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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

JULY 2000

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

This is the fourth year of the TRIUMF collaboration with CERN in providing accelerator components and expertise for the Large Hadron Collider (LHC) project. As indicated in previous Annual Reports, much of the initial work was involved in upgrades and consolidation of the injector synchrotrons – the PS Conversion project. About 15 separate equipment tasks and 2 beam dynamics tasks have been worked on, and by the end of 1999 essentially all of the hardware tasks, with the exception of a second batch of transfer line power supplies, were completed or delivered to CERN and awaiting commissioning.

This year saw the fabrication and delivery to CERN of a fast blade scanner and nine (4 horizontal, 4 vertical and 1 spare) fast wire scanners for the PS Booster. Both beam diagnostic devices have to move a blade or wire across the circulating beam in the synchrotron at high rate – 10 m/s for the blade scanner and 20 m/s for the wire scanner – with a position accuracy and reproducibility of 0.1 mm. The blade scanner is a new design and the wire scanner a redesign of the PS scanner. Both projects were challenging but by the end of the year these devices were at CERN awaiting further testing, installation and commissioning.

An order for six 100 kW and two 250 kW transfer line power supplies was placed in October, 1998. These supplies are being designed and built by an alliance of three firms in Ontario: I.E. Power, Inverpower Controls and DPS. A prototype of each supply was required before the series production could start and the 100 kW prototype was completed and shipped to CERN in August. In October, CERN requested that four of the 100 kW units be expedited so that they could be installed in the winter shutdown. By the end of the year, in addition to the 100 kW prototype, two of the units were at CERN with the others to follow in February, 2000.

The prototype twin aperture quadrupole manufactured by ALSTOM Canada in Quebec was completed and shipped to CERN for testing in 1998. Magnetic field measurements showed that the harmonic content was larger than desired and correlated with the physical measurements of the pole gaps. Even tighter assembly tolerances than originally specified are required. Three further contracts were awarded to ALSTOM during the year. A new punching die was ordered with several modifications for improved assembly accuracy. A tooling contract was placed to enable ALSTOM to start manufacture of the stacking tables for the series production. In September, an order was placed for 17 of the 52 twin aperture quadrupole magnets. The first production series is scheduled for completion about May, 2000.

In 1998 the prototype 60 kV resonant charging power supply (RCPS) for the LHC injection kickers was completed at TRIUMF and sent to CERN for testing with a prototype pulse forming network (PFN) built at CERN. Approval for the production of five of the RCPSs at TRIUMF was given, and by year-end this work was completed except for final testing. TRIUMF is also responsible for manufacturing nine PFN assemblies. The detailed design of the PFN tanks is well under way with capacitors and resistors ordered after an extensive testing program. A new clean room and assembly area is required with an overhead crane inside the clean area. The design and fabrication contract for this structure will be awarded in January, 2000.

In the beam dynamics area work has continued on studies of second harmonic acceleration in the PS Booster, leading to improvements in the hollow-bunch scheme to reduce instabilities. Further refinements were made to the ACCSIM code, and comparisons of calculated beam profiles with those measured in the PS Booster were encouraging.

The task to study impedances of the LHC components continued with calculations and measurements of ferrite materials used in the LHC kickers.

The beam optics of the LHC cleaning insertions was finalized and accepted by the LHC Parameter Committee. The solution requires 48 of the warm twin aperture quadrupoles, both symmetrically and antisymmetrically powered.

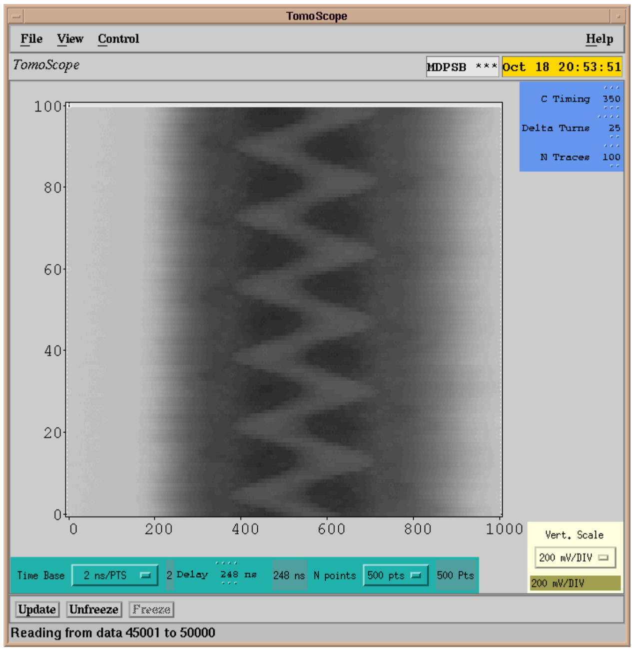
A new instrumentation task was initiated based on the success of the collaboration on the SPS beam position front end electronics. This work is intended for the readout of the LHC beam position monitors. TRIUMF has been asked to design and build a prototype 40 MHz acquisition card and provide some software design effort. If funds permit, series production of these modules could be envisaged.

