the optics must be convoluted with the spatial spectrum of motion which properly includes the correlation information.

The analog of revolution frequency of circular machines is repetition frequency in linear colliders. For linear colliders, continuous beam-based feedback operating at the repetition frequency is indispensable. This divides the frequency scale in two ranges:

1. fast motion which cannot be corrected by feedback and produces a relative beam offset at the interaction point

2. slow motion which primarily results in beam emittance growth.

For typical parameters this boundary lies at a scale of about 1 Hertz.

Although ground motion problems have different effects for each particular accelerator, the phenomena to be understood are similar: ground motion amplitudes and its spatial and temporal correlation properties. For all accelerators, the technical solution for ground motion problems is to first locate the accelerator in a quiet place, if possible, and minimize the generation of additional vibrations, and then typically to use beam-based feedback. For linear colliders, there is an additional problem with the final quadrupoles nearest the Interaction Point. These must be stabilized by a system which is not limited by the repetition frequency and, hence, cannot be beam-based. This requirement creates an interesting connection to developments in the field of gravitational wave detectors.

A highlight of the workshop was the participation of LIGO experimenters who presented ground motion problems for gravitational wave detectors and their solutions. Fast ground motion, in this case, can mimic gravitational waves and therefore the detecting masses must be isolated by many layers of passive and active stabilization. The vibration suppression methods developed for LIGO were very impressive and certainly set a benchmark for what is ultimately possible. The LIGO team also described some of the issues in achieving maximal performance of a stabilization feedback by very careful design, proper combination of sensors, and choice of the right algorithm. Collaboration with the gravitational wave experiments may prove fruitful to future linear collider development.

There have been extensive measurements of the fast ground motion and the correlation functions around the world. Mathematical models of the motion have been created in order to evaluate the effect on an accelerator. One of the outstanding questions is the effect of the “cultural noise” which can be generated in the vicinity of the accelerator and can vary significantly over short distances. This noise has not yet been satisfactorily modelled. The synchrotron light source community worldwide has extensive experience on cultural noise and vibration studies, and their presentations underscored how difficult these problems can be if external and in-tunnel noise sources are not carefully avoided by proper design and site selection. The light sources have also studied in detail the optimal design of support girders, which cannot be perfect and always represent a tradeoff, a fact which tends to be ignored.

A major topic during the Workshop was a discussion of slow motion (minutes – years time scale). Two different models for slow motion have been proposed:

1. a diffusive model governed by the ATL law $\langle X^2 \rangle = A \cdot T \cdot L$

2. a systematic model which behaves as $\langle X^2 \rangle = A \cdot T \cdot T \cdot L$.

Here, X is the transverse misalignment, A is a coefficient, T is time and L is the distance between two points.

Measurements presented showed evidence for both types of motion where the systematic component seems to dominate on the year time scale, and the diffusive for shorter periods. The difficulty in measuring such motion and the lack of data with sufficiently good statistics both in space and time still allows considerable controversy over the interpretation of existing data. In particular, the evidence for an L dependence in diffusive motion has been questioned. On the other hand, during the Workshop there was significant progress on a systematic approach to the analysis of existing data, including proper decomposition of measurement errors from real motion. Such an approach has been applied to the LEP alignment data (700 quadrupoles measured yearly over 10 years) and plans were made for a collaboration between CERN and SLAC to further analyze the LEP data. In order to understand the region of validity of these models, it is necessary to make thorough studies with better statistics. A collaboration between SLAC, FNAL and BINP plans a series of experiments to measure the dependence of slow motion on temporal and spatial separation and on geological conditions.

A thoughtful review of the implications of geology and tunnel construction techniques returned the discussion to real life as compared to models. The question is how to balance an affordable cost with the requirements for tunnel stability and a specialized tunnel engineering workshop was proposed. It is also clear that not all of the impacts of tunnel engineering on ground motion are understood. For example, there is evidence that bored tunnels may be more stable than those which used blasting. There are also questions about the effect of discontinuities due to the tunnel that modify the external noise and trap the internal noise. Little is known about the hour–day stability of existing tunnels such as LEP and this certainly warrants future measurements.

The Workshop was considered a success by all participants. In addition to the healthy exchange of technical details and solutions, it provided links between groups working on similar problems for different applications. A follow-up Workshop is planned in 1–2 years to keep track of progress in this exciting field of science. For further information, copies of the presentations are available on the Workshop web site:

`http://www-project.slac.stanford.edu/lc/wkshp/GM2000/`

and the Proceedings will be published as a SLAC report.

2.4 Workshop on Quantum Aspects of Beam Physics in Capri

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The 18th Advanced ICFA Beam Dynamics Workshop on "Quantum Aspects of Beam Physics" was held from October 15 to 20, 2000, in Capri, Italy. This is the second workshop under the same title. The first one was held in Monterey, California, in January, 1998. Following the footstep of the first meeting, the second one in Capri was again a tremendous success, both scientifically and socially.

About 70 colleagues from astrophysics, atomic physics, beam physics, condensed matter physics, particle physics, and general relativity gathered to update and further explore the topics covered in the Monterey workshop, namely,

1. Quantum Fluctuations in Beam Dynamics;
2. Photon-Electron Interaction in Beam Handling;
3. Physics of Condensed Beams;
4. Beam Phenomena under Strong Fields;
5. Quantum Methodologies in Beam Physics;

as well as a newly introduced subject on

6. Astro-Beam Physics and Laboratory Astrophysics.

The nature of the so-called "Unruh radiation", an analog of the famous Hawking radiation when a particle is undergone a violent acceleration, was warmly discussed (or even debated) during the Monterey Conference. In view of the rapidly growing interest in laboratory tests of astrophysical phenomena, the organizers of the Capri workshop has decided to formally recognize these activities with the name "astro-beam physics", and had formed a separate working group.

The conference started with a series of plenary talks that provided overviews on the progress of the particular subjects within quantum beam physics during the past two years, as well as reports on the speakers' recent important findings. The plenary speakers and their talks are listed below.

R. Ruth (SLAC):	"Fundamental Aspects of Low Emittance Electron Beams"
C. Hill (Fermilab):	"Quantum Limit of a Linear Collider"
C. Schroeder (UCLA):	"Quantum Fluctuations in Free Electron Lasers"
S. Chattopadhyay (LBL):	"Femto- and Atto-Second Pulse Generation for Probing Quantum Entanglement"
W. Ertmer (U. Hanover):	"Bose-Einstein Condensate and Atom Laser"
R. Chiao (UC Berkeley):	"Weakly Interacting Photon Gas in Two-Dimensions: Bose-Einstein Condensate, Superfluidity, and Vortices"
J. Wei (BNL):	"Crystalline Beams"
E. Uggerhoj (U. Aarhus):	"Recent Results in Crystal Channeling Experiment"

S. Klein (LBL):	"Nonlinear QED Effects in Heavy Ion Collisions"
R. Fedele (Napoli):	"Landau Damping in Nonlinear Schroedinger Equation"
P. Chen (SLAC):	"Supersymmetry and Beam Dynamics"
F. Mirabel (Saclay):	"Microquasars"
L. Scarsi (Palermo):	"Gamma Ray Bursts and Ultra-High Energy Cosmic Rays"
R. Ruffini (U. Rome):	"Black Holes and Gamma Ray Bursts"
J. Leinaas (U. Oslo):	"Unruh Effect in Storage Rings"

The six topics listed above were sorted into four Working Groups, which were ably lead by the following chairs:

Group A — Topic 1	
Co-Chairs:	K.J. Kim (ANL) and H. Mais (DESY)
Group B — Topics 2 and 3	
Co-Chairs:	V. Telnov (BINP) and F. Hartemann (LLNL)
Group C — Topics 4 and 5	
Co-Chairs:	J. Ng (SLAC) and K. Yokoya (KEK)
Group D — Topic 6	
Co-Chairs:	A. Dragt (Maryland) and M. Pusterla (Padova)

These Working Group chairs not only gave introductory overviews of the topics involved in their working groups, respectively, but also gave Summary Reports at the end of the conference. About 40 presentations were made during the parallel working group sessions, that covered a very wide range of subjects. These presentations, together with the plenary talks, can be found on the workshop web site,

`http://qabp2k.sa.infn.it`

In addition to the effort of fund-raising from the various Italian scientific agencies, the workshop organizing committee, lead by Dr. Stefania Petracca, has constructed a series of exciting social programs throughout the week. On the opening night, there was a piano recital in the church, Certosa di San Giacomo, by the famous pianist, Maestro Francois Joel Thiollier. On Wednesday (October 18) a whole-day excursion to Pompeii was made. During the conference banquet on Thursday night (October 19), a local folk song-and-dance group made a warm and inspiring performance on the famous Neapolitan songs. All participants were invited to join the performers to make music together. Of course, the beautiful scenery of the island of Capri requires no persuasion. Everyone left his/her heart there when we had to return to the real world after the workshop.

