# Development of Advanced Ultrasonic Inspection System for Nuclear Power Plant Reactor Vessels

Kazuo SAWARAGI, Yoshio MIYAKE, Junji NAKAYAMA, Kiyoshi TACHIBANA
*Mitsubishi Heavy Industries, Ltd., Kobe, Japan*

Takao OOMICHI, Yukio FUKAGAWA, Masahiro FUJIWARA, Shiro HONMURA
*Mitsubishi Heavy Industries, Ltd., Takasago, Japan*

ABSTRACT

Ultrasonic inspection machine consisting of large and stiff columns and guide rails has been usually used in the pre-service inspection (PSI) and inservice inspection (ISI) of the nuclear power plant reactor vessels.

However, the machine is so large-sized and heavy that maintenance and handling are degraded.

To solve these problems, our robotics technology and idea obtained from experience of reactor vessel ISI have been applied to develop a new second generation machine that can dramatically reduce critical path time of reactor vessel ISI.

This system is characterized by the following features.

(1) It can move automatically and can set the position accurately by underwater positioning system.
(2) Inspection is made by the articulated manipulator of high rigidity and high path accuracy.
(3) The total weight is approx 300 kg in air (0 kg underwater).
So the plant's polar crane is not required during inspection.

Realization of this system, we have studied and designed all of the systems.

We have also fabricated prototype machine to make the functional test using full scale mock up of reactor vessel.

## 1 PROBLEMS OF CURRENT MACHINE

In accordance with the requirements of the Japan Electric Association Code (JEAC-4205), equivalent to ASME Code Section XI, we developed automatic remote-controlled ultrasonic testing machine for reactor vessels of PWR plants in 1974. Using this machine, we have carried out PSI and ISI on fifteen and ten reactor vessels of PWR plants in Japan, up to now, respectively.

Fig. 1 shows the outside view of current machine system. This system consists of large and stiff columns and guiderails, three kinds of ultrasonic transducer plates which have many transducers and ultrasonic instruments etc.

This machine enables highly accurate operation by rigidity and accuracy of its structures.

However, the machine is so large sized and heavy that it takes long time for maintenance and handling during inspection.

Our efforts have concentrated on reducing critical path time of reactor vessel ISI dramatically by reducing its weight and performing inspection with no use for plant's polar crane.

## 2 DESIGN PHILOSOPHY OF ADVANCED MACHINE

The following philosophy is the base of the design of the advanced machine.

(1) Reducing critical path time dramatically.
The current machine is placed on the vessel flange and uses three kinds of ultrasonic transducer plates to perform the required inspections.
To change and calibrate the ultrasonic transducer plates, the machine must be removed from the vessel flange.
This procedure requires long time during the vessle inspection.
To reduce those time, the advanced machine is designed to be small-sized, light-weight vehicle type and quite different from current column type.

(2) Maintain the high accuracy of positioning.
The structure of current machine makes it possible to keep rigidity and high accuracy.
To maintain high positioning accuracy, the advanced machine is designed as follows.
- It can move automatically and can set the position accurately by underwater positioning system.
  Conventional large-sized columns are disused.
- Inspection is made by the articulated manipulator of high rigidity and high path accuracy and no guide rails are used.

(3) Reliable data acquisition and evaluation.
To acquire all of UT data and to process them as A, B, C scope etc. by off-line also contribute to reduce time and reliability of inspection.
Optical fiber cable and fully computerized data acquisition and evaluation system make it possible to process a large amount of high quality data from many transducers in a short period.

(4) Complete satisfaction of the Code's requirements.
The ultrasonic examination method are in accordance with JEAC-4205, equivalent to ASME Code Sec XI.

## 3 DEVELOPMENT OF ADVANCED ULTRASONIC INSPECTION SYSTEM

Advanced ultrasonic inspection system has been developed for two, three and four loops reactor vessels of PWR plants to perform ISI and PSI in a short time.

The outline of this system is shown in Fig.2.