A second contribution to the LHC is included in the request for TRIUMF funding for the next Five Year Plan (2000–2005), which is to be announced by April, 2000. The first priority for these funds is to complete the series production of twin aperture quadrupoles and the LHC kicker work. If more funds are available, a decision will have to be made on whether to provide power supplies for the warm magnets in the cleaning insertions or the electronics modules for the LHC beam position measurement system.

Second Harmonic in PSB

The CERN PS Booster has a dual-harmonic rf system, and rf feedback is employed in both the $h = 1$ and $h = 2$ systems to reduce the cavity impedance; this avoids the obvious coupled and within-bunch instability modes. Consequently, the major remaining source of problems is the low-level rf system which, if unfortunate gain/phase-advance relationships occur, can cause longitudinal instability. Summer, 1997 to summer, 1998 was spent diagnosing and explaining these problems, for a variety of low-level feedback configurations, in terms of the dual-harmonic beam transfer functions (BTFs). During that time, the harmonics migrated from $h = 5, 10$ to $h = 1, 2$, which has much reduced the phase advance due to signal delays. This year, reworking of calculations with revised parameters has shown that delays are not an essential component of the instability, but rather that BTFs and the topology of the feedbacks are alone sufficient cause.

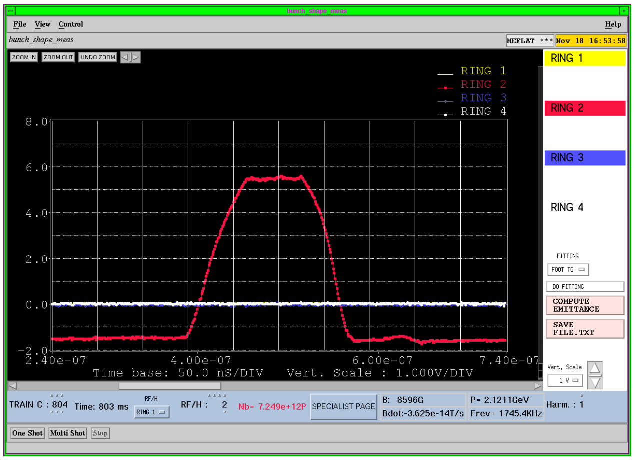
During fall, 1998, the focus shifted to ameliorating space-charge effects in the Booster and PS by reducing the peak charge density, which is achieved by forming and accelerating a hollow phase-space distribution. Initial attempts with dual-harmonic rf led to dramatic instability and were abandoned in favour of single-harmonic acceleration. This year, work has concentrated on flat rather than double-peaked bunches, using $h > 20$ high-harmonic buckets with large voltages and fast frequency sweeps. It was found that the less hollow bunches are more stable, and that the previous lack of reproducibility is due to a beam instability, rather than to variable preparation. The hollow bunch can be considered as the superposition of a large positive and a small negative bunch; these will have differing frequency responses, implying that the beam becomes unstable when the phase loop is closed (see Fig. 166). However, the growth rate depends on the degree of hollowness and can be made slow enough to survive 600 ms in the Booster and 1.5 seconds in the PS without any adverse effects on the transverse emittances. Success with the nominal LHC beam (1.2×10^{12} ppp) led, after further improvements to the hollow-bunch scheme, to even greater success (see Fig. 167) with the neutron TOF beam (7.5×10^{12} ppp); an empty-bucket sweep was introduced to homogenize the coasting-beam phase-space density, and a blow-up scheme added to better tailor the hollow distribution, making it azimuthally more uniform, thereby giving a smaller seed for the dipole instability.



C Timing 350
Delta Turns 25
N Traces 100
Vert. Scale 200 mV/DIV
Time Base 2 ns/PTS
2 Delay 248 ns 248 ns
N points 500 pts 500 Pts

Reading from data 45001 to 50000

Fig. 166. Waterfall display of line density versus turns; shows dipole instability for hollow bunch.



Time base: 50.0 nS/DIV Vert. Scale : 1.000V/DIV
Vert. Scale 1 V
TRAIN C : 804 Time: 803 ms RF/H RING 1 RF/H : 2 Nb= 7.249e+12P
B: 8596G Bdot:-3.625e-14T/s P= 2.1211GeV Frev= 1745.4KHz Harm. : 1

Fig. 167. Flat bunch for TOF immediately prior to extraction from Booster to PS.

Late in the year an investigation was begun into space-charge stabilized “cold spots”. Voids in the linac beam, dubbed “bubbles”, and the holes introduced by the $h > 20$ empty bucket deposition, survive much longer than anticipated from a naive calculation of their debunching time. The holes also display interesting collision and coalescing phenomena. This is work in progress.

Injection and Collimation in the PSB

This task involves the development and support of the ACCSIM multi-particle tracking and simulation code, used to study the behaviour of intense proton beams in synchrotrons. This year we pursued further the evaluation of the newly implemented hybrid fast-multipole (HFM) treatment of space-charge and its application to injection in the CERN PS Booster.

A series of benchmark tests showed that the speed and accuracy of the HFM method compared favourably with those of conventional multiple fourier transform routines being used in ACCSIM at Oak Ridge. Tracking studies with different beam intensities were done in simplified uniform focusing scenarios and in realistic F0D0 lattices. In all cases the space-charge tune shifts and envelope frequencies, as measured from the tracking data, were in very good agreement with analytical predictions.

