CONSTRUCTION AND FIRST OPERATION OF UPGRADED LINEAR ACCELERATOR

S. Fukumoto, Z. Igarashi, K. Ikegami, T. Kamei, T. Kato, C. Kubota
S. Machida, Y. Mori, T. Shintomi, A. Takagi, E. Takasaki and T. Takenaka

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Abstract: A new Alvarez linac cavity was built and installed to boost 20 MeV beams to 40 MeV. Protons were replaced by H^- ions for more efficient charge-exchange injection to the synchrotron. As the peak intensity reduced greatly, extensive beam loading compensation is no longer needed and the rf system is modified so that both the old and new cavities are fed by the power amplifiers which excited previously the old 20 MeV cavity. The linac beam is 8 ∿ 10 mA, 20 Hz and usually with pulse duration of 20 to 50 μS. Polarized H^- beam of 12 μA with 58 % polarization is achieved. The debuncher compresses momentum spread of 0.7 % FWHM to a half of it in routine operation.

Introduction

Both users of 12 GeV protons and 500 MeV ones had strongly demanded more intensities. The ring of TRISTAN, a 30 GeV e^+e^- collider, was decided to pass through under the beam line which guided the 20 MeV linac beam to the 500 MeV booster synchrotron, and during its construction the proton synchrotron complex was shut down for more than one year. The long shutdown offered a chance of upgrading the injector linear accelerator and other equipments. In May 1985, the machine resumed the operation with charge-exchange injection of H^- ions. It was demonstrated that 20 MeV ions were still effective provided the charge-stripping foil was thin enough[1]. Obviously, however, higher injection energies are no doubt preferable.

Upgrading of the injector linac had been planned[2,3]. A new Alvarez cavity was designed and partly fabricated in 1984. Alnico-9 permanent quadrupole magnets were tested and high power rf system was modified[4]. After two month operation of June and July in 1985, the synchrotron complex was shut down again to install the new linac cavity which would accelerate protons or H^- ions from 20 MeV to 40 MeV.

H^- Ion Source

Two H^- ion sources are prepared, ordinary and polarized. It was already recognized that a multicusp ion source produced a very stable and quiet H^- beam under a condition of 100 μS and 20 Hz. It was an urgent problem that its tungsten filament cathode had no enough life for a high energy accelerator complex. When new cathodes were installed, the cesiated molybdenum converter should be carefully commissioned by discharge to yield sufficient H^- ions. Poly-crystalline directly heated LaB_6 cathode was developed during the long shutdown of the TRISTAN tunneling[5]. After operation of more than 2600 hours, a very slight reduction in its thickness was observed. The beam current was normally 20 mA. The cathode temperature was 1400 °C, much lower than that of the tungsten filament. This cut down consumption of cesium greatly, so that the source, which was directly mounted to the accelerating column, could run more than six months with one charge of 5 g cesium without serious problem of breakdown in 750 kV Cockcroft preaccelerator.

Beam pulse duration and repetition of the source are fixed to 150 μS and 20 Hz. Beam to be injected to the linac is regulated by an electrostatic chopper and a graphite beam stopper at the low energy beam line. Typical 750 keV H^- beam emittance at the entrance of

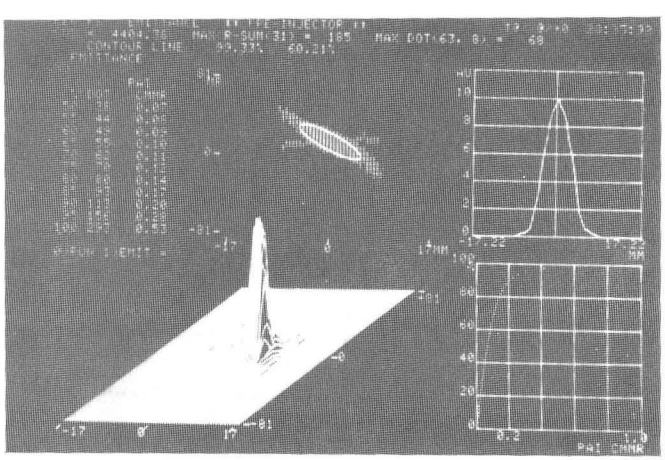

Fig. 1 18 mA H^- beam emittance at the entrance of the linac. ε_n = 2.0 πmm mrad at 90 %.

