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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2001

The contributions on individual experiments in this report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission from the authors.

CERN COLLABORATION

INTRODUCTION

Funding for a second accelerator contribution to the Large Hadron Collider (LHC) at CERN was provided in the Five-Year Plan (2000–2005) which was announced at the end of February. These funds will allow TRIUMF to complete the two large commitments that were already under consideration: the series production of 52 twin aperture quadrupole magnets, and the components for the LHC injection system.

This year saw the completion of the last tasks that were included in the PS Conversion project, with the wrapping up of two beam dynamics projects associated with the PS Booster and the delivery of the final two 250 kW power supplies. Two beam dynamics tasks related to the LHC continue. A CERN yellow report, "The PS Complex as Proton Pre-injector for the LHC – Design and Implementation Report", was released in April, describing this project and the TRIUMF involvement.

A new instrumentation task, started in 1999, involves the design and fabrication of electronics for the readout of the LHC beam position monitors. Prototypes of this VME based data acquisition board (DAB) were successfully tested in the SPS beam during the summer. Some changes related to moving the digital portion of the readout system out of the LHC tunnel are now being considered and a new version of this board will be tested in 2001 prior to the series production.

In 1999, ALSTOM Canada (Tracy, Quebec) was awarded the contract for the production of the first 17 of the twin aperture quadrupole magnets, with the awarding of the remaining 35 magnets contingent on the new Five-Year Plan funding, and on the successful completion of the first series magnet. ALSTOM had previously built a prototype magnet which did not meet the magnetic field requirements due to poor assembly tolerances, which were to some extent inherent in the design. New tooling for the redesigned laminations and the stacking tables was required. This year ALSTOM produced the necessary tooling and produced laminations to the required accuracy. The stacking of one type of lamination to the required straightness tolerance proved very difficult, but was eventually solved. The production of coils was plagued with a number of problems, but eventually sufficient coils for the first series magnet were produced. However, the final assembly of the first magnet was delayed at the end of the year by union problems at the factory and delivery is now expected in February, 2001.

TRIUMF is also designing and building 6 resonant charging power supplies (RCPS), 9 pulse forming networks (PFN), and 20 thyratron switch tanks for the LHC injection kickers. During this year the RCPS were completed, although final testing was delayed due to a capacitor failure in the dummy load. The clean room with crane coverage for assembling the PFN tanks was completed in the proton hall extension, and contracts for fabrication of components for the PFNs were awarded. The 5.2 metre long tanks are being fabricated by Brandt Industries (Saskatchewan), with the remaining parts being manufactured by local machine shops. Capacitors were obtained from ZEZ Silko (Czech Republic), and resistors from HVR Advanced Power Components (USA). By the end of the year the first 28 cell PFN was assembled to the point where low voltage testing could begin.

BEAM DYNAMICS

This year has seen the successful completion of the two beam dynamics tasks associated with the LHC injector chain, both involving the PS Booster. The first explored ways of improving the longitudinal dynamics at high beam intensity, including the addition of second-harmonic rf. The second involved development of our simulation code ACCSIM – now adopted at several major labs – for studies of injection and collimation.

Of the ongoing tasks, beam stability studies have taken a new direction by providing support for simulations of the beam-beam interaction near the LHC collision points, enabling space-charge effects to be more accurately modelled. The collimation insertions and their beam optics had their final details settled this year, and efforts on that task have now shifted to studies of the sensitivity of the "resonance-free lattice" to magnetic field errors.

Second Harmonic in the PS Booster

Bunches which are hollow in longitudinal phase-space have the advantage of lower peak charge density and space-charge forces. Acceleration of hollow bunches in the PS Booster became almost routine in 1999. One component of that success was the use of high-harmonic rf "clearing sweeps" to homogenize the coasting beam prior to the deposition of empty buckets – a procedure that was developed empirically, but whose mechanism was not understood. Another component was the availability of longitudinal tomography for visualization of the hollow phase-space.

