

Report of the External Advisory Committee Of the HIPPI JRA Inside CARE

September 28-30, 2005

Introduction

The second general meeting of the European Collaboration on High-Intensity Pulsed Proton Injectors (HIPPI05) was held in Abingdon, UK, from the 28th through the 30th of September, 2005. The objectives of the HIPPI collaboration are to encourage and coordinate accelerator research and development activities, which are distributed among nine European laboratories, to establish a technology base supporting a new class of high-intensity accelerators within the European Community. To the same end, HIPPI supports the improvement of existing and supporting accelerator facilities at GSI, RAL and CERN. The collaboration expects continuing support from the European Union through 2008.

The committee heard approximately 34 presentations covering the technical work undertaken at 10 institutions since September, 2005 as well as plans for future work and facility improvements. The technical sessions were organized by work package.

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| Work Package 4: | Choppers |
| Work Package 2: | Normal Conducting RF Accelerating Structures |
| Work Package 3: | Superconducting Accelerating Structures |
| Work Package 5: | Beam Dynamics and Beam Diagnostics |

Committee Membership

- | | |
|---------------------|--------------------------------------|
| Andrea Pisent | INFN, Legnaro, Italy |
| James Stovall | Los Alamos & Oakridge, USA (retired) |
| Yoshishige Yamazaki | JAERI, Tokai, Japan (in abstentia) |

Charge to the Committee

The External Scientific Advisory Committee (ESAC) was asked to evaluate the technical work completed to date as well as proposed activities within in the framework of HIPPI. The purpose of this report is to provide an independent assessment of these activities and make recommendations for future guidance to the HIPPI management. Specifically, the committee was asked to address the following questions:

1. General. Please review and comment on the overall scientific quality of the research carried out. What were the most important accomplishments of the first year? How does the work compare with the international level?
2. Labs & Groups. Does the work presented by the different laboratories match with the HIPPI work? Is it consistent and sufficiently transparent scientifically? Comment on the proper use of resources. Is it clear how the groups proceed in the second year?

3. Work Packages. Comment on the effectiveness of interaction within WP's. Is there enough visibility of WP collaboration? Comment on what needs to be strengthened.

General Assessment

With the completion of the SNS linac there are now only 2 new high-current proton injectors still under construction worldwide, the committee knows of no new (funded) facilities presently under design except for possible upgrades. The HIPPI activities, therefore, represent the bulk of R&D activities addressing high-current linac technology under way worldwide. The committee (two members in attendance) has chosen to concentrate primarily on the technical aspects of the work and have not addressed the work planning or use of resources for which we ask management's indulgence.

In many cases, the HIPPI work is being carried out by individuals who are well recognized in the accelerator community for their special expertise and who, in some cases, are serving as mentors to younger scientists. We find the work to be of high quality and are encouraged to see HIPPI being used as a vehicle for recruiting new members to the fraternity of accelerator designers. It is very encouraging to see that some of the funding has been directed towards facility improvements aimed at advancing the art.

Because there are no common, well-defined goals with specific performance objectives or deliverables, assuring strong collaborations among multiple institutions is challenging for the work-package managers. The committee is pleased to observe no reluctance among the participants to collaborate with their colleagues and in some cases to note strong inter-lab collaborations.

In some cases the work presented represents efforts that are complimentary to laboratory's individual programs and objectives. In a few cases it was not clear how the work directly supported the HIPPI objectives. The committee believes that it would still be helpful to **define a hypothetical set of HIPPI performance goals** or ranges of performance parameters so that committee members and researchers could more easily access the relevancy of their work.

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Work Package 4, Beam Chopping

While the HIPPI activities are focused on the technologies applicable to linear accelerators up to an energy of ~200 MeV, we can assume that some applications will include injection into circular machines, synchrotrons, or storage rings. To facilitate "lossless" injection, the circulating beam must include an extraction gap. This gap must be created, or chopped out, at low energy and preserved, without degrading beam quality, through the final energy. To minimize machine activation, it is important to chop the beam cleanly, leaving no partially chopped microbunches.