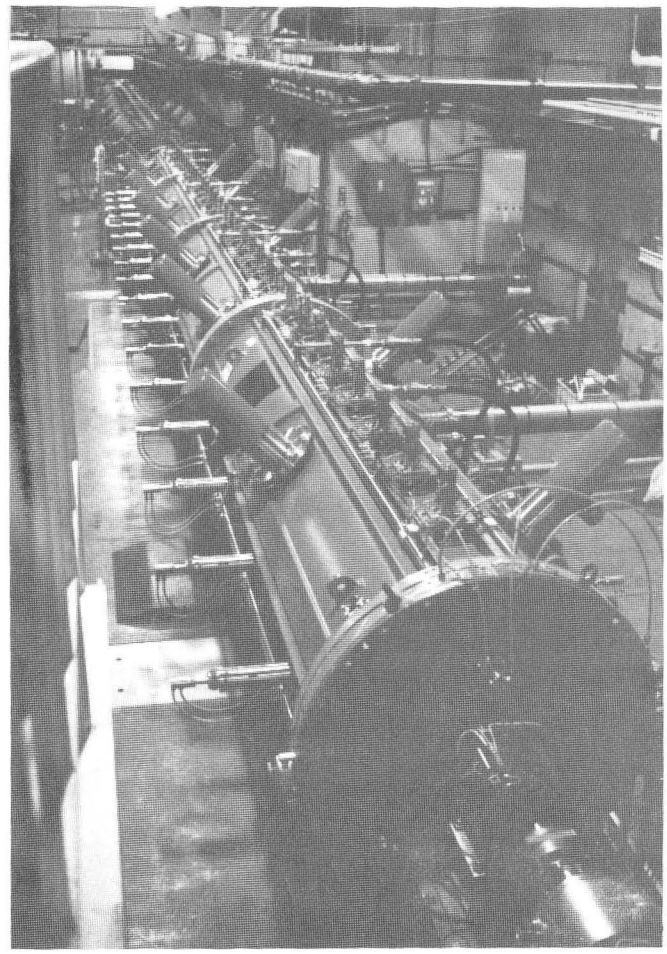

Fig. 2 Injector Alvarez linear accelerator seen from the 40 MeV end.

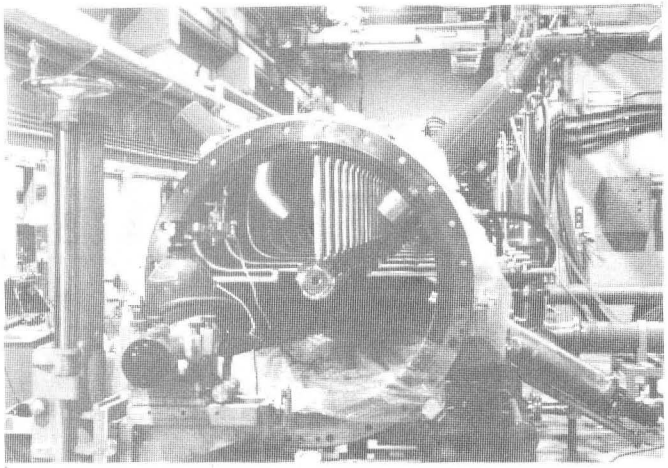

Fig. 3 New Alvarez cavity is being aligned.

the linac is shown in Fig. 1.

As a flash lamp-pumped dye laser was developed[6], the optically pumped polarized H^- source delivered 50 μA beam with a pulse duration of 70 μS at 750 keV. A train of 9 pulses of the polarized H^- and that of 41 pulses of ordinary H^- are sometimes accelerated successively in the linac and also in the booster in one main ring cycle of 2.5 S.