In late 1999, an experimental study revealed that the voids in the linac beam, dubbed "bubbles", and the holes introduced by the empty bucket deposition survive in the PSB much longer than anticipated (see Fig. 171). It was recognized that these "cold-spots"

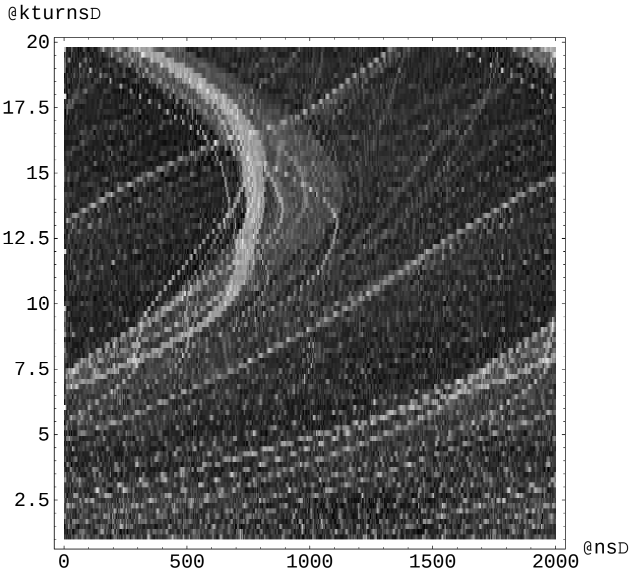

Fig. 171. Waterfall plot of coasting beam density around the PS Booster observed with 4×10^{12} protons over 20,000 turns, showing the survival and drift of voids or "bubbles".

could be stabilized by space-charge forces. Experimental evidence indicates that hole longevity increases with beam current; and by imposing an $h = 1$ modulation it was shown that holes are steered by momentum differences.

These observations initiated a comprehensive set of LONG1D computer simulations of periodic arrays of holes, single stationary holes and two-hole collisions. This culminated in an understanding of: (i) the method of "clearing sweeps"; (ii) the role of momentum steering as an agent for collisions; and (iii) the non-coalescing of holes. A simple Hamiltonian criterion for self-consistency and stationarity of holes was derived in terms of the competition between space-charge and momentum spread.

It became clear that the longevity of the holes could not be explained in terms of the usual Keil-Schnell criteria for perturbations on coasting beams. The mystery was solved in August, by suggesting a radical departure from the usual treatment of the Vlasov equation. Based on the observation that this equation is "obsessed by derivatives", the steady-state distribution is neglected in comparison with the highly localized perturbation, and this leads to an equation for soliton-like holes propagating over a background distribution, provided the particle density is high enough.

Tomography is the technique whereby several projections of an object are combined to infer its internal structure. A particle beam confined in a potential well rotates in phase-space, and over time presents many different projections. Hence one may infer the longitudinal distribution of a bunched beam by recording the bunch shape turn-by-turn. Space-charge forces do not require any knowledge of the phase-space distribution (which is initially unknown) but can be derived purely from the measured profiles. This realization led this year to our developing a longitudinal space-charge option for the tomographic software originated at the CERN PS, and to showcasing the technique using mixed dual/single harmonic operation of the PSB.

Injection and Collimation in the PSB

This task, which came to the end of its term on March 31, involved the development and support of the ACCSIM multi-particle tracking and simulation code, used to study the behaviour of intense proton beams in synchrotrons. In the closing months a further milestone was passed in the treatment of space-charge effects, with the introduction of image forces to account for the effects of the charge and current induced in conducting vacuum chambers. These forces depend on the beam position, the charge distribution, and the chamber shape and dimensions, which may vary around the ring. In practice, they are often omitted in space-charge simulations because the FFT-based field solvers usually used do not admit the necessary boundary conditions. At energies above 1 GeV, however, their contribution becomes significant.

In ACCSIM, which uses a fast-multipole field solver, a new method was developed for accurately deriving the image-force contributions for arbitrary beam distributions and vacuum chamber geometries, with only a modest computing time requirement. Once the "direct" (free space) field has been computed, there is a second processing stage where a discrete fast Poisson solver, using harmonic functions and a minimization technique, is applied to a set of boundary points representing the vacuum chamber surface. The result is a parameterized solution for the image field and consequently a rapid evaluation of the image force for each macro-particle.

With suitable sets of points to represent the boundary surfaces, tracking tests were carried out for various "textbook" cases of centred and offset beams in circular, elliptical and rectangular chambers, where the space-charge tune shifts contain a known image-force term. Tunes measured from ACCSIM tracking data were found to be in good agreement with these predictions. A paper and poster on this work were presented at EPAC'2000.

Beam Stability

Following last year's feasibility study, a new project was begun this year in support of studies of the "beam-beam" effects caused by electrical forces between the counter-rotating bunches of protons in the LHC interaction regions, where the two beams approach and cross each other. The problem here is how to compute the beam-beam forces efficiently in the large-scale multi-particle simulations which are used to identify potentially unstable coherent oscillation modes.

