TRIUMF

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ASSOCIATE MEMBERS:

UNIVERSITY OF MANITOBA
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APRIL 1998

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 year the TRIUMF collaboration working with CERN on the LHC had a challenging time producing the equipment required for the PS (proton synchrotron) conversion and the PSB (booster) energy upgrade. The schedule for most of these activities specified delivery in time for the 4 month shutdown at CERN which started on December 1. Fortunately TRIUMF personnel and the many companies manufacturing the components came through and the commitments were met, although not without a lot of extra effort and having to rely on air freight for some deliveries.

In the power supply area, this work included the manufacture of 36 transfer line power supplies and 8 high voltage supplies by Inverpower Controls, several smaller supplies and control boards by other firms, the construction of 5 large rectifier transformers for the booster main magnet supply by Ferranti-Packard and the construction of a 20 MVar static var compensator by GEC-Alsthom in the UK, but with significant components made in Canada. TRIUMF's role in this work was primarily contract management but in some cases this required more effort than anticipated to meet the required specifications and delivery times.

For the PSB-PS transfer line 7 water-cooled BT quadrupoles, 5 DVT steering dipoles and 3 larger BVT bending magnets were designed and fabricated by industry. Some magnets were assembled and all were field mapped at TRIUMF. These magnets were required to replace existing magnets but with laminated construction for pulsed operation and with higher magnetic fields for the increase in energy from 1.0 to 1.4 GeV. Extensive shimming was required to meet the tighter tolerances on the dipole magnets imposed by CERN.

In the radio frequency area the delivery of ferrite rings for the h=1 cavities was completed in August. The design of the higher order mode dampers for the PS 80 MHz cavity was completed at TRIUMF, with fabrication done by a local company, and assembly and electron beam welding done by the TRIUMF shop. Four different designs of HOM dampers were required, together with six filter assemblies.

Not all of the tasks worked on during the year were related to the PS shutdown work. In beam dynamics a new task was added to develop a simulation tool for the LHC/SPS tune control. TRIUMF will look after the beam dynamics part and CERN the beam control part. Work has continued on studies of second harmonic in the booster, with participation in machine development runs at CERN, and in developing the ACCSIM code. The task to study impedances of the LHC components has continued, with calculations on the injection and abort kickers. The task to study beam collimation in the cleaning insertions has progressed from transverse collimation to momentum collimation. For the latter two tasks, TRIUMF personnel have made extended visits to CERN to permit closer participation.

In controls and instrumentation ten 200 MHz and four 47.5 MHz calibrator modules were built and tested successfully at TRIUMF, and sent to CERN for upgrade of the SPS orbit monitor electronics. A further 40 of the 200 MHz modules are required before the end of the shutdown, and 250 next year. The PS Controls group have tested the 15 timing surveillance modules (TSM) produced by TRIUMF and require a further 30 more. A detailed design for the fast blade scanner prototype was completed by the end of the year, and procurement of parts started.

Good progress has been made by GECA (Tracy) on the construction of the prototype twin-aperture quadrupole for the beam cleaning insertions. By the end of the year 4 of the 8 coils and 2 of the 6 stacks of laminations, were manufactured. Difficulties in achieving the required tolerances on the stamping of one of the lamination designs caused some delay.

The design and fabrication of the prototype 60 kV resonant charging supply received most of the attention of the Kicker group during the year. The cabinet, panels, busbars and support brackets were designed, fabricated and assembled. All purchased components were delivered and a dummy load fabricated. Some initial tests of the circuitry were successfully completed. A new task has been added to fabricate and test 9 pulse forming networks for LHC injection. CERN is presently building the prototype for this system. Much of the hardware for these PFN tanks can be made by local companies.

At the Particle Accelerator Conference (PAC'97) held in Vancouver, May 11–16, there was an opportunity for a joint TRIUMF-CERN technical collaboration meeting, which was attended by 17 TRIUMF personnel and 13 CERN personnel. There were 10 papers presented at the PAC conference on the TRIUMF collaborative work with CERN, 7 with joint TRIUMF-CERN authors. In addition, there was the inaugural meeting of the CERN-TRIUMF Cooperation Committee, which is required to meet once a year under the terms of the CERN-TRIUMF Cooperation Agreement. At that time it was reported that, of the agreed \$19M in M&S, approximately \$12M was already allocated or spent on tasks, leaving about \$7M to be allocated in the future. Several possible new tasks were discussed, which were compatible with the remaining funds, although specific timings of decisions to proceed with these tasks were not clear at that time. In September E. Blackmore visited CERN to discuss the detailed status of equipment being provided by TRIUMF for the upcoming shutdown, and to have discussions on the technical requirements and timing of decisions on potential tasks for future work.

BEAM DYNAMICS

Second harmonic in PS booster

Dual harmonic rf systems, in synchrotrons, are used to promote Landau damping or to improve the bunching factor so as to reduce transverse space-charge. Since its introduction into the CPS booster in 1982, dual harmonic operation has suffered from an unexplained longitudinal instability occurring when the second harmonic cavity is anti-phased and controlled by the first harmonic gap signal. In machine development experiments in July and October, as part of the CERN-TRIUMF collaboration, the instability was diagnosed as a sextupole mode, and beam loading and space charge effects were eliminated as possible causes.