Two approaches were presented, both of which rely on electrostatic deflection but differ in amplifier design, duty cycle, and beam-line design. In both approaches the primary challenges are to make the rise time of the deflection voltage shorter than the time between beam bunches (~2 ns at 352 MHz), operate with a high duty factor (~50 MHz) and minimize beam emittance growth.

The “fast-slow” chopper system, developed at RAL, has enjoyed several years of R&D support and its engineering design is already fairly mature. In the last year single and dual polarity generators have been procured and tested, demonstrating the main required performances, and with a field corrected droop of 2.8%. A slow-pulse generator has been prototyped and tested. For the design of the beam-line design itself, three different chopping schemes have been evaluated which include new features (like a separate location for the dumper) and with new considerations on the hardware involved (for example the bunchers).

The CERN approach uses a double meander-line deflector housed within a large-aperture quadrupole. The lay-out of the beam transport line has been frozen, and the mechanical designs of main components are ready. In particular, quadrupoles have been identified that are available from previous projects and two bunchers have been produced and tested at low power. The beam dump, realized with a water cooled Glidcop structure with a nickel coating to minimize neutron activation under bombardment by the 3 MeV protons, is ready for manufacturing. Different approaches for the meander line construction have been tested.

Regarding the chopper itself, in the approach shown last year the deflection plates were driven by high- and low-frequency pulse amplifiers to achieve the required rise time; measurements shown at that time using prototype amplifiers have demonstrated the validity of the approach, but indicate further design work is required to meet voltage and bandwidth requirements. This year a new bipolar amplifier design, based on solid state components and hybrid couplers, has been shown. This amplifier which has been built and tested, meets the rise time specification ($<2\text{ns}$ rise time) with 3% noise. This last figure has been shown to be compatible with linac beam dynamics.

The chopper is just one of many devices comprising a complex, integrated system. The committee recommended that WP-4 collaborate with WP-5, Beam Dynamics, to investigate the “long-range” effects that the two chopper designs may have on beam quality at high energy using realistic particle distributions in a representative ~1-GeV linac. This is **only partly done for CERN linac4**, with the integration of the MEBT in the low energy linac part; but the absence of beam losses or even rms emittance increase at low energy is of course not enough to **demonstrate the solidity of the design**.

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Regarding the recommendation of last year, the committee registers a stronger collaboration between the two laboratories, resulting in improvements in the design of both the chopping lines. For the future it should be interesting to **simulate RAL design on linac4**; moreover it is important to produce a **plan for the MEBT tests** in the remaining part of HIPPI program.

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Work Package 2, Normal Conducting Accelerating Structures

The committee heard presentations from 5 laboratories that addressed 4 different normal Conducting (NC) accelerating structures including 2 DTLs, a CH-DTL, a CCDTL and a SCL. In addition we heard about progress on a high power rf coupler for NC applications.

Last year the committee felt that the CERN DTL suffered from design shortcomings and dated technology. We are very pleased to learn that CERN responded

by forming a task force to address these issues. As a result both electromagnetic quads and diffusion bonded copper tanks have been abandoned in favor of permanent-magnet quadrupole (PMQ) lenses and copper plated tanks. Two different PMQ designs are being further investigated.

The decision to use PMQs reopens the lattice options. Two lattices have been studied, each yielding equivalent beam performance, with a final decision awaiting cost and quality comparisons of two prototype PMQs. In a new design the field ramp was eliminated with the longitudinal dynamics now being programmed by tailoring the phase and transit time factor. This is an unconventional approach but the beam dynamics look satisfactory and the change may simplify the tuning of tank 1.

The DTL is intended to be resonantly stabilized using post couplers. For the post couplers to perform properly the distance from the drift tubes to the tank wall should be 5 to 10% less than a quarter wavelength (the post-coupler criteria). In the CERN design this distance is 1% larger than a quarter wavelength. As a result the tank stabilization may be marginal. Because the prototype tank is relatively short this effect may be negligible however in a longer tank any significant beam loading may detune the tank. The stability can be verified using a cold model having a scaled geometry.