Our main activity was to introduce the hybrid-fast-multipole (HFM) techniques, previously developed for ACCSIM space-charge computations in the PSB, into a beam-beam simulation code ss_HOLR in use at CERN. The relevant ACCSIM routines were modified and made into a self-contained package which accepts two arbitrary macro-particle distributions and returns the electric field components at each macro-particle location. The ss_HOLR code was formerly limited to a non-self-consistent "soft-Gaussian" model which did not give a complete description of the beam-beam interaction and tended to overestimate the lower of the two fundamental coherent-mode frequencies for head-on collisions. With the new fast-multipole field solver, this problem was cleared up and the spectrum of coherent motion exhibited all the expected characteristics.

Initial tests with parasitic (long-range) "collisions" have also obtained reasonable results, but the computation times need to be reduced somewhat, either through further code optimizations or by migration to faster (e.g., 1.5 GHz) computing platforms, in order to get the desired turnaround times for a full-scale study of beam-beam coherent effects. This work will continue in 2001, and pending further validation the HFM beam-beam field solver package will be made available from the ACCSIM Web page on the TRIUMF WWW server.

Beam Optics and Collimation

LHC collimation

During the past year, with the LHC engineering in its final stages, the collimation insertion layouts remained essentially unchanged. Nevertheless, some lattice work (mostly rematching) had to be carried out as a consequence of revisions to the database terminology and input formats during the year. Via careful optical matching, the collimation quality for beam 2 was made equal to that previously reported for beam 1. Beam 2 requires a slightly different collimator set-up, since the final hardware does not allow some of the collimators to be placed at exactly the optimum locations, while the optics of the two LHC beams are linked via common focusing fields. Some database errors of a technical nature also had to be corrected.

Resonance-free LHC optics

Using "resonance-free" linear optics for the LHC ring means that the strengths of the two families of main quadrupoles are set to achieve a special betatron phase advance in the arc cells. This has been demonstrated to cancel many non-linear resonances, since their driving terms are proportional to "systematic-per-arc" higher-order multipole errors. Systematic-per-arc errors dominate if the dipoles in each arc are manufactured on a single production line, but different arcs on different lines (the scenario foreseen).

Our task has been to look at the effect of field gradient errors. While easily correctable and therefore not very important for the nominal LHC optics, these can destroy the beneficial effects of the resonance-free optics, since they change the betatron phases. For the most important higher-order errors (normal and skew sextupole b_3 and a_3, and normal and skew octupole b_4 and a_4, the task is to find the tolerable level of normal gradient error b_2. With the quite complicated multipole error table (up to 11$^{\text{th}}$ order), this by itself also provides a good proof that the improvements – higher dynamic aperture (MAD8 and DIMAD codes) and lower driving terms (SODD code) – are indeed caused by resonance cancellations.

The study of gradient error effects has been completed for the case of the normal sextupole b_3, while the studies of a_3 and b_4 are under way. The a_3 task is also linked to the proposal to convert three normal sextupole correctors in each arc to skew correctors, and to improve the nominal optics.

CONTROLS AND INSTRUMENTATION

Fast Blade Scanner

Measurement of the transverse beam emittance is an important diagnostic for obtaining high performance beams destined for the LHC. The fast blade scanner (FBS) built at TRIUMF and shipped to CERN in May, 1999, is to be used for destructive diagnosis of the betatron amplitude distribution in ring 1 of the PS Booster. TRIUMF involvement is essentially completed.

In December, 1999, CERN prepared a laser/photodiode system for recalibration and to gain more experience with the scanner prior to installation in the spring. CERN activities with the wire scanners delayed beam tests of the FBS until September through November. In these tests, the blade scanner was compared against the "Beam Scope" and profiles in an external measurement line. Beam energies of 1.0 and 1.4 GeV, and intensities from 3 to 13 injected turns were used with FBS speeds ranging from 500 to 1500 rpm. To facilitate the comparison, measurements were made in the vertical plane to avoid the effects of dispersion and of the longitudinal beam control. Although there is a rather satisfactory agreement of the average emittances between all three methods, as shown in Fig. 172, the repeatability and calibration of the FBS still needs some improvement. The FBS was dismounted from the machine later in the year and placed on the concrete

