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Trip Report:Moscow Area Accelerator Laboratories and CERN

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Period covered by report: 5 January '89 to 7 February '89			
Arrival Date	Installation	City	Country
6 January	Inst. for High Energy Physics	Protvino (Moscow Region)	USSR
12 January	Inst. for Theoretical & Experimental Physics	Moscow	USSR
17 January	Inst. for Nuclear Research	Troietsk (Moscow Region)	USSR
18 January	Inst. for High Energy Physics	Protvino	USSR
27 January	CERN	Geneva	Switzerland
7 February	Fermilab		

Purpose

The trip was taken to survey the current state and trends in proton linac design with special emphasis on high gradient structure for $\beta = v/c > 0.4$ and matching between structures operating at different frequency. These interests are related to the proposed 400 MeV upgrade of the Fermilab Linac. A secondary interest was to look for ideas applying to $\beta < 0.05$ for improved beam brightness.

Abstract

Meetings were held with Prof. V. M. Tepliakov, Assoc. Dir. for Accelerators, IHEP (Serpukhov), and his close colleagues to discuss advantages of rf focusing in linear accelerators both in RFQs at low β and in modified drift tube linacs at higher β. The beam dynamics of the six-dimensional matching required where an accelerator chain has an abrupt change in transverse and/or longitudinal focusing between successive components were also discussed. Tepliakov made a pitch for the high shunt impedance (power efficiency) of the H-resonator used by them in their rf focused 30 MeV linac injector. I gave a seminar on the plans for Fermilab Tevatron Upgrade. I heard in detail the proposal of Carlo Rubbia to trade the CERN antiproton rings and UA1 detector to IHEP for superconductor and cryostats; the IHEP response is one of great interest but some as yet unresolved reservations.

At the Institute for Theoretical and Experimental Physics at Moscow I talked to I. M. Kapchinskii and others about RFQ design and matching problems. Their small accelerator program has recently received much greater support because they have had to close down their reactor based research post-Chernobyl. They have a variety of interesting linac work underway including a Bi^{++} RFQ intended as an inertial fusion driver.

A one day visit to the Institute for Nuclear Research at Troietsk provided some new information on disk-and-washer structure development in the Soviet Union and some impressive evidence on development of efficient computer code for calculation of electromagnetic fields in accelerating structures including a nearly finished three-dimensional program. Matching problems and techniques were also discussed. My principal host was S. K. Esin, Head, Accelerator Dept., but the largest fraction of the interesting information came from the mathematical physicist/designer V. V. Paramonov.

The visit to CERN provided me an update on a wide miscellany. I heard about the attitude of the AA Group to Rubbia's swap proposal. I received some critiquing of the Fermilab 400 MeV linac upgrade proposal from linac experts in the PS Division and once again solicited ideas on the matching between existing and proposed linac.

Narrative Trip Report

Purpose for Travel to Moscow Area Accelerator Laboratories

During the study of structure candidates for the 400 MeV upgrade of the Fermilab linac in 1988 we looked at some papers from the Soviet Union which showed interesting work which we were unable to learn about in detail. In particular, there appeared to be continuation in the development of the disk-and-washer accelerating structure (DAW) which we had under active consideration and development at the time.

Furthermore, we are interested in improvement of the low energy end of the Fermilab linac and want to pursue the relevance of rf focusing schemes including, but by no means limited to, the now more or less conventional RFQ. The URAL-30 linac at the Inst. for High Energy Physics at Serpukhov (IHEP) uses what they call "spatially inhomogeneous", *i. e.* intermittent, RF focusing to 30 MeV following their 2 MeV RFQ. There were several papers on the concepts and design of this machine but little we could find on how it was working in practice. We knew that the design resulted in high electric fields on the surface of the focusing electrodes (about three times the so-called Kilpatrick limit); we had not been able to learn whether sparking breakdown is an operational problem in this machine.

Because we were also in the process of developing or borrowing computational tools for calculating beam dynamics and fields in various structures, we were interested to find whether there were useful new ideas from these well established laboratories with a reputation for innovation in linac design. These interests were related specifically to the Fermilab 400 MeV linac upgrade and to a general desire to be current on innovations in accelerating structures and computational techniques.