Based on the continuing success of this workshop series, a joint meeting of the International Advisory Committee and the Program Committee has decided to organize the third QABP Workshop in early 2003 in Japan. Professor Atsushi Ogata of the Hiroshima University will be in charge of the local organization. We are confident that the importance of quantum beam physics will continue to grow and we invite all the colleagues to join in the exploration of quantum effects in laboratory and astrophysical beam phenomena.

2.5 17th Conference on Particle Accelerators in Russia

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The 17th National Conference on Particle Accelerators was convened in Protvino (Moscow Region) from the 17th to 20th of October, 2000. It was hosted by Institute for High Energy Physics, and constitutes a continuation to a series of regular National Conferences on the topic organized since 1968. This time, the Conference was held under the auspices of the Russian Academy of Science, of the two Federal Ministries — for Atomic Energy and for Industry, Science and Technologies, and of two accelerator centers — JINR (Dubna) and IHEP (Protvino). Local municipal authorities of Protvino have also extended their support to the event.

The 17th Conference was attended by some 300 accelerator scientists and engineers from Moscow, St. Petersburg, Novosibirsk, Tomsk, Dubna, Troitsk, Obninsk, Khar'kov, Protvino, etc. Major world accelerator centers like CERN (Switzerland), FNAL and BNL (USA), DESY (Germany) have also sent their representatives to Protvino.

In total, around 240 reports were delivered on the statuses of existing machines and development of the new ones, and on application of accelerators in diverse areas of science and technology. About 50 invited and oral talks and 190 poster reports were presented in frames of 11 sessions:

1. New trends in accelerator technology, large accelerator projects (chairman A. Ageyev, IHEP)
2. Colliding beams and storage rings (V. Balakin, Branch of BINP)
3. Accelerating structures and high power RF equipment (S. Esin, INR RAS)
4. Accelerator control and beam instrumentation (A. Dunaitsev, IHEP)
5. High intensity cyclic and linear accelerators (V. Teplyakov, IHEP)
6. Superconducting magnets and cryogenic systems (K. Myznikov, IHEP)
7. Magnet and power supply systems for accelerators (I. Meshkov, JINR)
8. Beam dynamics in accelerators and storage rings, new methods of acceleration (V. Parkhomchuk, BINP)
9. Radiation problems in accelerators (V. Lebedev, IHEP)
10. Upgrade and development of accelerators (E. Troyanov, IHEP)
11. Accelerators for medicine, industry and applied purposes (V. Glukhikh, Efremov SRIE-PhA)

The highlights of the Conference were the comprehensive review talks presented by A. Skrinsky ("Electron-Positron Colliding Beams at Novosibirsk: Status and Perspectives"), V. Balakin ("Future Linear Colliders"), G. Kulipanov ("SR Sources and FELs, their Present and Future"), V. Parkhomchuk ("Development and New Methods of Electron Cooling"). The audience highly appreciated invited reports presented by foreign participants: C. Wyss ("The LHC Progress" and "The LHC SC Dipoles"), K. Cornelis ("Acceleration of High Intensity Beams in SPS"), A. Gamp ("Recent Results from the TTF"), R. Gupta ("BNL SC Magnet Program for Particle Accelerators"), P. Lebrun, ("Feasibility of Neutrino Source Based on Intense Muon Beam"), and others.

Major bulk of the papers related to beam dynamics issues was presented at Sessions ## 8, 5 and 10.

A significant progress has been reported (N. Agapov) in further development of JINR SC heavy ion accelerator, the Nuclotron, which has now got a slow extraction system. Its commissioning involved dedicated studies of beam dynamics in a non-linear magnetic field under a ripple of magnet power supplies (I. Issinsky, O. Kozlov, V. Mikhailov).

A huge program of linear and non-linear beam dynamics studies is under way in JINR, Dubna (I. Meshkov et al) in frames of DELSY Project (Dubna ELectron SYnchrotron). This project is aimed at construction of a 3rd generation SR source of accelerator components and equipment supplied by NIKHEF, Amsterdam, the Netherlands. Use of the former NIKHEF AmPS facility in a new role implies a major redesign of optics so as to accommodate wiggler and undulator. To this end, the JINR task team has to follow and accomplish most of the prescriptions adopted word-wide in a design of a modern SR source equipped with insertions.

Technique of electron cooling of heavy ion beams has now reached maturity, and the BINP team (V. Parkhomchuk et al) has briefed on a new endeavor in this direction — a cooler system for CSR Project of IMP, China.

I. Nesterenko of BINP, Novosibirsk reported experimental studies of coherent beam-beam effects observed at VEPP-2M collider where they split conventional head-tail transverse modes of beam motion into in-phase and out-phase beam-beam modes.

N. Karamysheva of JINR, Dubna presented multi-particle tracking studies used to simulate effects of space charge in beam dynamics of low- and medium-energy beams of H^+ or H^- in a high intensity sector cyclotron. The studies indicate a feasibility of accelerating 10–15 mA beam from 0.5 to 5–15 MeV.

S. Ivanov and O. Lebedev of IHEP, Protvino, have outlined their proposal to suppress coasting-beam longitudinal instability on flat top of U70 PS with a dedicated beam feedback circuit closed via an RF cavity. This instability is caused by a fundamental mode of idle RF cavities and is suspected hamper slow extraction from U70.

The same authors have described a technique employed to study stability of accelerating system (tuned ferrite-loaded cavities) of IHEP U70 PS. This system is encircled by a number feedback loops (both, dedicated and spurious, 6 in total) that cross-talk due to a heavy beam loading, a high accelerating rate and overlapping loop passbands.

E. Masunov has reported about a continuing effort of a team from MEPhI, Moscow, to study feasibility of alternative schemes of low-energy (around 1 MeV) linear ion accelerators – linacs with undulator and axisymmetric RF focusing. Up to now, macro-particle computer simulations are reported to comply with theory, and the team is about to proceed to proof-of-principle experimental studies.

There were also many other interesting contributions that fall beyond the scope of this report. All these will be soon available in the Conference Proceeding to be published by IHEP, Protvino.

To conclude, according to the 17th Conference OC Chairman A. Ageyev, Vice-Director of IHEP (Protvino), the event was well successful and had shown a certain sign of revival in the field of particle accelerators in Russia.

As it was announced at the closing session, the next, 18th Conference will be called in the year of 2002 in St. Petersburg. It will be hosted by Efremov Scientific Research Institute of Electro-Physical Apparatus (SRIE-PhA).

3: Activity Reports

3.1 Beam Dynamics Activities at CERN-PS on CLIC

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The CLIC study deals with the design of a multi-TeV e^+e^- linear collider, based on the two-beam technology proposed and developed at CERN [1]. The study has shown that this technology is applicable to a linear collider with centre-of-mass energies from 500 GeV or less up to 5 TeV. The nominal 3 TeV CLIC collider configuration is described in detail in ref. [2]. The following activity report only briefly covers the progress made during the last fifteen months on particular beam dynamics questions in CLIC, associated with the injector systems, the main-beam linac, the drive-beam decelerator, some feedbacks and the test facilities. Other activities are also carried in the accelerator physics group of CERN-SL.

3.1.1 The Injector Complex

The beam dynamics of the CLIC injector complex covers the electrons and positrons production, the beam acceleration in 5 linacs, three damping rings, two stages of bunch compressors and finally two long transfer lines. A short summary is given below of the progress made in two beam dynamics areas.

The first area concerns the positrons production. The peak energy-deposition density has been simulated for the CLIC positron source with the EGS4 code [3]. The results are compared with the SLAC experiments. The energy density per surface unit is a factor 4 higher than the limit found at SLAC, while the energy density per volume is only a factor 1.5 larger. A new tracking code has been developed. The program is based on the code which was used for the design of the positron generator of the KEK B-factory. An exact phase space distribution of the final state is obtained together with a good estimation of the positron yield. At the exit of the capture section (200 MeV), the normalized positron yield is 0.3 e+ per e- and per GeV. Nevertheless the following effects are not included: the space charge, the wake fields from the accelerating structures and the beam loading for the multi-bunch beam.

The second area is the Fast Beam Ion Instabilities (FBII) in the long transfer lines. FBII [4] rise time estimates were done according to three models: linear treatment, with decoherence and frequency spread, and finally in non-linear regimes. The results applied to CLIC have shown that a pressure in the range of the 10^{-9} Torr and of 10^{-10} Torr would avoid this instability in the drive-beam and the main-beam transfer line, respectively.

