DEVELOPMENT OF PORTABLE 950 KEV X-BAND LINAC X-RAY SOURCE FOR ON-SITE NONDESTRUSCTIVE EVALUATION

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We are developing a portable X-ray non-destructive evaluation (NDE) system by using 9.4 GHz X-band linac with 250 kW magnetron. A conventional 1 MeV X-band machines use a power source of large 1 MW magnetron system. In order to realize a remarkable compactness and reduce the heat loss of the RF power, we adopted 250 kW magnetron for the RF source. This system consists of the X-band magnetron, modulator, thermionic 20 kV electron gun, X-band linac and metal target for X-ray generation. Our ultimate goal is to achieve the X-ray spot size of less than 1 mm. We designed the linac structure of the π mode at low energy parts and the $\pi/2$ mode at high energy parts, and analyzed the electromagnetic field by SUPERFISH and the electron beam dynamics by GPT. We finished to measure resonant frequency, and electromagnetic field on axis used by bead-pull method. These devices are to be applied to on-site NDE at petrochemical complex, nuclear- and thermal-power plants. We are going to verify the total device at Nuclear Professional School, the University of Tokyo this year.

In this paper, the details of the whole system and experimental results of high power test of accelerating structure will be reported.

I. Introduction

In generally, NDE is carried out by using ultrasonic, radiation, neutron, eddy-current, and X-ray. Particularly, nondestructive evaluation by using X-ray is the most useful technique to inspect with higher resolution. Especially by the high energy X-ray NDE system, we can evaluate corroded pipes of petrochemical complex, nuclear- and thermal-power plants. General X-ray NDE system is 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, we design a mobile "Suit-case-sized" X-band 950keV linac for NDE applications. The NDE system with X-band linac uses 1 MW magnetron, where the RF heat loss is serious. If we use this portable NDE system, we can inspect inner imperfections of many remarkable industrial products.

I.A. Compact NDE system with X-band Linac

We have developed a compact X-ray non-destructive evaluation (NDE) system using 9.4 GHz X-band linear accelerator (linac) driven by a tunable 250 kW magnetron [1,2,3]. Figure 1 is the schematic illustration of our compact NDE system.

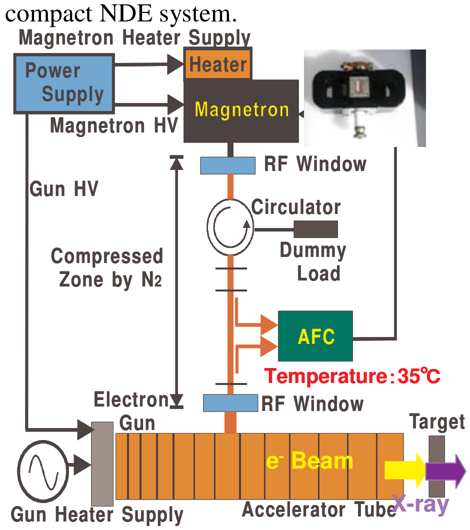

Fig.1. Schematic view of NDE system.

Instead of a large 1.5MW magnetron conventionally used in 1 MeV X-band linacs we have chosen a low power, marine radar magnetron to significantly reduce system cost and enhance portability. Our system consists of the magnetron, microwave components, pulse modulator, thermionic 20 kV electron gun, X-band linac, target for X-ray generation, and control system. The total system size consists of two boxes of 50 cm x 30 cm x 30 cm for power supply, 50 cm x 30 cm x 30 cm for magnetron, linac, cooling system and metal target of X-ray generation. The operation temperature of the system is 35 deg C.

I.A.1. Linear Accelerator

The resonant frequency of the linear accelerator is X-band (9.4GHz). The accelerator tube is the on-axis coupled standing-wave cavity. A single cell cavity is alternating periodic structure (APS) [4, 5, 6]. The detail of accelerating tube design and experiment will be explained at Sec.II.

I.A.2. Magnetron

The magnetron (E3570W) is manufactured by Toshiba Electronic Tube Devices Inc. It commercially uses weather radar. The frequency band is from 9.3 GHz to 9.5 GHz. Its max power and pulse width are 250 kW and 2 μs, respectively. The size and weight are 20 cm x 20 cm x 20 cm, and 7.5 kg, respectively. Therefore by using the magnetron, it becomes cost-effective and the total system size would be mobile.

I.A.3. Automatic Frequency Controller (AFC)

In order to tune the frequency of magnetron to the resonant frequency of accelerator, we have adopted a feedback circuit, so-called Automatic-Frequency-Controller (AFC). AFC is usually used by medical linac for high stability.

I.B. Application

With this NDE system, we can carry out on-site evaluation of industrial products at various plants and petrochemical complexes. Considering X-ray energy and spot size, this system can evaluate corrosion and wastage of tube. The corrosion and wastage size are more than 1mm (see TABLE I).

TABLE I. Objects of evaluation

Flaw	 Corrosion	 Wastage	 Small crack
Size (mm)	> 1	> 1	< 1

Figure 2 is an example of NDE system use. We will use this NDE system for corrosion check at chemical complex tower, Kashima, Japan at the start.