Summary of Activities

Institute for High Energy Physics, Serpukhov I was given a summary of the Serpukhov programs by the Scientific Secretary Ryabov and additional detail on the 3 TeV "accelerator-storage complex" (UNK) by Vladimir Alexandrevich Tepliakov, associate director for accelerators. It included experimental program, international collaboration, and, with greater detail, the history, status, and plans for accelerator systems. The briefing was followed by a series of tours of linacs, booster, U-70 synchrotron, experimental areas, shops for the fabrication of superconducting magnets, and the magnet measurement facility. Most of this has been reported at conferences *etc.*, so I report only some items that seemed somehow novel or curious.

Status of UNK There are 13 km of tunnel ready for installation. The rest of the tunnel will be finished by 1990. Out of about 2500 conventional magnets being made in Leningrad (Effremov Institute) for the injection line and 400 GeV injector (UNK-I, 600 GeV max.), somewhat over 50 have been delivered. These will be installed in the 2.5 km injection tunnel this year for a 70 GeV beam test of few superconducting magnets. They have so far four satisfactory full scale cold iron magnets. The completion date for the first 3 TeV ring (UNK-II) is 1993; the second (UNK-III) is due in 1997. They are very adamant about keeping to the schedule. They feel that the priority and visibility of the project has been raised to the point that they can not allow significant slippage. There are two approved experimental activities. One is a continuation of Prokoshkin's long-standing search for exotic states, *e. g.* glueballs. The other is a general multiparticle spectrometer for heavy quark physics. They also expect as a first experiment to look at a gasjet target from 400 to 3000 GeV. They are expecting a broad international collaboration for that experiment. There is no intention to use the warm magnet injector directly for experiments.

The biggest excitement involves the the late November '88 proposal of Rubbia and Brianti to exchange the CERN antiproton source and UA1 detector for superconducting cable and perhaps some cryostats to build a Large Hadron Collider in the LEP tunnel. The basic proposal is that CERN would turn over the source in 1993 so that IHEP could get into the colliding beam business with the UA1 detector at 6 TeV almost as soon as the first 3 TeV ring works. Even though they had decided against the INP (Novosibirsk) antiproton source proposal rather recently, they are very tempted by the CERN proposal. They believe that with reasonable enhancement of the U-70 synchrotron they could reach a luminosity of $10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}in3 \times 3$ TeV $p\bar{p}$ collisions in the mid 1990's. However, they have major concern about the feasibility of Soviet industry producing enough cable in the time span needed to both finish UNK-II and the LHC on nearly the same time scale. The exact terms of the swap are apparently not fixed, but the amount of cable that CERN wants is apparently about one third of the total for LHC. However, Tepliakov says that it would take a large increase in industrial capacity, a factor of 10(?), to meet the schedule. They also worry about taking on a sophisticated installation with woefully inadequate resources in electronics, *etc.* That problem they are starting to deal with immediately by sending many people to CERN for extended periods, probably about 50 this year. I heard about the other side of this deal at CERN and have some further observations in that part of my report.

Linac Matters The URAL-30 linac now works reliably (c. 0.1% pulses lost to sparking) even though the maximum surface fields are far higher than common practice. There were two or three years when breakdowns built up to a level of several percent lost pulses after having started out at turn-on with much lower rates. This was a period when the tanks were being opened frequently for adjustments and improvements. They discovered that extreme cleanliness was needed to avoid such problems and that the breakdowns did not generally occur at the high field points. The problem rather seemed to be that the form of their accelerating structure made it very difficult to clean certain areas if they got any dust during an opening of the tank. Eventually, over a period of years, their spark rate has returned nearly to its initial satisfactory values.

I discussed with Tepliakov and his beam dynamics specialist Anatoli Pavlovich Mal'tsev the matching of the RFQ to URAL-30 which involves a transition from stronger to weaker transverse focusing similar to that planned in the Fermilab upgrade. They felt our transition section would be improved by making a more gradual change in the strength of the transverse focusing. They use about 12 quads in their matching section which has, however, the additional role of changing the focusing regime from azimuthally symmetric to alternating gradient.