3.1.2 The Damping Rings

Damping Rings for Linear Colliders have to produce very small normalised emittances at a high repetition rate. The CLIC 3 TeV option aims at normalised emittances of $0.4 \cdot 10^{-6}$ m·rad. An analytical model of the Damping Ring arcs, made of Theoretical Minimum Emittance (TME) cells, was first used to study the relations between the target emittance, the damping time, the turbulence threshold, the energy spread, the momentum compaction, the field in the arc dipoles, the emittance detuning of the lattice and the cell length. The analytical approach was then extended to the detailed design of Damping Rings, taking into account the straight sections and the damping wigglers. Complete rings, including wiggler and injection insertions, were modelled with the MAD program, and their performance was found to be in good agreement with the analytical calculation. This model was used to optimise a Damping Ring design capable of meeting the requirements of CLIC centre-of-mass beam energies ranging from 0.5 to 1 TeV [5]. More recently a new optimisation was performed for the 3 TeV option of CLIC [2].

For the CLIC 3 TeV option, the proposed electron (EDR) and positron (PDR) damping rings are assumed to have the same ring, cell and wiggler geometry. The design uses a ring circumference of 485 m. The chosen *emittance detuning ratio* ϵ_r of 3.9 yields reasonable values for the momentum compaction and the strength of the chromaticity correction. The positron collector ring (PCR) is assumed to operate at the same beam energy as the damping rings. Although the damping time parameters are similar to those of the damping rings, the large target emittance requires a much smaller number of arc cells. With a circumference of only 155 m this collector ring could be installed inside the damping rings. The optimum beam energy of the Damping Rings depends on optics considerations, but also on Intra-Beam Scattering and polarisation. The polarised electron option requires beam energies of $(n + 0.5) \cdot 0.44$ GeV so as to stay away from depolarising resonances. The γ^3 dependence of the normalized equilibrium emittance and the importance of IBS problems at low energy lead to the choice of 1.98 GeV. The target value of the normalised vertical emittances, at the exit of both damping rings, is in the range of $3 \leq \epsilon_y \leq 11$ nm·rad.

3.1.3 The Main-Beam Linac

The control of the bunch to bunch energy spread requires the compensation of the beam loading in the main linac. A new method has been developed for this compensation [6]. It consists of generating a ramp in the RF output of the power Extraction and Transfer Structures (PETS) by modifying the time structure of the drive beam. In the basic scheme of the drive beam generation, the switching system and the combiner rings allow to generate 130 ns long pulses of electron bunches uniformly distributed. The resulting pulse of the accelerating voltage is rectangular. In the method proposed, the switching times are delayed and irregularly distributed in such a way that the pulses of electron bunches have initially different length. Subsequently superimposing these various pulses in the combiner rings provides a final pulse with a modulated distribution of the bunches whose density is lower at the head of the pulse and grows toward a constant value in the core. This corresponds to a current ramp which in turn produces a ramp in the PETS power output. Simulations show that a full bunch to bunch energy spread of less than $5 \cdot 10^{-4}$ can be obtained in the main beam, below the target value of 0.1%.

The emittance growth in the main linac due to a phase error between the main beam and the RF has been studied [7]. An error of $0.2°$ leads to an energy error of about 0.1%, which might be on the limit of being acceptable. The energy error is mainly limited by the final focus acceptance. The emittance growth resulting from this phase error is only 1%. The limit on the phase error is therefore given by the energy acceptance of the final focus system rather than by the emittance growth.

3.1.4 The Drive-Beam Decelerator

The effects of the transverse wake-field in the drive-beam decelerator has been further investigated for the four wave-guide structure [2]. Particularly the dependence of the beam stability on the frequency of the transverse mode and on the length of the decelerator have been simulated. Considering a four-sigma beam and a one-sigma initial off-set, the dependence of the amplification of this initial jitter at the end of the drive beam decelerator on the frequency of the dipole mode has been investigated. The results show that a deviation in frequency from the fundamental mode value by 2% generates an important, not symmetric increase of the amplification factor between 3 on one side and 10 to 100 on the other side of the minimum. Studying the beam stability, the envelopes obtained after trajectory correction are found to be close to filling the aperture at the low energy end. One possible remedy is an increase of the decelerator length, with proportional increase of the initial and final energies. Simulations showed that increasing this length (and the energy) by a factor 2 reduces the 4-sigma envelope of the beam by a factor of the order of 1.6. Another remedy could be the improvement of the correction algorithm. These simulations have however to be redone with the newly calculated structure parameters.

Simulations with the six wave-guide structures [8] showed a significantly more stable situation. Even with the nominal length the beam envelope remained well below the acceptance in each of the ten simulated cases of machines aligned with the beam.

3.1.5 The Intra-Pulse Interaction Point Feedback

Vertical position displacements between the beam centres at the Interaction Point (IP) generates a loss of luminosity. In order to limit this loss, related to beam jitter at the IP, fast position feedback systems have been modelled [9]. They consist of correctors and beam position monitors located very close to each other on the same side of the IP. The estimated correction is not applied to the beam used for the measurements but to the bunch train moving in the opposite direction, as rapidly as possible. Simulations have been performed in order to evaluate the possible performance of such an intra-pulse interaction point feedback. They showed that typically the luminosity loss due to small coherent offsets (of the order of a beam-size sigma) of the bunch trains can be reduced by a factor three. For larger offsets ($10\,\mathrm{nm}$ at $E_{cm} = 1\ \mathrm{TeV}$) one can recover 50% of the nominal peak luminosity. Without feedback only 2% of the nominal value would remain.

3.1.6 Coherent Synchrotron Radiation Investigations in CTF2

The present CLIC test facility (CTF2) is made of two parallel beam lines, to reproduce at low energy (40-50 MeV) the conditions for nominal-power transmission from the transfer structures to the accelerating structures at 30 GHz. The studies on coherent synchrotron radiation (CSR) in CTF2 have been extended. Series of measurements [10] have been taken of the emittance growth, the energy loss and the increase in energy spread induced in high-charge (5 to 10 nC) bunches when they are compressed from about 1.2 mm rms to less than 0.2 mm rms in the CTF2 magnetic chicane. In particular, for 10 nC bunches, the mean beam momentum decreased by about 5% while the FWHM momentum spread increased from 5% to 19%. The experimental results were compared with simulations made with the code TraFiC4, obtaining in general a very good agreement. Simulations made with the TraFiC4 code, which include transients, have also been made for the isochronous cells of the CTF3 combiner ring [11]. These simulations have shown that the influence of transients is relatively small, justifying the analytical approach that has been used so far in the longitudinal beam dynamics studies.

3.1.7 Preliminary Phase of CTF3

The time structure of the CLIC drive beam is obtained by the combination of electron bunch trains in rings using RF deflectors [12]. The next CLIC Test Facility (CTF3) at CERN will be built in order to demonstrate the feasibility of such a scheme and to provide a 30 GHz RF source with the nominal parameters [13]. CTF3 will be installed in the area of the present LEP Pre-Injectors (LPI) complex, now consisting of the 500 MeV LEP Injector Linac (LIL) and the 125 m long Electron Positron Accumulator (EPA) ring. As a preliminary stage, the existing installation will be modified in order to perform a test of the combination scheme at low charge [14]. Optics studies have been performed in order to define the new lattices. In particular, new quadrupole families will be introduced in the EPA ring in order to obtain an isochronous lattice. The lattice of injection line to the ring has been also modified to be isochronous. The linac will be shortened and a new optics has been studied, together with a new matching section to the injection line. A series of beam measurements have been made in order to determine the initial values of the optics functions after the bunching system and check the linac model used for simulations. In this context, different simulation codes (TRANSPORT, MAD version with acceleration) have been compared to analytical models and measurement results. The beam measurement campaign has also shown that the bunch length at the end of the linac is below the 20 ps FWHM limit required by the injection process with RF deflectors.

3.1.8 CTF3 Linear-Accelerator Lattice

The design of CTF3 is based on the use of a fully loaded linac. Three different options for the lattice of this drive-beam linac have been investigated [15]. Two are based on triplets, the other one on simple FODO cells. A compromise between the amplification at the end of the linac of the initial beam-jitter at the end of the linac and the effects of the misalignment of beam-line elements has to be found. The simulations showed that the triplet lattices allow a better performance than the FODO lattice in both areas. A final decision about which lattice should eventually be implemented has to take into account the characteristics of the two possible designs of the accelerating structures which are being investigated.

