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REPORT ON THE ITEP 24.6 MeV and SERPUKHOV 100 MeV LINACS

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Introduction

In April 1967, the 24.6 MeV proton linac injector of the Moscow 7 GeV P.S. produced 130 mA beam pulses after a few months of "tuning-up". In February 1968, the 100 MeV injector of the Serpukhov 70 GeV P.S. also produced a high intensity beam (100 mA) after only 6 months of adjustment and trimming.

The purpose of this paper is to record some of the details of these machines as given by Professor Kapchinskij during a visit to CERN in Feb. 1968, together with some information gathered by the author during a visit to these machines in Nov. 1967.

ITEP I-2 24.6 MeV Proton Linac Injector

The 7 GeV proton synchrotron of the Institute for Theoretical and Experimental Physics (ITEP or the "Alikhanov" Institute) was served for some years by a 4 MeV electrostatic generator injector. The design and construction of a new 24.6 MeV injector was the joint undertaking of a number of institutes in the Soviet Union, the main contributors being the ITEP design team under Professor Kapchinskij, the Radio Technical Institute of the Academy of Sciences ("Mints" Institute, Moscow) and the Scientific Research Institute for Electrophysical Apparatus ("Komar" Institute, Leningrad).

An excellent account of this machine (Kapchinskij et al 1967) was published in the Sept.-Oct. 1967 (No. 5) edition of "Pribory i Teknika Eksperimenta". This journal is published in English translation by the Instrument Society of America as "Instruments and Experimental Techniques".

In brief, the machine comprises a 700 keV pulsed H.T. pre-injector more or less as described by Solnyshkov et al (1963) at the Dubna Conference, followed by the Alvarez section which consists of one long resonator 1.37 m in diameter (148 MHz) divided by a septum into a 6 m tank accelerating to 6.12 MeV followed by an 11.7 m tank continuing up to 24.6 MeV. The resonator is surrounded by a stainless steel vacuum tank and the assembly is pumped by oil diffusion pumps with liquid nitrogen baffles. The position of each drift-tube (18 plus end halves in Tank I and 33 plus end halves in Tank II) is determined by a single vertical stem which rises from an adjusting mechanism mounted on a heavy longitudinal girder which is in turn supported by a concrete foundation beam running the length of the machine.

An unusual feature of the Linac is the $2\beta\lambda$ accelerating period in the first tank with 2 quadrupoles in each drift-tube in the + - + - mode. During the design of this machine it was considered that the advantages of this scheme (smaller number of drift-tubes, less difficulty with space problems for the adjusting mechanisms at the low energy end, improved use of drift-tube volume for quadrupoles, reduced multipactoring due to a higher rate of rise of gap voltage) overcame any disadvantages in the lower accelerating rate.

In March 1966 when the accelerating structure had been assembled but not finally aligned nor flattened, RF power trials were carried out, and some interesting observations of the multipactor effect are reported in the reference above. Later, after the results of an accidental oil penetration had been cleaned away, the tests were continued, and with a short period of multipactoring conditioning, it was possible to excite the cavities to 15 - 20% above nominal field level (respectively 9.9 and 14.1 MV/m mean gap fields) without breakdown. These figures correspond to peak surface fields of > 19 MV/m at the beginning of Tank I and > 24 MV/m at the beginning of Tank II.

The above reference gives details of the proton dynamics and of the design of the structure, the low and high-power RF, mechanical and vacuum aspects and the pre-injector, and concludes with an account of the tuning-up and beam measurements.

Informal talk given at the Linear Accelerator Conference at Brookhaven in May 1968

Serpukhov 100 MeV Proton Linac Injector

The design proposed for the 100 MeV Serpukhov injector was described in the 1963 Dubna Proceedings (Kapchinskij et al 1963) and the machine as constructed is essentially as it was in 1963 (see also Polk, 1963). Further details have been reported recently at the Cambridge Conference (Mints et al 1967).

As in the case of the ITEP Linac, the Serpukhov Linac was a co-operative effort, involving the Alikhanov Institute, the Mints Institute, the Komar Institute, and the Serpukhov* Laboratory staff which was built up in the latter years to cope with the installation, running-in, operating and future development of the machine.