Accompanying theoretical studies have traced the cause to two ingredients:

1. the large gain of the beam transfer function when the bunch length is sufficiently long that the derivative of synchrotron frequency with respect to oscillation amplitude is zero;

2. the large phase shifts that are contributed by the long delays in the beam-phase loop and second harmonic corrector loop.

The same study suggests that the instability should not occur when the beam fundamental is used as reference, nor when the rf harmonics are in-phase; this is in agreement with experiment. In future work, it is intended to remove the simplifying assumptions of a non-accelerating beam and harmonic voltage ratio $V_1/V_2 = 1/2$.

Injection and collimation in the PS booster

This task involves the development and support of the ACCSIM multiparticle tracking and simulation code. This year saw the usual crop of user-requested features being added, but the main efforts were put into improving the accuracy and generality of the code.

The closed-orbit finder was replaced with a more robust and accurate one which utilizes 5-turn test-particle tracking data to derive the closed orbit and ellipse parameters. This routine can also be applied to off-momentum test particles, and this led to the implementation of a new feature for finding a fast momentum parameterization of the lattice optics. When there is significant momentum spread, this feature allows more accurate computation of particle betatron amplitudes and tune-shift rotations.

To allow for complex injection schemes where several machine and injected-beam parameters may be varying simultaneously, some entry points for "user-coded functions" were added to the program. These allow the user to write code to directly intervene on a turn-by-turn and element-by-element basis to modify time-varying quantities in arbitrary ways that cannot be expressed or anticipated through the program's input parameters and options. Initially this was applied to injection steering and closed-orbit bump dipoles, with other applications likely to follow.

The increasing user interest in improving the treatment of transverse space charge prompted some collaborative work with BNL and CERN and the addition to the program of a framework for a detailed space charge potential and kick-based tracking model. A candidate model using a 2D parameterization of the potential data (derived by summing over individual line charge potentials) was investigated, with this work slated to continue and intensify in 1998.

Beam stability

Our program of wakefield and impedance calculations, using MAFIA, for LHC components which might affect beam stability, has been continued, concentrating on the injection kickers. These have a ceramic pipe with thin copper stripes on the inner surface, intended to screen the ferrite from the beam and thereby reduce heating, although the significance of this effect for the LHC is in question and is being tested experimentally on LEP. MAFIA calculations have been carried out for the kickers, with and without a ceramic chamber, but show no significant differences in transverse and longitudinal impedances at low frequency. The effect of metallization has also been studied, both analytically and using MAFIA. The copper stripes were too thin (5–10 μm) to be included explicitly in the MAFIA calculations; therefore in the MAFIA model they were made thicker, with correspondingly reduced conductivity of the material, so that the ratio of the thickness of the metallization to the skin depth remained the same as in the real kicker. The main effect of the metallization on the ceramic chamber is an increase in impedance at higher frequencies, although the loss factors calculated for the LHC bunches change only 30% (this could be an effect of the rough structure used for the metallization simulations).

MAFIA calculations of wakefields and impedances have also been made for strip-line beam position monitors and collimators, and their implications on single bunch stability in the LHC studied. In order to maintain better communication with CERN the ongoing results of the impedance calculations are placed on the Web site which is updated regularly.

The LONG1D code for multiparticle tracking has been modified and installed at CERN on CERNSP (UNIX AIX) cluster. Work is under way on upgrading this code, which currently can only handle narrowband and space charge impedances, for use with LHC beams.

Beam optics and collimation

Our numerical optimization study of collimator jaw arrangements has been continued, and a search begun for efficient lattice optics for the betatron and momentum cleaning octants of the LHC.

An improved minimization method, "simulated annealing", has been implemented in the code distribution of jaws (DJ). This provides an automatic optimization procedure, and for a given lattice, was found to generate a large number of almost equally efficient jaw distributions. We then chose one which did not conflict with the rest of hardware.

Off-momentum effects have also been added to DJ this year, so that the code can minimize the area occupied by the halo particles in transverse and momentum amplitude space. The user can control the shape of the surviving halo by choosing appropriate weights.

For betatronic collimation (Interaction Region IR7) our optimization study followed the changing design of the dispersion suppressor through versions 4.2, 5.-2, 5.-1 and 5.0 of the LHC lattice, with the solution adopted for version 5.0 being shown in Fig. 127. For each new version, the IR7 lattice was retuned to improve the results obtained by DJ. Optics criteria were formulated for achieving the best betatron collimation and an analytical formalism developed explaining these criteria. This theory revealed the importance of having high $x-y$ tune split at appropriate locations in the lattice for efficient betatron collimation. It may be considered a simple two-dimensional generalization of the Teng criterion.

For momentum collimation in IR3, the modified DJ code was used to optimize the collimator distribution in a lattice constructed by the CERN team. It was demonstrated that the secondary halo can be trimmed back to the desired limit at the edges of the rf bucket, so that the arcs are indeed protected against off-momentum particles.

Other tasks completed included translating the DJ output into MAD/DIMAD input, translating the LHC error database into DIMAD input, and tracking with DIMAD in the presence of collimators, multipolar errors, etc.