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The recommended numerical studies of the CERN linac, including the MEBT, RFQ, and choppers, plus errors have been carried out using theoretical particle distributions.

Preliminary design studies for a 324 MHz DTL at RAL are under way. This design can benefit significantly from the CERN design experience and the committee recommends a close collaboration between the two groups. Initial investigations of candidate cavity geometries do not address the post-coupler criteria.

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Construction and assembly of a 352 MHz CCDTL has been completed at CERN and initial field measurements look promising. Theoretically a CCDTL would be the NC structure of choice in the energy range between 40 and 90 MeV. The beam dynamics performance has been shown to be excellent in an integrated linac model. There are claims made for certain advantages of the CCDTL over a DTL in the same energy range however, as a practical matter they may not be justified in light of the fact that an additional structure requires an additional engineering effort. It is for this reason that the SNS abandoned the CCDTL, a decision resulting in an overall cost saving with no degradation in performance. It would be very helpful to access the cost benefits of a CCDTL in a facility construction scenario.

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A coupled-cavity $\pi/2$ -mode structure (CCL) is the clear choice for the high-energy portion of a NC linac. This structure comes in several varieties. Both RAL and CERN have selected the side-coupled linac (SCL) structure. However, because there is not unanimity within the community, the committee again recommends that this work package objectively compare the virtues of the various candidate structures, especially in light of recent fabrication and operating experience. The CERN group has developed an EXCEL tool making it very easy to explore the parameter space of SCL designs. The Grenoble group has completed a theoretical study of fabrication and tuning tolerances for a conventional SCL design and have begun thermal analysis of the structure using an interesting new cooling circuit design. The committee recommends that the collaboration

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between RAL and LPSC be strengthened as personnel are available and is pleased to note the proposal of the Napoli group to contribute to this effort.

Collaboration between LPSC and CEA Saclay has resulted in an optimized design of a high power wave guide iris coupler. Thermal and structural analysis has been completed and a prototype coupler has been fabricated and tested at low power.

The prospect of accelerating high currents in a CH-mode DTL structure is very intriguing. Since last year's meeting the Frankfurt group has carried out beam simulation studies of an 11 tank 3- to 70-MeV NC linac design operating at 352 MHz. In the initial design the emittance growth of a 70 mA beam appears to be significantly larger than one would expect for a conventional DTL. The group has made good progress on the mechanical design and has begun the fabrication of a cold model.

Work Package 3, Superconducting Accelerating Structures

Work package 3 addresses the development of superconducting (SC) linac structures in the intermediate energy range (~ 5 -250 MeV), to be operated in pulsed high-duty-cycle mode. The primary challenges of these new structures include mastering the Lorenz-force detuning (LFD) in pulsed operation and preserving the beam, since the focusing periods are generally longer than in NC linacs.

The research groups involved in this work package, from six institutions (CEA, CNRS IPNO and LPSC, FZJ, IAP-Fu and INFN-Mi), have shown new important results in cavity prototype development. These prototypes are built in the three main European industries that represent the leaders in this technology worldwide.

IAP-Fu has now built a 19-gap prototype CH superconducting structure; this is an impressive construction, being one of the most complex superconducting cavities ever built. Tuning results at room temperature and first Q0 curves in a vertical cryostat are promising; achieved field flatness is better than 5%, $B_s=26$ mT and $E_s=26$ mT. Tuner development, foreseen in HIPPI program, can now begin.

IPNO has realized a second prototype spoke cavity (352 MHz, $\beta=0.15$), corresponding to an optimum beta of 0.2. The first tests (both at 4 and 2 K) have shown a promising Q vs. E curve, with a slope that resembles other low beta cavities.