Brief Description

To recall the main feture of this linac, it consists of 3 tanks, 30, 27 and 22 metres in length, accelerating from 0.7 to 38 MeV, 73 MeV and 100 MeV. It operates at 148 MHz and is driven by the same 5 MW triode, the GI-27A, as used at ITEP. The main difference in the RF system is that the final power amplifiers at Serpukhov (at present one per cavity) are mounted directly upon the accelerating cavities near their centres, (Fig. 1), and employ the cavities themselves as tank circuits. Another important difference is that $\beta\lambda$ acceleration is used throughout the linac. As with the ITEP linac, the highest RF fields appear in the second cavity - the mean gap fields in the 3 cavities are 7.4, 9.9 and 8.2 MV/m respectively, somewhat lower than the ITEP figures (see above). Each drift-tube houses one quadrupole lens, and lens gradients vary from 6 kG/cm at the input end to 400 G/cm at the output. The focusing system works in the + - + - mode. The 2 m long matching channel from the 700 keV pre-injector to the linac input (Fig. 2) contain 6 quadrupole pairs, as well as a buncher, TV station, steering windings (in the quadrupoles), beam transformers, quartz plates and a Faraday cup. The pre-injector (Komar Institute) is similar to that of ITEP, with an average gradient of about 3 MV/m along a 25 cm reentrant gap (Fig. 3).

The RF and structure design was the responsibility of the Mints Institute, and they have put considerable emphasis on mechanical precision and stability and vacuum cleanliness. In the absence of suitable copper-clad steel supplies they have produced a double vacuum system, with a few 10^{-7} to 10^{-6} T pressure in the vacuum-tight inner copper resonator and 0.1 mm between the resonator and the outer mild steel vacuum vessel. This approach entails a certain complexity in the design of those elements which must pass through both inner and outer vessels. The single drift-tube support stem, the adjusting mechanism and the support foundation are all massively conceived (Fig. 4) because of the longer wavelength (2 m) used and because of the tight specifications imposed on drift-tube alignment. The allowable radial error was set at 50 μ r.m.s. and in fact this figure was improved upon in the final alignment. The drift-tube assemblies were submitted to inspection tests consisting of side thrusts of 30 - 40 Kg and measurement of the resulting residual error, and measurement of the logarithmic decrement of the vibration amplitude. Natural periods of 8-12 Hz and Q's of the order of 150 were typical. The clamping of the mechanism produced a small displacement of the order of 10 μ and the final position of a drift-tube was arrived at by iteration. Optical alignment methods were used.

The fine vacuum is produced by a set of 30 Titanium sputter-ion pumps. Before mounting of the drift-tubes, the high molecular-weight surface impurities in the resonator were fractionated by an axial stainless-steel bar heated to 650° C and pumped away.

RF Behaviour

Sparking difficulties appear to have been unimportant, and seem to have been associated with a vacuum incident in the pre-injector which permitted oil to enter the accelerating cavities. Multipactoring however produced some interesting effects until it cleared up after a few months (Mints et al 1967). The nearest mode is separated from the dominant mode by 62 kHz and 120 kHz in the 1st and 3rd cavities respectively and initially the excitation of these modes by non-uniform multipactor loading was sufficient to cause large amplitude beating on the RF envelopes (or "scalloping"). The multipactoring responded to a faster rise time produced by changes of input power and tank tuning, and by the application of negative feedback.

The RF power required to reach a stable phase angle of 38° is of the order of 2.2, 2.4 and 3.5 MW in the 1st, 2nd and 3rd cavities respectively. The corresponding measured unloaded Q factors were 66,000 , 50,000 , and 42,000 (to be compared with the design figures of 72,000 , 50,000 , and 36,000).

Beam Characteristics

A proton beam was first accelerated to 100 MeV in July 1967. For the first few months the intensity was around 8-10 mA, and this was the state when the author visited Serpukhov in late November and had the opportunity of observing the RF scalloping and the resulting modulation of the beam pulse. However, in late February 1968, when Professor Kapchinskij visited CERN, he was able to report that the scalloping had disappeared and that an intensity of 100 mA had been reached in mid-February.

With 270 mA into the linac, they had obtained 50 mA without the use of the buncher and 70 mA with the buncher. This was then increased to 100 mA by careful trimming of the last two quadrupole pairs in the 700 keV matching channel. Kapchinskij has, for a number of years, laid special emphasis on the need for careful 6-dimensional matching between the pre-injector and linac at high currents (Kapchinskij and Vladimirskij, 1959). His practical solution to the transverse motion problems is to connect the first and second doublets in series and the third and fourth in series, but to leave the 5th and 6th doublet with separate controls. These quadrupole elements have an aperture of 40 mm φ, and a length of 8 cm per quadrupole, with a spacing of 1 cm between the elements of a doublet.

