ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWI009

DEVELOPMENT OF UN-DESTRUCTIVE INSPECTION SYSTEM FOR LARGE CONCRETE INFRASTRUCTURE BY USING ACCELERATOR BASED COMPACT NEUTRON SOURCE*

A. Taketani[1#], Y. Seki[1], H. Ohta[1], T. Hashiguchi[1], S. Yanagimachi[1], Y. Otake[1], Y. Yamagata[1], Y.Ikeda[1], H. Baba[1], [1]RIKEN, Wako, 351-0198, Japan
S. Wang[1,2], Q. Jia[2,1], G. Hu[2,1], [2]XI'AN Jiaotong university, Xi'an, 710049, China
K. Hirota[3,1], [3]Nagoya university, Nagoya, 464-8601, Japan
S. Tanaka[4], [4]IPNS, KEK, 305-0801, Japan
K. Kino[5], [5]Hokkaido university, Sapporo, 060-0808, Japan

Abstract

Aged large concrete structure, such as highways, bridges and boating docks, need to be inspected by un-destructive method in order to determine whether maintenance or rebuild. If maintenance work is appropriate, diagnosis will be needed. We have been developing un-destructive inspection system by using fast neutron which can penetrate thick concrete. Fast neutron detector is developed with plastic scintillator and semiconductor photon sensors. It can identify 16mmϕ steel rod through 300mm thick concrete. After prototyping detector experiments, new large area detector are designed and build.

INTRODUCTION

In Japan, many bridges were built in 1960 to 1970's, when Japanese economy had been expanded rapidly. So they will become end of life in next a few decades. However society will not able to rebuild all of them by budget limitation. It is urgent needs to develop and establish a method to investigate with un-destructive way.

Thirty nine percent of the bridges of Japan, which are longer than 15m, are built by pre-stressed concrete (PC) construction method [1]. It is combination of high tensile strength of steel and concrete's great compressive strength. Solid duct is inserted in the concrete structure. Steel rods or wires are put in the duct with pre-tension. Then the duct is filled by the concrete. However it has been known that techniques in 60's and 70's could not guarantee the duct was filled without void. Rain water can penetrate into voids in the duct through cracks in the concrete structure and make corrosions on the steel. Hence the steel rods or wires degrade their strength. As result, the structure may fall down. Thus it is important to investigate gap in the concrete and size of the steel rods or wires. The typical size of the duct is about 3cm diameter. Therefore our target is 3cm imaging resolution.

Fast Neutron

The absorption cross section of fast neutron, which energy is around 1MeV, is order of 1 barn (10^{-24}cm^2) against to major elements of concrete, oxygen, aluminium and silicon [2]. For X-ray case, it is order of 1000 barn [3]. Neutron has much higher penetration power for concrete structure. It is suitable to obtain transmission image.

Needs to Develop

The requirements, which are needed to establish fast neutron imaging system, are (1) transportable neutron source, (2) 2D fast neutron detector, and (3) image processing which can reconstruct as 3D view of the inside of concrete structure. Fig.1 shows final goal of the project. A neutron source is mounted on an automobile with a target station. Fast neutron is emitted to downward. Thus bridge floor is exposed to the fast neutron. Transmitted neutrons are detected underneath of the bridge by 2D fast neutron detector, which is attached to a swing arm.

By the Japanese law of concerning the prevention from the hazards due to radiation and others [4], it is allowed to operate transportable accelerator with less than 4MeV out of doors for un-destructive inspection of bridges.

Figure 1: Transportable neutron source and 2D fast neutron detector.

In this paper, we report about a prototype of 2D fast neutron detector, which was tested with accelerator-based compact neutron source.

Because the detector will be used out of doors, stable operation with mechanical movement, temperature and humidity excursion, and low power consumption are required. By the above technical reasons, combination of plastic scintillator and semiconductor photon sensor is chosen.

#taketani@riken.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWI009

EXPERIMENTAL SETUP

RIKEN Accelerator-based Compact Neutron Source (RANS) is used as fast neutron source, which has been operated since 2013 April. Concrete samples are placed at 5m away from neutron production target. Arrays of plastic scintillator are used as fast neutron detector.

RANS

RANS is composed of 7MeV proton LINAC, which is model PL-7 by AccSys technology Inc. [5], a target station and a beam line. The accelerated proton is bombarded into thin beryllium target [6]. Proton beam size is tuned to 20mm in diameter for preventing the heat damage by the beam. Since RANS is used as fast and thermal neutron source, at the beryllium target back, there is a plastic moderator to convert to thermal neutron. These neutrons are guided into a detector box through shielded beam line. Both are consisted of 5 to 10cm borated polyethylene. A beam dump in the detector box is covered by lead to absorb gamma-ray from neutron capture by hydrogen.

