APPLICATIONS OF X-BAND 950 KEV AND 3.95MEV LINAC X-RAY SOURCE FOR ONSITE INSPECTION

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Abstract

Our portable X-band (9.3GHz) 950 keV linac has been successfully upgraded. The problems of RF power oscillation, beam current oscillation and reduction and finally lack of X-ray intensity were solved by replacing the axial coupling cavities with the side-coupled ones. Designed X-ray dose rate of 0.05 Sv/min@1m is going to be achieved. X-ray source part with the local radiation shielding is connected by the flexible waveguide with the box of a 250 kW magnetron and a cooling unit. The total system consists of the three suit-case-size units, the last of which is one for the electric power supply. We have also developed a portable X-band (9.3GHz) 3.95MeV linac for on-site bridge inspection. The system consists of a 62kg X-ray source part without 80kg target collimator, a 62kg RF power source and other utility box of 116 kg. Designed X-ray dose rate is 2 Sv/min@1m with 200 pps repetition rate and we have achieved 0.5 Sv/min@1m with 50 pps repetition rate. Demonstration of measurement of wall thinning of metal pipes with thick thermal shielding and onsite inspection for nitric acid concentrating tower by 950 keV linac has been successfully achieved. Development of new X-ray detector for better sensitivity for hundreds keV through a few MeV and partial CT for reconstruction of degraded inner structure with the 3.95 MeV system are under way.

BACKGROUND AND OBJECTIVE

Outer surface corrosion of pipe has been serious in a petrochemical complex. Because it is adjacent to the sea, corrosion of outer surface of the pipe due to severe salt damage is more serious than other regions and consequently becomes a big issue on maintenance. In order to inspect exterior corrosion, many works have been done such as installation of temporary scaffold, removal of insulation, and even shutdown the plant. These works must cause enormous cost since there are very long pipes there. For the purpose of quantitative evaluation of the corrosion which is covered with insulation material, the X-ray CT is expected to be used.

We expect to realize onsite inspection and evaluation of exterior corrosion of the pipe with insulation material by using our upgraded X-band 950 keV linac.

There is another demand for which we developed X-band 3.95 MeV linac. As the increase of ageing bridges, the collapse accidents of old bridges also become serious issues. Additionally, load bearing ability of a Prestressed Concrete (PC) bridge relates to the condition of inner wire. On the other hand, X-ray NDT (Non-destructive Testing) system has been developed for inspecting artificial structures in many fields. There are several X-ray NDT systems, such as X-ray tube assembly, synchrotron accelerator and linac. However, the problem of conventional systems is that those systems need long time to get an X-ray radiographic image (e.g. 60 min for 40cm thick concrete using 300keV X-ray tube assembly) and another problem is the size of those X-ray NDT system. They are too heavy for onsite inspection (mostly over tons). Therefore, we developed a portable high intensity X-band 3.95 MeV linac system to inspect the PC bridge inner wire condition.

We are also focusing to improve the X-ray detection system to realize that NDT system enables to achieve radiographic image of 40 cm thick concrete in few seconds, with 2mm spatial resolution.

X-BAND 950KEV & 3.95MEV LINAC

We have successfully solved problems of RF power oscillation, beam current oscillation and reduction and finally lack of X-ray intensity by replacing the axial coupling cavities with the side-coupled ones [1]. The length of the accelerating tube is reduced to less than 25 cm, and the weight of X-ray source part with the local radiation shielding and magnetron are only 44kg and 49.5kg, respectively. Such a light linac system and the energy of 950 keV (there is no need to set radiation controlled area if the beam energy is below 1 MeV in Japan) is suitable for onsite inspection operated by remote control robot. The linac system is shown in Figure 1.

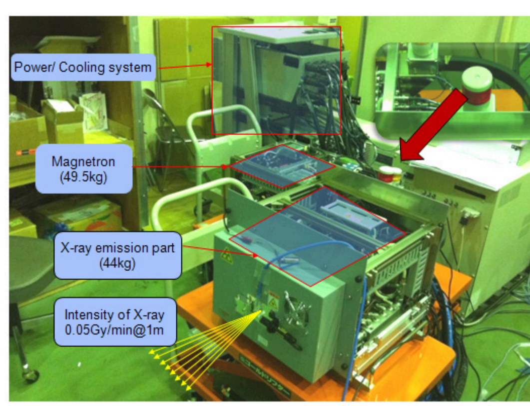

Figure 1: Upgraded X-band 950KeV linac.

