UPGRADED X-BAND 950 KeV LINAC X-RAY SOURCE FOR ON-SITE INSPECTION AT PETROCHEMICAL COMPLEX

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Abstract

Our portable X-band (9.3GHz) 950KeV 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. Length of the accelerating tube is reduced to less than 25 cm. X-ray source part with the local radiation shielding is connected by the flexible waveguide with the box of the 250 kW magnetron and cooling unit. The total system consists of the three suit-case-size units, the last of which is one for the electric power supply. Even on-line dynamic transmission imaging is available by using the high intensity X-ray camera. Demonstration of the measurement of wall thinning of metal pipes with thick thermal shielding has been conducted with imaging plate, and artificial defects with size of 3mm, 5mm, 7mm and 10mm have been measured.

BACKGROUND AND OBJECTIVE

Outer surface corrosion of pipe has become problem in Kashima Petrochemical complex. Because it is adjacent to the sea, corrosion of outer surface of the tower and pipe due to severe salt damage are more serious than other regions and consequently bring big issue on maintenance. In order to inspect exterior corrosion, many works has to be done such as installation of temporary scaffold, removal of insulation, and even shutdown the plant. These works must cause enormous cost since there are approximately 100,000km long pipes in Kashima. For the purpose of quantitative evaluation of the corrosion which is covered with insulation material, the X-ray photography is expected.

In this study, we expect to realize onsite inspection and evaluation of exterior corrosion of the pipe with insulation material by using our upgraded X-band 950KeV Linac. Inspection and evaluation of the sample pipe have been conducted at laboratory.

UPGRADED X-BAND 950KEV 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. 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 light Linac system and with the energy of 950KeV (there is no need to set controlled area if the beam energy is below 1MeV in Japan) is suitable for on-site inspection operated by remote control robot. So we could say we have successfully realized compact Linac system. But, accordingly there are difficulties in repairing and adjusting because of compact size. The Linac system is shown in Figure 1.

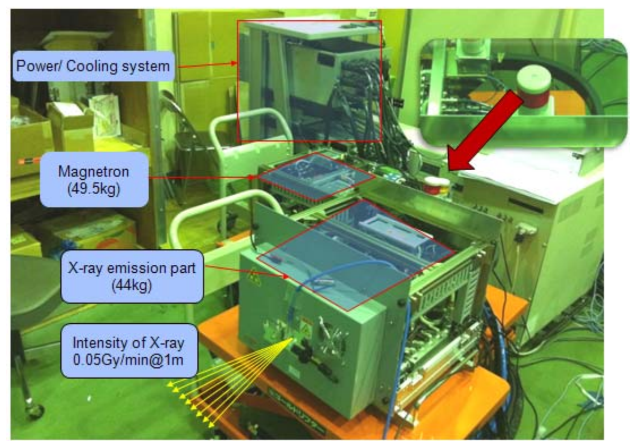

Figure 1: Upgraded X-band 950KeV Linac.

The biggest breakthrough in design is the flexible waveguide which connect magnetron to X-ray source part. Conventionally, waveguide is made of copper, so it has bad 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 Linac are as follows.

Table 1: Parameters of accelerator

Operating frequency	9.3 [GHz]
RF source	Magnetron
RF Power	250KW
Width and number of repetitive of pulse	3[μs], 280[PPS]
Length of acceleration tube	25[cm]
Form of acceleration tube	Side coupled structure
Number of accelerating cell	Half1 + full8
Coupling between cells	3％

Filling time	0.18μs
Shunt impedance	110-130MΩ/m Regular part
Beam current	64mA or more
Focusing fashion	RF focusing
Intensity of X-ray	50[mGy/min] or more at 1[m]
Voltage of electron gun	20KV
Electron gun	Triode

EXPERIMENT AND RESULTS

Sample

Figure 2a shows the sample pipe where artificial defects were designed at exterior surface of iron pipe. The dimension of sample pipe and artificial defects are shown in Fig. 2b and Table 2. The sample pipe has three layers that are inner layer of 8mm thick iron pipe, middle layer of 55mm thick insulation material and outer layer of 0.5mm steel sheet.

