DESIGN OF 9.4 GHZ 950 KEV X-BAND LINAC FOR NONDESTRUCTIVE TESTING

Tomohiko Yamamoto, Katsuhiro Dobashi, Takuya Natsui,

Mitsuru Uesaka, University of Tokyo, Ibaraki, Japan, Eiji Tanabe, AET, Inc., Kawasaki, Japan

Toshiyasu Higo, Shigeki Fukuda, Mitsuo Akemoto, Mitsuhiro Yoshida, KEK, Tsukuba, Japan

Abstract

We are developing an X-ray nondestructive testing (NDT) system using 9.4 GHz X-band linac with 250 kW magnetron[1]. A conventional 1 MeV X-band machines use a large magnetron system[2]. We have chosen the 250 kW magnetron so that the RF heat loss is remarkably reduced. This design leads compactness and portable. The 20 kV thermionic electron gun, accelerating structure, RF system and control system are under design. The whole system is to be constructed in 2006.

INTRODUCTION

Methods of NDT are ultrasonic-, radiation-, neutron-, eddy-current- testing etc. An X-ray nondestructive testing is most visible and comprehensive. Especially by the high energy X-ray NDT system, we can evaluate inner flaws in reactor pressure vessel (RPV), engine, pipe, etc. (see Fig. 1).
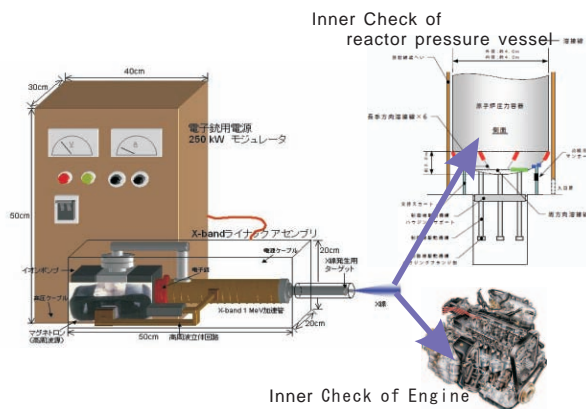

Figure 1: NDT applications

We design a mobile "Suit-case-sized" X-band (9.4 GHz) 950 keV linac for NDT applications. If we use this portable NDT system, we can inspect inner imperfections of many industrial products.

Conventional devices for the purpose are based on the S-band linac, but it is rather large and the electron beam spot size and the spatial resolution are about 3 mm. On the other hand, the NDT system with X-band linac uses 1 MW magnetron, where the RF heat loss is serious.

We aim at realizing the smaller spot size of about 500 μm by low emittance beam in the X-ray NDT system.

Now, we are designing the accelerator structure of the $\pi/2$ mode calculating the electromagnetic field (EMF) by

SUPERFISH. We have finished the fundamental RF design and the RF supply system is under construction. The design parameters and construction status are presented here.

SYSTEM DESIGN

The proposed system consists of a 250 kW magnetron, a modulator, a thermionic electron gun, a 9.4 GHz X-band linac and a metal target for X-ray generation (see Fig. 2). The gun voltage is 20 kV, and the final electron energy becomes 950 keV.
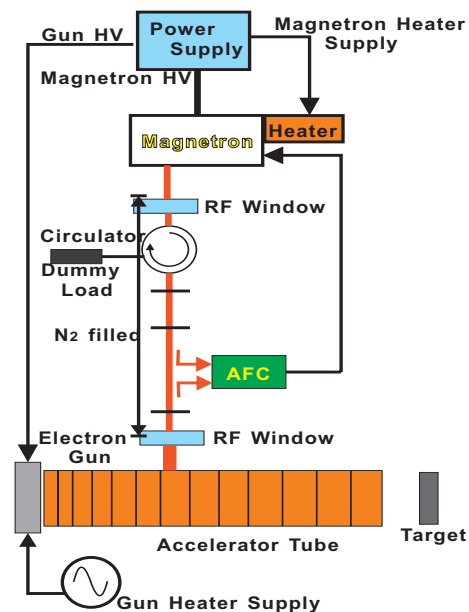

Figure 2: System diagrams of the linac

The magnetron manufactured by TOSHIBA Inc. for weather radar system is commercially available. The magnetron becomes cost-effective. The size and weight are about 20 cm × 20 cm × 20 cm, and 7.5 kg, respectively. Therefore by using this magnetron, the total system size would be mobile. In order to tune the frequency of magnetron to the resonant frequency of accelerator, we have adopted a feedback circuit, so-called Auto-Frequency-Controller (AFC).

We adopt a thermionic electron gun. The cathode radius of the electron gun is 2.5 mm. The beam spot size at the exit of the gun and the X-ray spot size are both less than 1 mm.

