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1 GeV リニアック検討資料
1 GeV LINAC DESIGN NOTE

題目 (TITLE) PROTON LINEAR ACCELERATOR DEVELOPMENT FOR THE JAPANESE HADRON PROJECT

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概要 (ABSTRACT)

Present status of development of the 1 GeV proton linac for the Japanese Hadron Project is reported. Our program includes development of a high peak current and low emittance H^- ion source, a long RFQ linac, a drift-tube linac with high gradient SmCo and NdFe permanent quadrupole magnets, and a high-β linac that can accelerate the high beam current stably and efficiently. Development of reliable high power RF sources is crucial for stable operation of the linac.

KEY WORDS:

Ion source, RFQ, DTL, CCL, Magnet, Monitor, Beam Dynamics,
Transport, Vacuum, Cooling
Klystron, Low level rf, High power rf, Modulator
Control, Operation, Radiation, Others

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KEK Preprint 90- 15
April 1990
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PROTON LINEAR ACCELERATOR DEVELOPMENT FOR THE JAPANESE HADRON PROJECT

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Submitted to the 18th INS International Symposium on Physics with High-Intensity Hadron Accelerators, March 14-16, 1990, Tokyo, Japan.

National Laboratory for High Energy Physics, 1990

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ABSTRACT

Present status of development of the 1 GeV proton linac for the Japanese Hadron Project is reported. Our program includes development of a high peak current and low emittance H^- ion source, a long RFQ linac, a drift-tube linac with high gradient SmCo and NdFe permanent quadrupole magnets, and a high-β linac that can accelerate the high beam current stably and efficiently. Development of reliable high power RF sources is crucial for stable operation of the linac.

1. INTRDUCTION

The 1 GeV proton linac[1-4] with a total length of about 500 m will be constructed to inject negative hydrogen beams to the ring accelerator for the Japanese Hadron Project (JHP). The required average current is higher than 200 μA with a repetition rate of 50 Hz. The designed linac is composed of a volume-production type H^- ion source, a 432 MHz RFQ linac (3MeV), a 432 MHz drift-tube linac (148MeV), and a 1296 MHz high-β linac (1GeV). Detailed design parameters of the linac are presented in Refs. 1-4 together with rationale for the chosen parameters. Further optimization of the design of a highly stable machine with easy maintenance and operation requires technical data and experience that can be accumulated only through construction and operation of major components of the machine. Therefore we have been mainly

engaged in technical development of the major components. The present status of the developments is reported below.

2. ION SOURCE

It is expected that a volume-production type H^- ion source can produce a high intensity H^- beam with low emittance. Thus, a test H^- ion source[5] was constructed to study the mechanism of the volume production. We have obtained the beam current density of 10 mA/cm^2 with the anode hole diameter of 7.5 mmϕ, where the normalized 90 % emittance was 0.5 π mm·mrad. It is interesting to note that introduction of the cesium vapor increased the current density of the volume source by a factor of more than four. Further development of the volume source is under way.

3. RFQ LINAC

A 432-MHz RFQ linac will accelerate the beam from 50 keV to 3 MeV. A design study for the beam dynamics has indicated that its vane length amounts to 2.7 m (about four times of the wave length).[6] However it is difficult to fabricate a conventional four-vane RFQ linac that is long compared with the wavelength for the following reasons. First, a slight strucure imperfection easily gives rise to field tilt in the long tank. Second, an RFQ linac consists of four cavities separated by the four vanes and the four cavities are coupled very weakly. Thus, a slight azimuthal asymmetry gives rise to the non-uniform distribution of the stored energy among the four cavities. (The effect is closely related with the mixing of the dipole modes to the quadrupole mode.) As a result very severe specification is required for the structural dimension. It has been believed that the specification becomes the more severe for the longer RFQ. On the other hand the accurate machining naturally becomes the more difficult for the longer vanes.

Neither of a four-vane RFQ with vane coupling rings nor four-rod RFQ that may cure the above problems can easily match the present requirements of the high duty and high frequency. On the other hand, the above diffiulty with the four-vane RFQ was not understood quantitatively enough to make a final decision for a choice of the RFQ parameters. Thus a cold model[7] was fabricated to develop a machining method that can match the severe specification and to study the effect of the dipole mode. Silver was added (0.2 percent) to oxygen-free copper in order to strengthen the material mechanically.

The distributions of squares of the magnetic fields in the four cavities are shown in Fig.1. It is seen that the distributions are uniform within ± 10%. (The field uniformity is within ± 5 %.) Here, the geometries of the vane ends and the end plates were adjusted to obtain this uniformity.