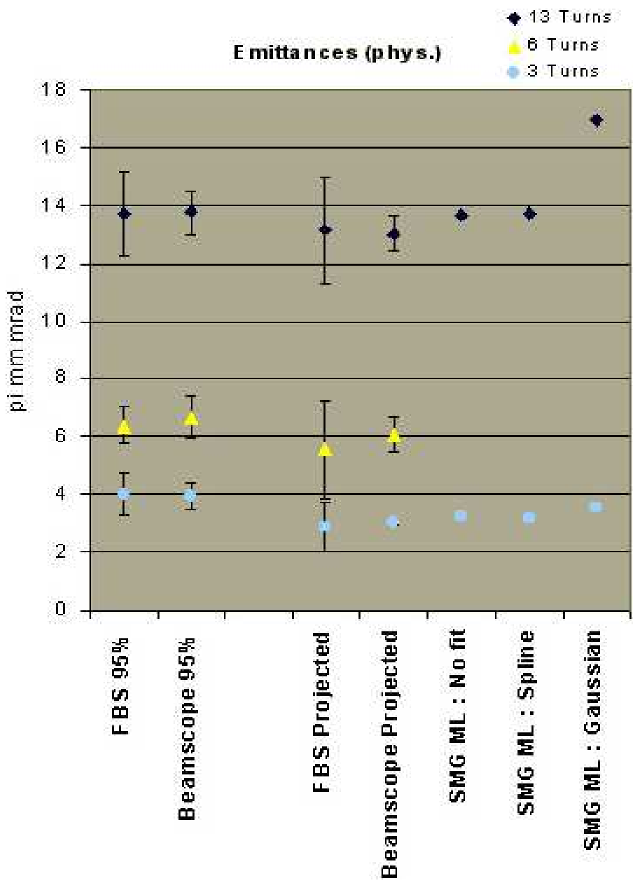

Fig. 172. Average emittances between all three methods.

pedestal next to its normal place, set under vacuum and connected to its normal cables, so that calibrations can be made under real operating conditions.

Fast Wire Scanner

Fast wire scanners (FWS) provide an almost non-destructive measurement of horizontal or vertical beam profiles. In 1998, CERN requested TRIUMF to build 4 horizontal, 4 vertical and 1 spare wire scanners. This work was essentially completed in 1999. The scanners were assembled and tested to 20 m/s at TRIUMF and, together with the stand and the calibration device, they were shipped to CERN in December, 1999. The scanners were calibrated in February, and two sets of X and Y wire scanners were installed in the PSB (see Fig. 173), one in ring 1 and the other in ring 3, in line with the beam PS. The other two sets will be installed during the winter/spring shutdown of year 2001. Integration with the control system was much delayed due to the need for new motor control processors to replace parts no longer commercially available, and the need to develop new software to accept them. Completion of this work is anticipated in the summer of 2001.

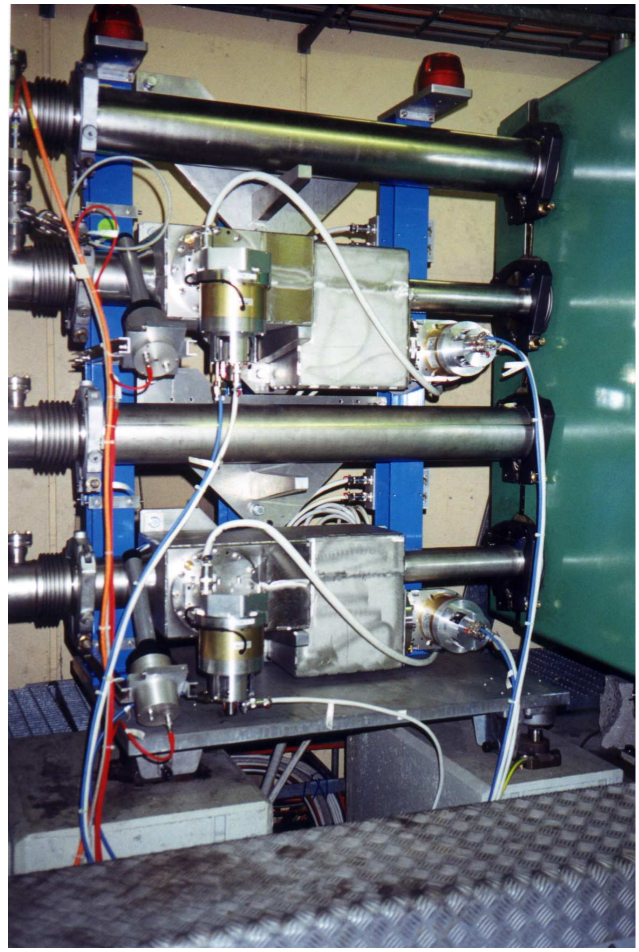

Fig. 173. Two sets of X and Y wire scanners installed in the PSB.

LHC Orbit System Components

The electronics intended to read out the LHC beam position monitors (BPM) comprise a calibrator, 70 MHz low-pass filter, wide-band (time) normalizer (WBTN), and 40 MHz digitization of the signals and some data treatment. TRIUMF was asked to build a prototype VME data acquisition board (DAB), write application software, and find suitable commercial matched-pairs of filters; leading to a production run of about 1200 boards and 2500 filters to be managed by TRIUMF. Partial specifications were received in August, 1999, and prototypes of three DABs and several filters were delivered to CERN during the year for testing.