New Alvarez Linac Cavity

The new Alvarez linac cavity is 13 m long with an inside diameter of 0.9 m. Its main parameters are already reported[2,3,4]. It is equipped with post couplers and permanent quadrupole magnets. To shorten the shutdown of the proton synchrotron complex, the cavity was assembled in a separate room in advance. Cold test of its rf characteristics and tuning of post couplers and tuners were completed there[7]. Then it was divided to four sections, moved to the site and assembled again as shown in Fig. 2. The four sections were connected with Helicoflex metal gaskets for both vacuum seal and good rf contacts.

The quadrupole magnets in the drift tubes were magnetized according to beam-optical calculation after all the drift tubes were aligned. The cavity is evacuated by seven 1000 ℓ/s ion pumps and the pressure is 1×10^{-7} Torr during beam acceleration. Two tuners out of fourteen ones were equipped with motors. Phase difference of the cavity field and the power source is detected and used to drive the tuners to adjust the resonant frequency of the cavity to 201.07 MHz, that of the 20 MeV linac cavity.

RF System Modification

Two Thomson TH516 amplifiers had excited the 20 MeV single cavity Alvarez linac with two-feed system. The excitation power of the cavity was about 1 MW, whereas the beam power was 2.6 ∿ 2.8 MW for proton beams of 130 ∿ 140 mA. As the H^- current was expected to be 10 mA, the beam power would reduce to 0.2 MW. Thus the high power system was modified so that one power amplifier was separated from the 20 MeV cavity and connected to the new cavity. The energy gain of the new cavity was determined to be 20 MeV to avoid thorough modification of the power supplies. The two-feed system is applied to both cavities, ie, each output rf of about 1.2 MW is divided by a Tee power splitter, then each divided power passes through a circulator and is fed to the cavity with a loop coupler at 1/4 or 3/4 along the cavity. The forward and reflected rf powers to and from one coupler of the new cavity is shown in Fig. 4. The output power is modulated twice in a pulse, to accelerate building up the field in the cavity and to compensate the beam loading by modulating the driving power to the TH516 amplifier (Fig. 5). No beam loading compensation is required for the polarized beam. Figure 6 shows the field in the new cavity with the beam pulse. After the modification

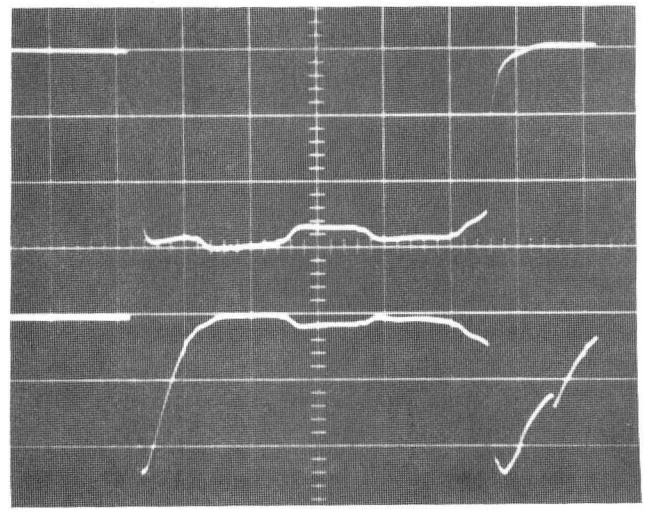

Fig. 4 Forward (upper) and reflected (lower) rf to and from one rf coupler of the new cavity. X: 50 μS/div.

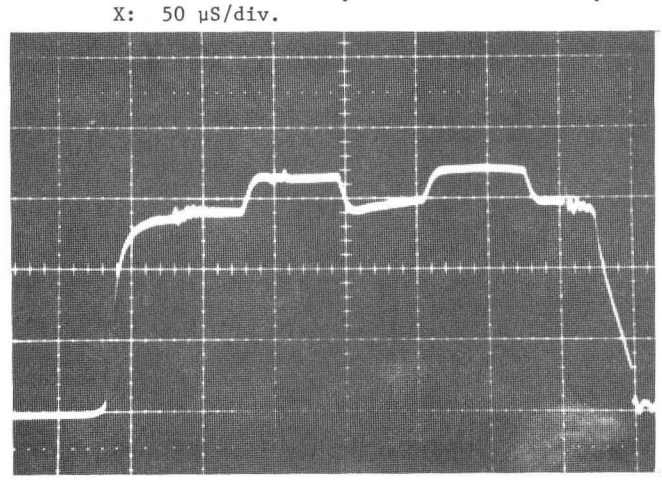

Fig. 5 Driving power of TH516. Modulated for fast build up and beam loading compensation. X: 50 μS/div.