3.1.9 Isochronicity Tunable Modules

In the CLIC main linac, the length of the bunches is critical and bunch-compression is needed [16]. It should be 30 μm and carefully controlled in the bends of the injector system. In the drive beam generation complex, the isochronous rings and transfer lines require that the bunch length be modified, either by stretching, in order to limit the coherent synchrotron radiation effects, or by compression, in order to optimise the power transfer to the main beam. Though the R_{56} parameter of the various insertions can be fixed at the design stage, the operation of both the accelerator and the decelerator are more flexible if it is possible to modify R_{56} in a given range. This flexibility becomes a feature in CTF3 whose purpose is to validate the RF Power Source design and at the same time to study the coherent synchrotron radiation for which theory and simulations remain to be confronted with experimental data. Thus a study was started to find a magnetic insertion, capable to generate both a negative or a positive R_{56} by only changing the strength of the quadrupoles [17]. Naturally the isochronous insertion developed five years ago and which is the basis for the design of the CTF3 combiner ring, was chosen as a promising candidate. It turned out that to be possible to obtain the expression for the absolute values of the focal lengths in the thin lens approximation, but it demanded tedious algebra to derive the necessary conditions on the minimum and maximum values of R_{56} and on the lengths of the drift spaces. The first application done concerns the preliminary design of the CTF3 transfer line between the Delay Loop and the Combiner Ring, which should allow the bunch length to be either increased or decreased by 1.6 mm at most. Given the $\Delta p/p$ of the order of 1%, the range of R_{56} is between -0.16 m and 0.16 m. To accomodate this transfer line in the available space, it is made of two insertions, one bending the beam by 75° and the other bending it back by -75°. The analytical approach has permitted an identification of the ranges of possible solutions without using numerical searches which are very unstable in this specific case. The insertion could then be optimised to find a compromise between the overall length imposed by the building dimensions, and the optics parameters. The three dipoles of the selected insertion have the same length (0.4 m) and generate the same beam deflection ($25°$). The drift lengths are L_1 = 1.2 m, L_2 = 0.6 m and L_3 = 1.55 m. All the quadrupoles have the same length of 0.2 m. For a beam energy of 400 MeV, the gradients of the first and second quadrupoles vary between 12.04 T/m and 7.81 T/m, and between 12.13 T/m and 1.29 T/m respectively.

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The CLIC notes and other references can be obtained from the CLIC site on the Web:

`http://www.cern.ch/CERN/Divisions/PS/CLIC/`

3.2 Recent ITEP Activity in Particle Dynamics

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At present, the Terra Watt Accumulator Project (TWAC) is under construction at Moscow Institute of Theoretical and Experimental Physics (ITEP). The main goal of the Project is to accumulate, in the existing ring of the ITEP proton synchrotron, intense heavy-ion beam using charge exchange injection. The stored beam should be compressed into a short bunch (with a bunch length of 50–100 ns), extracted from the ring and focused on an external target for high temperature plasma experiments [1]. Similar projects are considered in GSI (Germany, Darmstadt) and RIKEN (Tokyo, Japan). During the last two years, the major part of theoretical work in ITEP was devoted to theoretical and numerical analysis of different stages of the process and their optimization. This work is performed in a collaboration with JINR (Dubna, Russia), GSI and RIKEN.

For high temperature plasma experiments the beam should satisfy the following requirements:

1) specific energy deposition of the beam at the target E_{sp} is more than 1 kJ/g;

2) time t_H of hydrodynamic expansion is about to be equal to the ion pulse duration τ (for simplicity, the pulse is assumed to have a rectangular shape).

On taking into account a dependence of plasma sound velocity on specific energy deposition ($c_T = \sqrt{E_{sp}} = \sqrt{P \cdot t}$), one can write the following expression for a plasma temperature:

$$T_{\max} \simeq f \cdot (1.5 \cdot P \cdot a)^{1/2} = f \cdot \sqrt{K_b}.$$

Here, f is an universal constant ($f \simeq 50$ eV if $T_{\max}$ is expressed in eV), P is beam specific power in TW/g, a is beam spot size in cm (for beam with an uniform density), and factor $K_b = 1.5 \cdot P \cdot a$. To optimize this factor, it is necessary to develop adequate tools which would give a possibility to simulate beam evolution during accumulation. To this end, two methods have been developed:

1) a simplified model which calculates evolution of beam rms invariants for a Gaussian beam;

2) a Monte-Carlo method which enables to study evolution of beam distribution functions in a 5D phase space (two transverse degrees of freedom and momentum deviation).

The latest option of Monte-Carlo code [2] takes into account the following processes: (a) interaction of ions with a stripping target (which includes particle losses due to charge exchange and nuclear interaction, ionization losses, angular and energy straggling); (b) an intra beam scattering (IBS) of the stored high current ion beam; (c) effect of electron cooling system (ECS).

Analysis of the accumulation process with these methods has shown that in absence of ECS beam momentum spread increases, mainly, due to an intra beam scattering of the stored high current ion beam (leading to an energy transfer from the transverse plane to the longitudinal one) and a random character of the beam interaction.

However, application of ECS for such high ion currents (of about 10–50 A) can be doubtful due to effects induced by ion space charge — increase of cooling time and coherent electron-ion interaction. Influence of the first effect has been investigated by both the numerical methods ("Gaussian beam" approximation and Monte-Carlo code). Numerical analysis has shown that for reasonable currents (corresponding to a limitation of Coulomb incoherent tune shift) increase of cooling time usually does not exceed a factor of 1.5–2 and, thus, allows to use ECS. As for a coherent electron-ion interaction (the so called "Parchomchuk's effect"), analysis of influence of electron cooler on long-wave dipole ion oscillations results in conclusion that in a frame of such an approach this effect is not very essential. However, it is desirable to undertake a further theoretical and experimental analysis of such limitations.

Analysis of coherent effects has shown that the most important ones are transverse one-beam instability due to beam interaction with its environment, and transverse two-stream instability due to interaction with electrons appearing during ionization of residual gas. (It is necessary to underline that electron concentration in high current beams can be significant due to high focusing potential of the ion beam). For typical beams with small momentum spread which is required for beam compression it is necessary to design a special broad-band damping system in order to suppress dipole instabilities. Problem of higher-order mode transverse instabilities requires further investigation.

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3.3 Ongoing Beam Dynamics Activity in Department of Electro-Physical Facilities of MEPhI

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Department of Electro-Physical Facilities of Moscow State Engineering Physics Institute (MEPhI) was established more than fifty years ago. The Department trains specialists in charged particle beam physics and accelerator engineering. Now, its graduates are employed at all accelerator centers of Russia. The Department has a broad experience in R&D of linear accelerators, computer simulation of high intensity beam dynamics, radio- and micro-frequency electronics, vacuum technology. It is here where the first, in the former USSR, family of small-energy electron linacs has been developed. Early works on theoretical studies of non-linear effects in beam loading and blow-up effect in linacs were accomplished by a Laboratory of Beam Dynamics (DINUS). Now, the pressing task for the DINUS Lab is to improve RF focusing efficiency of ion beams, and put forward new methods of focusing and acceleration of high intensity ion beams in low energy linear accelerators.

3.3.1 Axisymmetric RF Focusing in a Low Energy Ion Linac

It is known that simultaneous longitudinal and transverse stability of beam motion in a linac can be ensured either by employing external focusing elements or by applying a special configuration of accelerating RF field (RF focusing). The second way is more effective for low energy ion linacs. There are few ways to obtain the latter type of focusing known by now:

alternating phase focusing (APF),
radio-frequency quadrupoles (RFQ), and
undulator RF focusing (RFU).

For axisymmetric RF systems, APF method can be used. The main principle of the APF can be described by means of a two-wave approximation method: in a periodical RF structure the beam is accelerated by a synchronous space harmonic of the wave while another, non-synchronous, harmonic is only responsible for focusing the particles.

Methods which were used in early papers to describe APF had some important shortcomings. Namely, both (i) a relationship between longitudinal and transverse motion and (ii) effect on focusing of fast longitudinal oscillations of particles in a field of non-synchronous wave were not taken into account. All the more, the averaging technique used to analyse RF focusing was not well-defined. Therefore, use of existing APF theories did not allow to recover all the RF focusing capabilities. There has been a great deal of practical interest in enlarging transmission coefficient K for low energy linacs. In frames of a conventional APF description, it is hardly possible to expose ways to achieve large values of longitudinal acceptance at entry to and high output current at exit from linac. It is a small accessible transmission that caused an obvious decay of interest to axisymmetric RF focusing in the recent years.