Moving from F0D0 structures to the triplet lattice of the PS Booster, with appropriate tailoring of the tracking-step to the quadrupole placements, yielded equally good tracking results. We then proceeded to a fully self-consistent simulation of multi-turn injection into the PS Booster in a 14-turn LHC injection scenario, with particular attention to the evolution of the sharp "septum cuts" in the beam distribution due to the shadow of the injection septum. The results showed an expected rapid diffusion of the septum cuts under space-charge, with phase-space distributions that were very similar to those predicted by AGILE, a tracking code using direct (particle-particle) space-charge force evaluation. Comparisons of beam profiles derived from ACCSIM data and those measured in the Booster were also encouraging. A paper on this work was presented at the PAC'99 conference and published in the proceedings.

Other activities during the year included: a new public release of the ACCSIM code; preparation of a new User's Reference Guide; extension of the space-charge model to bunched beams; addition of a solenoid element; and support for comparison studies with the RAL TRACK2D code.

Beam Stability

Permittivity and permeability measurements

A new technique has been developed and applied to determine the permittivity and permeability of the ferrite materials (8C11 and 4A4 from Philips) to be used in the LHC kickers. Recent measurements have indicated that the complex permeability of 4A4 is lower than that of 8C11, so that the losses in 8C11 may be significantly higher than previously expected. The power losses in the LHC kickers have been recalculated using 8C11 data.

Impedance measurements of the SPS MKE extraction kicker

The impedance of the SPS MKE kicker has been measured using the coaxial wire technique. These measurements showed a significant impedance ($\Re[Z] = 1500\,\Omega$) in the frequency range up to 1 GHz, so that the ferrite will have to be shielded to limit the power dissipation in the material (and to reduce the impedance).

Beam-beam effects

Tests have been carried out to determine whether the hybrid fast-multipole method (HFMM) introduced into ACCSIM to speed up space-charge calculations (see above) could be usefully applied to the simulation of strong beam-beam effects in the LHC. The results showed that if the boundaries are close to the core of the beam, FFT can be as fast as HFMM, but when the boundary is moved far enough (as is necessary to simulate the long-range interaction) HFMM is a factor of $\sim$3 faster. It is therefore planned to incorporate HFMM into the existing CERN codes (or to modify ACCSIM to be used for studying collective beam-beam effects).

Beam Optics and Collimation

The layouts of the two collimation insertions IR3 and IR7 have been finalized. By mid-year both insertions had been accepted by the LHC Parameters and Layouts Committee, and by year-end IR3 had been converted into engineering drawings (with IR7 to follow). The lattices (including collimators) have been introduced into the official MAD-based LHC database, and to make the results easily available to CERN colleagues, several scripts have been written to perform automatic matching, collimator installation, and halo generation and tracking.

Extensive efforts made early in the year to further optimize the optics and collimation quality led to no significant changes – the number of warm quadrupole modules of both kinds (symmetrically and asymmetrically powered) remained as before, as did their approximate locations (see Fig. 168). Later tasks included a flexibility study (in which the insertion lattices were matched to the arcs for the whole range of machine tunes and for both LHC beams) and minimization of the quadrupole strengths while obeying aperture limits. In particular, the maximum strength of the symmetric modules was decreased by 1/6, allowing their power supplies to be replaced by cheaper and more compact ones which can be placed within the tunnel. Other hardware-related tasks included separating warm modules to accommodate jaw(s) between them, and opening space for vacuum ports, orbit correctors, etc.

Figure 168 also shows the final collimator jaw layouts derived using the code DJ (distribution of jaws). IR7 is equipped with 4 primary and 16 secondary jaws. The latter restrict the maximum betatron amplitude invariants of escaping halo particles to $A_{\max} = 8.9$, $A_{x,\max} = 7$, and $A_{y,\max} = 7$ (in units of rms beam amplitude σ). In IR3 there are 1 primary and 6