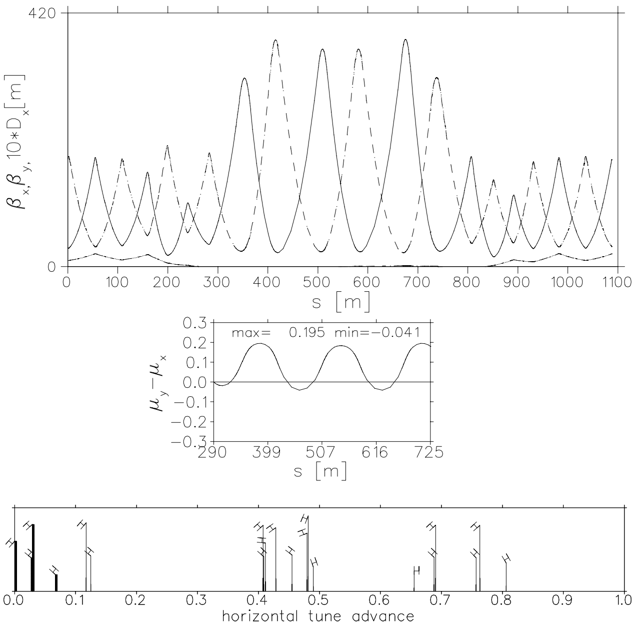

Fig. 127. IR7 lattice, tune-split function and jaw distribution. The quadrupoles are tuned for high positive tune split giving maximum halo amplitude $A_{\max} = 8.45\sigma$.

Simulation tool for LHC/SPS tune control

This is a new task in support of the proposal to continuously excite and measure the coherent betatron tunes and the chromaticity in the LHC. In this effort, CERN is responsible for beam measurement and lattice control, and TRIUMF for beam dynamics. The first step has been to conduct a pilot project for the much simpler and more familiar SPS.

Of particular interest for later on-line tune control is the question "How do time-variable non-linearities of the LHC magnets (snap-back, etc.) affect these measurements?" To answer this question seven years before commissioning begins, a computer beam model is required to stand in place of the real charged particle beam. "Fast Map" (FM), a non-linear transfer map iterating engine has therefore been written at TRIUMF, optimized for high speed tracking of particles (using COSY-generated maps) and customized to allow an unlimited number of tuning parameters (quadrupole and sextupole strengths, etc.) in addition to the six kinematic variables. FM has been interfaced with an off-line tune-measurement simulator (written at CERN) that chooses the strengths of the magnetic lattice elements.

A number of tests have been carried out to validate the simulation of the SPS using FM, such as:

1. identifying non-linear versus chromatic tune shifts with the help of FFT spectra for maps of different orders,

2. betatron-tune measurement by scanning the kicker excitation frequency,

3. observation of the decoherence of the transverse beam-centroid signal and its modulation due to chromaticity,

4. chromaticity measurement via the head-tail phase shift, performed at CERN using FM following beam experiments at the SPS.

These and other tests not only validated the FM beam model but also helped solve a number of interface problems between FM and tune-measurement software under development at CERN.

In the first stage of this collaboration, sixth order maps of the SPS with up to six free parameters have been delivered to CERN. The study will next be extended to encompass the LHC maps; the much larger lattice implies a number of new technical challenges which will require the writing of additional software.

CONTROLS AND INSTRUMENTATION

Fast blade profile monitor

The fast blade scanner detail construction drawings were completed for the blade pivot bellows actuation mechanism and vacuum box cover plate assembly. This prototype will be fabricated in the first few months of 1998. Next to be designed and built is the vacuum box support structure assembly. When fully completed, this prototype assembly will be installed and tested in the CERN PS booster ring. Assembly drawings have been sent to CERN for approval by the Vacuum group and other key PS group personnel.

Upgrading SPS orbit observation system

In 1996, CERN requested six 47.5 MHz calibrator modules (plus one spare) for 20-bunch Pb ion beam tests, in the SPS, starting in October. In January, CERN reported that the operating team was satisfied with the installed modules and that the first turn and closed orbit were measured. In November, 1996, CERN requested four more calibrator modules for additional beam position monitors that will operate at 47.5 MHz. These modules (incorporating minor changes to improve 'system integration') were delivered by May. Documentation of the 47.5 MHz calibrator modules, a design note [TRI-DN-97-9] and accompanying list of parts and specifications were prepared, and a conference paper was submitted to the PAC'97 describing both the 47.5 MHz results and the 200 MHz filter work.

By mutual agreement with CERN, the delivery date for a set of ten pre-production 200 MHz modules was pushed back several months to accommodate the 47.5 MHz work and the heavy work load due to ISAC. In May, CERN presented a schedule for the delivery of the 300 units (including spares), 10 by September, 40 by January, 1998, and 250 by January, 1999. Unlike the 47.5 MHz units where CERN provided the filters, the 200 MHz modules include a narrow band filter with challenging specification and tolerances, to be supplied by TRIUMF. A number of 200 MHz sample filters were received from commercial suppliers and their characteristics measured. These filter samples were sent to CERN for their evaluation, and in May it was agreed that the Microwave Company filter has the best price/performance and best delivery. The design is simple and yet allows full adjustment. Eleven pairs of 200 MHz filters were ordered with several improvements for long-term reliability.