The total system size consists of two boxes of 50 cm × 30 cm × 30 cm for power supply, 50 cm × 30 cm × 30 cm

08 Applications of Accelerators, Technology Transfer and Industrial Relations

U02 Materials Analysis and Modification

for magnetron, linac, cooling system and metal target. The operation temperature of the system is $35 \,^\circ$C.

ACCLELERATOR DESIGN

The accelerating mode is the on-axis coupled $\pi/2$-mode in a standing-wave cavity [3, 4, 5, 6]. The resonant frequency is 9.4 GHz.
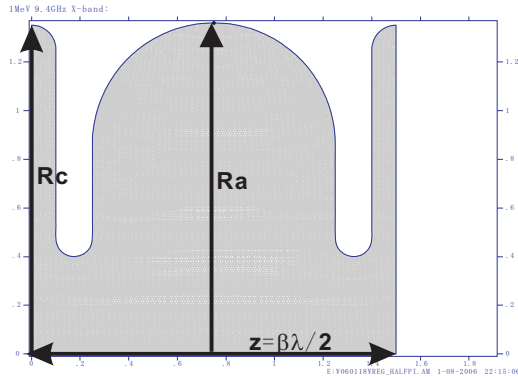

Figure 3: Cell geometry (R_a: radius of acc-cell, R_c: radius of coup-cell)

Figure 3 shows a typical geometry of a period of cell. R_a is a radius of the accelerating cell, while R_c is that of the coupling cell. z corresponds to the average electron velocity in the cell β in unit of light velocity, as $z = \beta\lambda/2$, where λ is c/f, c the light velocity in vacuum and f the resonant frequency. At $f = 9.4$ GHz, λ is about 3.19 cm. Fixed paramerters are the disk thickness of 1.5 mm and the iris radius of 4 mm for all of the cells.

Injection energy of an electron beam, 20 keV, corresponds to $\beta = 0.27$. The accelerator cells are arranged to smoothly accelerate the electrons to the final electron energy of 950 keV, with $\beta = 0.94$. The RF field pattern in this configulation of accelerator tube is shown in Fig. 4. Coupler cell is located in the middle of the accelerator tube, at the last cell of $\beta = 0.8$.
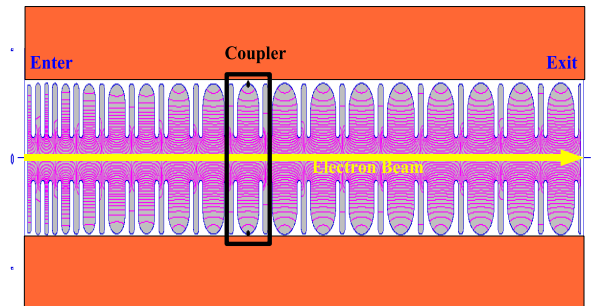

Figure 4: Accelerator tube & EMF pattern

Table 1: Type and number of cells

β	z (cm)	Ra (cm)	Rc (cm)	Numbers
0.4 half	0.3883	1.3245	1.3560	1
0.4	0.6383	1.36577	1.3560	1
0.5	0.7989	1.34546	1.3535	1
0.6	0.9574	1.3405	1.3525	1
0.7	1.1170	1.3429	1.3520	2
0.8	1.3000	1.3502	1.3515	3
0.9	1.4400	1.3574	1.3515	3
0.94	1.5000	1.3607	1.3515	5

We use as few cell types as possible for easier fabrication. As shown in Table 1, we set 8 groups for 17 accelerating cells. Total number of cells including couplig cells is 33. The energy profile of the accelerator tube is shown in Fig. 5. Typical accelerator tube parameter are listed in Table 2. We calculate the energy profile of each accelerating cell using wall loss and the shunt impedance.
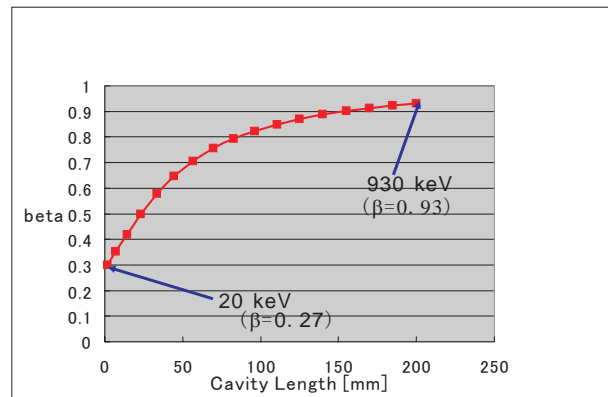

Figure 5: Energy profile calculated from the accelerating cell wall loss power and the shunt impedance of the cell

Table 2: Parameter of accelerator tube

Frequency	9400 MHz
Table Length	20.7 cm
Final Energy	950 keV
Accelerating Gradient	4.49 MV/m
Q Value	6643.52

The accelerating gradient shown in Table 2 is based on the total wall loss of 85 kW in the cavity.