The predictions of the useful linac acceptance area turned out to be somewhat pessimistic. With a 1 cm aperture radius at the input, the region of good field was taken as 0.75 of the radius which led to a "good field" acceptance of 0.5 cm mA (ie $\frac{\text{area}}{\pi}\ \beta\gamma$) for a total acceptance of 1.2 cm mR. In fact the useful or effective acceptance has been found to be 1 cm mR. At the other end, the output normalised emittance had been computed to be 2 cm mR Measurements have shown that 20 mA lie within 0.5 cm mR at 100 MeV.

The trapping efficiency of the linac for 100 mA output is over 50% (270 mA input with 70 - 85 % proton percentage gives $\eta > 53\%$). The injected 700 keV beam has an average phase space density of 700 - 900 mA per cm mR normalized, and 400 mA lie within < 0.5 cm mR.

Once a beam had been accelerated throughout the machine, it was possible to check the focusing structure by switching off the quadrupoles one by one and plotting the output beam current as a function of drift-tube number. The resulting periodic curve, which is related to the Floquet function of the focusing channel (Kapchinskij and Vladimirskij, 1959) was found to give a sensitive indication of perturbation to the incoherent particle motion (2 quadrupoles were found to be of wrong polarity) and to the coherent motion (1 drift-tube out of alignment).

The beam loading compensation at the moment is only that which is inherent in a generator-load system, and the tank levels drop appreciably during the 15 μs beam pulse (The P.S. revolution time is 11.6 μs and the pre-injector produces a 30 μs pulse which is chopped by electrostatic plates to 15 μs through the linac). The RF levels in the 3 cavities fall by 16%, 12% and 15% respectively during the 15 μs. They have made use of these known relative changes along the tanks to obtain a fairly precise calibration of the monitoring loops for relative field changes due for example to tuner plate movement. Provision was made in the design for a second final amplifier per tank for beam loading compensation, adjacent to the first.

At 100 MeV the mean momentum moves about 0.3% during the 15 μs beam pulse due to beam loading field changes. The momentum spread at 1/3 full height, as measured with a bending magnet and slit system of 0.1% momentum resolution, is as follows :

$I_{0.7\ \text{MeV}}$	$I_{100\ \text{MeV}}$	$\frac{\Delta p}{p}$
mA	mA	%
23	10	± 0.1
150	50	± 0.5
270	100	± 0.7

The nominal acceptance of the P.S. is ± 0.3%. The pulse shape remains fairly good throughout the machine for 100 mA pulses.

General

The Linac Hall, which is 100 m in length and air-conditioned (Fig. 5) forms part of the main Injector Building in which are situated the Linac Control Room, and, adjacent to it, the P.S. Control Room. The Linac Control Room (Fig. 6) is equipped with an operating console on which are grouped the main controls and indications, including an 8-position TV monitor with remote panning and focusing, and control of the tank focusing and accelerating field laws. Beam currents are read directly from a peak-reading meter.

Acknowledgements

The author wishes to acknowledge the generous supply of information provided by Professor Kapchinskij and the staff of both ITEP and Serpukhov and also wishes to thank Professor Kapchinskij for agreeing to the publication of this information.

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Footnote

* Serpukhov is a town about 100 km south of Moscow, but the Institute and P.S. is located some 20 km to the southwest at Protvino.