Tepliakov pointed out economic advantages in two of the features of URAL-30 which are not exploited at other laboratories. RF focusing is much less expensive than using magnetic quadrupoles; also, the H-resonator that they use for producing the accelerating field has a higher shunt impedance (power efficiency) than the widely used Alvarez structure.

I gave a seminar on the plans for the Fermilab Tevatron Upgrade with most detail reserved for the linac upgrade which I claimed to know about. The matters of greatest interest to them are the dates and specifications for Phase III which factors into their strategy for $\bar{p}p$ at UNK. They think our linac proposal is ok, but not of much direct significance to them. They are more interested in anything new we find on DAW. They also expressed interest in our experience with H^- sources, especially with respect to contamination of the column by Cs. They are under instructions to implement charge exchange injection into their booster as part of the program to improve U-70 performance as an injector for UNK. They also would like to know more about the Fermilab medical linac proposal because of interest in a $\sim$ 10 MeV linac to supply shortlived radio-isotopes in a hospital setting.

Institute for Theoretical and Experimental Physics, Moscow I spent a week in Moscow getting in a one-and-a-half day visit to ITEP and a day at INR. It was arrangements for the latter which proved to be the harder to pin down because of vacations of people I was planning to see. ITEP provided me with a flat while I got things worked out.

At ITEP I talked mostly with I. M. Kapchinskii, Head of the Accelerator Department, and Nikolai Vladimiravich Lazarev, Director of its Injector Laboratory. They have long operational experience with a 25 MeV drift tube linac and are well along in a modern 56 MeV replacement for it. They have developed alternating phase focused structure for a He^+ pre-injector for the DTL and a vane type RFQ for the new linac. The new linac starts with a 3 MeV RFQ at 150 MHz followed by 3 Alvarez tanks at 300 MHz. The drift tube quads are all PMQs of the same strength except for the first six which come down in even steps from 6 kG to 5 kG on the pole tips.

The matching required between RFQ and the following drift tube linac has some features in common with the Alvarez-to-SCS match in the Fermilab upgrade. They use a single 300 MHz cavity phased as a buncher included in the same vacuum tank as the 150 MHz RFQ. They use about seven quads over a distance of a little more than a meter to do the transverse matching. They do not think that a radial post-matching section is especially useful because the major function of the matching is to transform between azimuthally uniform and FODO focusing; the size matching is easily accomplished in the process. They find no emittance growth in simulation of this system but do find some in practice, apparently because the beam leaving the

RFQ is not exactly at a waist. They may reach closer to the planned transverse focusing during further commissioning tests.

I toured the injector linac, the new linac, and RFQ and saw the He^+ pre-injector and the Bi^{++} RFQ. The tanks for the new linac and its RFQ are made from stainless steel with diffusion welded copper sheet inside. I thought the surface looked very good; I would certainly look into this technique if I needed a large high-Q cavity.

Institute for Nuclear Research, Troietsk The visit to INR was just a day but included a facility tour and some hours of discussion with S. K. Esin (Head of Accelerator Department), L. V. Kravchuk (the leader of the group for the Alvarez and disk-and-washer linacs), and V. V. Paramonov (mathematical physicist and structures specialist). Beam tests of the Meson Factory have involved only the drift tube linac up to 20.5 MeV so far, but all of the rest of the linac is basically ready. They will move DTL tank 2 into line to be ready for DAW tests up to 100 MeV in August and about 160 MeV in the fall. The full 600 MeV is expected in 1990. The parts of the project which are now setting the time scale are electrical power distribution and chilled low-conductivity water.

INR is another place that is being shaken up a bit by the higher priority and better access to material resulting from the recent government policy decision to make particle physics a national priority. Esin says that their idea to build a K-factory has been approved even though they have yet to submit a proposal. They are trying to put something together for February '89 which will describe a pair of rapid cycling synchrotrons, probably 125 μA at 7.5 and 45 GeV but the same radius. An interesting feature of having a large radius for the lower energy ring is that it would be able to accelerate H^- to about 3.5 GeV. This beam can be slow extracted as an extremely low emittance proton beam by moving it slowly onto a charge exchange foil.