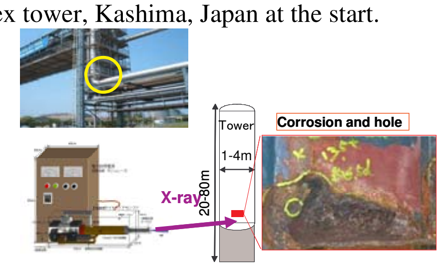

Fig.2. Example of NDE (Corrosion check)

II. Accelerator Design

To optimize the accelerating structure we used "SUPERFISH" to design the cavities, "MICROWAVE STUDIO" for the waveguide coupler and "D-GUN" and "GPT" for the electron gun and beam dynamics, respectively.

The accelerating tube is the on-axis coupled standing-wave cavity. At low energy parts of accelerator tube is π-mode and at high-energy parts is APS type π/2-mode so that electron beam acceleration become efficiently. The resonant frequency is 9.4 GHz. By these components, electron beam is accelerated from 20 keV to 950 keV.

We could calculate beam energy shift by GPT and SUPERFISH E-field data, and confirmed this accelerator structure is effective.

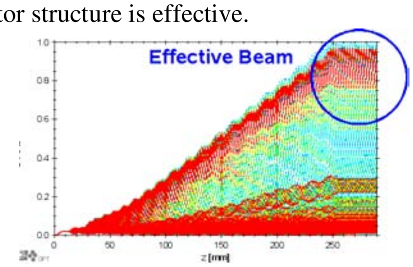

Fig.3. Beam accelerating simulation by GPT

Figure4 is a photograph of the assembled accelerator, welded RF window, and electron gun.

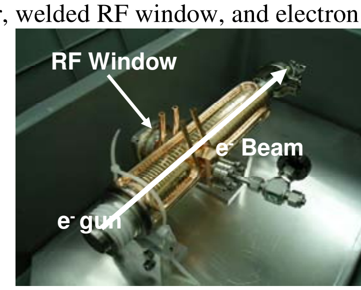

Fig.4. Photograph of X-band Linac

III. Experimental Result and Setup @ NPS

After the design of the accelerating structure, we performed low power test (cold test) at KEK, and RF aging and electron emission experiment at Nuclear Professional School (NPS), the University of Tokyo.

III.A. Cold test

We completed the measurement of resonant frequency. Axial electromagnetic fields using the bead-pull method. We have also checked the design parameters. TABLE II is the result of design frequency and Q value. We can confirm that measurement data have good agreement with SUPERFISH calculated data.

TABLE II. Comparison of Cal. and Meas.

	Frequency [MHz]	Q Value
Calculated data	9400.1	6609
Measurement data	9399.9	6618

Figure5 is the result of axial electromagnetic field measurement by the bead-pull method. We obtained good agreement.

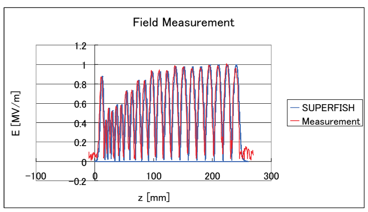

Fig.5. Field measurement by Bead-pull method
(Blue line: SUPERFISH, Red line: Measurement data)

III.B. RF aging and electron emission experiment

We can see that the measurement result agrees with SUPERFISH design by Table 1 and Fig.6. Now, the whole system included beam diagnostic section is under construction at Nuclear Professional School, the University of Tokyo.

We completed RF aging and electron emission test without RF. On RF aging, E-field could be put in 250 kW with 50 pps. Figure 6 is typical waveform of oscilloscope. You can see over-coupling reflection.

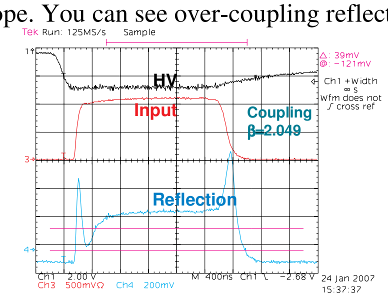

Fig.6 Waveform of oscilloscope
(Ch.1: HV, Ch.3:Input, Ch.4: Reflection)

After RF aging, in the condition of no-RF, electron emitted. In the result of electron emission test, we could get 20 keV electron beam with 400 mA.

Now, we are constructing an experimental setup for electron beam acceleration and X-ray generation experiment. Figure 7shows the schematic configuration of the experimental setup. For beam current measurement

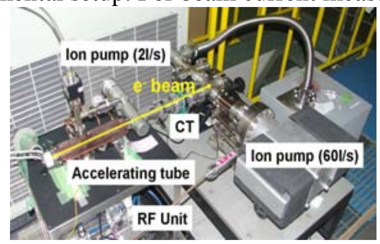

Fig.7. Current measurement setup

IV. CONCLUSIONS

We have designed and developed a compact, non-destructive X-ray evaluation system using the 9.4 GHz X-band linac with a 250 kW magnetron. By using X-band linac and low power magnetron, the accelerator length becomes shorter, and the RF heat loss is remarkably reduced. Therefore, the cooling system becomes smaller, and the total system size becomes more compact and portable. With this NDE system, we can carry out on-site evaluation of industrial products at various plants and petrochemical complexes.

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