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Conceptual Design of Compact HIF Driver by RF Linac with High Acceleration Rate

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Abstract

The Interdigital-H(IH) type linac is well known for its high shunt impedance at low and medium particle velocity. Therefore the IH type structure is possible high acceleration rate by same power. The IH linac cavity is able to generate 10 MV/m (effective acceleration voltage) with focusing particle by super conducting solenoid. We designed the compact HIF driver by the IH linac with high acceleration rate. The IH linacs can accelerate particles with a charge to mass ratio (q/A) greater than 1/250 from 0.3 MeV/amu up to 50 MeV/amu. The total effective length of the IH linac cavities is about 1250 m.

1. Introduction

Until now for the electric power plant of 1 GW, Heavy Ion Inertial Fusion (HIF) driver system was needed to the length of several km, even if it were RF linacs[1-3] or Induction linacs. In the case of Induction linac, we could not make the acceleration rate up because of the voltage limit of ferrite. And in the case of RF linac because of beam focus and wall loss of Alvarez type cavity, we could not make acceleration rate over about 2 MV/m. So that driver system of HIF is necessary the length of several km.

The LBL and LLNL group[4] in USA presented the plan of compact HIF driver in 1991. It was the type of Induction linac, the aim was to be compact of driver by combination of Induction linac and circular ring.

On the other hand, the progress of RF linac was shown in 1980's and 1990's. Especially the study of the IH linac was remarkable. In the IH type structure, it was proved that the shunt impedance was high in low and medium energy region, comparing to other linac structure. So it was possible to keep the acceleration rate to 10 MV/m in energy region of about 50 MeV/amu by using high shunt impedance. From consequence of it we chose the IH type to main linac of HIF driver, We found that the length would be 1~2 km. As we designed the conceptual design of compact driver for HIF, the following is the report.

2. High Shunt Impedance of IH Linac

2.1 IH type Linear Accelerator

In 1956, an interdigital H (IH) type linear accelerator was first proposed by J.P.Blewett[5]. As one of the various candidates for an injector of BNL proton synchrotron, AGS. In the survey of the BNL injector, Blewett indicated that the shunt impedance of the IH type structure is high at low and medium particle velocity. At higher

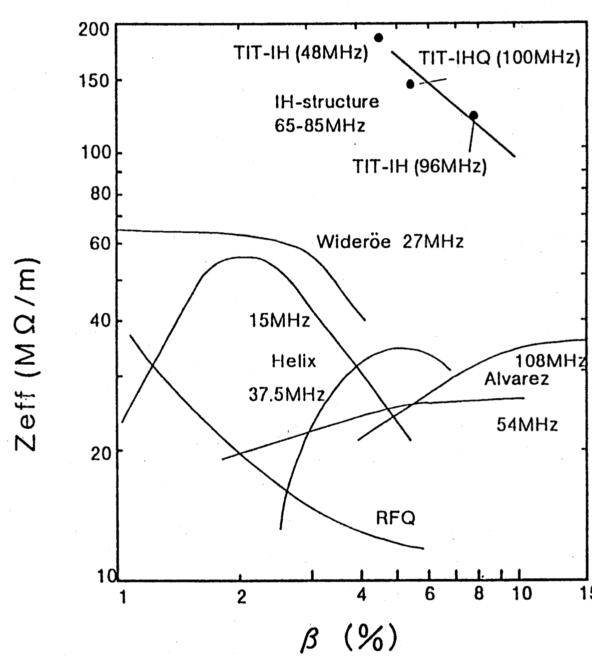

Fig.1 Effective Shunt Impedance of IH and other type.

energies, however, its shunt impedance falls rapidly. The further development of this structure has been abandoned in USA for a long time. The RF characteristics of an IH resonator, instead, have been extensively studied by Russian[6,7] and French [8,9]. According to their experimental results, the HI structure has the substantial advantages of small transverse dimensions and high shunt impedance especially at low velocity region ($\beta \leq 0.1$).