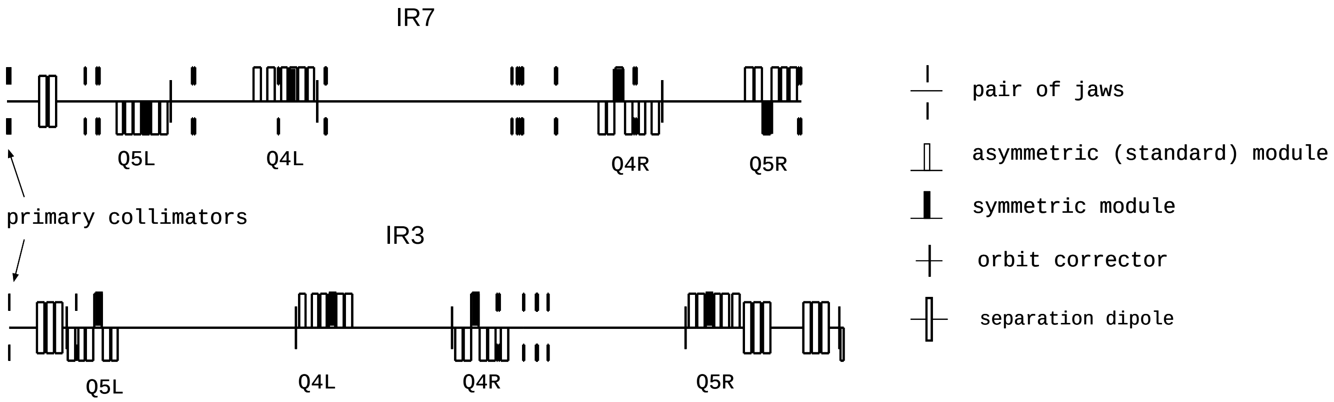


Fig. 168. IR3 and IR7 hardware layouts.

secondary jaws to ensure protection of the arc against off-momentum halo particles; for those with momenta near the edge of the rf bucket the safety margin is $\sim 3\ \sigma_x$.

Single- and multi-turn tracking simulations were performed using DJ, MAD and DIMAD to (successfully) verify the collimation design, and also to perform an initial study of the effects of optical errors on collimation. The latter provided estimates of the allowable incoming beam steering errors, incoming beam mismatch, quadrupole and monitor displacements, and quadrupole powering errors.

Simulation Tool FASTMAP for LHC/SPS Tune Control

The FASTMAP suite of computer programs has been written to facilitate high-speed particle tracking, using COSY-generated maps, for simulation of LHC betatron tune and chromaticity measurement and control. For this, the maps are customized to at least 12 tuning parameters, in addition to the six kinematic variables. To minimize computing time for the enormous LHC lattice, identical sections are identified, maps made once for each unique section, and then combined to give a full one-turn map. FASTMAP was made compiler independent, and thereby accessible by FORTRAN or C programs, by wrapping in C procedures; the programs have been converted to ActiveX/COM, allowing FASTMAP to link seamlessly with other microsoftware and COMs.

Last year FASTMAP predictions were successfully validated against measurements of tune, chromaticity and emittance growth on the SPS. Also, following a promising FASTMAP simulation of chirp excitation, successful head-tail chromaticity measurements were made at DESY by this method, the analysis of the data being carried out this year.

Final software developments have included implementation of a novel scheme for complete 3D beam matching, and the generation of quasi-random particle distributions. The correct simulation of beam behaviour in an accelerator requires proper matching of the beam to the hardware. This is simple when each phase plane can be treated independently, but becomes complicated when there is coupling between them. The new procedure allows a matched beam to be obtained for a general transport channel with strong coupling between the planes.

Initial CERN tests of our program for generating a Gaussian beam matched to the lattice optics in the presence of coupling, showed that statistically random particle distributions produced too much noise to allow proper simulation of beam measurements for an acceptable number of particles. Switching to quasi-random sequences, which fill phase space more uniformly, has resulted in complete elimination of non-physical centring errors and a thousand-fold reduction in the random error in beam size, without any increase in the number of particles. Work on this task finished in April.

CONTROLS AND INSTRUMENTATION

Fast Blade Scanner

The fast blade scanner (FBS) is intended to provide a reference measurement of the beam transverse profile in the PS Booster. The device sweeps across the beam at speeds up to 10 m/s in approximately 50 ms. The blade assembly was fabricated and assembled in 1998 (see Fig. 169), but it was not until this year that work began in earnest on an acquisition system for control, verification and calibration. In January it was discovered that the scanner has a mechanical resonance; though this was never completely eliminated, the performance was improved by returning the response to “slow damped” rather than “fast oscillatory”, and sharpening the rise and fall times with velocity feed forward.

In February, with most of the VME acquisition

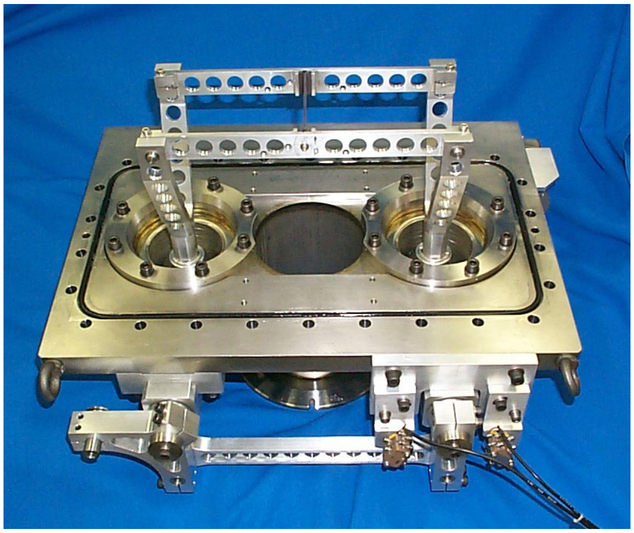


Fig. 169. Fast blade scanner mechanism showing swing arms mounted on back plate of vacuum box.

software complete, the motion control was tested over again, but with the motion profile independently acquired using the DPRAM and INCAA digitizer driven with a precise 50 kHz clock.