The neutron from the RANS has two intense energy-components of 1MeV and 50meV. Both regions have a few of 10^4 neutron/cm^2/s intensity with full proton current 100μA. Thermal neutron takes more than 1ms to reach to 5m away sample position.

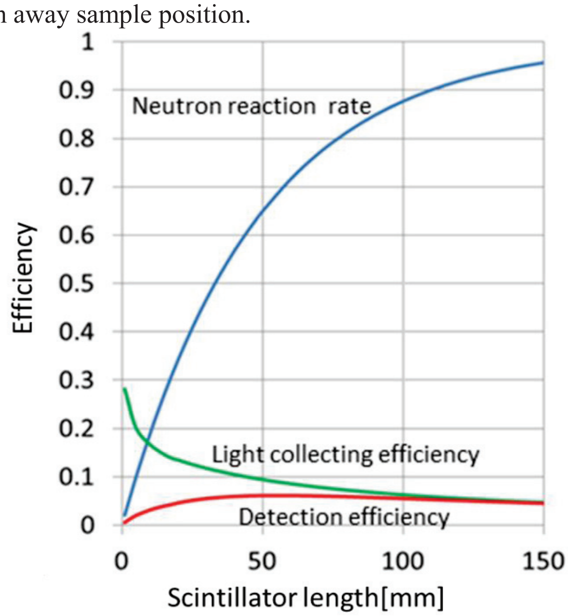

Figure 2: Scintillator length and efficiency.

Detector

Combination of BC-408 plastic scintillator [7] and Multi-Pixel Photon Counter (MPPC) [8] is used for detector. The MPPC is composed of multi-pixels avalanche photo diode and able to count number visible photon. Size of scintillator is 30(w)×30(d)×50(l) mm^3. The MPPC with 3×3mm^2 size is attached downstream end of the scintillator. Fig.3 represents the scintillator length and detection efficiency, simulated by GEATN4 toolkit [9]. Incident neutron recoils proton in hydrogen atom of plastic scintillator. It runs a few 10μm with generating scintillating photons. Photons arrive at the MPPC directly or are reflected by scintillator surfaces. Neutron reaction rate increases with length, but light collecting efficiency decreases, because average solid angle of MPPC's sensitive area decreases with increasing of length of scintillator. Total detection efficiency is multiplication by these two factors. It saturates above 50mm in the scintillator length [10].

In order to compensate for gain fluctuation of the MPPC due to the temperature excursion, bias voltage (~70V) is changed during experiments by using the monitored temperature of the MPPC. Signal from each MPCC is fed into an amplifier and then into a comparator. The threshold levels of the comparator are set to the voltages which are equivalent to 13 photo electrons in order to distinguish neutron signals from noise. Time of flight for the fast neutron is about 100ns at 5m away from the target. Signals are coincided with accelerator timing signal and then are counted. 1×3 array of the scintillator is built and used for the experiments.

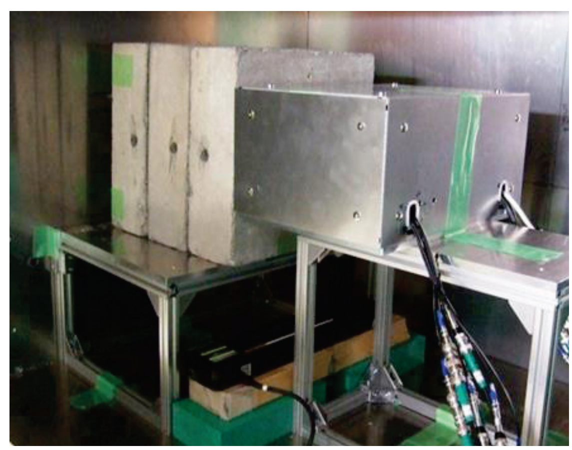

Figure 3: Experimental setup in the detector box.

Experiment

The scintillator array detector is installed 5m away from the target in the detector box. Upstream of detector, concrete block and sample are settled. Fig.3 shows the experimental setup in the camera box. The neutron beam comes from left to right in the photo. Three of 100mm thick concrete with a vertical hole is used. The scintillator array with analogue amplifies, and bias voltage circuits are in the aluminium box at the centre. Amplified signals are fed into comparators through 20m long coaxial cables. Iron rods of 16mm in diameter are inserted vertical holes.

The proton beam was tuned with 100μs pulse width, 20Hz repetition frequency. The beam current was limited to 10μA at the experiments. Each measurement point took 10min for exposure.

