DESIGN OF 40 MeV ALVAREZ LINAC

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## ABSTRACT

The second linac, which accelerates protons or $H^-$ ions from 20 MeV to 40 MeV is designed. It is 13 m long, 0.90 m in diameter and has 35 cells. It is equipped with ALNICO permanent quadrupole magnets in drift tubes instead of electromagnets of the first tank. Post couplers are also to be installed together with two motor-driven tuners to adjust the resonant frequency of the second tank without disturbing the accelerating field distribution. One of the high power RF systems of the first linac is to be used for the second tank. A 20 MeV beam transport is designed. Vacuum system is being examined.

## INTRODUCTION

Higher intensity is still demanded strongly by users for KEK 12 GeV Proton Synchrotron. On the other hand, however, capture efficiency decreases for higher intensity beams at the injection into 500 MeV Booster, and residual activity might be serious for maintenance of the accelerator in near future. A charge-exchange injection system[1] can cure the problem. Restriction denoted by Liouville's thorem does not work in the system, because protons are "produced" in a stripping foil on the stable orbit of a synchrotron. Ideally, there is no limitation in accumulating protons in a ring. Practically, however, the stripping foil must be thick enough to produce protons from $H^-$ ions effectively, and thin enough to prevent serious energy loss and multiple scattering during injection. The efficiency of $H^-$ to proton conversion depends on the $H^-$ energy as shown in Fig. 1. The energy loss decreases with in-

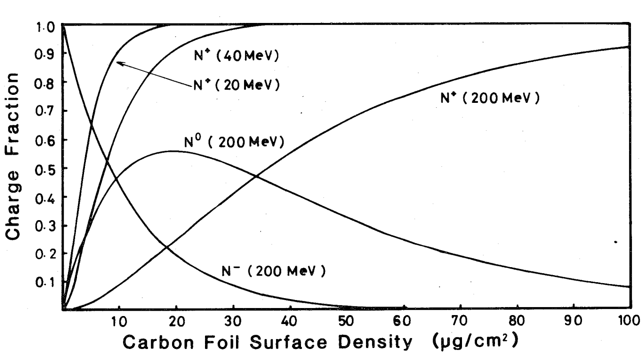


Fig. 1 Carbon foil thickness and H to proton conversion efficiencies for 20, 40 and 200 MeV $H^-$ ions.

crease of the $H^-$ energy, for example, a loss of 2.8 keV by a 120 $\mu g/cm^2$ thick carbon foil at 20 MeV decreases to 1.6 keV at 40 MeV. The multiple scattering decreases also as shown in Fig. 2. Thus the energy of the $H^-$ and the available stripping foil determine the injection loss and the maximum accumulated intensity.

The charge-exchange injection system was applied to a synchrotron at ANL[2], then adopted at FNAL[3], BNL[4] and RAL[5]. It was tried at KEK with 20 MeV $H^-$ ions[6], the lowest injection energy so far. As it is very difficult to get a sufficiently thin but tough foil for 20 MeV beams, a higher $H^-$ energy is preferable, so that upgrading of the injection energy is examined[7].

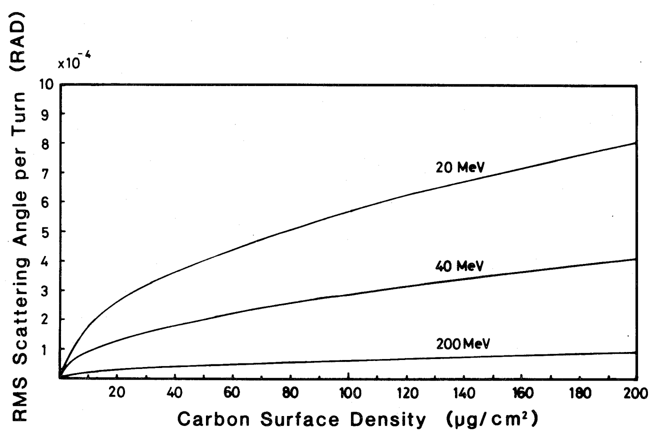


Fig. 2 Carbon foil thickness and multiple scattering for 20, 40 and 200 MeV protons.

## RESTRICTION TO LINAC EXTENSION

There is a space for another linac tank between the 20 MeV linac tank and the 500 MeV booster. However, TRISTAN tunnel is going through under the area and it is hardly possible to build a new building for an additional RF system. Moreover, the present RF room is so crowded that extra equipments, such as power supplies for quadrupole magnets in new drift tubes, can not be installed.