A new printed circuit card layout, incorporating all the changes since the 47 MHz version, was developed. A key requirement of the variable phase-shifter is low insertion loss. To achieve this, customized quadrature hybrids were ordered from M/A-Com in May, with the supplier promising delivery in August. However, a second source of quadrature hybrids was found from Olektron in the same packaging and with lower VSWR and insertion loss. Consequently the Olektron hybrids were selected for the production run.

By September, eleven of the 200 MHz calibrator modules were completed at TRIUMF. Ten were destined for CERN, and the spare retained as a model for the commercial assembly. Of the eleven pairs of filters ordered, ten are within 3 degrees of each other, but the last pair differed by 10 degrees and was later opened for inspection. J-P. Papis visited from CERN for the final laboratory tests. The ten 200 MHz calibrator and filter modules were subsequently installed at CERN, and tested satisfactorily with beam in multi-turn and turn-by-turn acquisition modes.

Several local assemblers, Link Technology, Pachena Industries and SME, were asked to quote on the assembly for the production run, with Link Technology selected. A new version of the printed circuit card which eliminates the daughter card and provides better isolation was manufactured, assembled and tested in November. The final PCB uses the "solder mask oven bare copper" (SMOBC) technique to allow surface mount components to be soldered using automated equipment. The first 40 assembled units are scheduled to arrive at TRIUMF in January, 1998.

Design and production of VME TSM module

The VME timing surveillance module (TSM) passed CERN acceptance tests just before the end of the 1996. A first production batch of 15 modules was manufactured, tested and sent to CERN in February. During operation at CERN, it was detected that some modules in a heavily loaded VME crate produced phantom empty events, in addition to the real time events. The conditions for this happening are not well described and the problem is being investigated before the second production batch is manufactured.

POWER SUPPLIES

Activities of the year involved mostly contract administration for contracts for power conversion equipment which were placed the previous year.

Booster transfer line power supplies

The group 1 series of supplies consists of 36 supplies in the 15–35 kW range. A fully functional prototype of the 15 kW type A-1 unit was delivered at the beginning of the year for testing at CERN. Based on the test results, conditional approval was obtained to proceed with the production run. A number of changes were required to improve air circulation and to minimize the self heating of the supplies as well as minor modifications, mostly involving the interface to the CERN control system.

First testing on the 35 kW unit again showed the need for additional cooling, specifically on the magnetics, which were running uncomfortably hot. The use of water cooling was expanded to the magnetics, as well as to a number of power resistors, which previously were a significant source of internal heating in the supply. For production units, a larger cabinet than initially specified was selected to improve convection cooling.

During the production phase of the project the vendor was in the process of restructuring the company, and this resulted in great difficulty in meeting the delivery deadlines as defined by CERN. Extensive interaction was required to bring the project back on track, with delivery of the production units occurring during October and November. Inspection and testing of the supplies at CERN verified the performance of the supplies but also resulted in some quality assurance issues being raised, which are being addressed by the company.

In addition to the converters, orders were placed for the electronic crates as well as for the CERN circuit board for these crates.

High voltage and auxiliary rf supplies

In January the first two prototype high voltage supplies for the 40 MHz cavity were delivered to CERN. Delivery of these units had been delayed due to difficulties experienced with a sub-contractor for the high voltage output stage. Performance of the supplies was satisfactory to the higher continuous output power requirements, which evolved over the course of the project. Both units were re-wired at CERN to use halogen-free wire which, although required, had not originally been specified. To satisfy cost concerns, as well as to clarify the 80 MHz requirement, a meeting was held at the factory with a number of changes implemented for the new units. A total of 8 units were ordered, 4 of each type, 2 of each for October delivery, with the balance due in April, 1998. New output stages were incorporated for both types of supplies, for reliability reasons.

8 power supplies using a standard topology were also supplied by industry, 4 units of 15 VDC at 300 A, and 4 units of 8 kV at 10 A, as well as a number of smaller switchmode units.

Rectifier transformers/static var compensator

The 5 rectifier transformers and the static var compensator for the booster ring energy upgrade were delivered as scheduled in October and November. Meeting the very stringent electrical specifications of the transformers proved to be more challenging than anticipated by the manufacturer. The factory tests revealed that the short circuit impedance was about 10% lower than specified, thus making necessary a series of short circuit tests to prove that the mechanical design was a robust one. The tests were carried out at IREQ (Quebec). The first test failed. After additional bracing and reinforcement of the coils and leads, the second short circuit test was successfully passed. Installation was carried out at CERN starting in December.

The static var compensator had much smoother factory tests and was shipped to CERN in mid-November. Installation started soon after and will continue in January, 1998. Energization and commissioning is planned in February, 1998, as systems are started up after the shutdown.

MAGNET DEVELOPMENT

BI and BT quadrupoles

4 air cooled BI quadrupoles were installed in the 50 MeV linac to booster transfer line at CERN. They were successfully put into operation with a proton beam in the first week of March.

TRIUMF designed and built 3-singlet and 2-doublet BT (water cooled) quadrupoles. Figure 128 shows a photograph of one of the stacked doublets. For these quadrupoles the steel assemblies were manufactured by Tesla Engineering (UK), the coils were manufactured by Elma Engineering (USA), and the assembly was performed by Ebco Technologies (Canada). Some of these magnets were on display for the IEEE Particle Accelerator Conference in May. All the quadrupoles were field mapped in June, shipped to CERN in July and arrived at CERN in September.