This system consists of vehicle which has manipulater, laser position orientating unit, their controller, multi-functional ultrasonic instrument/ transducer, and data acquisition/evaluation system.

This system is characterized by the following features.

(1) Small-sized, light-weight vehicle which has six axes manipulator can move automatically and be set on the all position of reactor vessel inspection area.

(2) Vehicle position can be set accurately by laser underwater position orientating system.

(3) Inspection is made by the articulated six axes manipulator having high rigidity and high path accuracy. The ultrasonic transducer plate is mounted on the free end of manipulator.

(4) Many transducers are used at the same time for flaw detection. UT signal

transmited from small sized multi-plexer set in the vehicle are transfered via optical fiber cable to UT instrument and all the data are stored on data acquisition system.
These data can be played back in order to evaluate flaw indications precisely by A, B, c Scope display etc. after completion of the scanning.

(5) The weight is very light so that plant's polar crane is not required for not only changing and calibrating the ultrasonic transducer plate but also assembling and dismantling the machine.

To realize this system, we have developed the following components.

(1) Small-sized, light-weight vehicle which travels on the underwater wall.
(2) Highly accurate, light-weight, watertight manipulator.
(3) Highly accurate laser underwater position orientating unit.
(4) Optical fiber cable which transfer UT signal from vehicle to UT instrument to reduce the cable weight and get high quality UT data.

These items are discribed as follows.

3.1 Small-sized, light-weight vehicle which travels on the underwater wall

The structure of the vehicle is shown in Fig.3.
This is composed from following parts.

(1) Main body
It is designed to be 0 kg underwater using buoyancy.
Several kinds of sensors and electical parts are installed in this body.
It has also 360° rotating axis and base axis of manipulator.
(2) Propeller
It has six propellers and can move vertical and holizontal direction of reactor vessel underwater using two and four propellers, respectively.
(3) Driving mechanism
It has four wheels of 4WD4WS and travels on the underwater wall freely.
(4) Adsorptive mechanism
It can adsorb on reactor vessel wall with making vacuum using water pump when inspection is performed.
(5) Laser target
It has corner cube made of glass which straighten itself and reflect the laser ray from laser underwater position orientating unit.

3.2 Highly accurate, light-weight, underwater manipulator

The structure of manipulator is shown in Fig.4.
Manipulator has six axes and vehicle has two base axes. Each axis from $M_1$ to $M_6$ of manipulator is driven by DC motor and encorder is used as position detector.
It has UT transducer plate and scan in any direction with approx ±2.5 mm scan path accuracy.
1 m$\ell$ x 1 m$^W$ area can be covered by this manipulator at one vehicle position.

3.3 Highly accurate laser underwater position orientating unit

The structure of the laser underwater position orientating unit is shown in Fig.5.
This unit installed on guide stud bolt can trace the vehicle's target automatically following the movement of vehicle.
When the vehicle stop on the wall of reactor vessel, the vehicle position can be got by measuring the length from the unit to the vehicle's target

using Ar laser.

The principle of laser position orientating is shown in Fig.6.

Circumferential and vertical direction position of reactor vessel can be got using the information of punchilt's θ and measuring distance D, respectively.

The accuracy of laser position orientating is approx ±2 mm and ±5 mm in θ and L direction, respectively.

3.4 Optical fiber cable which transfer UT signal from vehicle to UT instrument

Current UT machine has many UT cables as same as UT instrument channels and these weight are heavy for the reason that co-axis cable is used to prevent noise.

To reduce cable weight and get smooth movement of vehicle, optical fiber cable is preferable.

In this concept, small-sized multi-plexer which compose of high brid IC board has been developed and installed the body of vehicle.

## 4 TRIAL FABRICATION OF ADVANCED MACHINE

To confirm that our conception is feasible and test the machine's function using full scale mock-up of reactor vessel, we designed and fabricated prototype of vehicle, manipulator, laser position orientating unit and transducer plate etc.