The DAB VME module groups all the necessary digital functions associated with a BPM: 2-plane position measurement, intensity measurement, and test and calibration control. On-board logic provides the interface to the VME bus and control of data transfers from the WBTN to the SRAM local memory. A phase-locked loop (PLL) synchronizes all internal timing using signals provided by an external timing control module. Simulations of the VME hardware began in October, 1999, followed by parts/vendor selections. A detailed design document was sent for CERN approval in January, and PC board manufacturing and component assembly followed. After successful local testing, the three DABs were delivered to CERN in June for evaluation: two were used for beam tests and the third for irradiation tests.

After adjustments to the PLL, laboratory tests with various timing sources and the CERN normalizer (WBTN) demonstrated that the board worked as specified in calibration and capture modes. Following this, the board captured LHC-beam position data in the SPS ring. Figure 174 shows the average position and standard deviation of all 84 bunches in an LHC batch during 80 turns. It can be seen that the orbit appears to vary along the batch, but this might be an artifact of the normalizer. Figure 175 shows the turn-by-turn position of a single bunch which commences an instability at around 1000 turns.

The third DAB module was tested during operation in a radiation field of approximately 100 Gy/year.

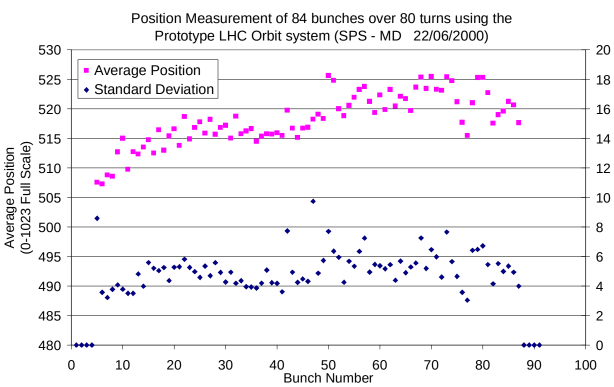

Fig. 174. Average position and standard deviation of all bunches in one LHC batch for 80 consecutive turns compiled from DAB acquisition data.

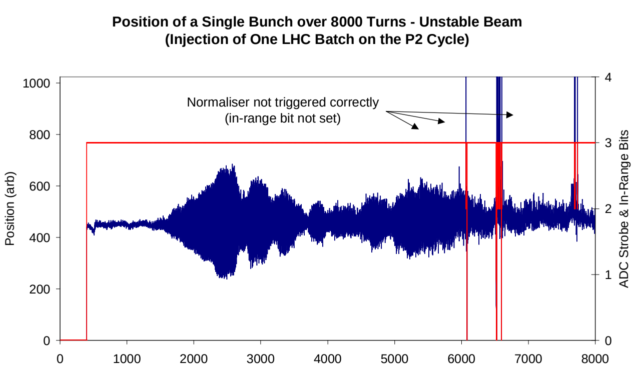

Fig. 175. DAB acquisition of a single bunch. Acquisition begins 200 turns before injection. An instability is seen to occur around 1000 turns after injection. Beam losses lead to incorrect triggering of the normalizer as indicated by the status bits (red trace) which the DAB receives.

Although components survived, results showed significant single event error rates in the SRAM. To eliminate the need to qualify all the components in the VME acquisition system for radiation tolerance, it was decided, in November, to move the system out of the radiation field entirely. This requires the redesign of both the WBTN and the DAB. The digital portion of the WBTN will reside on a 2U daughter card that plugs into the DAB module. The analogue portion will remain in the LHC tunnel. The WBTN analogue signal will be transmitted through 3 km of fibre optic cable to the DAB module. Specifications will be finalised in 2001.

To aid in DAB testing and software design, a VME software development package has been loaned by CERN since November, 1999. With CERN input on software specification and procedures in March, driver/equipment module development progressed smoothly from design through testing of the driver and diagnostic software on the prototype boards, to firmware and software completion in preparation for beam tests in the SPS in July.

Sample low pass filters were received from Lorch (2 pairs) and K&L Microwave (1 pair), tested in January, and shipped to CERN in February. The CERN evaluation revealed that input reflection and mechanical tolerance were a problem for both manufacturers. In general, the K&L filters had better electrical characteristics. Measurements were passed to the manufacturers and improved prototypes were requested. Lorch corrected the component values in their design and, in September, sent two more filter pairs which are in much better compliance with the specifications. Lorch was chosen as the supplier and it is anticipated that a pre-production run of 150 pairs will be ordered in January, 2001.