The quadrupoles were mapped using a rotating coil which TRIUMF developed specifically for these quads. The rotating coil was linked to a lap-top computer,

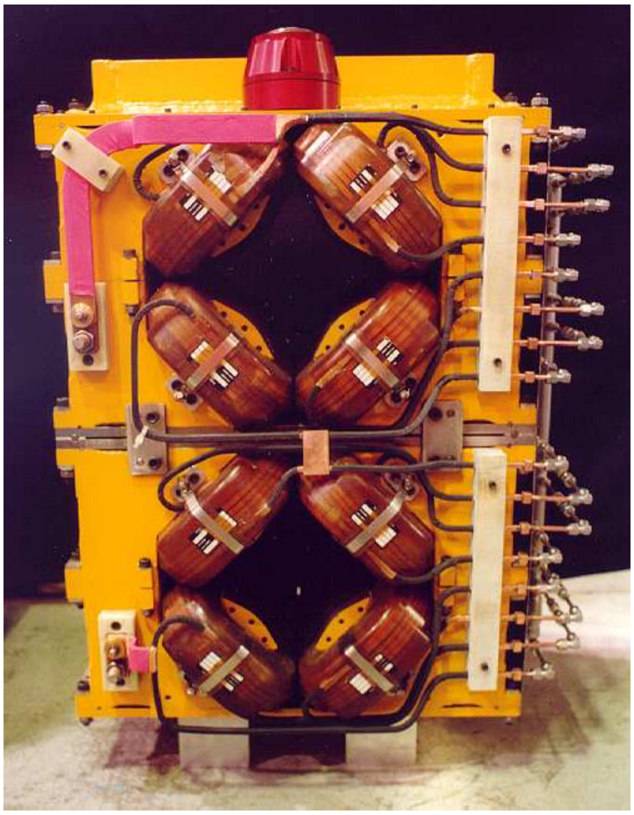

Fig. 128. Photograph of two water cooled quadrupoles stacked one above the other for the PSB-PS transfer line.

which stored and analyzed the measurement data. The amplitude of the harmonics measured, using the rotating coil system, is in good agreement with those measured using a hall probe. The phase angles of the high order, low amplitude harmonics, obtained from the rotating coil system, had significant errors. The worst case harmonic amplitude in the central region of the BT quads was 0.7% and occurred for the 6th harmonic. However, the 6th harmonic of the integrated field is less than 0.1%. The rotating coil measurement system was the subject of a paper.

DV dipoles

TRIUMF was asked to deliver 5 DVT dipole magnets plus 2 spares. The difficult to make splice free coils were manufactured by Everson Electric (USA). The steel assemblies were made by a local machine shop. TRIUMF assembled, field mapped, and shimmed the 7 magnets. The worst case homogeneity for the integrated flux density over the beam aperture was –0.94% in DVT serial No. 4. The magnets were shipped on October 17, by air freight to CERN and arrived October 22.

BV benders

TRIUMF designed and built 2 BV1 benders, 1 BV2 bender, and 2 spare coils. The coils were manufactured by Elma Engineering (USA). The steel assemblies were made by a local machine shop. TRIUMF assembled, field mapped, and shimmed the magnets. As a result of the specification for good field uniformity, it was necessary to ensure that the measurement system was extremely stable over the several hours required for a survey. The capabilities of the new magnet measurement software, to log quantities such as power supply current to file, were used so that the measured field could be corrected for small variations in magnet current. The worst case homogeneity for the integrated flux density was –0.236% in BV1 serial No. 2 and +0.156% in BV2 serial No. 1. In both cases the worst homogeneity was in a corner of the rectangular area surveyed. The BV1 magnets arrived in Geneva on November 12. The BV2 magnet arrived at CERN on December 17.

Twin aperture quadrupole

TRIUMF went to tender for a fixed price contract to finish the twin aperture MQW quadrupole design and to build a prototype. The contract was awarded to GEC Alsthom Energies (Canada). The design was completed and reviewed by TRIUMF and CERN. GEC Alsthom is building the prototype in Tracy (Quebec). By the end of the year 4 of the 8 coils, and 2 of the 6 stacks of laminations were finished. GEC Alsthom had tolerance trouble with the type 1 lamination (two-pole), but this problem appears to be fixed. The lamination tolerance problem created a shortage of steel sheet which CERN solved by shipping more steel to Tracy. The prototype is now expected to be shipped directly to CERN in April, 1998. Figure 129 shows a photograph of one of the lamination stacks.

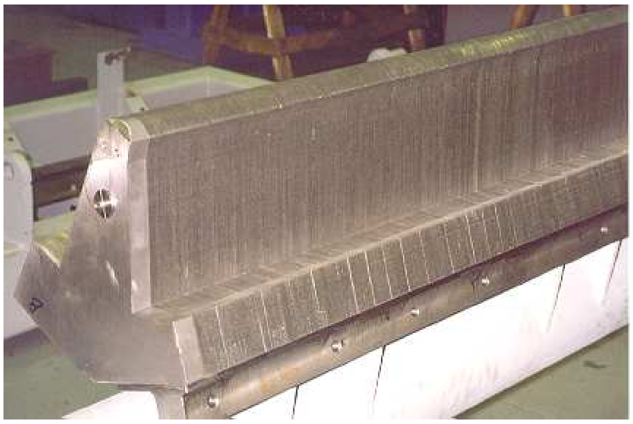

Fig. 129. One of the lamination stacks for the twin aperture quadrupole used in the LHC cleaning insertions.