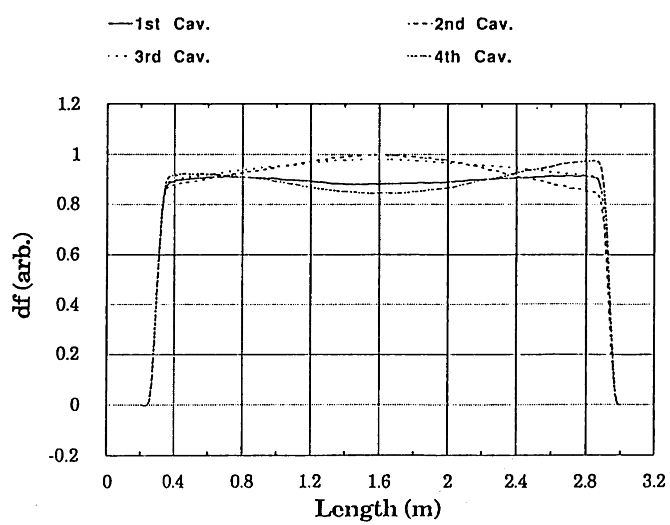

Fig.1 Distribution of the square of the magnetic fields in the four cavities measured by the bead method.

The measured dispersion curves of the dipole and quadrupole modes shown in Fig. 2 indicate that the accelerating quadrupole mode (TE210) is located just at the middle of the dipole modes (TE111, TE112) and fairly separated from the dipole modes resulting in the little mixing of the dipole modes. Also the good

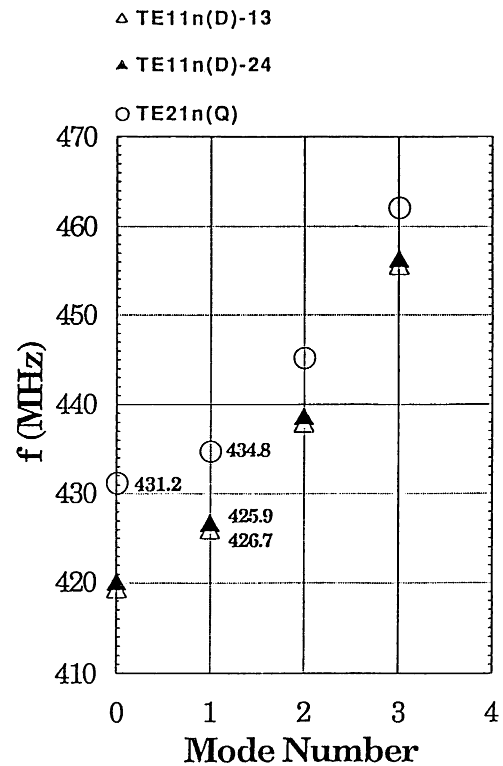

Fig.2 The Measured dispersion curves of the quadrupole and dipole modes in the present RFQ.

machining accuracy is seen from the small breaking of the degeneracy of the dipole modes. It is noted that more mixing of the dipole modes is expected for the shorter RFQ, where the TE210 mode becomes closer to the TE111. In other words the longer RFQ will be easier to fabricate than the shorter one in this region of the length.

Since the 2.7 m four-vane RFQ becomes promising from the present study, we will continue development including the study of the effect of the matching section, vane modulation and input coupler to obtain the necessary data for a final design of the high power model of the RFQ.

4. DRIFT-TUBE LINAC

For the 432-MHz drift-tube linac (DTL)[8,9] permanent quadrupole magnets, such as SmCo and NdFe,[10] will be used, since they require neither of electrical wiring nor wate-cooling and become maintenace-free. However, it is difficult to seal drift tubes containing these permanent magnets, since the magnets cannot stand high temperature during silver brazing; also, the strong magnetic field of the permanent magnets bends the electron beam for the electron-beam welding (EBW).

Thus, an electroforming method[11] has been developed to seal the drift tubes from vacuum, since electroplating is possible at room temperature. A drift tube and NdFe permanent quadrupole magnet were assembled and successfully electroformed. The EBW of drift tubes with the permanent magnets was also successful by shielding the electron beam from the strong magnetic field. We are improving these two techniques for the mass production of the drift tubes.

A cold model (3 to 8 MeV, 35 cells, 2.6 m) made of aluminum for half of the first DTL tank has been fabricated to obtain the necesssary data for the final detailed design. Without post couplers, field flatness within 1.2 percent was obtained throughout the tank.