To eliminate the sophisticated pulsed power supplies, permanent quadrupole magnets are considered. Rare earth magnets have been recently taken into account for the purpose at some laboratories because of their excellent magnetic properties. It is, however, difficult to magnetize or demagnetize them in drift tubes. As protons or $H^-$ ions are already accelerated to 20 MeV, no extremely high magnetic field is necessary in the second tank. An ALNICO-9 quadrupole magnet can yield field gradient of 2.0 - 2.05 kG/cm for 34 mm aperture. It can be magnetized and demagnetized in a drift tube, so that the electron beam welding may be applied to fabrication of the drift tubes without special precaution. Then an ALNICO magnet was made and installed to the last drift tube of the first tank. No appreciable change in the 20 MeV beam was detected for about one year operation. Further studies are in progress[8].

## RF SYSTEM

The 20 MeV tank has been excited by two TH 516 RF systems. Its cavity loss (= exciting power) is 1 MW, whereas the beam power is, for example, 2.6 MW for 130 mA. Therefore, an RF power of 1 MW is fed for 300 μS to the tank and 3.6 MW should be supplied at the end of each pulse synchronized to the proton beam. The beam pulse duration is about 5 μS. For suitable beam loading compensation, the RF power is fed at two points, 1/4 and 3/4 along the tank.

Proton beam current is limited not by the duoplasmatron ion source but by space charge in the high gradient accelerating column in the KEK preinjector. However, as mechanism of $H^-$ production is much more

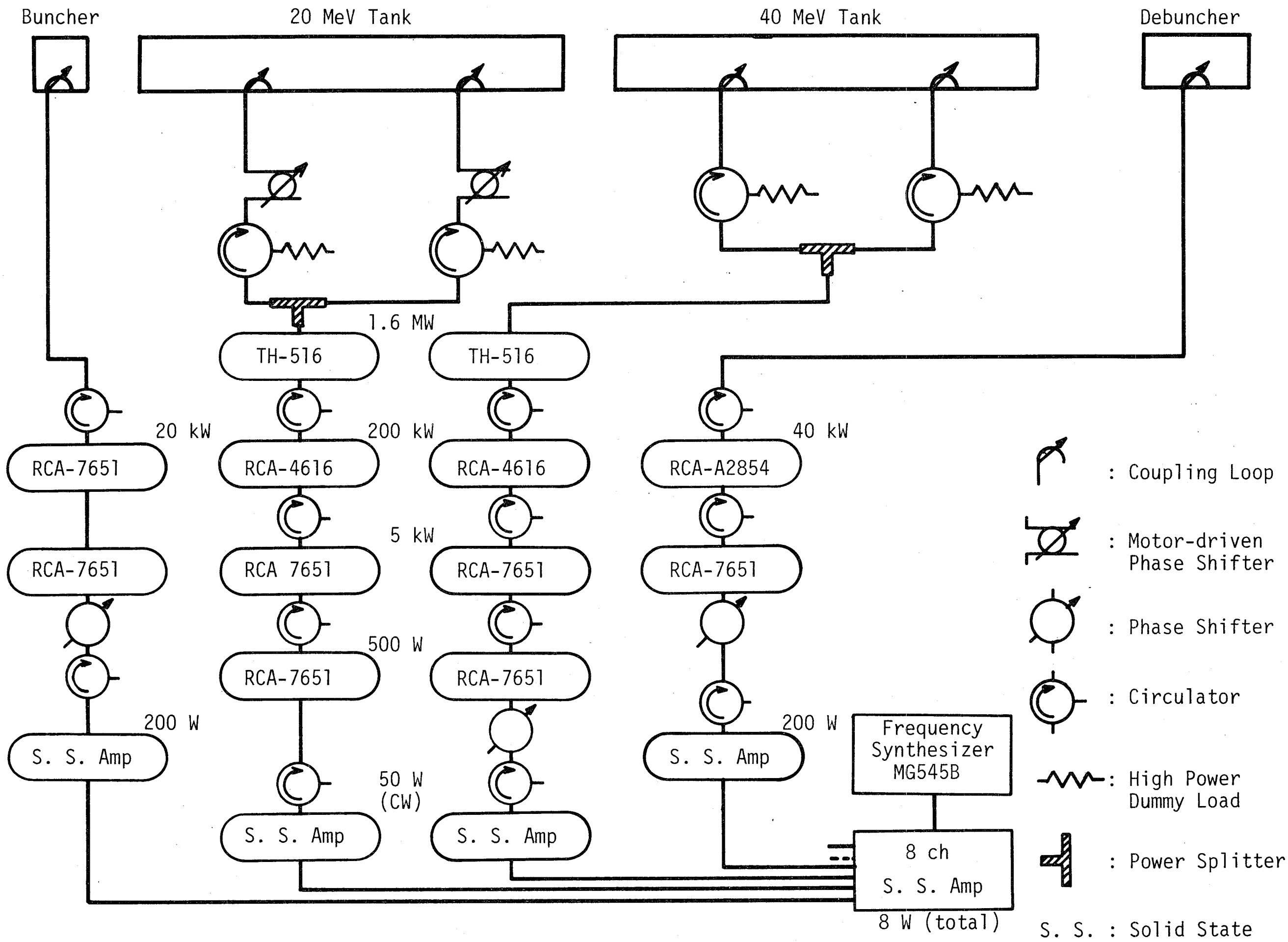


Fig. 3 Block diagram of modified RF system.