The small tank diameter gives relatively low Q-values of the resonator, and therefore, the RF excitation is very easy to handle. A simple mechanical structure of linac cavity is also one of the most attractive points of the IH resonator. This accelerating structure, therefore, is suitable for heavy ion accelerator.

The high shunt impedance has been realized in a post accelerator of the large Tandem Van de Graff accelerator in Munich[10-13]. The beam energy boosters for tandem accelerators have a relatively small energy gain in comparison with incident beam energy. r

Table 1 Measured Effective Shunt Inpedance and Cavity Parameters of IH Structure

Institute	Z_{eff} (MΩ/m)	D (m)	f (MHz)	L (m)	β_{av}	E_{out}/E_{in}	E_{in}-E_{out} (MeV/u)	C*
INS(3π-π) (1983)[14)	496	0.48	100	0.92	0.0121	10.7	0.015-0.16	0.652
TIT&TUM(1994)[23)	337	0.65	103	1.89	0.0360	15.5	0.1-1.55	1.43
GSI (1991)[24)	320	0.63	108	3.55	0.0401	4.7	0.3-1.4	1.57
TIT-1 (1986)[16)	179	1.4	48	7.0	0.0470	10.0	0.24-2.4	1.88
TIT-IHQ (1989)[18)	132	0.54	102	0.92	0.0534	2.50	0.82-2.0	2.23
TIT-2 (1987)[25)	130	0.76	96	3.0	0.0784	1.42	2.4-3.4	2.10
NBI-1 (1990)[12)	142	0.72	100	3.64	0.0803	1.54	2.4-3.7	2.45
TUM-1 (1982)[11)	150	1.0	78	5.0	0.0842	1.79	2.4-4.3	2.54
UT (1984)[13)	137	0.75	100	3.0	0.088	1.27	3.4-4.3	2.66
NBI-2 (1990)[12)	105	0.72	100	3.64	0.0955	1.32	3.7-4.9	2.57
TUM-2 (1990)[12)	150	0.5	157	3.0	0.1044	1.4	4.3-6.0	2.71

An IH structure having large energy gain as main accelerator was studied in INS university of Tokyo[14] and RLNR Tokyo Institute of Technology[15-19]. Figure 1 shows comparison of effective shunt impedance of the IH structure and of other acceleration structures. Table 1 shows linac parameters and measured effective shunt impedance of IH structure until now.

2.2 Effective Shunt Impedance of IH Structure

In order to obtain a rough estimation of a shunt impedance for the IH structure linac, let's consider the simplest case where the acceleration structure is approximated by a double ridged circular wave guide resonator. As suggested by J.Pottier[20] and other groups[10,21], the shunt impedance of the ridge wave guide is estimated as.

$$Z_s = C' \cdot \alpha \cdot \beta^{-2} \cdot D^3 \cdot f^{3.5}.$$

Where the symbols are Z_S: shunt impedance, f: operation frequency, D: diameter of cavity, β: synchronous particle velocity divided by light velocity c and α: correction factor du to the surface roughness.

The effective shunt impedance is given as follows.

$$Z_{eff} = C' \cdot \alpha \cdot T^2 \cdot \beta^{-2} \cdot D^3 \cdot f^{3.5}$$
$$= C \cdot \beta^{-2} \cdot D^3 \cdot f^{3.5} \quad ,$$

where T: transit time factor, C(ß): coefficient of effective shunt impedance for IH structure linac. C(ß) is displayed

$$C = Z_{eff} \cdot \beta^2 \cdot D^{-3} \cdot f^{-3.5}.$$

Figure 2 shows comparison of coefficient of effective shunt impedance (C) and particle velocity. The empirical coefficients are near the straight line as log-log plots as shown in Fig.2. If diametor of resonator cavity is estimated, the effective shunt impedance is expected various energy region by using the empirical line.