Here, it is noted that the β dependence of the effect of stems was corrected by adjusting the gap lengths between the drift tubes in order to make the frequencies of all cells uniform. With post couplers, the field tilt intentionally produced by frequency tuners could be eliminated by adjusting the positions of the post couplers.[12]

5. HIGH-β LINAC

The standing wave coupled-cell linac operated at $\pi/2$ mode will be used[13] for the high-β linac rather than $2\pi/3$ mode. Among the various possible candidates for the high-β structure, manufacturing techniques of an alternating perioodic structure(APS)[14] or an on-axis coupled structure (OCS) and side-coupled structure (SCS)[15] have been developed[2,16]. The axial symmetry of the APS has potential advantages of mechanical simplicity and beam stability over the axially asymmetric SCS. However, the shunt impedance of the APS is much lower than that of the SCS. In this context the annular-coupled structure (ACS)[17] became attractive, owing to its symmetric structure.

Thus, we have extensively studied the annular coupled structure (ACS) both theoreticlly and empirically. Although it was reported[18] that a serious depression of a quality factor was arising from the excitation of a coupling-cell quadrupole mode, we succeeded in improving the shunt impedance of the ACS with four coupling slots.[19-21] The measured coupling-factor dependence of the quality factor is shown in Fig. 3 as divided by that of a single cell without coupling slots. Also the dipole and quadrupole modes in the coupling cells are situated at higher frequencies than the passband of the accelerating mode. As a result the ACS becomes one of the most promising structures for the JHP proton linac. Thus we are fabricating an ACS cavity with two 5-cell tanks connected by a 5-cell bridge coupler,[22] that is to be tested with a full RF power. The cells of the cavity being fabricated are shown in Fig.4.

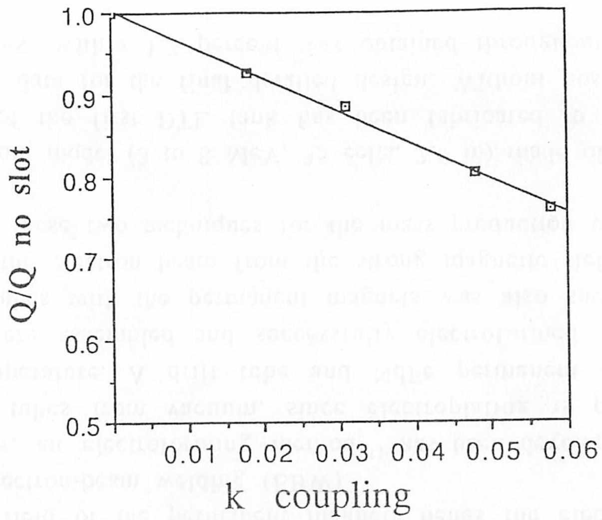

Fig.3 Measured coupling-factor dependence of the Q value of the four-slot ACS divided by that of a single cell without slots. The 5 % coupling will be used.

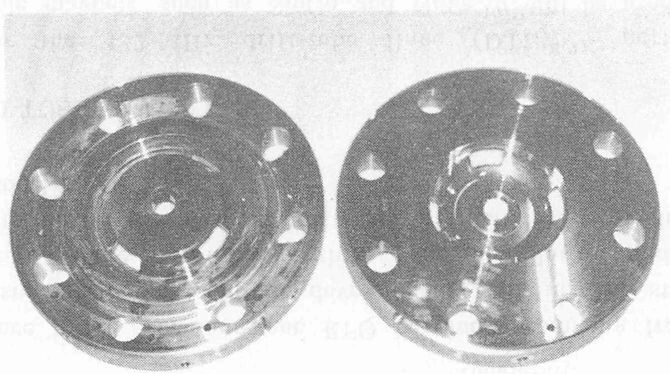

Fig.4 Unit cells of the ACS cavity.

6. RF POWER SOURCE

Since one of the most difficult components of the proton linac will be a high power rf source(several MW) with a long pulse length (600μs)[23-28], it is crucial to test the possibilty and performance of the rf source for success of the project. Thus a high-power test station was prepared as shown in Fig.5. A line-type modulator with an output power of 15 MW has been constructed. The line-type was chosen for its excellent stability with a de-Qing circuit and its high efficiency. At present, the pulse length of its pulse-forming network (PFN) is 400 μs. An L-band 5 MW klystron (THOMSON TH2104A) with a pulse transformer (step-up ratio of seven) were installed to the station. A test of a full system has been successfully accomplished to a full power with a repetition rate of 30 Hz.[29-32] A test with the full repetition rate of 50 Hz is under way. The pulse of the modulator will be lengthened up to the full length in the next fiscal year.