KICKER MAGNETS

Coordination/project planning

During February, M. Barnes and G. Wait travelled to CERN for discussions with the SL Division kicker group, and also to both NCL (UK), and FUG (Germany), to witness tests on components for the prototype resonant charging power supply (RCPS). The two main topics of discussion at CERN were the simulation work being carried out on the LHC injection system, and the 66 kV RCPS currently being built at TRIUMF. N. Kahn carried out several ANSYS calculations for the cabinet, and the predictions were presented at CERN.

Meetings were also held with the CERN PS Division Kicker group. A summary of the PSpice simulations carried out to date for the PS FAK kicker was presented: the goal for the FAK is to achieve a 0.5% to 99.5% field rise time of 121 ns.

During May, a visit was made to Stangenes Industries in Palo Alto to witness tests on a high voltage, low inductance, pulse transformer for the RCPS. During June, L. Ducimetière from CERN SL Division visited TRIUMF for discussions regarding the simulation work being carried out on the LHC injection system and the 66 kV RCPS.

TRIUMF has been heavily involved in the design of 5 Ω pulse forming networks (PFNs) for LHC injection kickers. The prototype PFN is presently being built at CERN, and TRIUMF has been asked to build 9 more PFNs and 20 thyratron switching systems. The estimated cost of components is $2M.

Injection kicker system for LHC

Counter-rotating proton beams will be injected into the LHC at an energy of 450 GeV by two sets of kicker magnets, with each set producing 1.2 Tm magnetic field pulses. Both injection systems are composed of 4 travelling wave kicker magnets of 2.65 m length each, powered by PFN's, and matched to their characteristic impedance of 5 Ω.

The kick-strength rise (fall) time must be less than 910 ns (3.16 μs), including timing jitter. The ripple must be less than ±0.5% of the flat-top, including RCPS, PFN, thyratron switches, kicker magnet, and resistive terminator. PSpice has been used to model the complete electrical circuit with the goal of obtaining a theoretical solution with a ripple of less than ±0.1%.

A summer student carried out PSpice analyses to determine the sensitivity of the predicted field to the value of both individual and groups of components in the PFN, and in the transmission line kicker magnet. The results of the sensitivity analysis show that the capacitors for the kicker magnet can be specified in the following manner: total capacitance of 133.32 nF (33 off 4.04 nF) with a tolerance of 0%, –2%, and individual capacitors have a tolerance of ±5%.

A Physica macro which selects PFN capacitors from a manufactured batch into pairs, to optimize field quality, has been refined, based on experience from PSpice analyses of the LHC inflector. In addition, the macro has been modified to significantly reduce the CPU time required to select capacitor pairs. CERN purchased a set of 50 PFN capacitors from ZEZ Silko in Czechoslovakia. The capacitor sorting algorithm was used to select the optimum value of PFN capacitor, for the prototype PFN, from the ZEZ Silko values. The re-optimized mean radius of the prototype PFN was reduced from 42.4 mm to 41.5 mm. Opera2D AC analyses were carried out to determine the frequency dependency of resistance and inductance of the PFN coil, for several different radii: the resulting plots can be used to rapidly select the final coil radius, based on the optimum choice from a future manufactured batch of approximately 500 PFN capacitors.

66 kV resonant charging power supplies

Resonant charging systems are used to charge PFNs for kicker magnets in order to reduce, as much as possible, the number of untriggered thyratron discharges. The PFNs for the LHC injection kickers will be charged to 55 kV, 1 ms or 2 ms, before the thyratrons are triggered. The stability and reproducibility of the charging voltage must be maintained to a precision of ±0.1%. The design and construction of the resonant charging systems is being carried out at TRIUMF.

The construction of the prototype RCPS was delayed by approximately 4 months due to a shortage of manpower in the Design Office. A pre-prototype mock-up of the electrical circuit was put together to permit initial tests to be carried out. The pre-prototype was tested initially with a short-circuit secondary, and subsequently with one of two dummy loads connected to the secondary of the 1:23 step-up transformer.

The GTO switch is used in gate assisted turn-off (GAT) mode in order to minimize recovery time. During testing, with a short-circuit secondary, the GTO was used in GAT mode to turn-off currents up to 300 A. The subsequent dV/dt across the GTO is relatively severe: the anode-cathode voltage rises to 160 V in 1 μs, then continues to rise at a rate of 120 V/μs for several microseconds. The maximum voltage following turn-off was 1.4 kV. The GTO was operated in this mode at 0.2 Hz, continuous for 30 minutes. The measured delay time from issuing a turn-off command to the gate drive unit (GDU) to the anode current falling to 30 A (10% of GAT current) is 7.1 μs. As a result of this delay time, the maximum current that the GTO is expected to turn-off, during any operating condition, is 150 A and the worst-case dV/dt expected is 110 V/μs.

During the short-circuit tests, the pre-prototype was operated with GTO currents of 5.25 kA at 0.15 Hz. The consequent rms current of 55 A is 20% greater than would be required for a PFN voltage of 66 kV. In single shot mode the GTO has been tested with peak currents of up to 7.5 kA: under worst-case fault conditions the GTO is expected to conduct 10 kA.