POWER SUPPLIES

Booster Transfer Line Power Supplies

The year saw completion of the two power converters rated at 250 kW output power. These units had associated modules which permitted reversal as well as energy recovery during ramping down of the magnets. The supplies were based on the design of batch 1 supplied earlier by Inverpower Controls, and were a further development of the six 100 kW supplies provided last year by I.E. Power in Toronto.

The project proceeded relatively smoothly with some difficulties experienced with the temperature of some of the magnetic components. These were resolved and final factory testing was witnessed by CERN prior to shipment.

All major equipment has now been shipped with provision of a few spare parts being under way. This effectively brings to an end the magnet power portion of the CERN collaboration for the PS division, with a total of 44 magnet supplies delivered.

MAGNET DEVELOPMENT

TRIUMF has agreed to provide CERN with fifty-two twin aperture resistive quadrupole magnets for the LHC cleaning insertions. The prototype magnet was delivered in 1998. As a result of measurements on the prototype, CERN asked that TRIUMF improve the magnetic properties of the magnets by a factor of 5 to 10.

In 1999, TRIUMF awarded three contracts related to these magnets to ALSTOM Canada (Tracy, Quebec). The first contract was for new punching dies needed because the lamination shapes changed. The second contract is to supply stacking tables, and the third contract is to manufacture the first 17 quadrupoles. TRIUMF expects to increase the order to 52 quadrupoles once ALSTOM delivers a satisfactory magnet.

After die corrections in February and press corrections in March, ALSTOM supplied acceptable laminations. In April, ALSTOM punched enough laminations to make two magnets. In August, the die was found to be out of tolerance. ALSTOM made several changes to the press set-up and modified the die, and at year-end the laminations were again acceptable.

By March, ALSTOM had manufactured the stacking tables. During installation they found that the factory floor was not strong enough for the precision alignment required. Portions of the floor were torn up and heavy concrete foundations were poured. After installing the stacking tables, ALSTOM began learning how to stack and weld straight stacks. Stacking and welding type 1 stacks is considerably easier than type 2 stacks, probably because these stacks have some symmetry. After considerable trial and error, ALSTOM learnt how to make acceptable type 2 stacks.

ALSTOM had manufactured prototype coils without difficulty, but the production coils were plagued by problems. The problems that they encountered included bad fibreglass tape, bad sealing brazes, water inside the coil cooling channel turning to steam during impregnation, bond breaker contamination on the fibreglass tape, and vacuum system failures. The subcontractor winding the bare coils had difficulty keeping the coils in tolerance. ALSTOM will try to recover the copper from some reject coils by burning off the epoxy.

The year-end status at ALSTOM was not good. They are well behind schedule on delivering the first series magnet. The first half-magnet is ready to weld, but labour union problems have temporarily stopped the work.

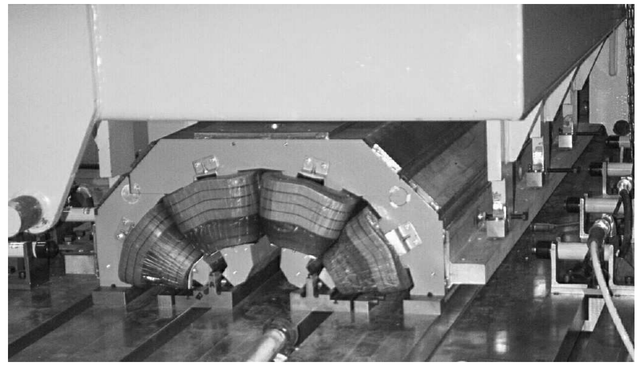

Fig. 176. The first MQW half-magnet ready to weld.