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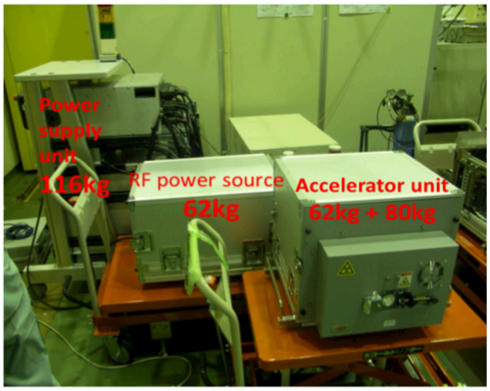


Figure 2: X-band 3.95MeV linac.

As shown in Figure 2, 3.95 MeV linac system consists of 62 kg X-ray head without the target collimator 80 kg, the RF power source 62 kg and other utility box 116 kg. The X-ray intensity of this system is 2 Gy/min at 1m.

The biggest breakthrough in design is the flexible waveguide which connect magnetron to X-ray source part. Conventionally, a normal waveguide is made of copper, so that it has poor flexibility. The adoption of flexible waveguide is for the purpose of on-site use in which the X-ray source part can move depending on the situation.

The detailed parameters of the 950 keV and 3.95 MeV linac systems are as follows.

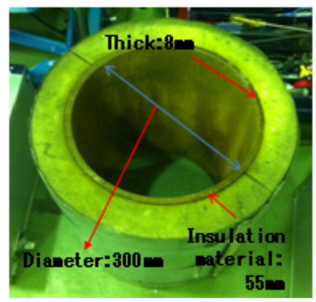
Table 1: Parameters of 950keV and 3.95MeV Linac

	950keV	3.95MeV
Operating frequency	9.3 [GHz]	9.3 [GHz]
RF source	Magnetron	Magnetron
Input RF Power	250kW	930kW
Width and repetition rate of RF pulse	3[μs], 330[PPS]	4[μs], 200[PPS]
Length of acceleration tube	25[cm]	50[cm]
Form of acceleration tube	Side coupled structure	Side coupled structure
Accelerating cell Number Cells coupling	Half1 + full8 3%	Half 1+full 20 3%
Filling time	0.18μs	0.23μs
Shunt impedance	110-130MΩ/m (Regular part)	110-130MΩ/m (Regular part)
Beam current	64mA or more	95mA or more
Focusing fashion	RF focusing	RF focusing
Intensity of X-ray	50[mGy/min]	2[Gy/min]
Voltage of electron gun	20KV	20KV
Electron gun type	Triode	Triode

EXPERIMENT AND RESULTS

Sample

Figure 3a shows the pipe sample where artificial defects of 1mm, 3mm, 5mm, 7mm, 10mm diameters and 3.5 mm depth were made at exterior surface of iron pipe. The pipe sample has three layers that are inner layer of 8 mm thick iron pipe, middle layer of 55 mm thick insulation material and outer layer of 0.5mm steel sheet. The 40cm thick concrete sample is shown in Figure 3b. There are several thick rods, and pipes where 12 ϕ 7mm wires are put, inside for reinforcement.



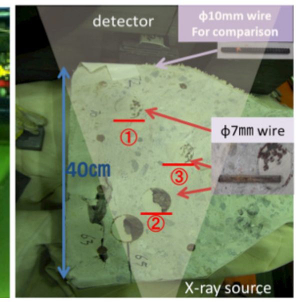


Figure 3a: Pipe sample Figure 3b: Bridge sample

Detector

In this experiment, we chose a 295 mm × 360 mm × 22 mm size scintillation type flat panel detector, which is manufactured by PerKin Elmer Co.. The integration time of scintillation detector can be raised up to 20 sec by external pulse. The specifications of flat panel detector are shown in Table 2.

Table 2: Perkin Elmer XRD0822

Size (mm)	295×360×22
Maximum integration time	20s
Scintillator	Gd_2O_2S:Tb
Pixel number	1024×1024
Pitch	200 μm 400 μm with 2x2 Binning
Radiation energy	40 KeV – 15 MeV

Results

Upgraded X-band 950 keV linac is now operated stably. The intensity of X-ray can be up to more than 25 mGy/min@1m for 280pps. For the iron pipe sample, we measured all artificial defects within 1sec. The results for detection of artificial outer defects in the pipe sample are shown in Figure 4. The measurement time is 1 s.

X-band 3.95MeV linac is also in stable condition. The intensity of X-ray can be up to about 0.5 Gy/min@1m under 50 pps. Using this X-ray source, we measured the concrete sample with 20 sec measurement time. As shown in Figure 6, only a few wires can be identified in all projection image with different directions, although there were 12 wires in all. Therefore, CT reconstruction is needed to check the state of all wires. Considering the access to the bridge structure, a full CT scanning is not practical. Therefore, we have started to adopt partial CT, where the rotation range and translation range are rather limited. Schematic drawing of simulated partial CT scanning is explained in Figure 6. Simulation results for 180 degree by 5 degree and three translations and 120 degree by 5 degree and no translation are shown in Figure 7. If we focus on ROI (Region of Interest) at the area of fine wires, the partial CT with limited rotation and translation can gives reasonable reconstruction.