The analogue and digital portions of the controls and interlocks were simulated using PSpice. A "pre-prototype control box" was manufactured, which permitted the pre-prototype RCPS to be operated. Based on experience with the pre-prototype the controls were modified. M. LeRoss carried out the PCB layout for the controls and interlocks, and also designed the mechanical layouts of the controls and silk-screening.

All of the major components were received before the end of 1997, and final assembly has commenced. One of two dummy loads required for testing the RCPS was completed. Measurements on the dummy load showed that there were initial problems with load current flowing through signal cable grounds. This problem was cured by isolating the signal ground from the power ground. With a single dummy load the RCPS has been operated at 0.2 Hz, with a load voltage of 66 kV, for several hours. Figure 130 shows measurements carried out to 55 kV operation. An effective charge time of 970 μs was measured, which is in good agreement with the PSpice predictions. Temperature rise measurements were carried out to confirm that heating of components was acceptable. Stability measurements show that the pulse to pulse reproducibility of the PFN voltage is better than $\pm$0.03%.

CERN PS kicker magnets

Kicker magnets are used for injection and extraction in the CERN PS. The addition of the LHC facility to the complex of accelerators at CERN requires an

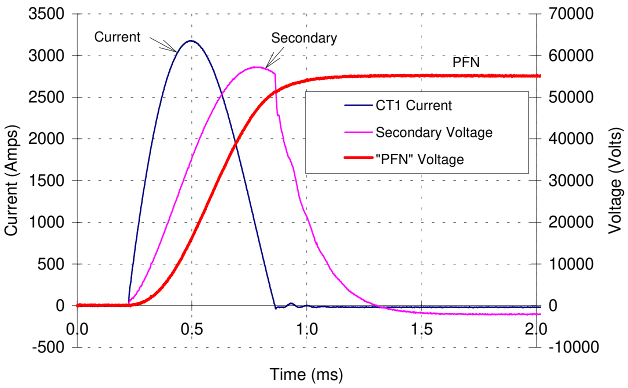

Fig. 130. Measured primary current and secondary voltage during 55 kV operation of the pre-prototype RCPS, at 0.2 Hz with one dummy load.

improved performance of the existing kicker magnet systems in the CERN PS. The injection kicker field must rise and fall from approximately 1% to 99% of full strength during the 96 ns time interval between bunches, whereas the extraction kicker field must rise from approximately 0.5% to 99.5% of full strength during a gap of 121 ns created in the beam. The kicker magnet systems require PFN voltages of up to 80 kV. Displacement current arising from the turn-on of a multi-gap thyratron can significantly increase the effective rise time of the kick. Saturating inductors can be used to reduce both the effect of the displacement current and the rise time of the main current pulse.

The test circuit consists of an 80 kV pulse generator which can deliver 40 kV pulses into a kicker magnet. The pulse generator is a 30 Ω system, on loan to TRIUMF from CERN PS Division, and has been modified to permit testing with saturating inductors connected on the thyratron anodes. The kicker magnet is a 10-cell, 31.5 Ω prototype transmission line kicker magnet which was designed and built at TRIUMF. The kicker magnet was housed in a vacuum tank and operated with PFN voltages of 60 kV and 80 kV. Measurements were performed with and without saturating inductors, and with the kicker terminated in either a short-circuit or 30 Ω.

Capacitive pickups were installed on the high voltage capacitance plates at the input and output to the kicker magnet: the field in the magnet is derived from these signals. There was a saturating ferrite on the anode of the dump switch thyratron for all of the measurements. A series of measurements was carried out using various combinations of ferrites, PFN voltages and terminations. The results showed that 12 cm^2 ferrite on the input to the magnet significantly improved the rise time, but that the ferrites on the anodes of the thyratrons do not significantly improve the rise time.

RADIO FREQUENCY SYSTEMS

40 MHz cavity and HOM dampers

The HOM dampers which were manufactured at TRIUMF and shipped to CERN in 1996, were tested in February at CERN. Some modifications to these dampers were carried out at CERN. Brazing with certanium 34C was not accepted due to the zinc content of the solder. Also, 304 stainless steel flanges were changed to low magnetic 316 LN type. Signal level tests of the dampers showed very good damping of the higher order modes. The design goal of damped shunt impedances of less than 1 kΩ for the monopole modes was achieved with a damping of about 5% of the fundamental mode. The dampers were also tested with rated cavity gap voltage, and test results show that the dampers couple negligible power at fundamental frequency. Also, no multipactoring due to the dampers could be observed. The 40 MHz cavity with higher order mode dampers was successfully installed in the PS ring.

40 MHz tuners

The coarse mechanical tuner and the mechanical servo tuner are still in operation in the 40 MHz cavity. A second coarse mechanical tuner, identical to the first tuner, was also installed in the same cavity for tuning of the nominal frequency of the cavity.