complicated than that of protons, $H^-$ intensities from ion sources are much lower than that of protons. At test run in 1983[9], 20 mA $H^-$, produced by a multi-cusp ion source, was injected to the linac, 8.5 mA was accelerated to 20 MeV and transported to the Faraday cup through the HEBT. A 30 mA $H^-$ linac beam is a goal of present ion source development. The beam power is only 0.6 MW even if it is attained. Although the beam pulse duration is extended from 5 μS to 100 μS, the sum of the cavity loss and the beam power is 1.6 MW for the 20 MeV linac. This is less than a half of the present maximum peak power. Thus the 20 MeV tank can be fed by one TH 516 RF system and the other can be diverted to the second tank.

This imposes the maximum energy to the second tank. As its effective shunt impedance is not so different from that of the first one, its energy gain is about 20 MeV as shown below.

As a high power circulator was developed and has worked well between the TH 516 output and the tank[10], modification of the RF system above mentioned is rather simple and straight forward as shown in Fig. 3. The output RF power of the TH 516 is divided by a power splitter instead of a complicated 4 arm hybrid because little reflected RF power goes back to the splitter from the tank. It has three arms, one for input and two for output. Impedance transformation is made by a quarterwave section of 70.7 Ω in each output arm. When two output arms are terminated with dummy loads, a VSWR of 1.03 is obtained at the input. No problem occurred for an input power of up to 2 MW. Thus no change is necessary at the output coupler of the TH 516 cavity as well as the RF coupler to the tank. These are already established technically. In principle, no phase shifter is required between the TH 516 output and the splitter, because the load is always matched at the TH 516 output.

A multi-cavity linac has a problem of tuning their resonant frequencies each other. So far, the master oscillator was tuned to the 20 MeV tank at KEK. It is preferred that the second tank should be tuned to the first one. Two motor-driven frequency tuners are being designed. Their diameter and stroke are 11.5 cm and ± 9 cm. Expected frequency shift is ± 1.4 kHz per ± 1 cm for each tuner. They have a conventional coaxial choke structure with carbon contactors. One is in a feedback loop and the other is fixed as a standby. To keep the accelerating field distribution constant while the motor-driven tuner adjusts the resonance of the second tank, post couplers are to be installed. Their merits were already confirmed in a model cavity[11].

## 40 MeV TANK

Table 1 shows main parameters of the second linac tank which accelerates protons or $H^-$ ions from 20 MeV to 40 MeV. Computer codes used are SUPERFISH and PARMILA. Its average accelerating field is flat and somewhat higher than that of the 20 MeV tank. The new tank will be assembled in another room, tested and adjusted with a low RF power, then partly disassembled and moved to the site.

## VACUUM SYSTEM

Cross sections of single electron loss by a $H^-$ ion in various gases are much larger than cross sections of single electron capure by a protons in the same gases. It means that higher vacuum is needed for $H^-$ acceleration than proton's. Cross sections of $H^-$ to $H^\circ$ at 20