FIG. 1: Tank with final amplifier

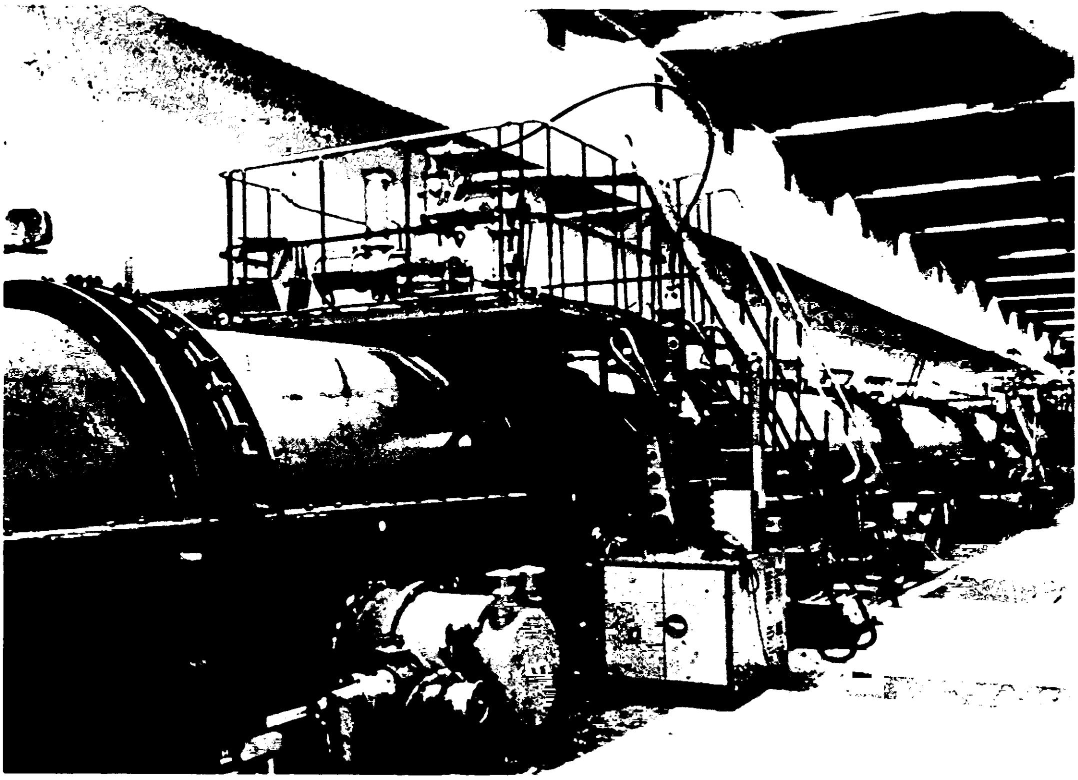

FIG. 2: 700 keV Matching Channel

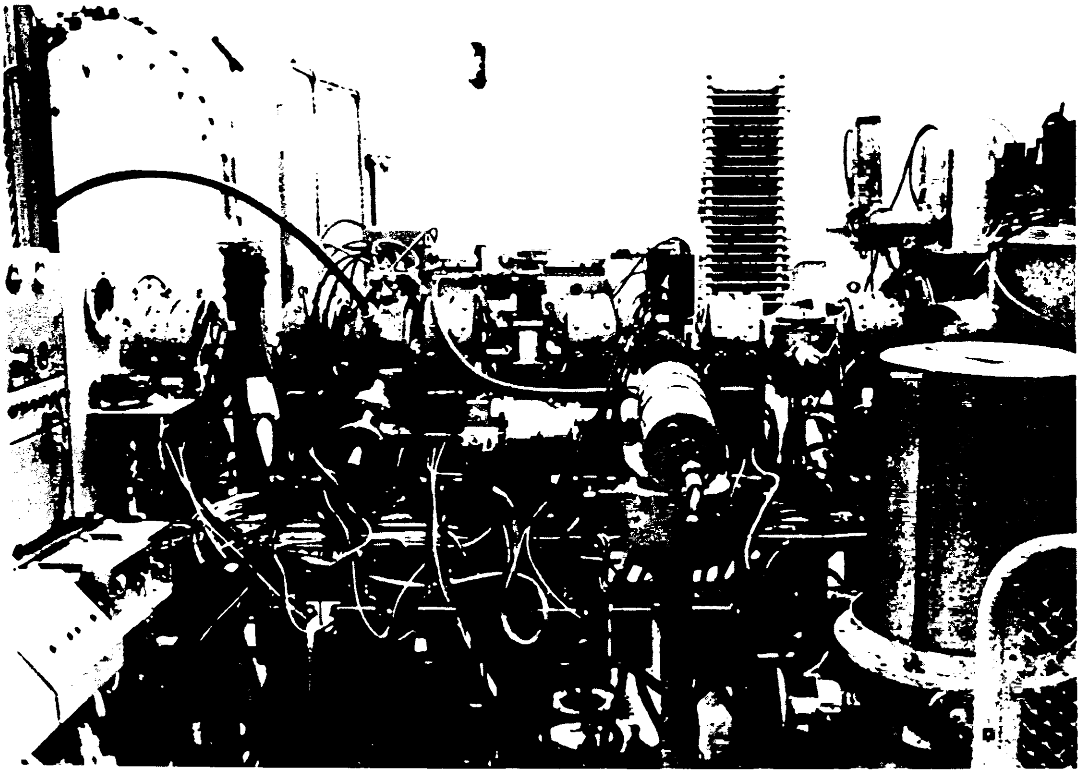

FIG.3: 700 keV Accelerating Tube and Vacuum Chamber

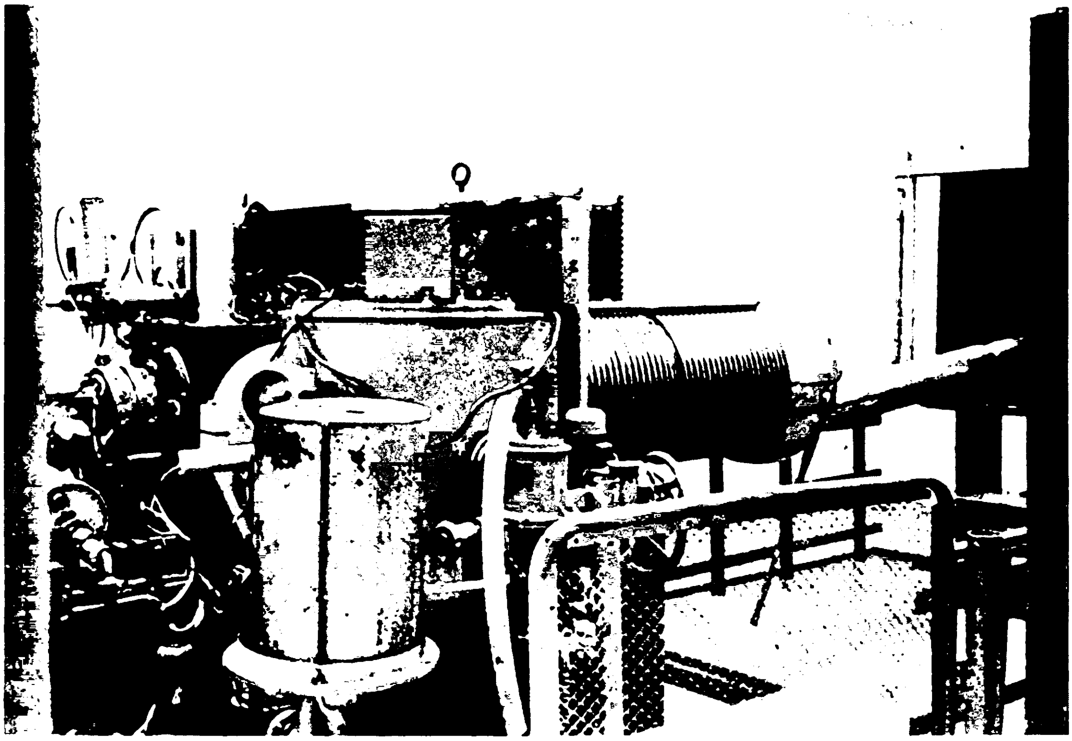