RESULTS

Transmmission factor are measured with the number of inserted iron rods in the concrete, which is showon in Fig.4. Red points respresent data from the scintillator

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWI009

looking iron rods. Blue and green points indicate the data from the scintillator not looking.

Blue and green points have some fluctuation, but red points indicate the transmission factor decreases with number of iron rod clearly. It shows the possibility to obtain transmission image by using fast neutron and scintillator detector.

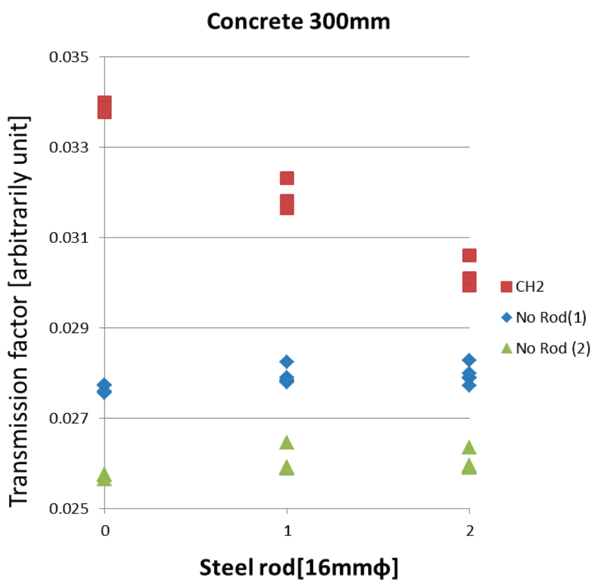

Figure 4: Transmission factor of iron rods in the concrete.

NEXT DETECTOR DEVELOPMENT

Figure 5: 32×32 array detector with network control.

After the test of the prototype detector, we designed and fabricated new detectors. The detectors are (a) 32×32 arrays of 20×20×50mm^3 scintillators, (b) 8×8 of 20×20×50mm^3, and (c) 8×8 of 10×10×50mm^3. The scintillator arrays, the amplifiers, the comparators, the bias voltage supplies, and a network control interfaces are housed in the water proofed chassis. There are three connections to the detector from outside, 24V power line, the accelerator timing signal, and the Ethernet instead of heavy coaxial cable connections for each scintillator on the prototype detector manner.

One can control the comparator threshold voltages of each scintillator, the coincidence timing, and the bias voltages by using a PC which is connected to the network interface through Ethernet as well as reading counts of incident neutron. The power consumption is about 12W per 8×8 array unit. Thus it enables the detector operation easier. Fig.5. shows inside of 32×32 array detector array.

The comparator threshold level of 64 array detector is scanned with counting number from noise and cosmic-ray. They present the offsets and slope value of threshold voltage dependence. This method will be used for automatic calibration of larger array detectors.

CONCLUSION

The fast neutron imaging detectors has been developed for un-destruction inspection of bridges. Transmission factors over 300mm concrete are measured and can identify the number iron rod well. New remote controlled detectors are built for outdoor usage.

ACKNOWLEDGMENT

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), “Infrastructure maintenance, renovation and management” (Funding agency: JST).

REFERENCES

[1] Ministry of Land, Infrastructure, Transport and Tourism of Japan, 2014 Status of Bridges, http://www.mlit.go.jp/road/ir/ir-data/tokei-nen/2014/nenpo03.html
[2] K. Shibata et.al. JENDL-4.0: A New Library for Nuclear Science and Engineering," J. Nucl. Sci. Technol. 48(1), 1-30 (2011).
[3] M.J. Berger et.al. XCOM: Photon cross-section database, NBSIR 87-3597. http://www.nist.gov/pml/data/xcom/
[4] http://law.e-gov.go.jp/htmldata/S32/S32HO167.html
[5] http://www.accsys.com/pulsar.html
[6] Y. Yamagata et al. “Development of a neutron generating target for compact neutron target sources using low energy proton beams", J. Radiana. Nucl, Chem.To be published http://link.springer.com/article/10.1007/s10967-015-4059-8
[7] http://www.crystals.saint-gobain.com/
[8] https://www.hamamatsu.com/resources/pdf/ssd/mppc_kapd0002e.pdf
[9] S. Agostinelli et.al. Geant4 a simulation toolkit, Nucl. Inst.Meth. A506,(2003),250-303.
[10] T. Hashiguchi et al. "Simulation of fast neutron detector for un-destructive inspection of large concrete structure", JSP meeting 2014 Mar. 30aTJ-5.