In Ref. [1], a smooth approximation technique is adopted as a basis to describe systems with RF focusing. Equation of a particle motion in a field of two waves is written using a Lagrangian function. On averaging over fast oscillations, one obtains a time-averaged equation of motion for a non-relativistic ion

$$\frac{d^2\vec{\mathbf{r}}}{dt^2} = -\frac{d}{d\vec{\mathbf{r}}} U_{eff}, \tag{3.1}$$

where 3D effective potential

$$U_{eff} = U_0\left(\vec{\mathbf{r}}^{\perp}, \psi\right) + U_1\left(\vec{\mathbf{r}}^{\perp}\right) + U_2\left(\vec{\mathbf{r}}^{\perp}, \psi\right) + U_c\left(\vec{\mathbf{r}}^{\perp}, \psi\right) \tag{3.2}$$

is a function of slowly varying transverse coordinate $\vec{\mathbf{r}}^{\perp}$ and phase ψ. Effective potential function U_{eff} completely describes a 3D particle dynamics. Besides, it determines the system Hamiltonian

$$H = \frac{1}{2}\left(\frac{d\vec{\mathbf{r}}}{dt}\right)^2 + U_{eff}. \tag{3.3}$$

In such an approach, the Hamiltonian analysis can be used for a complete 3D description of beam motion. Ref. [2] applies this method for a periodical RF structure, while Ref. [3] uses Eq.(3.1) to find out a condition of axisymmetric RF focusing in a linac.

Terms composing U_{eff} are determined by RF field harmonic structure. Item U_0 describes interaction of a particle with a synchronous harmonic that accelerates and defocuses the beam. Term U_1 accounts for transverse focusing and does not depend upon phase and amplitude of the synchronous wave. These two items correspond to the so-called two-wave approach when both, a synchronous and a non-synchronous harmonic are maintained in the cavity. Term U_2 describes effect of higher-order harmonics on beam motion, and U_c is a summand of potential function responsible for beam space charge forces.

The necessary condition for a simultaneous transverse and longitudinal focusing is existence of a total minimum for U_{eff}. It is arranged by a proper choice of field harmonic amplitudes. In this case, U_{eff} is a 3D potential well in the beam frame. By means of a Hamiltonian analysis in a 4D phase space, it is possible to find out a relationship between given longitudinal acceptance and the limiting value of transverse beam emittance which provides the maximal transmission coefficient $K \simeq 1$. In a two-wave approach, the rate of energy gain $dW_c/dz = eT_sE_{v,n}\cos\psi_c$. To yield $K \simeq 1$, acceleration efficiency factor must be $T_s \leq (eE_{v,s}\lambda)/(4\pi mc^2\beta_s)$, and amplitude of non-synchronous harmonic $E_n \gg E_s$. Computer simulation of high intensity ion beam dynamics in a polyharmonic axisymmetric RF field shows a good agreement with results obtained for a low energy linac in a smooth approximation. For example, simulation shows that for a proton buncher (input/output energy 0.1/2.2 MeV, current J =0.1 A) accelerating gradient $T_sE_{v,1}$ =0.7 MV/m and axisymmetric RF focusing efficiency are close to those of RFQ. Still, this focusing method is much simpler for realization than the RFQ one.

3.3.2 Using Undulators for Focusing & Acceleration of Low Energy Ions

In a conventional RF linac the beam is accelerated by a synchronous wave. Another method to accelerate ions — in the fields without a synchronous wave — was suggested in Ref. [1] in which case accelerating force is to be driven by a combination of two non-sychronous waves (two undulators). In an undulator linac in question, one of the undulators must be of the RF type (it drives non-synchronous RF wave field), the second one being, optionally, of magnetic, electrostatic or radio frequency types. The 3D dynamics of ion beam in an undulator linear accelerator (UNDULAC) is governed by the particular type of undulator and transverse structure of its field [4].

In case when phase velocities $v_{ph,n,l} = \omega_{n,l}/k_{n,l}$ of two waves differ significantly from the average velocity of the particles v_b, the equation of motion can be averaged over fast oscillations. Then one arrives at Eq. 3.1 provided beam velocity $v_b \simeq v_c \equiv (\omega_n \pm \omega_l)/(k_n \pm k_l)$. In this case, $U_0 = 0$ in effective potential U_{eff}, and longitudinal bunching and acceleration is provided by a combined wave whose phase velocity v_c is close to beam velocity. Choice of the undulator field amplitudes is not arbitrary because, simultaneously to acceleration, it must ensure transverse focusing of the beam. A few versions of the accelerator are possible:

1. UNDULAC-E(M) that employs a combination of RF field ($\omega_n = 2\pi c/\lambda, k_n = 2\pi c/\beta_{ph,n}\lambda$) and of a static periodical electric (or magnetic) field of an undulator ($\omega_l = 0, k_l = \mu_0/\lambda_0 + 2\pi l/\lambda_0$) where $l = 0, 1, 2, \ldots$, λ_0 is a slowly varying period of structure, μ_0 is a phase advance of field per period;

2. UNDULAC-RF that employs a combination of two space non-synchronous harmonics of RF field in the periodical resonator structure ($\omega_n = \omega_l = 2\pi c/\lambda, k_n \neq k_l$) where $k_n = \mu_v/\lambda_0 + 2\pi n/\lambda_0$, μ_v is phase advance per a period of RF structure; $l, n = 0, 1, 2, \ldots$ and $n \neq l$.

Rate of acceleration is proportional to amplitudes of the RF and undulator fields. Still, increase of beam energy occurs due to RF field only. For UNDULAC-E(M) the energy gain is given by $dW_c/dz = eT_{e,m}E_v \cos\psi_c$. The choice of field amplitudes is not independent since it is necessary to provide a large transmission coefficient K. In this case, acceleration efficiency factors are $T_m \simeq T_e = (eE_v\lambda)/(4\pi mc^2\beta_s)$. For a low injection velocity when $\beta_c \simeq (eE_v\lambda)/(4\pi mc^2)$ the rate of energy gain is the same as in a conventional linac.

The combined acceleration field can be driven without use of a magnetic or an electrostatic undulator. Indeed, consider ion beam dynamics in a periodical RF structure without synchronous space harmonics. Interaction of beam with each harmonic can be treated as ion interaction with a radio frequency undulator (UNDULAC-RF). The combined field of two harmonics would accelerate the beam if $\beta_b \simeq \beta_c = \omega/ck_c$ where k_c is a wave number of combined wave field, $k_c = (k_n \pm k_p)/2, k_c \neq k_n \neq k_p, n = 0, 1, 2, \ldots, p = 0, 1, 2, \ldots$. The rate of energy gain $dW_c/dz = eT_{rf}E_{v,1} \sin 2\psi$ where T_{rf} is acceleration efficiency factor, $T_{rf} = (eE_{v,0}\lambda)/(2\pi mc^2\beta_s)$. For an undulator where RF field has a phase advance $\mu_v = \pi$ per a period, value of T_{rf} can be larger than T_m and T_e. Besides, amplitudes of harmonics E_0 and E_1 can be chosen independently, their peak values being found from RF performance data of the resonator, transverse acceptance and beam current.

3.3.3 Undulac and RF Focusing in a Linac

It is interesting to compare methods in question of acceleration in an UNDULAC and in a linac with an axisymmetric RF focusing. Given two fundamental harmonics $s = 0, n = 1$ and a phase advance $\mu_v = \pi$ per period, the efficiency factor RF focusing amounts to $T_s \simeq (eE_n\lambda)/(4\pi mc^2\beta_s)$. This magnitude is close to $T_{m,e}$ but is twice lower than T_{rf}. The condition of focusing in an UNDULAC-RF can be fulfilled for any value of E_0/E_1, and the frequency of ion beam bunching is doubled $\omega_b = 2\omega$ in this case.

Use of undulators for acceleration and focusing of ion beams looks extremely promising. First, the problem of design of UNDULAC RF system is simplified considerably since focusing and acceleration of particles is possible with both transverse (TE or TEM) and longitudinal (TM) RF fields without any external focusing elements and dedicated slow-wave systems. No drift tubes are required for a TEM wave. Second, an efficient bunching and a large transmission coefficient of particles can be achieved solely by changing amplitude and period of the static undulator field. This eliminates serious problems involving adjustment and matching of the RF system since the latter can be made uniform. Third, an UNDULAC can be used for acceleration high intensity ion beams [4]. Indeed, the main factor limiting beam intensity in ion accelerator is a space charge force. There exist, at least, three ways to increase ion beam intensity in a linear undulator accelerator: (i) to enlarge beam cross-section; (ii) to accelerate several beams in a channel of RF structure; (iii) to compensate for space charge by accelerating ions with opposite charge signs within the same bunch. In other words,

(i) In an UNDULAC where there are no drift tubes, a ribbon or a hollow beam having large cross-section can be accelerated. Acceleration of a ribbon ion beam with current $J > 1$ A in a plane electrostatic undulator was studied in Refs. [5]. It was shown that a large cross-section and electrostatic shielding of space charge field decreases Coulomb defocusing of the particles in the narrow accelerating channel.