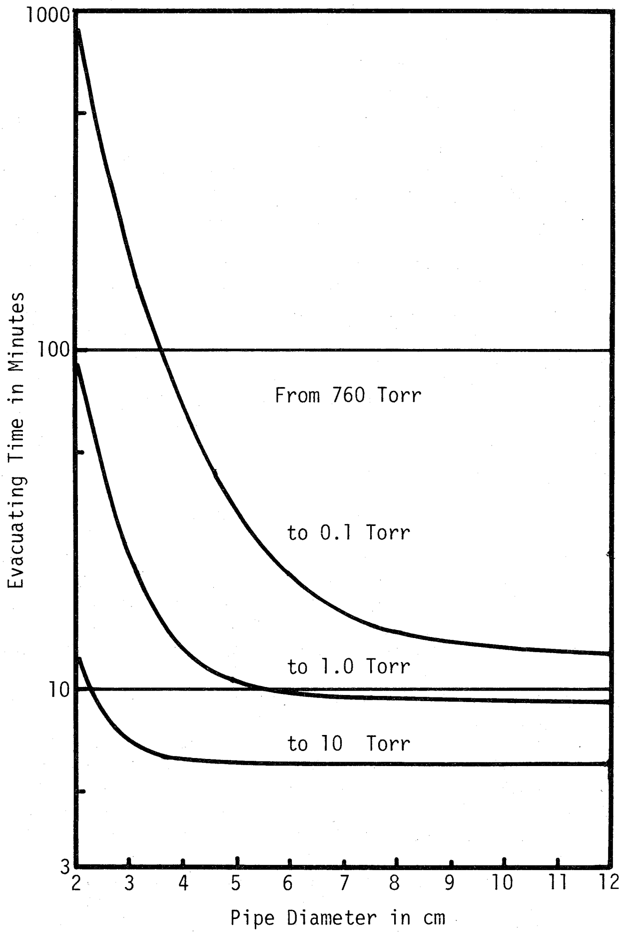


Fig. 4 Pipe diameter and evacuating time of the 40 MeV tank of 8.2 $m^3$. It is assumed that the tank is connected to the rough vacuum system of 6000 ℓ/S with a 10 m long pipe.

MeV are extraporated from the data[11]. They are 1.2 x $10^{-18}$ $cm^2$ in $H_2$ and about 1.8 x $10^{-17}$ $cm^2$ in $N_2$ and $O_2$. $H_2$ may be predominant in residual gas of the tank. However, a cross section of $1.8 \times 10^{-17}$ $cm^2$ is chosen to estimate a necessary vacuum. When 0.1 % loss of $H^-$ ions is assumed, the pressure should be $1.2 \times 10^{-6}$ Torr in the 13 m long tank. The operating pressure of the first tank has been $2 \sim 3 \times 10^{-7}$ Torr. If the outgas rate is equal, then a pressure of less than $3.9 \times 10^{-7}$ Torr will be achieved by a pumping speed of 7000 ℓ/S in the second tank.

The main pump is seven 1000 ℓ/S ion pumps. A 500 ℓ/S turbomolecular pump is prepared for starting the ion pumps. The rough vacuum system of the 20 MeV tank, which consists of two 3000 ℓ/min rotary pumps, will be utilized for the second tank of 8.2 $m^3$ too. The tank is to be evacuated from the atmospheric pressure to 0.1 Torr, at which the turbomolecular pump can work, in about 30 minutes through a pipe of 10 m long and 5 cm in diameter (Fig. 4).

## 20 MeV BEAM TRANSPORT

A 20 MeV beam transport is being designed. It is 2.5 m long and will be equipped with four quadrupole magnets, a toroidal current monitor, a profile monitor, a polarimeter and a bunch monitor. The design parameters of the magnets are, 52 mm bore radius, 150 mm long and 9.6 T/m field gradient. The middle part of the transport is reserved for a bending magnet, which might inject ions from a future preaccelerator to the second tank. The current monitor should be sensitive both to ordinary beam of 10 mA and to polarized beam of several μA. Beam emittance will be measured with a set of quadrupole magnet and the profile monitor.

Table 1

Main parameters of 40 MeV linac tank

| | |
|---|---|
| Energy | 20.60 - 40.46 MeV |
| Frequency | 201.070 MHz |
| $\beta$ | 0.2062 - 0.2846 |
| $\beta\lambda$ | 0.3091 - 0.4226 m |
| $\beta^2\gamma^3$ | 0.04537 - 0.09190 |
| Tank | Steel, copper plated |
| Length | 12.84 m |
| Inside diameter | 0.90 m |
| Number of cells | 35 |
| Drift tube | Stainless stell, copper plated |
| Length | 23.32 - 28.79 cm |
| Outer diameter | 16 cm |
| Bore diameter | 3 cm |
| Stem diameter | 3.6 cm |
| Quadrupole magnet | Permanent (ALNICO-9) |
| Aperture | 3.4 cm |
| Length | 16 cm |
| Outer diameter | 13.5 cm |
| Field gradient | 2.0 - 2.05 kG/cm |
| Synchronous phase | - 30° |
| Average axial field | 2.2 MV/m |
| Shunt impedance | 70.33 - 68.71 MΩ/m |
| Transit time factor | 0.8699 - 0.8143 |
| Effective shunt impedance | 53.22 - 45.56 MΩ/m |
| Excitation power | 1.078 MW |
| Beam power (for 30 mA) | 0.596 MW |
| Total RF power | 1.674 MW |
| RF coupling | Loop, two feeds |
| Stabilizer | Post couplers |
| Post diameter | 3.0 cm |
| Vacuum system | Ion pump (1000 ℓ/S × 7) |
| | Turbomolecular pump ( 500 ℓ/S × 2) |
| Temperature regulation | ± 0.1°C |

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