In March, defective commercial software for the Smart Drive was replaced and the blade scanner ran for the first time at 10 m/s. In April, final calibration based on comparison of the resolver against a laser/diode set-up (with a slotted target) demonstrated reproducibility of 0.1 mm at a given sweep speed. However, there were significant differences in calibration profile with sweep speed (attributed to inadequate bandwidth of the phase-quadrature demodulator), and a set of correction tables was devised. The scanner was shipped to CERN on May 6. During the high temperature vacuum firing of the vacuum box the phosphor bronze dowel pins melted causing contamination of the system. Both the vacuum box and the bakeout system problems were resolved at CERN without serious difficulties.

Though the scanner was functional at 700 rpm, subsequent testing revealed a vacuum leak in a damaged bellows and installation into the Booster ring was postponed. In the intervening period, TRIUMF staff helped with system integration at CERN. Driver and control software was ported to a Motorola VME module, and enough low level software was written to start working on an equipment module and operator interface. Later, remote control over the network was demonstrated.

Though tests with the new bellows showed them to be vacuum tight, there was not sufficient progress with controls bench testing to go ahead with installation during the September technical stop, and TRIUMF staff again visited CERN to assist.

The November focus was to write and debug MOTIF GUIs, equipment modules and Galil controller codes, to provide two basic application windows: one large one for maintenance/development/diagnostic level commands, and a smaller one for high level commands by the physicist user.

In December, CERN reported they were preparing a laser/photodiode system in order to make a recalibration measurement to verify no changes from the TRIUMF data taken in April, and to gain more experience with the scanner prior to installation during the winter shutdown.

Upgrade to SPS Orbit Observation System

245 front-end electronics modules for beam position measurements in the SPS were replaced with TRIUMF designed and built modules in 1998. These units performed extremely well and in November, 1998, CERN requested 40 more units. Earlier units with NewYork-Microwave filters were reclassified as spares and were substituted by 40 extra modules with Lorch-made filters.

In the spring an inventory of leftover parts (from the run of 245) was made and additional parts for the 40 modules were ordered. The 40 filters arrived in February, and other parts by May. However, the custom quadrature hybrids did not arrive until August, thus delaying assembly to September.

Aimtronic, the previous contractor, decided to concentrate their business on large orders and declined to assemble the modules. The order was redirected to Peripheron Industries, who were able to assemble and then test, tune and document the modules using a TRIUMF-supplied network analyzer and test sequences.

In October, assembly and testing of the 40 calibrator modules was completed and they were shipped to CERN. This completes the SPS instrumentation upgrade task.

Design and Production of VME TSM Module

Following shipment to CERN of the FBS and associated control electronics, a member of the group spent two weeks at CERN adapting the control and data acquisition software used at TRIUMF to the CERN controls environment. This involved converting the VxWorks drivers to LynxOS and incorporating them in an equipment module.

This year a further 30 TSM modules were requested by CERN. These modules have an external clock detection modification which should clear up previous reported problems. This work has been completed and the modules tested at TRIUMF in preparation for shipping to CERN in January, 2000.

Fast Wire Scanner

Fast wire scanners (FWS) have been used successfully for beam profile measurements in the CERN-PS for 15 years. However, their employment in the PS Booster was questioned: the larger energy deposition at lower energy and consequent heating of the wire; and the much smaller particle and photon shower for signal acquisition. The satisfactory resolution of both these problems, and the very slow development of the competing blade scanner, led to the request to TRIUMF for 4 horizontal, 4 vertical and 1 spare wire scanners. Engineering drawings were supplied to CERN in November and approved in December, 1998.

A prototype wire scanner was fabricated and assembled in March, in time for inspection by a senior technician from CERN. Several flaws came to light: the swing arm was not sufficiently stiff and the angular sweep range not as precise as specified, and the flange had to be redesigned to be the same for horizontal and vertical scanners. During the same visit, the need to build a new “calibration device” was realized because the existing one at CERN could not accommodate the horizontal scanner. The designs for the stand and vacuum boxes were also revised. In May, drawings for the 4 vacuum boxes were submitted to the Machine Shop for fabrication, and work started on fabricating most of the scanner components.