(ii) In a new accelerator, one can accelerate several beams in a single channel of RF structure since there are no drift tubes involved. The problem is to choose a dedicated symmetry of transverse radio frequency and periodic magnetic field. The RF system must have a small transverse size. It is preferable to use a shielded multy-electrode line where transverse electromagnetic waves (TEM) can propagate. Configuration of RF field and magnetic undulator field must be such as to maintain several equilibrium trajectories simultaneously [4].

(iii) Study of feasibility of a simultaneous acceleration of both positive and negative ions with identical charge-to-mass ratios within the same bunch is of a great interest. The current limit of the ion beam can be increased significantly by using space charge compensation of positively $H^+(D^+)$ and negatively $H^-(D^-)$ charged ions accelerated in the same bunch. This conclusion can be drawn from Eq. (3.1). Indeed, effective potential U_{eff} depends on particle charge squared, i.e. averaged motions of positive and negative charged ions are identical. It allows to increase the beam current limit.

All the possible methods of focusing and acceleration in an undulator linear accelerator would be effective for low energy ions when $\beta_b \simeq (eE_n\lambda)/(4\pi mc^2)$. Acceleration efficiency factor $T_{m,e,rf}$ decreases with growth of beam velocity like in an RFQ accelerator. Therefore, an UNDULAC can be used as an initial part of a high intensity linear accelerator (buncher), or as an injector for a neutron generator or a nuclear fusion reactor.

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3.4 Beam Dynamics Activity in JINR

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Here, two areas of ongiong beam dynamics activity are described in brief. They are related to two accelerator projects now in progress at JINR.

3.4.1 Particle Dynamics in a Storage Ring with Strong Coupling of Transverse Modes

Project LEPTA (Low Energy Particle Toroidal Accumulator), which is under realisation in JINR, is dedicated to construction of a small storage ring and pursuits two general goals:

1. Being operated with a 10 keV circulating positron beam, LEPTA ring would be used for electron cooling of positrons and generation of antihydrogen and positronium in flight, Ref. [1].

2. Being run with a circulating electron beam at energies from about 1 to 4 MeV, LEPTA ring can be employed as an electron cooling system to cool down an ion beam in the GeV energy range, Ref. [2].

Application of a longitudinal magnetic field seems to be very attractive for particle focusing in this energy range. The LEPTA ring consists of 2 toroidal and 2 straight solenoids connected together as a racetrack, and surrounded by a common magnetic shielding. The ring peculiarities are its longitudinal magnetic guide field and a sectioned structure of its lattice cells (contrary to a modified betatron). Additionally, a quadrupole spiral field is used at one of the straight sections to form a closed orbit. The ring circumference is about 18 m long.

The longitudinal magnetic field provides particle magnetisation and, as a consequence, long lifetime of the circulating beam. However, it leads to strong coupling between horizontal and vertical degrees of freedom. Lattice design with programs usually used for strong focusing accelerators (like MAD) is not convenient in this case. Particle dynamics simulation for the LEPTA is performed with a dedicated computer code BETATRON based on BOLIDE package (Beam Optic Library & Interface Development Environment) developed in JINR. Motion stability regions and lattice functions are calculated with a matrix method, non-linear components of the focusing fields being taken into account using a Hamilton formalism, Ref. [3].

3.4.2 Magnet Lattice Studies of Synchrotron Radiation Source DELSY

Project DELSY (Dubna Electron Synchrotron) is aimed to construct a synchrotron radiation source of the 3rd generation at the Joint Institute for Nuclear Research. The DELSY synchrotron radiation source will be constructed on base of the accelerator facility of the Institute for Nuclear Physics and High Energy Physics (NIKHEF), Amsterdam, the Netherlands. This accelerator facility consists of a linear electron accelerator MEA (Medium Energy Accelerator) for electron energy of 700 MeV and electron storage ring AmPS (Amsterdam Pulse Stretcher) for the maximal electron energy of 900 MeV at the circulating beam current of 200 mA.

This source will be dedicated to investigations in condensed matter physics, atomic physics, biology, medicine, chemistry, micro-mechanics, lithography, etc. For DELSY, the layout with four straight sections was chosen. Every quadrant consists of MBA-structure and two halves of straight sections. The machine emittance at 1.2 GeV is 11 nm. Circumference of the ring is about 136 m. For the preliminary adopted working point of $Q_x/Q_y = 9.44/3.42$ the dynamic aperture in the presence of the very strong wiggler (10 T) and undulator (0.75 T, 150 periods) is large enough for efficient injection which is performed at 0.8 GeV.

For linear optics and dynamic aperture calculations with wiggler on, measured multipole components of the 10 T wiggler were used. The very strong wiggler inflicts a noticeable distortion to the linear optics. To maintain the same tunes with wiggler on using a limited number of matching quadrupoles available, the following procedure has been applied. Initially, strengths of two matching quadrupoles in the wiggler straight section have been modified to keep constraint ($\alpha_x = 0$, $\alpha_y = 0$) with wiggler on, as well as with wiggler off. This eliminates beating of beta functions everywhere outside of the wiggler section. The same procedure has been applied for undulator (0.75 T, 150 periods of 2.25 cm length), its effect on machine optics being much weaker. After these manipulations, machine tunes have changed significantly. To bring them back and maintain the required beta functions throughout the machine, a "global" matching procedure involving all matching doublets and three quadrupole families of the matching cells has been applied. As result, the deviation of the beta functions for machine with wiggler on from that one with wiggler off is minimised to less than 10%.

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3.5 Beam Dynamics Activities at IHEP (Protvino)

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Most of ongoing beam dynamics activity at Institute for High Energy Physics (IHEP, Protvino) is servicing its proton accelerator complex whose final stage comprises two proton synchrotrons — a 70 GeV U70 PS and its 1.5 GeV Booster.

3.5.1 U70 Proton Synchrotron

For a few years on, U70 is in a regular service with its two scheduled 1,500 hr long runs per year (winter/spring & autumn/winter). Benchmark intensity at MD sessions is around $1.4{\cdot}10^{13}$ p.p.p., its cruise value being normally at about half of this value.

At the moment, the major offending problem in the ring is a coasting beam instability at flat top (RF off). It hampers slow resonant extraction towards beam consumers. The instability depends on a filling pattern of orbit with bunches prior to debunching. A suspected culprit is a 5 MHz fundamental mode of 40 idle ferrite-loaded RF cavities (resonant frequencies of their Q-curves are tuned to an integer + 1/2 of a rotation harmonic to minimize coupling to beam). Attempts to employ a straightforward compensation scheme aimed at eliminating net circumferential beam voltage with an inverted pick-up signal fed back into drive chain of an RF cavity were of a limited success only. As an alternative, a mode-by-mode damping beam feedback circuit applying to frequency down/up conversion for signal processing is proposed and being discussed. Multi-particle tracking studies are underway as well.

Master oscillator, guide-field — radio-frequency program generator, phase and radial feedback circuits at RF are being modernized to a DSP grade. Prototypes have been tested with beam. To meet the demand of RF people and estimate feasibility of beam intensity upgrade, a comprehensive study of a stability of U70 RF system employing tuned ferrite-loaded cavities has been undertaken. This system is encircled by a number feedback loops (6 in total, both dedicated and spurious) that cross-talk due to a heavy beam loading, a high accelerating rate and overlapping loop pass-bands. To this end, a quadrupole mode of beam in-phase oscillations was found to be inherently unstable, without a dedicated beam amplitude feedback loop. In the wake of these research efforts, such a system has been developed, assembled and put into operation.

Acceleration in U70 is accomplished at RF of 5.5–6.1 MHz. As a heritage of the former UNK Project, there is a 200 MHz cavity installed as well. This cavity has proven to be a versatile device servicing various purposes. Say, it spills the bunch longitudinal emittance before γ-transition, was used to tailor out beam distribution over momenta and manipulate the beam at flat top. One of its applications has recently provided a food for thought to beam dynamics people here. Being switched on at injection flat bottom with a certain off-set w.r.t. a relevant integer harmonic of main RF, the 200 MHz cavity has yielded reproducible flat bunch shapes and a noticeable (a few %) increase in beam capture and transfer efficiency. As yet, this effect is not understood properly. An interplay between a steady-state longitudinal potential well distortion (increased non-linearity) followed by a destabilization of higher-order multipole modes of out-of-phase coupled-bunch oscillations is suspected to flatten the bunches.