The INP DAW structure is basically the original design of V. G. Andreev *circa* 1970. They now believe that the bi-periodic T-supported structure with washer diameter less than the disk diameter, like that modeled in the Fermilab development program, is the preferred structure for proton linacs above 100 MeV or so. They believe that the difficulties arising from the complicated mode structure are nearly eliminated by the mode-splitting induced by the T's and that remaining troublesome modes can be easily eliminated by cutting tuned T-shaped slots into the disks as they have done on the Meson Factory DAW. This technique is not supposed to reduce the shunt impedance for the accelerating mode.

It will be very interesting to see how easily their DAW can be commissioned. The slow progress to date reflects slowness to get things built which they attribute to the small size of the staff. The institute has about 1500 employees, a number which they say is very small for their mission under a system which requires that virtually everything be built from raw materials. They initially concentrated on rf structure development to work out any problems inherent in the new structure, leaving conventional facilities for last. They claim (ruefully) the world record for the duration of the construction phase for an accelerator.

INR is the most committed to DAW of any lab in the world, but we had seen papers with Serpukhov and Moscow State U. authors describing work directed toward DAW for a racetrack microtron. These papers were the result of a structure evaluation process carried out by Moscow State with INR collaborators. The Serpukhov people involved are applied mathematicians who work with V. V. Paramonov of INR. When the evaluation was finished, the microtron designers chose an on-axis coupled structure because they were familiar with it and did not need a long section. They wrote up their DAW work for the record, but Paramonov removed his name from the authors of the english language versions because he did feel the work was substantial enough. Thus, what seemed to us an indication of a new interest in DAW at Serpukhov was a very small effort and had its real center at INR. However, I did hear from Paramonov that there is a more serious effort under Karliner at INP (Novosibirsk) which has been described in an EPAC (Rome, '88) paper. This lead should be pursued because Karliner runs a very capable calculations/theory group.

I reviewed the dynamics of the six-dimensional match between the INR 198 MHz DTL and the 991 MHz DAW and the similar match in the Fermilab upgrade between 201 MHz DTL and 805 MHz SCS. At INR they use the final, short Alvarez tank as ramped-gradient, variable-synchronous-phase, longitudinal matcher that provides only a small amount of acceleration. The drift tubes provide many locations to install a smooth transverse matching as well. This arrangement provides close to the practical ultimate in smoothness of matching in all planes at the cost of considerable complexity and a reduced longitudinal acceptance.

One of the more impressive observations on my trip was the success of V. V. Paramonov in making electromagnetic field codes using a variational formulation with bi-quadratic finite elements which can fit a large structure calculation into modest computers. The two-dimensional version of this code (MULTIMODE) like URMEL calculates the higher azimuthal modes as well as the azimutally uniform modes. The speed is reasonable, but the outstanding feature is that good solutions are obtained with far fewer grid points. I saw two-dimensional examples in which various longitudinal modes were calculated for ~ 50 cells. A three-dimensional code using the same principles is in advanced stages of development; Paramonov expects it to be practically useful, at least to himself, by this spring. From my observation of Fermilab difficulties making accurate MAFIA calculations for the side-coupled structure, I think this work should be followed closely.

I noticed that their instrumentation specialist A. V. Feschenko has developed a very accurate and convenient device to measure the phase spread of bunches; precision is better than 1° at 200 MHz. It was written up for the 1986 Linac Conf. (SLAC), and I have called it to the attention of the beam diagnostics person in our linac group.

CERN The stop at CERN was primarily to learn from the experience of those who had worked on the design and building of Linac II. The payoff here was limited, but I got a chance to get a thoughtful critique of the Fermilab linac upgrade proposal from Mario Weiss and Dave Warner. Weiss was of the opinion that, regardless of the finesse in the transition section design, one should expect some transverse emittance blowup simply because the longitudinal focusing increases by 5x while the transverse focusing decreases by 0.5x, so that non-linearities, like space charge, will inevitably couple energy from longitudinal to transverse.