FIG. 4: Drift-tube Supports and Adjustments

FIG. 5: General View of 100 MeV Linac Hall. Pre-injector in the foreground, Outer vessel lids on the right

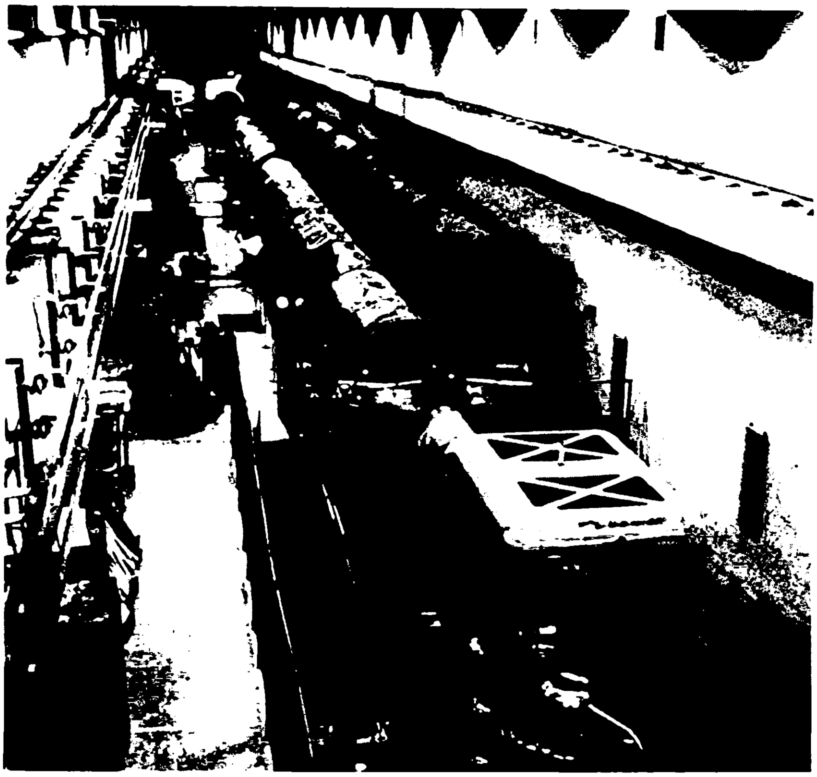

FIG. 6: Linac Control Room