CEA Saclay has launched the construction of a new prototype $\beta=0.47$ elliptical cavity operating at 704 MHz. This cavity, named model "B," has evolved from prototype "A" which was built at INFN-Mi and tested at Saclay within HIPPI collaboration. The primary objective of the model B design is to reduce, as much as possible, the LFD by adding symmetrical cut-off beam tubes and a double stiffening-ring system. INFN-Mi has continued the development of a new coaxial tuner for cavity A and is now ready to order the prototype.

The triple-spoke 760-MHz prototype ($\beta=0.2$), developed at FZJ, has been cooled down and measured. Preliminary measurement were limited by the available RF power and coupling conditions. Structural analysis of the 353 MHz ($\beta=0.48$) version of the triple spoke cavity has been carried out, including the effects of tuning, external pressure and LFD. From the same laboratory new ideas for cavities (Slot-Finger Superconducting

Cavities) including quadrupole RF focusing were described in a separate talk. Next year the committee would like to **hear a synthesis of these different research activities.**

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The measurement of the LFD factor K (frequency detuning divided by accelerating field squared) is especially important for HIPPI. Experimental data are needed to design a control system that can react to the detuning forces experienced under pulsed mode operation. Measurements of K are delicate and still not entirely reproducible, but measurements have been made for the IPNO spoke cavity and the INFN-Mi and CEA elliptical cavities. Efforts to improve these measurements have continued and results have been incorporated into a quantitative understanding of the role of cavity and frame stiffness in LDF. This is particularly important for the interpretation of the performance results of cavity A and for the design of cavity B. It is also clear that the mastering of the K factor depends on the overall design of the cryomodule.

The high-power rf test facility at CEA is an important HIPPI investment and the equipment procurement is proceeding. This facility is expected to be completed by the end of 2006 and ready for use during the last year of HIPPI funding. The development of high-power couplers, which will be tested in this facility, is following a coherent schedule.

The committee reiterates its recommendation of a **closer collaboration between WP-3 and WP-5.** Development of linac architectures capable of preserving the quality of high-current beams to high energies is crucial for the success of these SC structures. In the case of CH cavities, whose design is integrated with KONUS beam dynamics, a more detailed analysis of the beam performance can be undertaken using the new simulation code LORASR that includes a FFT Poisson solver (see WP5). For the spoke (and “slot-fingers”) cavities, a nominal lattice should be adopted and integrated with the rest of the linac and its performance analyzed. Hypotheses on linac architecture are fundamental for example to choose the best compromise between short cavity (and focusing period) length and large beam bore.

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The collaboration among members of this work package is very strong, with many examples of common design choices and common use of existing infrastructures and instrumentation. Such continued collaboration will assure optimum use of the high-power RF test stand presently under development.

Members of the NC and SC work package teams are studying structures that overlap each other in performance. The committee again recommends that these two teams attempt to **compare the cost and performance benefits of the two technologies.**

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Work Package 5, Beam Dynamics & Beam Diagnostics

In the introductory presentation, the HIPPI program was defined as research and development of the technology for high-intensity pulsed proton-linear accelerators. However, it should be stressed that the distinctive feature of this program is to pursue the **beam performance required for an injector to a ring**, rather than simply a “high-intensity” linac. This is why chopper development was incorporated into the program as an important item. The committee recommends that this point be more heavily stressed in

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the HIPPI activities, since this has been easily overlooked in many cases. In this context, more care should be taken of the beam momentum spread stability.

The code bench marking has been carried out quite extensively. A new code, LORASR, with a PIC 3D FFT space-charge routine was implemented. Static comparison regarding the electric field, the single-particle tune, etc. presented the advantages and disadvantages of each code. Studies have investigated the dependence on the number of the particles, the mesh size and boundary conditions. As expected, the code dependence becomes quite significant when space charge is included. It is very instructive that the simulation results are so code dependent and significant, in particular in the case of the longitudinal emittance. As stressed in the introduction, the momentum control is vital to achieving ring injection with low beam loss. An attempt should be made to elucidate the reasons for the simulated longitudinal motion being so code dependent.