The Carlo Rubbia $\bar{p}$ rings swap proposal seemed somewhat less fully known by some I talked to at CERN than it was to my Serpukhov contacts, although certainly the AA group (now called the Antiproton Rings Group) was well informed. There had not been any public presentation by the management, but a particle physics seminar scheduled for 9 February was announced as "Physics at UNK". The introduction was to be shared by Rubbia and Brianti and include a talk by Jacques Garyete on "First Ideas on a 6 TeV $\bar{p}p$ Collider". A sizeable delegation of IHEP people were expected to show up with N. Tyurin who was to give the talk on UNK machine and experimental program status. Objectively the proposal makes a lot of sense and probably will be pushed by CERN. They get rid of a detector and source which is sinking into the shadow of CDF and D0 at Fermilab; they get a good jump on SSC. It is a strict barter deal but has a value set at 250 MSF. If they can make a sufficiently inexpensive $\bar{p}$ source (< 50MSF, $\sim 10^7 \bar{p}$/s) for LEAR, then they think that the economics are ok. They would make funds available by eliminating the SPS fixed target program. The idea is that the European focus for fixed target would shift to the higher energy facility at Serpukhov. IHEP would thus be insured of strong international support it desparately wants. For maximum effect this deal should get moving promptly so that CERN can stockpile magnets in advance of the 1993 shutdown and be ready to go with LHC well before SSC gets started.

I looked over the new Novosibirsk made pulse transformer and the CERN made 38 mm dia. Li lens to be installed in March for the upcoming collider run. CERN bought two of the transformers for cash. They look quite good. Boris Bayanov and Alexander Chernyakin of Gregory Sil'vestrov's group at INP were there for the commissioning. They were just starting the pulsing tests as I left, but the same lens had been pulsed in a similar transformer at INP a year ago to 1.2 MA, I think. The objective for the present installation is 1.3 — 1.5 MA.

Appendix: List of Principal Contacts

Name of Contact	Title	Institution	Subjects of Discussion
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	Linac structures
Alexander B. Barsukhov	physicist	IHEP	
I. M. Kapchinskii	Head of Accelerator Dept.	ITEP	
Leonid Vladimirivich Kravchuk	Head, Main Accelerator Lab.	INR	
Valentin Vladimirivich Paramonov	physicist	INR	
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	6-D matching
Anatoli Pavlovich Mal'tsev	physicist	IHEP	
I. M. Kapchinskii	Head of Accelerator Dept.	ITEP	
Serge Konstantinovich Esin	Head, Accelerator Div.	INR	
Leonid Vladimirivich Kravchuk	Head, Main Accelerator Lab.	INR	
Mario Weiss	physicist	CERN	
David Warner	physicist	CERN	
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	Beam dynamics
Mario Weiss	physicist	CERN	
Valero	physicist	Saclay	
Alexander B. Barsukhov	physicist	IHEP	EM field calculation
Valentin Vladimirivich Paramonov	physicist	INR	
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	Linac operations
I. M. Kapchinskii	Head of Accelerator Dept.	ITEP	
Andre Antonivich Kolomiets	engineering physicist	ITEP	
V. V. Kurakin	engineer	ITEP	
Serge Konstantinovich Esin	Head, Accelerator Div.	INR	
A. V. Feschenko	physicist	INR	Linac diagnostics
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	CERN/IHEP $\bar{p}$ barter
Fleming Pedersen	Head Antiproton Rings	CERN	
Dieter Möhl	Assoc. Head Antiproton Rings	CERN	
Eifonydd Jones	Deputy Head PS Div.	CERN	
Fleming Pedersen	Head Antiproton Rings	CERN	Antiproton rings and targetry
Alain Poncet	engineer	CERN	
Peter Sievers	physicist	CERN	
Ryabov	Scientific Secretary	IHEP	IHEP program
Vladimir Alexandravich Tepliakov	Assoc. Dir. for Accelerators	IHEP	& UNK project
I. M. Kapchinskii	Head of Accelerator Dept.	ITEP	ITEP program
Serge Konstantinovich Esin	Head, Accelerator Div.	INR	INR program

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