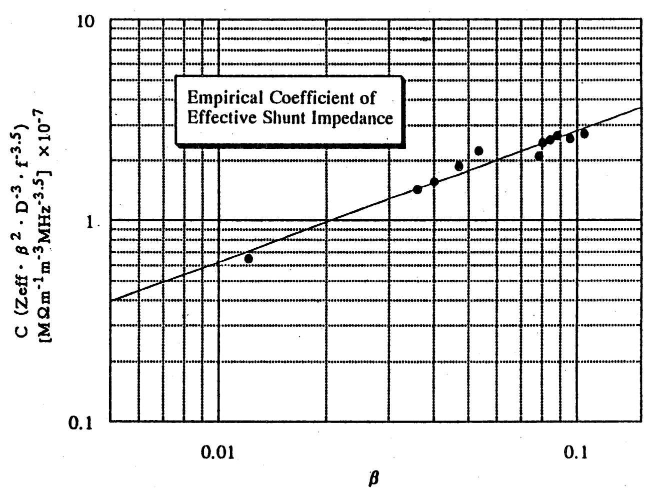

Fig.2 Comparison of Coefficient of Effective Shunt Impedance and Parrticle Velocity

3. Conceptual Design of Compact Driver by IH type Linac with High Acceleration Rate

First we examine main parameters using the empirical coefficient shown in Fig.2. We can keep cavity diameter large even if operation frequency is high, in condition of the drift tube without installing focusing elements. Therefor the shunt impedance of cavity is kept over 100 MΩ/m until 50 MeV/amu. Even if we control the voltage between drift tubes into below of twice of Kilpatrick limit, we can enough keep acceleration rate 10 MV/m. From this rate, the peak wall loss is 1.2 MW/m at normal temperature, and 120 kW/m at liquid N_2 temperature. So we can operate this linac system safely.

For the sake of it we can keep the acceleration rate 10 MV/m and construct the RF linac system of HIF driver in the length of 1 to 2 km. The main parameters of HIF driver linacs are shown in Table 2. As shown in Table 2, The effective length of the IH linac cavities is 1245 m and the total length of the RF linacs containing RFQ linacs is 1405 m. Considering the funneling and jointing sections, it is sufficient to be with 2 km. If acceleration rate is high at supper conducting RFQ linac cavity, the length will be shorter.

Table2 Main Parameters of RF linacs for HIF

Name of Linac	RFQ-1	RFQ-2	IH-1	IH-2	IH-3	IH-4
Frequency (MHz)	20	40	160	320	320	640
Input Energy (MeV/u)	0.01	0.18	0.3	1.3	4.9	10.1
Output Energy (MeV/u)	0.18	0.3	1.3	4.9	10.1	50.1
Total Length (m)	100	60	25	90	130	1000
Diam. of Cavity (m)	2	1.6	0.42	0.24	0.26	0.12
Zeff (MΩ/m)	10	20	377	325	208	138
Peak Wall Loss (MW)	1.8	0.8	11	46	103	1192
Wall Loss Rate (kW/m)	18	13	44	511	792	1192
at Liq. N_2			4	51	79	119
Acceleration Voltage (MV)	42.5	30	250	900	1300	10000
Acceleration Rate (MV/m)	0.4	0.5	10	10	10	10
Peak Beam Current (mA)	20	40	80	160	320	640
Beam Power (MW)	0.85	1.2	40	288	416	3200

4. Considering Subjects in the Future.

We did not mention about beam focusing in the above chapters. As the characteristic of the IH, the diameter of cavity gets small. The solenoid lens and quadrupole lens of supper conducting will be possible to set in outside of the cavity. It is efficiently expected to be focus. When it is constructed, because of the progress of super-conducting technology, stronger magnetic-field is possible to generate. We are planning to start the correct Particle analysis.

It is necessary to cool the cavity it self as the cooling shield of the super conducting system that is set outside of acceleration cavity. So it is possible that the wall loss of cavity decrease until 1/10. In the case of HIBLIC[2], HIF driver is operated in 10 Hz, and it will be driven 100 Hz. Ad in the case of 100 Hz operation, the 100 fusion reactors are possible to make electric power of 10 GW. We must carry out a farther examination of these problems.

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