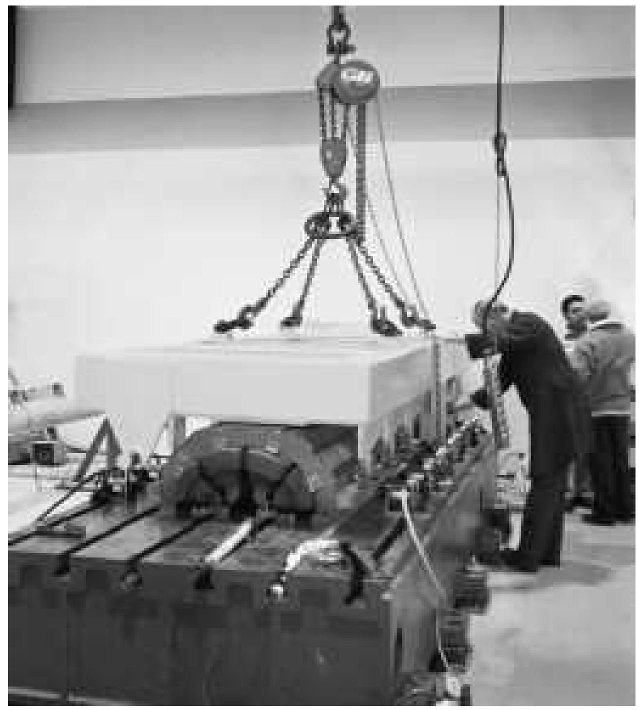

Fig. 177. Assembling the first MQW half-magnet.

When work restarts, ALSTOM has enough stacks and coils to make the first magnet. They have enough copper and steel to make the next three or four magnets. CERN has the magnet measurement bench ready to measure the first magnet when it arrives, hopefully sometime in February, 2001. The MQW half-magnet is shown in Figs. 176 and 177.

KICKER MAGNETS

In collaboration with CERN, TRIUMF is designing, building and testing 6 resonant charging power supplies (RCPS), 9 pulse forming networks (PFN), and 20 thyratron switch tanks which will operate at 66 kV. A CERN LHC injection kicker system will consist of one RCPS, two 5 Ω PFNs, four thyratron switch tanks and two kicker magnets. Four such systems plus spares are required. The prototype RCPS that was designed and built at TRIUMF and shipped to CERN in June, 1998 was extensively tested for over 1 million cycles during 1998 and 1999, in conjunction with the prototype 60 kV, 25 cell PFN which was designed by CERN/TRIUMF and built at CERN. Some design weaknesses were discovered and improvements were incorporated in the design of the final versions of the RCPS and the PFN.

Lab space

Lab space was organized to prepare for testing of 5 RCPSs, and assembly and testing of PFNs and thyratron switch tanks. One section of the kicker lab was enclosed and reorganized for high voltage testing of RCPSs and PFNs. Adjacent to the high voltage test area, the RF group clean lab was removed and a 5 ton bridge crane was installed by Kaverit Crane. The bridge crane structure now houses a clean room which is being used to assemble the PFNs, and in the future to assemble thyratron switch tanks.

RCPS

An RCPS has two parallel outputs, to charge two 5 Ω PFNs to 66 kV. The RCPS has a 2.6 mF storage capacitor bank charged to 3 kV. A thyristor is used to switch the energy on the capacitor bank onto the primary of a 1:23 step-up transformer of low leakage inductance. The output of the secondary is transferred to two 5 Ω PFNs through two coaxial cables, two diode stacks and two 70 Ω resistors. The RCPS is designed so that the PFNs can be charged up to 66 kV in less than 1 ms at a repetition rate of 0.2 Hz.

The TRIUMF Kicker group has now completed series production of 5 RCPSs, which incorporate several improvements over the prototype RCPS. The two dummy loads that were used for prototype PFN testing were returned to TRIUMF. The dummy loads were dismantled, cleaned and reassembled with new ceramic insulators, new charging resistors and new discharge resistors. While turning up the voltage on RCPS #4, one of the dummy load capacitors from NCL failed to an open circuit at only 51 kV. This capacitor had experienced more than 1 million shots at 60 kV at CERN. Four new 1.1 μF, 66 kV capacitors were ordered from ZEZ Silko (Czech Republic), and are due to be delivered at the start of February, 2001. Testing of the RCPS will proceed as soon as the dummy load capacitors are installed.

PFN

Each 5 Ω PFN is comprised of two parallel 10 Ω lumped element delay lines consisting of 4.3 m long precision wound coils, high voltage and high current capacitors, and damping resistors. There is a thyratron switch tank at each end of the 5 Ω PFN. In order to increase the duration of flat-top field from 6.8 μs to 7.8 μs, it was necessary to increase the number of cells of the PFN from 25 to 28.