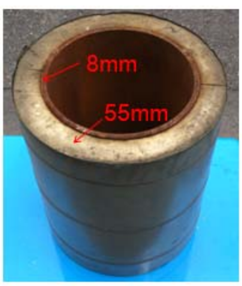

Figure 2a: Sample pipe.

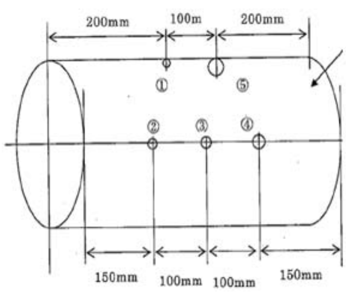

Figure 2b: Dimension

Table 2: Dimension of defects

Number	Diameter	Depth
1	1mm	2 mm
2	3mm	2mm
3	5 mm	2mm
4	7 mm	2mm
5	10mm	2mm

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. and a 200mm × 400mm size Fuji Imaging Plate. The spatial resolution of the scintillation detector and Imaging Plate are as high as 0.2mm and 0.05mm, respectively. The integration time of scintillation detector can be raised up to 20s by external pulse. Conversely, there is no exact integration time of Imaging Plate. In general, limitation of integration time of Imaging Plate depends on the intensity of X-ray source.

The specifications of both detectors are shown in Table 3 and Table 4.

Table 3: 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

Table 4: Fuji Imaging Plate

Size (mm)	200×400
Pixel size(μm)	50/100/200
Reading time	5 min. (50μm)
Dynamic Range	4/5 orders of magnitude
Detection Limit	^{32}P 0.11 dpm/mm2/hr ^{14}C 0.90 dpm/mm2/hr
Gradation	65,536 (16 bits)/256 (8 bits) selectable

Results

Upgraded X-band 950KeV Linac now began to operate stably. We can assume that the energy of beam is close to that of designed, because the RF power can be raised up to 225KW which is nearly approach to the specification value of 250KW. But the number of repetitive of pulse is only 80pps which is less than 30% of specification, and beam current is about 60mA which is two-thirds of the specification. Therefore the intensity of X-ray is about 1/5 of specification, namely 10mGy/min@1m. In addition, maximum integration time of the scintillation detector is only 20s. Because of low intensity and short integration time, we couldn't find artificial defects by scintillation detector. For comparison we used X-band 3.95MeV Linac to inspect the pipe, and we also made another sample for testing transmittance of 950KeV Linac X-ray source. These results are shown in below.

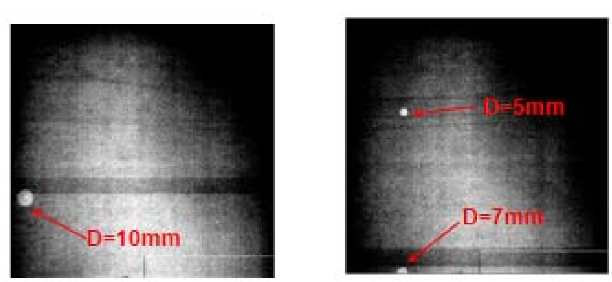

Figure 3: Artificial defects measured by 3.95MeV Linac with scintillation detector for 2s integration time.

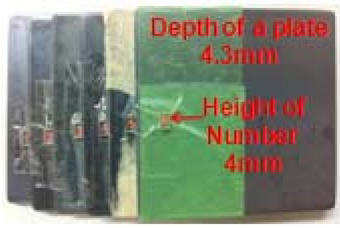

Figure 4: Test sample composed of iron plate.

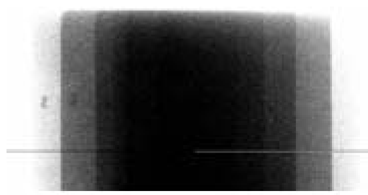

Figure 5: Test sample measured by 950KeV Linac with scintillation detector for 20s integration time.