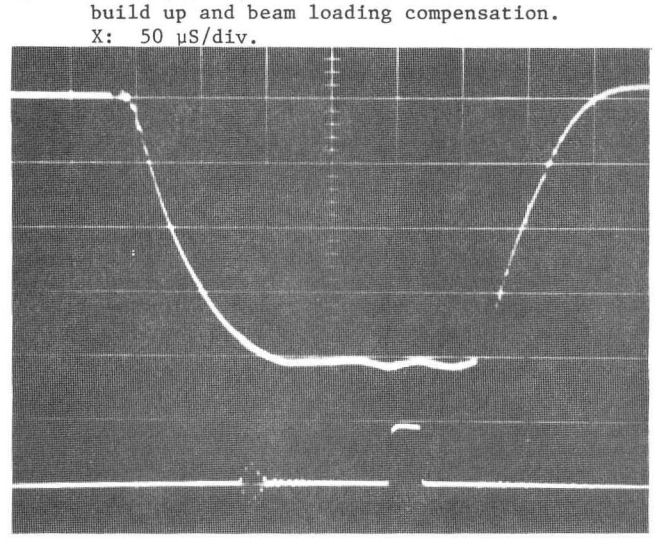

Fig. 6 Cavity field and 10 mA beam pulse. X: 50 μS/div.

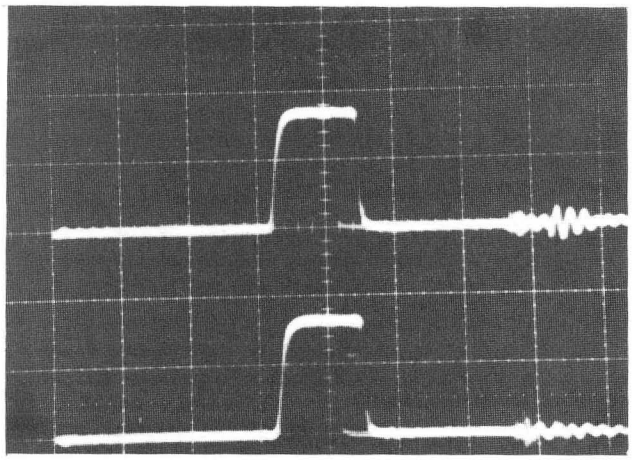

Fig. 7 20 MeV (upper) and 40 MeV (lower) H^- beams. X: 20 μS/div, Y: 5 mA/div.

of the rf system and its operation, anode loss of the TH516 reduced, but lives of the 5G57P or ITT1257 thyratrons in the anode modulators might be shortened.

Debuncher

A single-cell re-entrant cavity with nose cones was made and installed 10 m downstream the new cavity as a debuncher. Its gap length and beam-hole diameter are 12 cm and 7 cm respectively. It was made by copper plating of about 100 μm on steel vessels as the process of the linac cavity fabrication. Its Q_0 is 40,400 without tuners, 84 % of the calculated value.

Operation

On November 1, 1985, the first 40 MeV H^- beam was accelerated immediately after injection to the new cavity. Transmission of the beam is excellent as shown in Fig. 7. The beam pulse duration can be extended up to 100 μS at the request of the ring intensities. Tuning of H^- charge-exchange injection and other machine studies began on November 6. Patients were treated by proton beam on November 20 and high energy physicists received 12 GeV protons on the next day. Since then the accelerator complex is running as before the long shutdown. The linac beam is ordinarily 8 ∿ 10 mA for H^-, and 12 μA with 58 % polarization at 20 MeV is attained for polarized H^-. Two linac cavities are separated by 2.5 m to install a polarimeter, current and profile monitors. Four quadrupole magnets guide the 20 MeV beams. Beam emittances are being measured at 20 MeV and at 40 MeV with a set of a multi-wire profile monitor and a quadrupole magnet. A preliminary normalized emittance in the vertical plane is 4 πmm mrad at 40 MeV.