Demensions of this prototype are approx 800 mm wide, 2000 mm long, 900 mm high and 300 kg (0 kg in water) in size and weight, respectively.

Protorype fabricated to use for functional test is shown in Fig.7,8.

## 5 FUNCTION TEST

We performed function test of prototype using full scale mock up of reactor vessel.

Test was conducted as the following items,

- speed of vehicle and manipulator movement
- accuracy of scanning, position orientating
- detectability of artificial defects contained in the mock up
- operability etc.

Test results and views are shown in Table.1 and Fig.9, respectively.

From these results, we were able to get satisfactory function data and have high expectations for fabrication of practical one.

## 6 CONCLUSION

Trial production of the advanced machine and functional testing lead us to believe that this system will be practical and effective to shorten critical path time of reactor vessel ISI.

Also, when we will fabricate the one for practical use in near future, we believe the size and weight to be reduced than prototype.

Based on the results obtained so far, we need to develop automatic control method using computer and refine the whole system to make it more suitable for practical application.

REFERENCES

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T.Sato, T.Yamamoto, I.Shirasu, A.Matuya S.Suyama, A.Koga

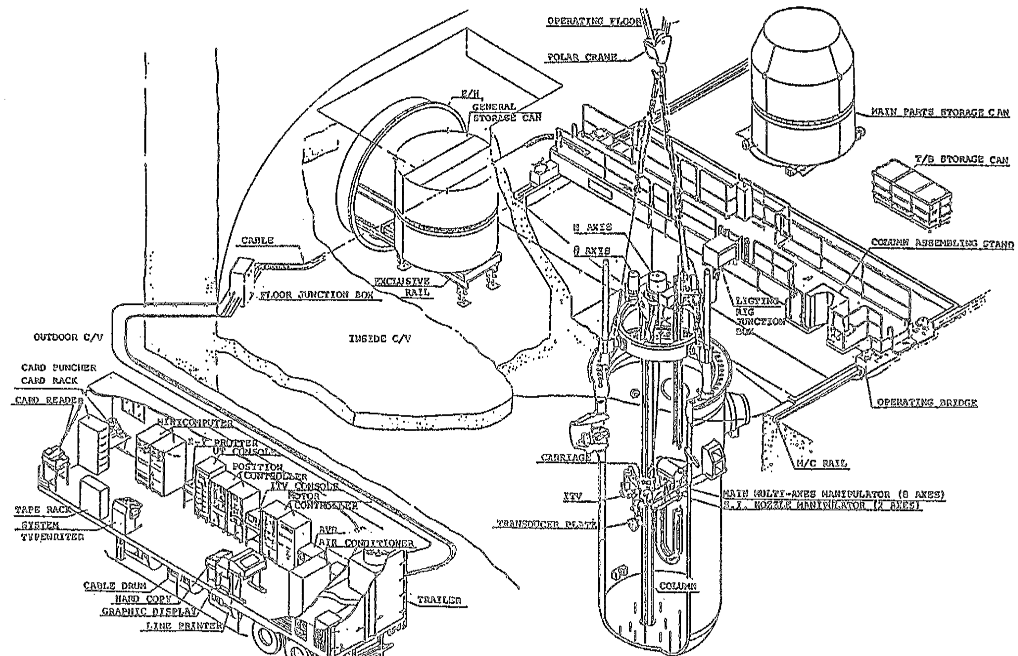



Fig. 1 - General view of current machine system

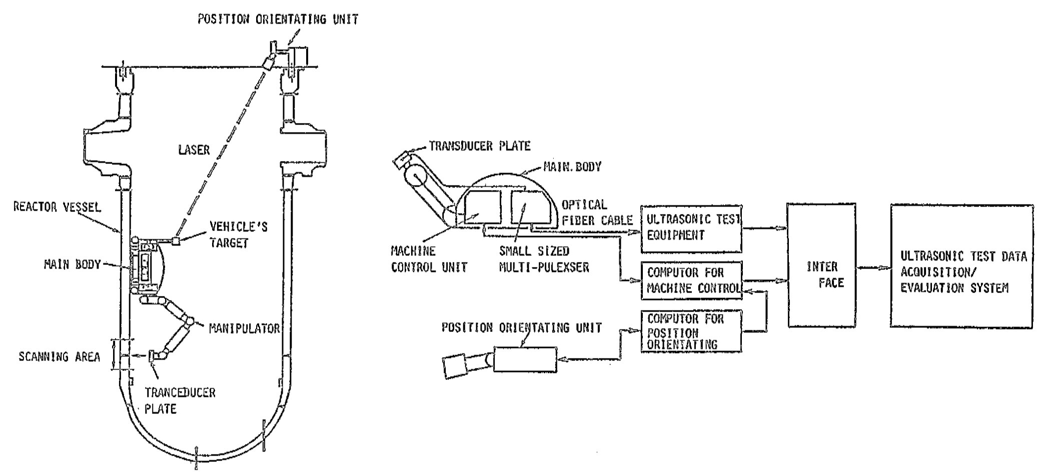



Fig. 2 - Advanced-UT machine system

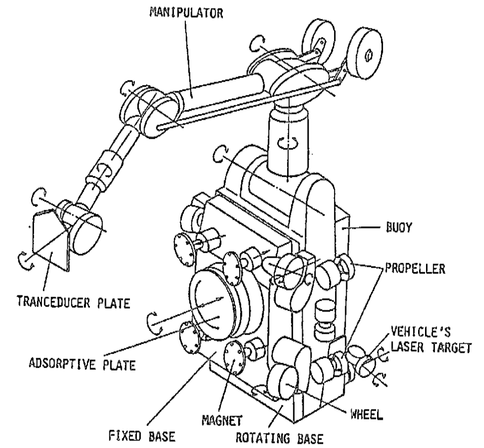



Fig. 3 - The structure of the vehicle

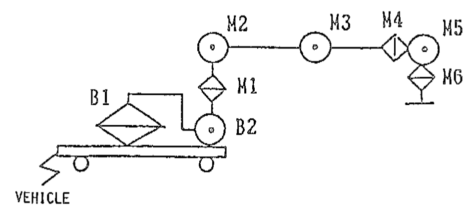



Fig. 4 - The structure of manipulator

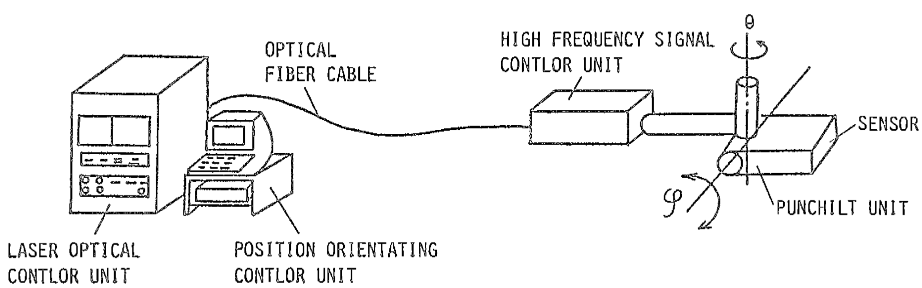
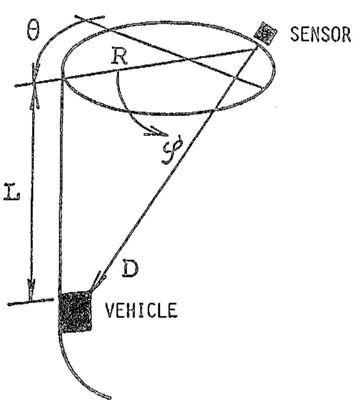