80 MHz structures and HOMs

Signal level measurements were made at TRIUMF on the copper clad wooden model of the 80 MHz CERN cavity to design and optimize the higher order mode dampers. Four antennae were found to be sufficient to damp the longitudinal (monopole) modes up to 1 GHz. The design goal of 2 kΩ shunt impedance for the higher order modes up to 700 MHz was achieved. It was difficult to obtain the same quality of damping for modes between 700 MHz and 1 GHz. However, one of the dampers absorbed fundamental power at 80 MHz and lowered the Q of the fundamental resonant frequency by 30%. During the development of these higher order mode dampers, it became obvious that high pass filters were required for at least three antennae to bring the total loss of Q below 5%. A three element coaxial high pass filter using rigid transmission lines was successfully developed. A modular design was undertaken so that the same filter could be attached to any of the three dampers. Two sets of four dampers and six high pass filters were fabricated at TRIUMF and delivered to CERN in November.

The higher order mode dampers were leak checked at CERN prior to mounting on the first 80 MHz cavity. Figure 131 shows the CERN 80 MHz cavity

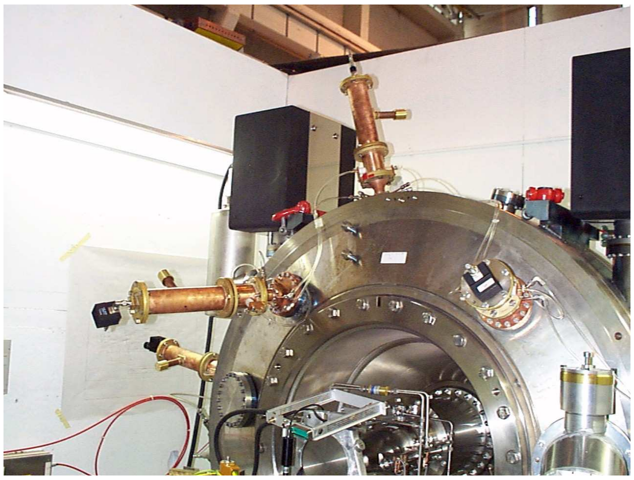

Fig. 131. CERN 80 MHz cavity with four HOM dampers installed.

with the higher order mode dampers mounted. The dampers met the CERN specification of vacuum and material quality. Signal level measurements were conducted with the dampers, and the filters installed on pre-designated ports on the 80 MHz cavity. The damping of monopole modes is illustrated in Fig. 132. The loss of Q at 80 MHz due to the dampers was measured to be less than 2%. The damping of transverse modes up to 500 MHz was also measured and found to reduce the transverse impedance by a factor of 60 for the first transverse mode at 220 MHz, and more than 200 for the other modes. The higher order mode dampers were also tested with full power on the cavity. The cavity was conditioned to a gap voltage of 300 kV (duty cycle <5%) with the dampers installed. No multipactoring was observed. The gap voltage was reduced to 200 kV with increased duty cycle of 33% and the dampers were provided with water cooling. The power was maintained for 8 hours without any breakdown.

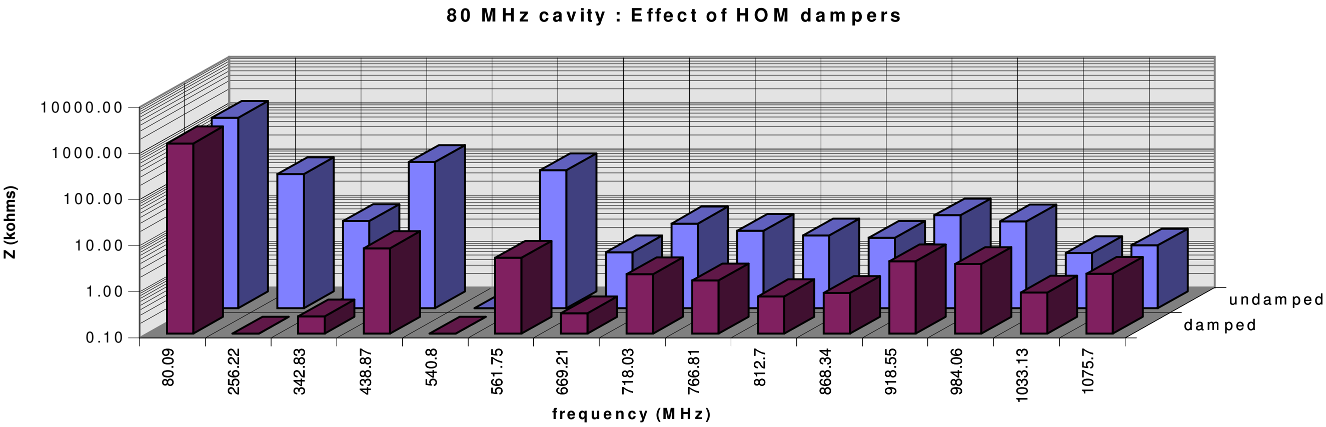

Fig. 132. Damping of monopole modes.

Since the power coupled by the damper-filter configuration was less than 2% at 80 MHz, the 50 Ω terminating loads were of air cooled 20 W rating. The second set of higher order mode dampers is being installed on the second 80 MHz cavity. Both cavities will be installed in the PS ring in January–February, 1998.

80 MHz tuners

Initially, two identical capacitive tuners were installed on the CERN 80 MHz cavity. It was found out that the tuning range of 385 kHz per tuner was adequate for coarse tuning for the nominal frequency of the cavity. Hence, the second tuner was taken out before the power test began.