Momentum spread of the 40 MeV beam can be monitored during operation by sampling a beam pulse in one main ring cycle and transporting it to a magnetic analyser which was just after the debuncher and a bending magnet. Figures 8 and 9 show the momentum spectra of the 40 MeV beams with and without the debuncher. They are typically 0.7 % FWHM without the debuncher and compressed to about a half of it in routine operation to increase capture of the booster ring.

The highest intensities of the 500 MeV booster synchrotron beam are 6.7×10^{11} ppp for 20 MeV protons, 9.1×10^{11} ppp for 20 MeV H^- and 1.55×10^{12} ppp for 40 MeV H^- ions.

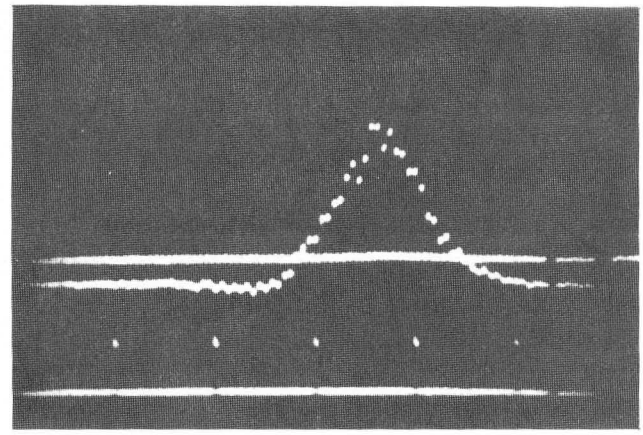

Fig. 8 Momentum spectrum of 40 MeV H^- beam, 0.7 % FWHM without debuncher. 16 bins are included in adjacent markers and correspond to $\Delta p/p = 0.6$ %.

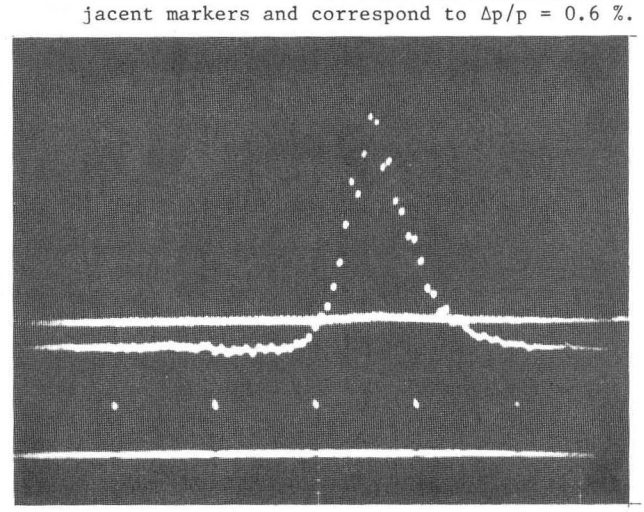

Fig. 9 Momentum spread is compressed by debuncher to 0.4 % FWHM.

Acknowledgements

The authors would like to express their gratitude to Dr. T. Nishikawa, the Director General of KEK for his support and encouragement. They are indebted to Mr. S. Emi, Mr. Y. Iino and their groups of Mitsubishi Heavy Industries, Ltd. for fabrication and installation of the cavities.

References

1. S. Fukumoto, Amelioration of KEK 12 GeV proton synchrotron - H^- injection and linac upgrading, submitted to Accelerator News of Particle Accelerators.
2. S. Fukumoto et al., Proc. 1984 Linear Accelerator Conf., 135 (1984).
3. S. Fukumoto et al., Proc. 5th Symposium on Accelerator Sci. and Tech., 53 (1984).
4. S. Fukumoto et al., IEEE Trans. Nucl. Sci., NS-32, 3181 (1985).
5. A. Takagi et al., ibid. 1982.
6. Y. Mori et al., Report on optical pumping of sodium vapor with a pulsed dye laser, KEK Report 86-2.
7. T. Kato et al., RF tuning of the KEK 40 MeV proton linac with post couplers, Proc. this conference.