In Figure 5, we can identify third iron plate (4.3mm×3) clearly, but it is difficult to say that we can identify forth plate. This shows that artificial defects wouldn't be detected clearly by scintillation detector with 20s integration time, since the thickness of iron pipe is 8mm, so we need to measure thickness of 16mm or more.

To break the limitation of integration time of scintillation detector, Fuji Imaging Plate was adopted, and the results measured by it are shown below.

Figure 6: Test sample measured by 950KeV Linac with Imaging Plate for 270s integration time.

In Figure 6, the fifth plate (4.3×5) was identified clearly. So we did experiment about sample pipe again as shown in Figure 7. There are two statuses. The one is when artificial defects are near X-ray source, another one is far from X-ray source. The results are shown in Figure 8.

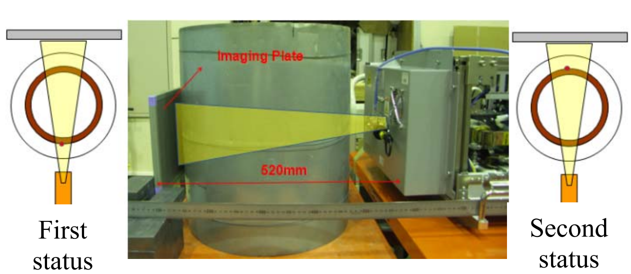

Figure 7: Configuration of experiment.

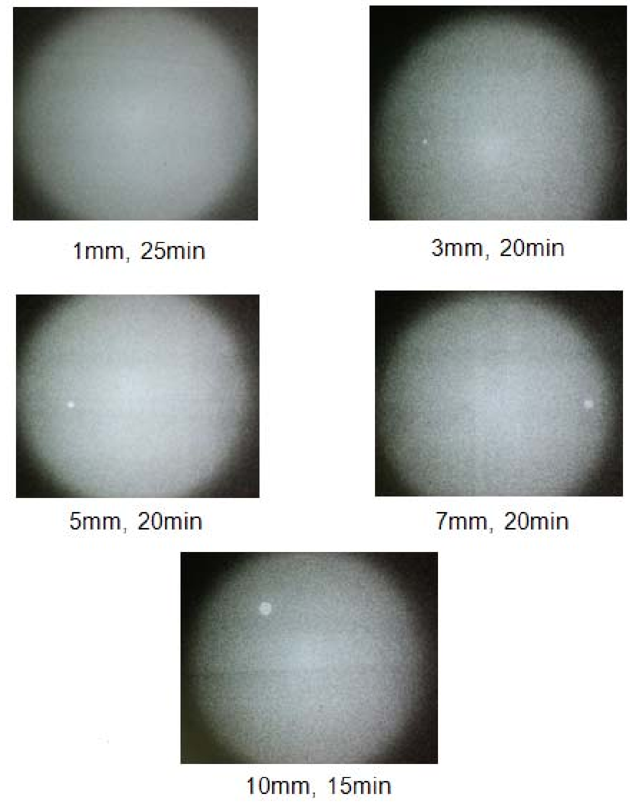

Figure 8: Artificial defects measured by 950KeV Linac with Imaging Plate.

Above results were obtained under first status. Under second status no defects were measured.

CONCLUSION

We have successfully identified artificial defects including 3mm, 5mm, 7mm and 10mm by using imaging plate, but 1mm defect have not been seen even though we irradiated it as long as 25 minutes. From this experiment, we can confirm that as long as the integration time is appropriate, defects larger than 3mm with 2mm depth can be detected by our upgraded X-band 950KeV Linac. We have also known that the distance between defects and the X-ray source have much influence on detecting defects. The reason is very simple. Because this X-ray is a cone beam, so apparently intensity of X-rays would decrease with distance. That is why we did not detect defects when these are far from the X-ray source.

REFERENCES

[1] Takuya Natsui, Mitsuru Uesaka, Tomohiko Yamamoto, Fumito Sakamoto, Eiko Hashimoto, Lee Kiwoo, Naoki Nakamura, Masashi Yamamoto, Eiji Tanabe, "Development of a Portable 950 KeV X-band Linac for NDT" The American Institue of Physics Conference Proceedings Series Volume1099 75-78 2009