3.5.2 Booster Synchrotron U1.5

Normally, the Booster accelerates protons from 30 MeV to 1.32 GeV at RF harmonic number $h = 1$. Beam intensity can be set in between (2–9)$\cdot 10^{11}$ p.p.p. on demand. It is a fast machine cycled at 16.7 Hz with a duty factor of around 0.2 acquired by a 0.1 Hz repetition rate of U70. Beam transmission efficiency through the cycle is around 75%. The main goal of beam dynamics studies is to increase this figure.

Many efforts were and are being spent to ease horizontal aperture limitations caused by a ripple in guide field. This ripple was found to result in a closed-orbit distortion at the 2-nd azimuthal harmonic that has demanded for an estimated (5–10)% of a free-aperture budget available. Proper synchronizing to the mains phase of control networks in add-on power supplies inside a “White Circuit” that feeds the ring magnet has already resulted in suppression of the closed-orbit distortion by a factor of 2. Further steps in this direction are planned.

A program is underway to study non-linear effects of betatron oscillations. The ultimate goal of these studies is to understand the causes of horizontal dynamic aperture reduction by a factor of 1.3 with respect to its anticipated value. To this end, the first step scheduled is to deal with non-linear coupling resonances inflicted by skew sextupolar magnetic field errors.

A noticeable amount of beam dynamics studies was invested into upgrade of beam extraction from the Booster. Now, energy of ejected beam can be varied from 200 MeV to 1.3 GeV which extends Booster’s capabilities in an applied research. At top extraction energy, the ring can now be operated in a PPM mode feeding U70 as well as external targets.

4: Forthcoming Beam Dynamics Events

4.1 NPSS Technology Emphasis at Snowmass 2001

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The Division of Physics of Beams and the Division of Particles and Fields of the American Physical Society in technical cooperation with the IEEE Nuclear and Plasma Sciences Society are sponsoring a workshop for planning the future of Particle Physics in July 2001 at Snowmass, Colorado. The NPSS contribution will focus on the technologies which impact the future of Particle Physics research. We are seeking to identify technologies and ways to bring insight about these technologies to the Snowmass participants.

The principal focus of these activities will be a "Technology School" with about a dozen half day or one day courses on critical technologies for experimental detectors and accelerators. The NPSS Short Courses, such as have been presented at the Nuclear Science Symposium, have addressed issues such as particle identification or pixel detectors in a one day format. Topics such as beam instrumentation or accelerator magnets which have been covered in 5 or 10 day courses at the US Particle Accelerator School could be covered with different emphasis. We will also consider other technologies, relevant to but not specific to our field whose development will be crucial to the future of our research. We will select with an eye on scientific opportunity and significance but the ultimate criteria will be presenters who can make excellent presentations on relevant topics. Funds to enable this effort will be provided by NPSS.

A related but separate activity which will also involve the NPSS will be working groups (the typical organizational structure at previous Snowmass studies) on the limits of technology for detectors and accelerators. These groups will seek to identify, for both mature and developing technologies, the expected state of development in a relevant one or two decade time frame. In these groups, the selection criteria for topics will seek those of greatest relevance, unlike the schools where the presentation excellence will be the necessary guideline.

Of IEEE Societies, NPSS is perhaps the most diverse. Committees within NPSS sponsor several conferences which you may know about: Nuclear Science Symposium and Medical Imaging Conference, Pulsed Power Conference, Radiation Effects Conference, Real Time Computing Conference, Int. Conf. on Plasma Science, Fusion Engineering Conference, and the Particle Accelerator Conference. Thus we have direct contact with experts in a variety of relevant technologies, including radiation hardness, pulsed power, data acquisition computing and particle sources in addition to those from the traditional detector and accelerator conferences. IEEE is also an excellent resource beyond the NPSS range of interest.

At this time we are beginning to examine options for schools and work groups at Snowmass. We are seeking suggestions for technologies and presenters for those technologies. To stimulate ideas we have the following introductory list:

— beam instrumentation,
— RF power generation,
— traditional and superconducting RF cavities,
— pulsed power for beam manipulation,
— superconducting magnets,
— permanent magnets,
— radiation hard detectors and electronics,

— robotics,
— alignment vs. ground motion,
— crystal radiation detectors and calorimetry,
— silicon for tracking and calorimetry,
— pixel detectors,
— controls,
— beam feedback systems,
— real time computing and data acquisition,
— wireless technology,
— computing in a network environment,
— new acceleration techniques,
— prospects for creating experimental caverns and accelerator tunnels.

A Web Site will be maintained for this activity at

`http://www-ap.fnal.gov/~bcbrown/NPSS_Snowmass2001_Home.html`

The Snowmass 2001 Web Site will be announced soon and links provided from the NPSS page. Please contact us with your comments and suggestions.

4.2 8th International Workshop on Beam Dynamics & Optimization

V. Stepanchuk `StepanchukVP@info.sgu.ru` SSU

The 8th International Workshop
on
BEAM DYNAMICS & OPTIMIZATION (BDO'2001)
Saratov State University, Saratov, Russia
June 25–29, 2001

This series of the BDO Workshops is supported by Russian Foundation for Basic Research and Russian Federal Program "Integration". The 8th Workshop is organized by Saratov State University, Joint Institute for Nuclear Research (Dubna), St. Petersburg State University, D.V. Efremov Institute of Electrophysical Apparatus (St. Petersburg) and Peoples' Friendship University of Russia (Moscow).

Organizing Committee:

D.I. Trubetskov	Chairman
D.A. Ovsyannikov	Co-chairman
V.P. Stepanchuk	Chairman of Local OC

The objective of the Workshop is to bring together mathematicians, physicists and engineers to present and discuss recent developments in the area of mathematical control methods, modeling and optimization, theory and design of charged particle beams.

Subjects to be discussed at this Workshop are:

- non-linear problems of beam dynamics;
- methods of control theory in problems of beams and plasma;

- mathematical modeling of electro-magnetic fields;
- computing problems in beam physics, application of object-oriented modeling to beam dynamics optimization;
- software for beam dynamics and optimization.

Request for a complete text of the First Announcement and the other relevant information should be addressed to E-mail: `GorbachevVP@info.sgu.ru`. Since December 2000, all the information on BDO'2001 will be made available on the Web, at the homepage

`http://www.sgu.ru/nuke`

of Nuclear Physics & Accelerators Laboratory of SSU.

5: Announcements of the Beam Dynamics Panel

5.1 Advanced ICFA Beam Dynamics Workshops

5.1.1 21st ICFA Beam Dynamics Workshop on Laser-Beam Interactions

Igor Pogorelsky `igor@bnl.gov` BNL

The 21st ICFA Beam Dynamics Workshop
on
LASER-BEAM INTERACTIONS
Stony Brook, USA
June 11–15, 2001

The subject of the interaction of high-power laser beams with high-brightness electron beams is very rich with interesting science, applications and opportunities for new discoveries. This field is experiencing a tremendous growth and there is a great need for scientists exploring various aspects of this exciting discipline to meet, exchange ideas and present late breaking results.

Ongoing progress in short-pulse high power lasers and low-emittance electron bunch compression opens possibilities for various interesting applications, such as a new generation of X-ray sources operating on the picosecond and femtosecond time scale. Development of such sources promises new avenues for multi-disciplinary exploration on the molecular and atomic time scale. It may revolutionize the field of X-ray research and add new capabilities to the Compton sources of X-ray and gamma radiation.

Shedding light on the new development in the technology and application of femtosecond X-ray sources, the workshop will promote progress in this fast evolving field and will help to develop better a scientific case for future FEL-based coherent femtosecond X-ray sources. The symposium will be a forum for discussion and planning ways to widen user's access to novel opportunities in femtosecond research: can it be approached by expansion or extending the existing light source facilities or by giving a fresh start to next generation facilities.

Bringing together specialists in high energy physics, laser science, nuclear physics, plasma physics, and from the interdisciplinary light source user's community, the workshop will become a unique forum for exchange and originating new ideas that will enrich the field.