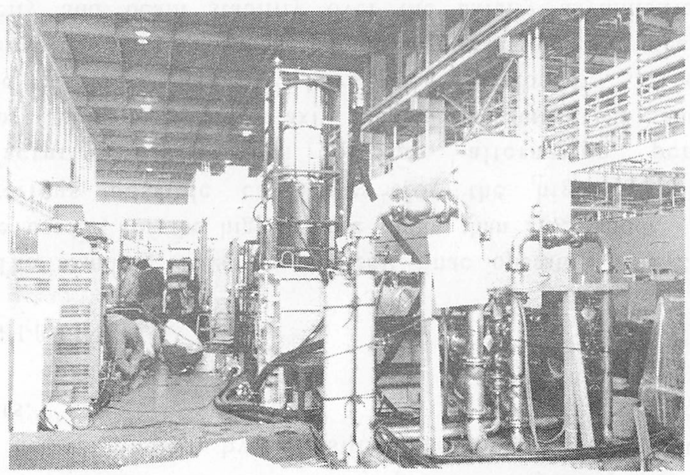

Fig.5 The high power test station showing the 5 MW klystron and the line type modulator.

REFERENCES

1) Y. Yamazaki et al., Proc. Advanced Hadron Facility Accelerator Design Workshop, Los Alamos 1988, LA11432C, p.80; KEK preprint 87-159.
2) Y. Yamazaki et al., 1988 Linear Accel. Conf. Proc., CEBAF 1988, CEBAF-Report-89-001, p.79.
3) Y. Yamazaki, T. Kato and M. Kihara, Proc. 13th Linear Accelerator Meeting in Japan, 242 (1988).
4) "Report of the Design Study on the Proton Linac of the Japanese Hadron Project [I]", JHP-10, KEK Internal 88-8 (in Japanese)..
5) Y. Mori, "Intense Negative Ion Sources at KEK." Submitted to 5th International Symposium on Production and Neutralization of Negative Ions and Beams, BNL, 1989.
6) N. Tokuda, S. Arai and N. Ueda, Proc. 13th Linear Accelerator Meeting in Japan, 248 (1988).
7) A. Ueno et al., Proc. 14th Linear Accelerator Meeting in Japan, 90 (1989) (in Japanese).
8) T. Kato et al., Proc. 13th Linear Accelerator Meeting in Japan, 257 (1988) (in Japanese).
9) F. Naito et al., Proc. 14th Linear Accelerator Meeting in Japan, 86 (1989) (in Japanese).
10) E. Takasaki et al., Proc. 14th Linear Accelerator Meeting in Japan, 355 (1989) (in Japanese).
11) Y. Yamazaki et al., "Development of the 1 GeV Proton Linac for the Japanese Hadron Facility", submitted to 1989 Particle Accelerator Conf., Chicago.
12) F. Naito et al., KEK Preprint 89-115.
13) Y. Yamazaki, KEK Preprint 89-122.
14) T. Nishikawa S. Giordano, and D. Carter, Rev. Sci. Instr. 37, 652 (1966).
15) E. A. Knapp, B. C. Knapp, and J. M. Potter, Rev. Sci. Instr. 39, 979 (1968).
16) T. Kageyama et al., Proc. 13th Linear Accelerator Meeting in Japan, 254 (1988).
17) V. G. Andreev et al., Proc. 1972 Proton Linac Conf., 114 (1972).
18) R. K. Cooper et al., Preprint LA-UR-83-95 (Los Alamos National Laboratory)
19) T. Kageyama, Y. Yamazaki and K. Yoshino, KEK Preprint 89-94.
20) K. Yoshino et al., Proc. 14th Linear Accelerator Meeting in Japan, 79 (1989) (in Japanese).
21) T. Kageyama, Y. Yamazaki and K. Yoshino, ibid., 82 (1989).
22) Y. Morozumi and Y. Yamazaki, ibid., 202 (1989).
23) S. Anami et al., Proc. 13th Linear Accelerator Meeting in Japan, 260 (1988).
24) H. Hanaki et al., ibid., 266 (1988).(in Japanese)
25) H. Hanaki et al., 1988 Linear Accel. Conf. Proc., CEBAF 1988, CEBAF-Report-89-001, 571 (1988).
26) S. Anami et al., Proc. 14th linear Accelerator Meeting in Japan, 240 (1989) (in Japanese).
27) E. Takasaki et al., Proc. 13th Linear Accelerator Meeting in Japan, 263 (1988) (in Japanese).
28) S. Anami et al., "Design and Construction of a Long-Pulse Modulator", submitted to 1989 Particle Accelerator Conf., Chicago.
29) T. Takenaka et al., Proc. 14th Linear Accelerator Meeting in Japan, 54 (1989) (in Japanese).
30) K. Kudo et al., Proc. 14th Linear Accelerator Meeting in Japan, 281 (1989) (in Japanese).
31) M. Ono et al., "Development of L-Band High-Power RF Source for the Japanese Hadron Project Proton Linear Accelerator", submitted to the XIV International Conference on high Energy Accelerators, 1989, Japan.
32) T. Kubo et al., "Design and Construction of a Pulse Transformer for a Long Pulse klystron", submitted to the XIV International Conference on High Energy Accelerators, 1989, Japan.