The complete set of PFN drawings was ready for review by the end of January. An engineering design committee reviewed the manufacturing procedures for the PFN tanks and lifting devices. Major contracts have been awarded as follows:

- ZEZ Silko for 650 pieces of 66 kV capacitors. Based on their experience, ZEZ Silko was able to supply 560 type 1 capacitors in 12 batches. The nominal capacitance value is 19 nF with a variation of approximately ±0.6% per batch. All the capacitors passed their factory tests and have been delivered to TRIUMF.
- HVR Advanced Power Components for 620 pieces of tubular damping resistors and 180 resistor disks for the end cells. All of these resistors have been received. All resistor values and their temperatures were measured and stored in an Excel file.
- Permali for 18 pieces of 5 m long fibreglass tubes for coil formers.
- Talvan Machine Shop (BC) for machining fibreglass tubes and winding 18 precision coils with copper tubing. Talvan also machined the PFN assembly stands and soldered more than 500 resistor connectors. All of the stands and resistor connectors and 4 of the coils were received by year-end.
- Sunrise Engineering (BC) for 9 sets of 28 cell capacitor tables and coaxial capacitor housings – one set has been received.
- Sicom (BC) for the CNC machining of internal PFN parts. 90% of these parts have been received.
- Brandt Industries (Saskatchewan) for the 9 PFN tanks and 2 sets of lifting beams. 3 tanks and 1 set of lifting beams have been received.
- Axton (BC) for the omega shields. These are expected in January, 2001.

The first 28 cell PFN (Fig. 178) has progressed as follows:

- One left hand and one right hand coil have been filled with NCL epoxy. The capacitor tables were aligned and installed on the tall assembly stands above the PFN tank.
- Selected capacitors were installed in the housings to give the correct capacitance grading and precision for the pair of 10 Ω PFN lines.
- The main switch (MS) and dump switch (DS) end-housings, resistors and capacitors were installed.

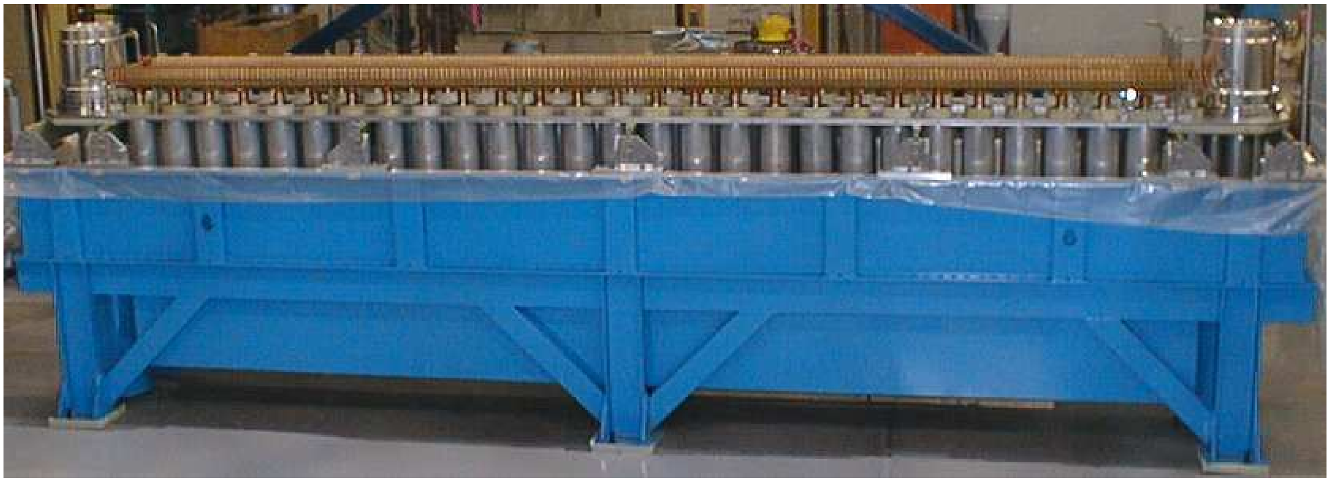

Fig. 178. The first 28 cell PFN.

- The RH and LH coils were installed.
- A test switch from CERN permits testing the PFN at low voltages. The PFN was tested at low voltage without damping resistors and without the omega shield present.

Thyratron switch tanks

The thyratron switch tanks will mount on the ends of the PFN tanks. The main switch (MS) thyratron will be connected to a 5 Ω transmission line kicker magnet, via 10 parallel 50 Ω coaxial cables, and the kicker magnet output is connected to a 5 Ω resistive terminator. The dump switch (DS) thyratron will also be connected to a 5 Ω resistive terminator.

The TRIUMF Kicker group designed a prototype HV grid/heater/reservoir bias circuit for the thyratrons. The electrical design was more or less fixed by CERN, although modern components needed to be specified. Two complete circuit boards, each consisting of four prototype transformers, were shipped to CERN in early September. CERN has requested that the bias supply circuit board be reduced in size to increase the clearance from the (floating) Faraday box to ground planes, and has agreed to allow the use of physically smaller capacitors, in place of four mechanically large Bosch capacitors.

The drawings for the thyratron switch tanks have been received from CERN. The final mechanical design of the 20 thyratron switch systems has been started.