MEASUREMENT OF TEST CELLS

We made test cells before actual fabrication. The purpose is to check the difference between calculation and reality for the resonant frequency and Q value. The test cells are the two groups of β=0.4, 0.8. The test cells are also used for the confirmation of the bonding parameter. Figure 6 shows the test cells and their measurement setup.

Upper and lower photographs show the test cells of β=0.4, 0.8, respectively,
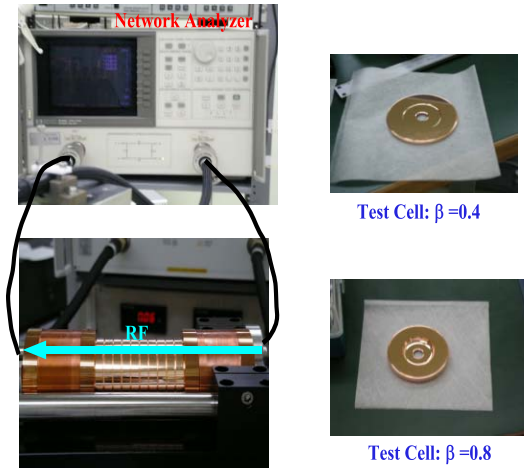

Figure 6: Measurement setup & test cells

Measured and calculation results are listed in Tables 3 and 4, respectively. All data in Tables 3 and 4 are calibrated to $35.0\,^\circ$C in vacuum. The data for various number of cells N are shown in Fig. 7. The nominal values are taken at $N \to \infty$.
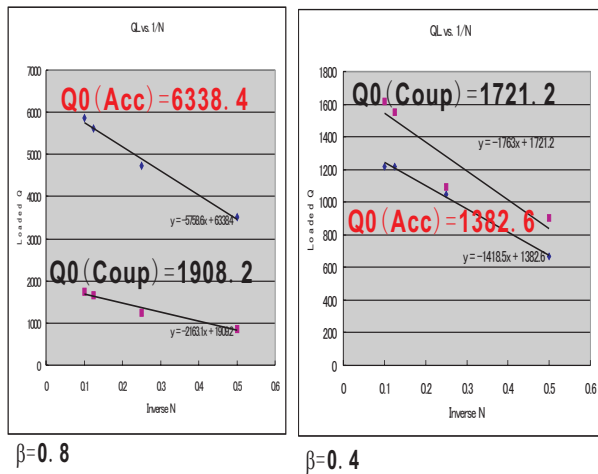

Figure 7: Loaded Q vs. 1/number of cells

Table 4: Cal. & meas. ($\beta = 0.4$)

	Frequency Cal.	Frequency Meas.	Q Value Cal.	Q Value Meas.
Acc-mode	9399.1 MHz	9397.9 MHz	1859	1382
Coup-mode	9396.6 MHz	9400.4 MHz	2595	1721

CONCLUSION

We are developing a compact X-ray nondestructive testing system with 9.4 GHz X-band linac and 250 kW magnetron. Using X-band linac and 250 kW magnetron, the accelerator length becomes short, and the RF heat loss is remarkably reduced. Therefore, the cooling system becomes small, and the total system size becomes compact and portable. With this NDT system, we can carry out insite inspection of various plants and industrial products.

Now, we finished the basic RF design of the linac. We are going to analyze the beam emittance and beam dynamics using PARMELA, and design the thermionic electron gun, the input coupler cell and modulator with the feedback control system.

The total system of X-ray generation is to be constructed in 2006, and NDT demonstration is to be carried out in 2007.

ACKNOWLEDGEMENTS

REFERENCES

[1] T. Yamamoto et al., *Proc. of 8th Symposium on ARTA 2006, Tokyo, JAPAN* (2006) pp.21-24

[2] Andrey V. Mishin, *Proc. of 2005 PAC, Knoxville, Tennessee* (2005) pp.240-244

[3] T. Nishikawa et al., *The Review of Scientific Instruments* Volume 37. Number 5 May 1966 pp.652-661

[4] D.E.Nagle et al., *The Review of Scientific Instruments* Volume 38. Number 11 November 1967 pp.1583-1587

[5] E.A.Knapp et al., *The Review of Scientific Instruments* Volume 39. Number 7 July 1968 pp.979-991

[6] C.J.Karzmark et al., *Medical Electron Accelerators* Mcgraw-Hill 1992

Table 3: Cal. & meas. ($\beta = 0.8$)

	Frequency Cal.	Frequency Meas.	Q Value Cal.	Q Value Meas.
Acc-mode	9399.0 MHz	9400.2 MHz	7889	6338
Coup-mode	9402.1 MHz	9400.3 MHz	2600	1909

08 Applications of Accelerators, Technology Transfer and Industrial Relations
U02 Materials Analysis and Modification