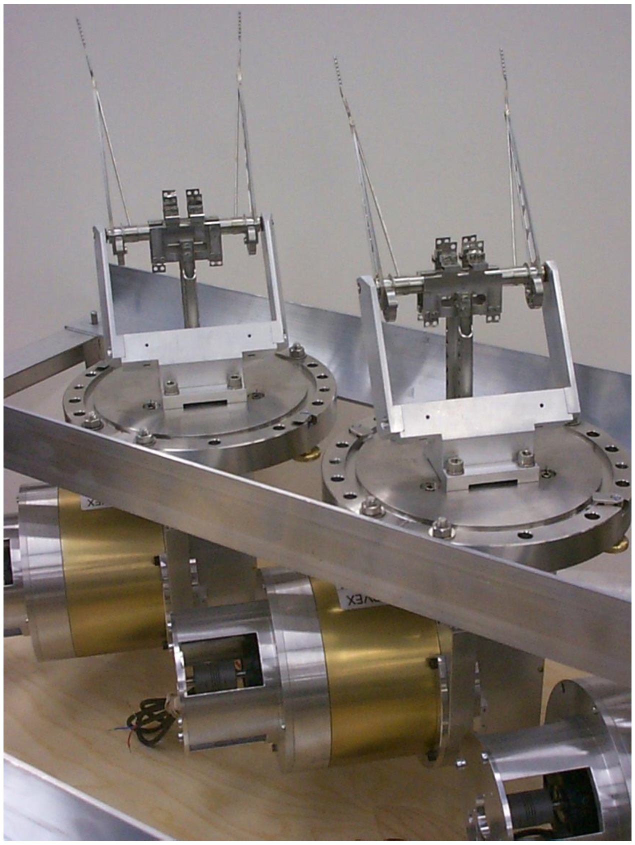


Fig. 170. Two wire scanners from an assembly of four units.

In June, drawings for the calibration device were sent to CERN for approval, and drawings were submitted to the Machine Shop for the new swing arm, and to Talvan Machine Shop (BC) for manufacture of the vacuum boxes. In July, scanner parts for 9 units were being machined at TRIUMF. In August, it was possible to test the prototype scanner mechanism with the improved swing arm.

Once confidence built up, the scanner was tested to its maximum required speed of 20 m/s and, surviving unscathed, the prototype was sent to CERN for acceptance. Soon after, approval was given to fabricate the remaining 9 swing arms (see Fig. 170). With so much concurrent mechanical work on the critical path (scanners, vacuum boxes, stand, calibrator), special attention was given to project coordination in order to complete it on time; and thanks to the efforts of all people involved, obstacles were overcome. The vacuum boxes were sent to CERN in November, and were successfully vacuum fired in December. The scanners were assembled and tested to 20 m/s at TRIUMF and, together with the stand and the calibration device, they left for Geneva on Christmas Day. The scanners were unpacked and inspected at CERN. Due to very minor problems with dimensional tolerances, the project experienced a short delay; but there is still sufficient time to calibrate the scanners and install them in the Booster during the winter/spring shutdown.

LHC Orbit System Components

Preliminary discussions on a new instrumentation task were held at CERN during the spring and at TRIUMF later in the year. As a result the group has been charged with the following tasks.

- The design of a 40 MHz acquisition card in VME.
- The writing of an application program in the CERN environment.

Three cards will be used for beam tests at CERN during the year 2000. In all, about 1,000 cards will be required. To aid in card testing and software design, a complete software development package has been loaned by CERN. This consisted of a PC running Linux and a VME system running LynxOS. This will facilitate the writing of all application codes in the CERN environment. A member of the CERN SPS Controls group spent a week at TRIUMF during November setting up the system.

The LHC beam position measurement system will require a matched pair of 70 MHz low pass filters in the front-end electronics of each monitor. We have obtained price quotes and two sample pairs of filters from

Lorch Microwave. Another sample pair has been built at K&L Microwave, but has not arrived yet.

POWER SUPPLIES

Booster Transfer Line Power Supplies

The year saw the start of production of the batch 2 power supplies for the PSB to PS transfer line. The production work is being carried out by I.E. Power in Toronto, in an alliance with Inverpower Controls and DPS. The contract calls for six 100 kW units and two 250 kW units, and prototypes of both units were required for evaluation at CERN before production of the series was able to proceed.

Both 100 kW and 250 kW prototypes were constructed with the 100 kW unit being shipped to CERN in August.

The 250 kW prototype required replacement of the high frequency output transformer which had not been manufactured to specifications. This precluded completion of the factory tests and due to the tight schedule these were then postponed to permit testing of the 100 kW production series as four of these units are required for the 1999/2000 winter shutdown at CERN.

Testing was completed on the first two 100 kW production units and these units were shipped to CERN before the end of the year. Units 3 and 4 are in progress and will be shipped early in 2000.

Effort will then shift to the 250 kW units and it is anticipated that the work will be completed by March, 2000. An additional order for spare parts for these supplies is expected to be placed early in the new year.

MAGNET DEVELOPMENT

The beam optics of the two collimation insertions in the LHC has been finalized (see Beam Dynamics section – Beam Optics and Collimation), and 48 warm twin aperture quadrupoles are required. As shown in the 1998 Annual Report, a prototype of this magnet was completed by ALSTOM Canada (Tracy, Quebec), and shipped to CERN in May, 1998. This magnet was extensively field mapped and mechanically measured at CERN. It was determined that an improvement by about a factor of 5 in assembly tolerances was required, even tighter than the original specification.

This year we worked on implementing these changes. The novel design with two apertures and eight poles results in the magnet having two different laminations. One type of lamination has two poles, the other has one pole. The shape of the laminations was changed to improve the punching and stacking accuracy, as shown in Fig. 171. A contract was awarded to ALSTOM Canada to manufacture the new punching dies. Sample laminations from the new die were delivered to CERN in July. Measurements of the laminations showed a problem with a pole profile on the two pole laminations, which turned out to be a problem in assembling the dies. The dies were corrected and new sample laminations were measured at CERN in November. These latest measurements show that the pole profiles are acceptable but there is a minor problem at the interface where the two types of laminations assemble. The problem was demonstrated to ALSTOM, and they have started to make the corrections. New sample laminations are expected at CERN in February, 2000.