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The code bench-marking activities are not yet well organized throughout the institutes participating in HIPPI program and it is difficult to evaluate the implications of these results. The committee recommends that the communication and organization among participants be further strengthened and emphasized in the next HIPPI workshop. The committee would like to hear a presentation in which a comparison between these results can be better understood and discussed.

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One attempt at bench-marking is based on a beam experiment in which the emittance was measured systematically on UNILAC DTL. The measurements were compared with simulations using the 3D code DYNAMON, which employs a unique as particle-particle (PP) method. Except for low-current emittance growth at the end of the DTL, the overall agreement is quite good. For sensible evaluation, more extensive measurements should be made, with very close attention paid to the error analysis of the emittance measurements.

The end-to-end simulations have been carried out for the CERN LINAC4. However, it is not clear how the results of these studies will influence its final design. Some discussion of how the simulation results should be taken into account is necessary.

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The effect of construction and operational tolerances on beam performance has initiated by the Grenoble group using the multiparticle tracking code TRACEWIN Inputs on the DTL. A more sophisticated treatment of expected beam loss as a function of error tolerances, than simple single particle tracking, is still required. In addition a specification on allowable beam loss as a function of beam energy is needed against which error studies can be evaluated. To date the consensus among the accelerator community is that rf amplitude and phase errors of 1 percent and 1 degree respectively, are tolerable regarding the beam loss and the emittance growth for the presently conceived beam intensities. Fortunately, these tolerances are achievable with the present control technology for rf sources coupled to a single resonant cavity. Further studies of systems in which single sources are used to drive multiple SC cavities are of particular interest.

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Development of real-time beam monitors is in progress at GSI, FZJ, and CERN. Non-intersecting monitors are very important for high-intensity beams. For this, fluorescence and electron spectroscopy are fully utilized on residual gases. The progress of these techniques is quite outstanding thanks to the HIPPI program. Although these

devices are practical for measuring the core distribution and rms emittances, the halo or tail measurements are not realistic on the basis of these technologies. The electrons of the negative hydrogen beams stripped by the carbon foil are measured very precisely. The developed technology is so promising that a beam experiment should be prepared at one of the HIPPI institutes. There needs to be somewhat better coordination and direction given to the monitor developments among HIPPI institutes.

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Big progress has been made in both the theoretical and experimental approach to understand beam neutralization phenomena. In particular, the simple formula predicting the rise time of the neutralization is very effective. Although the theoretical approach does not yet allow us to optimize the space charge neutralization regarding the suppression of the emittance growth, the progress in studying these phenomena will provide very useful insight for understanding neutralization. The effort in this direction should be continued.

PROGRAMME

| Wednesday 28, September, morning | | |
|---|--|--------------------------------|
| 9h00 | Welcoming address | C. Prior |
| 9h15 | Status of HIPPI and introduction to the meeting | M. Vretenar |
| | <u>WORK PACKAGE 4 (<i>Chopper</i>)</u> | |
| 9h45 | Introduction (10'+5') | A. Lombardi |
| 10h00 | Status of the CERN chopper (25'+5') | M. Paoluzzi |
| 10h30 | <i>Coffee Break</i> | |
| 11h00 | Status of the RAL 'Fast-Slow' beam chopper | M. Clarke-Gayther |
| 11h30 | development programme (25'+5') | A. Letchford |
| 11h50 | The FETS: Front End Test Stand (15'+5') | G. Bellodi |
| 12h05 | Beam dynamics studies and design options for the RAL | A. Lombardi |
| 12h20 | FETS chopper line (10'+5') | C. Plostinar |
| 12h30 | Status of the CERN Chopper line (10'+5') | |
| | Design of a rebunching cavity for the RAL FETS | |
| | chopper line (10') | |
| | <i>End of session</i> | |
| Wednesday 28, September, afternoon | | |
| | <u>WORK PACKAGE 2 (<i>Normal Conducting RF struct.</i>)</u> | |
| 14h00 | Introduction (10') | J.M. De Conto |
| 14h10 | Progress on DTL design for CERN (30'+10') | F. Gerigk |
| 14h50 | Waveguide RF coupler for NC structures (1) (2) (20'+10') | P.E. Bernaudin / J.M. De Conto |
| 15h20 | | C. Plostinar |
| 15h40 | Preliminary DTL studies at RAL (15'+5') | |
| 16h10 | <i>Coffee Break</i> | G. Clemente |
| 16h50 | Status of the RT CH-DTL development and beam | M. Pasini |
| 17h20 | dynamics layout of the GSI Proton Linac | M. Pasini |
| 17h40 | CCDTL design and prototype measurements (20'+10') | J.M. De Conto |
| 18h00 | Side Coupled Linac design at CERN (15'+5') | |
| | Side Coupled Linac analysis at LPSC (15'+5') | |
| | <i>Adjourn</i> | |
| 19h00 | <i>Social Dinner</i> | |