Very recently, we have successfully achieved onsite inspection for nitric acid concentrating tower.

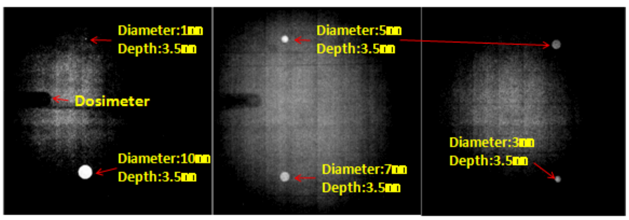


Figure 4: Artificial defects measured by 950keV linac with scintillation detector for 1s integration time.

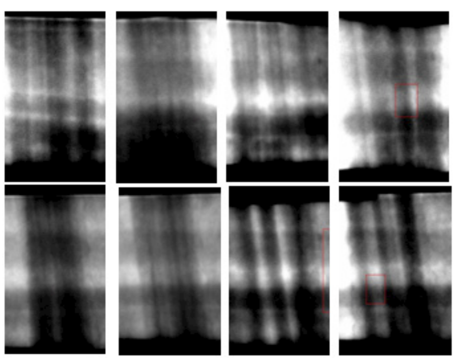


Figure 5: Images of ϕ 7mm iron wires in 40 cm thick concrete in several projection by the 3.95 MeV system and 5 sec measurement.

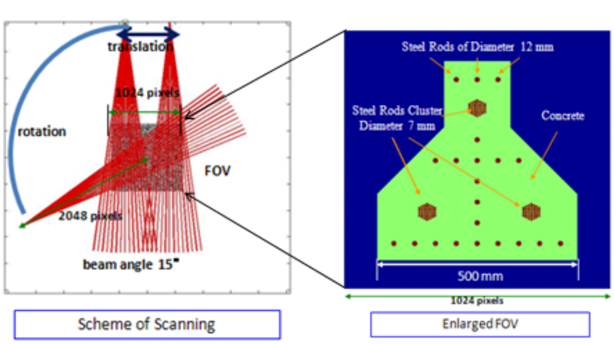


Figure 6:Scheme of partial CT and inner structure of PC sample.

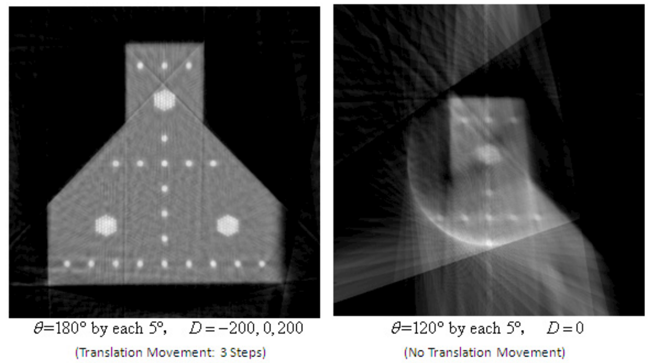


Figure 7: Simulation results.

SUMMARY

Upgraded side-coupled 950 keV system can provide X-ray intensity of almost design value (0.05 Gy/min@1m) at 2 μsec RF pulse and 200 pps. We are still checking the beam loading, vacuum problem etc. Petrochemical complex pipe sample was measured within 1 sec with the X-ray flat-panel camera. In the 3.95 MeV system, approximately 0.5 Gy/min@1m has been obtained under 50 pps in contrast to the design value of 2 Gy/min@1m under 200 pps. The electron current in 4μsec RF pulse reached design value. Transmitted image of the bridge PC material of 40cm thickness was acquired in 5 secs.

For the 3.95 MeV system, we will take a radiation safety review by the government at Civil Engineering Research Institute and then proceed to onsite inspection of PC-, RC (Reinforced Concrete; reinforced by thick rods)- and metal bridges. Development of better sensitivity scintillator and X-ray camera for 950keV and 3.95MeV X-ray source has also started.

We are going to apply those systems for strucctural

REFERENCES

[1] Mitsuru Uesaka, et al. "950 keV, 3.95 MeV, 6 MeV X-band Linacs for Non-destructive Evaluation and Medicine", Nuclear Inst. and Methods in Physics Research, A, NIMA53737, 2011.