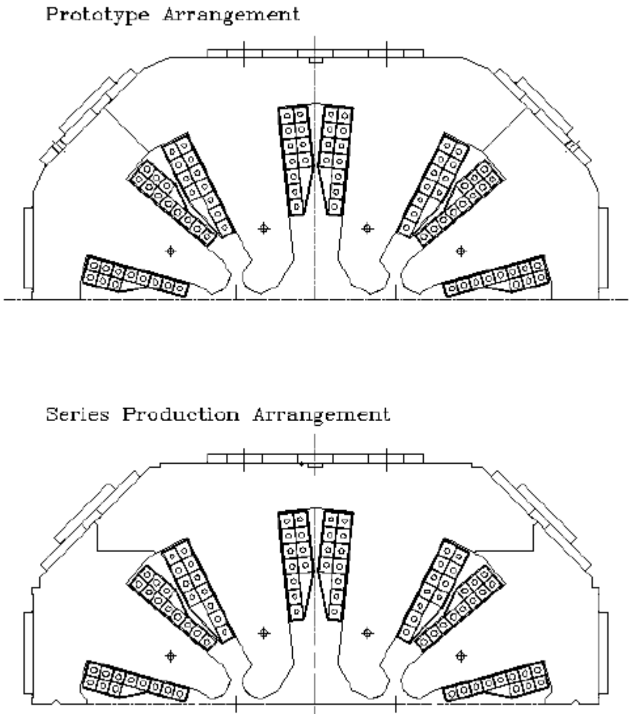


Fig. 171. Punching and stacking accuracy.

In 1998, CERN requested that we reduce the number of splices in the magnets' coils from the number in the prototype coil. TRIUMF awarded ALSTOM Canada a contract to make two prototype coils with at most 4 splices per coil. These coils were delivered in August. One coil failed a ground insulation test at CERN and was returned to ALSTOM for repair.

In June, TRIUMF awarded ALSTOM Canada a contract to design and build stacking and assembly tables for the series production of the magnets. The design of these tools has been reviewed by TRIUMF and CERN, and construction has started.

In July, TRIUMF issued the specification for the series production of the magnets. In September, TRIUMF awarded ALSTOM Canada the contract to manufacture the first 17 magnets. TRIUMF expects to increase the order to 52 magnets (48 plus 4 spares) once the Canadian government approves the required funding in the next five years.

CERN is supplying about 1,100 tonnes of steel sheet for the laminations. Eleven tonnes was shipped to Montreal in December. Another 70 tonnes should arrive in January, 2000, and 120 tonnes is expected in April, 2000. CERN is also supplying the copper conductor for the magnets. There are almost 10 tonnes of conductor in Canada, with 19 more tonnes expected in April, 2000.

CERN is supplying thermal switches, special metric fittings, vacuum chambers and measurement tools. ALSTOM has enough material to make the first few magnets. The special aperture measurement device, the Grabner meter (see Fig. 172), is expected to arrive in January, 2000. This device will be used to measure the mechanical accuracy of the pole assembly. In addition, a magnetic field measurement will be made at a fixed current to qualify the magnets prior to shipping to CERN.

At year-end, ALSTOM was working on finishing the magnet drawings, completing construction of the tooling, and correcting the dies.

Table XXX shows some important milestones for 2000.

Table XXX. Schedule of milestones.

Date	Activity
January 16	Die corrected
February 13	New laminations measured at CERN
February 27	Lamination approval by CERN
June 1	First magnet ready for inspection at Tracy
October 1	Finish CERN magnet measurements on first magnet

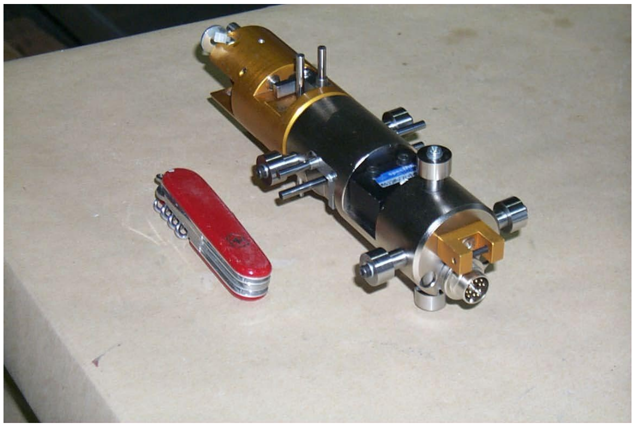


Fig. 172. Grabner meter.

KICKER MAGNETS

An LHC injection system will consist of a resonant charging power supply (RCPS), which has two parallel outputs, to charge two 5 Ω pulse forming networks (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 to be 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 at a repetition rate of 0.2 Hz. A PFN has thyratrons at both ends. 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 will be connected to a 5 Ω resistive terminator. The dump switch (DS) thyratron will also be connected to a 5 Ω resistive terminator. The DS thyratron is used to control the field flat-top duration to be either 5.76 μs or 7.8 μs. A kick stability of ±0.5% is required.