The symposium will address the most recent results and prospects in the following topics:

1. Generation of Femtosecond X-ray
2. Topics in high field science
3. Ultra-fast pump-probe experiments
4. Ultra-fast X-ray microscopy
5. Non-linear effects in laser-Compton scattering
6. High quality electron beams
7. High quality, high power laser beams

8. Generation of polarized gamma-rays and polarized positrons
9. Gamma-gamma colliders
10. Laser cooling of accelerator beams
11. Beam diagnosis
12. Laser acceleration
13. Laser induced radiation from electron beams: Coherent radiation, seeded FELs, harmonic generation...
14. Control, manipulation and microbunching of electron beams by lasers

To learn more about the program, location and facilities please visit the workshop's web site at

`http://nslserver.physics.sunysb.edu/icfa/Home.htm`

International Organizing Committee:

I. Ben-Zvi	(Stony Brook U. and BNL, USA),	Co-Chair
T. Hirose	(Tokyo Metropolitan U., Japan),	Co-Chair
P. Corkum	(NRC, Canada)	
H. Kamitsubo	(SRRI, Japan)	
K.-J. Kim	(ANL, USA)	
Y. Kimura	(KEK, Japan)	
J. Kirz	(Stony Brook U., USA)	
S. Krinsky	(BNL, USA)	
W. Leemans	(LBNL, USA)	
V. Litvinenko	(Duke U., USA)	
S. Milton	(ANL, USA)	
P. Siddons	(BNL, USA)	
A. Skrinsky	(BINP, Russia)	
D. Umstadter	(U. of Michigan, USA)	

Program Committee:

I. Pogorelsky	(BNL),	Chair
P. Chen	(SLAC)	
L. DiMauro	(BNL)	
T. Ditmire	(LLNL)	
E. Esarey	(LBNL)	
E. Johnson	(BNL)	
C. Joshi	(UCLA, USA)	
G. Kulipanov	(NBI)	
N. Marquardt	(Dortmund)	
K. McDonald	(Princeton Univ.)	

K. Moffat	(U. Of Chicago)
M. Murnane	(JILA, USA)
F. Pegoraro	(Pisa U.)
C. Pellegrini	(UCLA, USA)
A. Sandorfi	(BNL)
R. Tatchin	(SLAC)

Invited Speakers:

1. A. Ting (NRL): Review on Thomson (laser synchrotron) source experiments and applications in US
2. K. Nakajima (KEK): Review on Thomson source experiments and applications in Japan
3. P. Norreys (Rutherford Lab.): Vulcan PW laser, its applications for electron and ion acceleration and X-ray production, review on X-ray experiments in Europe
4. E. Esarey (LBL): Nonlinear Thomson scattering with electron beams and plasma
5. J. Hastings (BNL): X-Ray research between now and the LCLS
6. T. Tajima (Univ. of Texas at Austin): High field science
7. C. Jacobsen (SUNY at Stony Brook): Ultra-fast X-ray microscopy and holography
8. V. Litvinenko (Duke University): High intensity polarized monochromatic gamma-rays from storage ring FELs
9. Kwang-Je Kim (ANL): Gamma-gamma colliders and cooling of accelerator beams
10. P. Sprangle (NRL): Laser electron acceleration
11. M. Roth (GSI): Energetic ions generated by laser pulses
12. W. Kimura (STI Optronics): Generation of femtosecond electron-bunches
13. R. Falcone (UC Berkeley): Review on femtosecond pump-probe experiments and other potential applications of femtosecond laser synchrotron (Thomson) sources
14. X.J. Wang (BNL): High-brightness electron beam sources
15. C. Thorn (BNL): LEGS facility and review of tagging experiments

5.2 ICFA Beam Dynamics Newsletter

Editors in chief
Kohji Hirata (kohji.hirata@kek.jp) and John M. Jowett (John.Jowett@cern.ch)

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5.2.1 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 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.

5.2.2 Categories of the Articles

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

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 of Beam Dynamics related workshops and meetings

4. Announcements of future Beam Dynamics related international workshops and meetings.

   Those who want to use newsletter to announce their workshops etc can do so. Articles should typically fit within half a page and include descriptions of the subject, date, place and details of the contact person.

5. Review of Beam Dynamics Problems

   This is a place to put forward unsolved problems and not to be used as the achievement report. Clear and short highlights on the problem is encouraged.

6. Letters to the editor

   It is a forum open to everyone. Anybody can show his/her opinion on the beam dynamics and related activities, by sending it to one of the editors. The editors keep the right to reject a contribution.

7. New Doctoral Theses in Beam Dynamics

   Please send announcements to the editors including the following items (as a minimum):

(a) Name, email address and affiliation of the author,

(b) Name, email address and affiliation of the supervisor,

(c) Name of the institution awarding the degree,

(d) The title of the thesis or dissertation.

(e) Date of award of degree. (For a while, we accept the thesis awarded within one year before the publication of the newsletter.)

(f) A *short* abstract of the thesis is also very desirable.

8. Editorial

All articles except for 6) and 7) are by invitation only. The editors request an article following a recommendation by panel members. **Those who wish to submit an article are encouraged to contact a nearby panel member**.

The manuscript should be sent to one of the editors as a LaTeX file or plain text. The former is encouraged and authors are asked to follow the instructions below.

Each article should have the title, author's name(s) and his/her/their e-mail address(es).

5.2.3 How to Prepare the Manuscript

Here, the *minimum* preparation is explained, which helps the editors a lot. The full instruction can be found in WWW at

`http://www-acc-theory.kek.jp/ICFA/instruction.html`

where you can find the template also.

Please follow the following:

- Do not put comments (%) when sending the manuscript through e-mail. Instead, you can use `\comm` as `\comm{your comments}`. It is defined as \newcommand\comm[1]{}.
- Start with `\section{title of your article}`. **It is essential**.
- Then put your name, e-mail address and affiliation.
- It is *useless to include any visual formatting commands* (such as vertical or horizontal spacing, centering, tabs, etc.).
- Do not define new commands.
- Avoid TEXcommands that are not part of standard LATEX. These include the likes of `\def`, `\centerline`, `\align`, ...
- Please keep figures to a minimum. The preferred graphics format is Encapsulated Postscript (EPS) files.

5.2.3.1 *Regular Correspondents*

Since it is impossible for the editors and panel members to watch always what is going on all around the world, we have started to have *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

Liu Lin (liu@ns.lnls.br)	LNLS	Brazil
S. Krishnagopal (skrishna@cat.ernet.in)	CAT	India
Ian C. Hsu (ichsu@ins.nthu.edu.tw)	SRRC	Taiwan

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

5.2.4 Distribution

The ICFA Beam Dynamics Newsletters are distributed through the following distributors:

W. Chou	chou@adcon.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@bepc5.ihep.ac.cn) takes care of the distribution with Ms. Su Ping, Secretariat of PASC, P.O.Box 918, Beijing 100039, China.

It can be distributed on a personal basis. Those who want to receive it regularly can ask the distributor to do so. In order to reduce the distribution cost, however, please use WWW as much as possible (see below).

5.3 World-Wide Web

The home page of the ICFA Beam Dynamics Panel is at the address

http://www-acc-theory.kek.jp/ICFA/icfa.html

(which happens to be in Japan). For reasons of access speed, there are mirror sites for Europe and the USA at

http://wwwslap.cern.ch/icfa/
http://www.slac.stanford.edu/grp/arb/dhw/dpb/icfa/icfa.html

All three sites are essentially identical and provide access to the Newsletters, Future Workshops, and other information useful to accelerator physicists. There are links to information of local interest for each area.

5.4 ICFA Beam Dynamics Panel Organization

The mission of ICFA Beam Dynamics Panel is *to encourage and promote international collaboration on beam dynamics studies for present and future accelerators*. For this purpose, we publish *ICFA Beam Dynamics Newsletters* three times a year, we sponsor *Advanced ICFA Beam Dynamics Workshops* and *ICFA Beam Dynamics Mini-Workshops*, and we organize *Working Groups* in the panel to promote several important issues.

Chairman K. Hirata

Chief Editors of ICFA Beam Dynamics Newsletter K. Hirata and J.M. Jowett

Editors of ICFA Beam Dynamics Newsletter W. Chou, S. Ivanov, H. Mais, J. Wei, D.H. Whittum, and C. Zhang

Distributers of ICFA Beam Dynamics Newsletter W. Chou, H. Mais, S. Kamada

Leader and Subleader of Future Light Source Working Group K.J. Kim and J.L. Laclare

Leader and Subleader of Tau-Charm factory Working Group E.A. Perelstein and C. Zhang

Leader of High-Brightness Hadron Beams Working Group W. Chou

WWW keeper K. Hirata, J.M. Jowett and D.H. Whittum

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The views expressed in this newsletter do not necessarily coincide with those of the editors. The individual authors are responsible for their text.