| Thursday 29, September, morning | | |
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| | WORK PACKAGE 3 (<i>Superconducting RF structures</i>) | |
| 8h45 | Introduction (10') | S. Chel |
| 8h55 | Status report of coaxial tuner design (25'+5') | P. Pierini/N. Panzeri |
| 9h25 | Status of HIPPI activities at CEA-Saclay (35'+5') | G. Devanz |
| 10h05 | Measurements with the 760 MHz Triple Spoke Cavity | R. Eichhorn |
| 10h25 | (15'+5') | |
| 10h50 | <i>Coffee break</i> | E. Zaplatine |
| 11h10 | Final Mechanical Design of the 352 MHz Cavity and | G. Olry |
| 11h40 | Options for Tuning (15'+5') | H. Podlech |
| 12h10 | Status of spoke cavities activities at IN2P3-IPNO | Y. Senichev |
| 12h30 | (25'+5') | |
| | Status of the superconducting CH-Structure at IAP-FU | |
| | (25'+5') | |
| | Super-conducting slot-finger structure with RF focusing | |
| | (10'+10') | |
| | <i>End of session</i> | |
| Thursday 29, September, afternoon | | |
| | WORK PACKAGE 5 (<i>Beam Dynamics</i>) | |
| 14h00 | Introduction (10'+5') | I. Hofmann |
| 14h15 | Development of non-intercepting longitudinal and | P. Fork |
| 14h35 | transverse beam profile monitors (15'+5') | N. Vasyukhin |
| 14h55 | High Intensity beam dynamics in the slot-finger structure | R. Tölle |
| 15h10 | (15'+5') | A. Franchi |
| 15h30 | Status of diagnostics development at FZJ (10'+5') | |
| 15h50 | Progress in HIPPI code benchmarking (15'+5') | M. Hori |
| 16h10 | <i>Coffee break</i> | A. Lombardi |
| 16h25 | Status report on the beam shape and halo monitor | L. Groening / |
| | (15'+5') | W. Bayer |
| 16h50 | Beam dynamics in the Linac4 (10'+5') | R. Tiede |
| 17h15 | Measurements & simulations on emittance growth due to | R. Duperrier |
| 17h40 | space charge along the DTL of the GSI UNILAC | J. M. De Conto |
| 18h00 | (20'+5') | |
| | Status of LORASR Code Development and Recent | |
| | Benchmarking Results (20'+5') | |
| | Status of work at CEA (20'+5') | |
| | Tracewin: study of the conditions of use (15'+5') | |
| | <i>Adjourn</i> | |

| Friday 30, September, morning | |
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| 9h00 | Meeting on HIPPI administrative matters and planning for 2006 (<i>in parallel with ESAC deliberations</i>) |
| 11h00 | ESAC preliminary assessment |
| 12h30 | Concluding talk |
| Friday 30, September, afternoon: <i>Visit to Rutherford Laboratory</i> | |