As reported in the 1998 Annual Report, a prototype RCPS was designed and built at TRIUMF, and shipped to CERN in June, 1998. The prototype 66 kV RCPS has been extensively tested in conjunction with the prototype 60 kV, 25 cell PFN which was designed by CERN/TRIUMF and built at CERN.

The TRIUMF Kicker group is well into the series production of 5 RCPSs for the CERN LHC (see Fig. 173). Several design changes were implemented in the production series of RCPSs, including improvements in the mechanical design. In addition, the diagnostics module was re-designed to

Fig. 173. Production series of 66 kV RCPSs near completion.

accommodate the CERN choice of a CERN standard thyristor unit, rather than a TRIUMF designed GTO module. After testing the prototype RCPS for approximately 200,000 cycles, a problem was revealed in the RCPS step-up transformer. The production series of the transformers has been modified to minimize the possibility of future problems: the modified transformer has been tested for over 1 million cycles with no further problems.

In order to obtain a field flat-top duration of 7.8 μs, it was necessary to increase the number of cells of the PFN from 25 to 28. It was also decided to increase the PFN voltage rating to 66 kV. The behaviour of the 66 kV, 28 cell PFN system was re-optimized with PSpice. CERN has provided TRIUMF with the ACAD drawings of the 60 kV, 25 cell, prototype PFN. The drawings are being modified at TRIUMF to allow for an increased number of cells, an increase in the voltage rating of the PFN capacitors, improved design of the PFN damping resistors, and North American material standards. These modifications are almost complete and the first batch of PFN tank drawings is being reviewed.

Two new FET calibrators (push-pull mode) with a variable trailing edge time have been designed and built. The amplitude of a calibrator output pulse is variable up to 600 V, at frequencies of up to 1 kHz, and has a flat-top of better than ±0.1% within 100 ns of the collapse of voltage at the output. These will be used for calibration of high voltage oscilloscope probes to a precision of ±0.1%.

TRIUMF selected ZEZ Silko (Czech Republic) and NCL (UK) to build sample PFN capacitors based on competitive bidding from 5 manufacturers. These capacitors must be highly reliable and stable for the life of the LHC. Pulse test equipment was designed and built at TRIUMF (see Fig. 174). High voltage (66 kV) and high current (up to 12 kA) pulse tests were performed on sample film/foil PFN capacitors from the two manufacturers. Both the ZEZ Silko and NCL PFN capacitance values are stable to ±0.03%. A test circuit was designed and built to permit the voltage dependence of capacitance of PFN capacitors to be determined up to voltages of approximately 30 kV. The ZEZ Silko PFN capacitors have been tested and their capacitance values have been shown to be virtually independent of applied voltage. The production series of approximately 600 PFN capacitors has been ordered from ZEZ Silko due to their slightly lower cost and superior service in providing 10 sample capacitors, on schedule, with very few problems.

Several of the pencil damping resistors used in the prototype PFN failed. TRIUMF therefore obtained samples of the required four types of resistors from two manufacturers (Kanthal Globar and HVR), and extensively tested these resistors. Resistor testing was carried out in conjunction with capacitor testing. Test resistors were mounted as coaxial resistors (see Fig. 174) through which the test capacitors were discharged. The extensive testing revealed a weakness in the design of the connection of the Kanthal Globar resistors.

The high frequency inductance of the prototype PFN coil is approximately 1.4% greater than predicted from a 2D (solenoid) model of the helical coil. Opera-3D simulations of a solenoid and helix are being carried out to determine their relative inductance. Opera-2D simulations have also been carried out to assess the effect of an elliptical shape (keystoning) of the coil, which was produced during winding of the prototype coil. The predictions indicate that, for a given mean radius of coil, the inductance is not significantly affected by "keystoning" of the coil.

The PFN assembly must be carried out in a clean laboratory with 5 ton crane coverage. The specifications for this facility have been sent to three manufacturers. This facility will be installed in the proton hall extension, adjacent to the kicker laboratory.

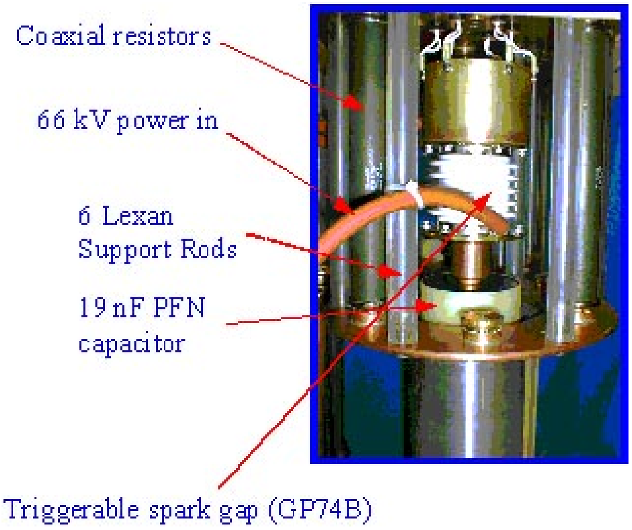


Fig. 174. Spark gap test photo.