Fig. 5 - The structure of the laser underwater position orientating




CIRCUMFERENTIAL DIRECTION

θ : MEASURING ANGLE

VERTICAL DIRECTION

D : MEASURING DISTANCE BETWEEN SENSOR AND VEHICLE

$$L = D \cdot SIN\,(COS^{-1} \frac{R}{D})$$

Fig. 6 - The principle of laser position orientating

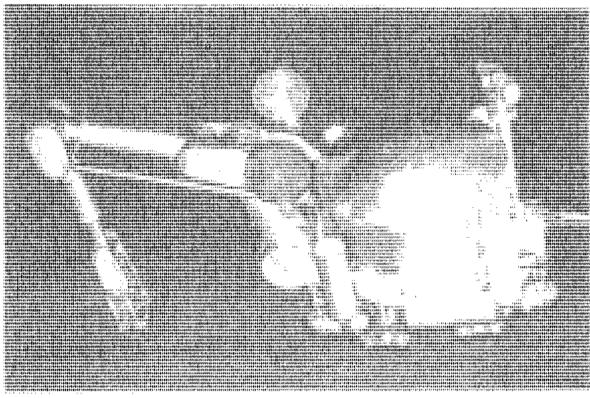
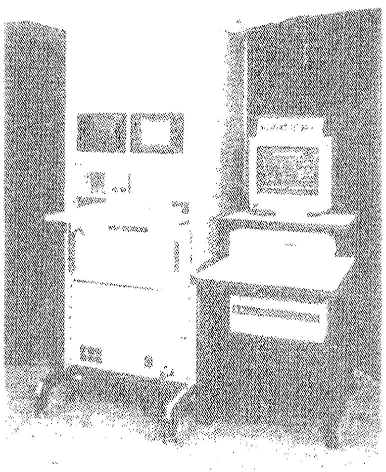
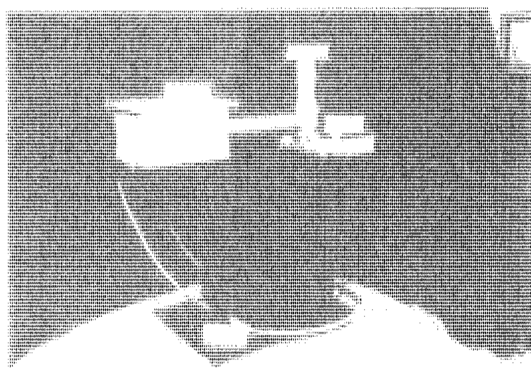


Fig. 7 - Prototype of vehicle and manipulator



LASER OPTICAL CONTROL AND
POSITION ORIENTATING UNIT



SENSOR AND PUNCHILT UNIT

Fig. 8 - Prototype of laser position orientating unit

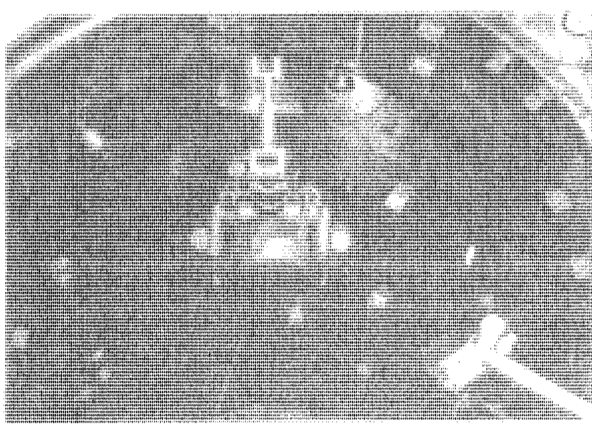


Fig. 9 - Function test using full scale mock up

Table 1 - Results of Function Test

| ITEM | TEST RESULTS |
|---|---|
| 1. FUNCTION | |
| ◦ DIVING SPEED | MAX 200mm/sec |
| ◦ MOVING SPEED (ALONG WALL) | MAX 200mm/sec |
| ◦ SCANNING SPEED | MAX 100mm/sec |
| 2. ACCURACY | |
| ◦ REPRODUCIBLE POSITIONING | ±5.0 mm |
| ◦ REPRODUCIBLE SCANNING PATH | ±2.0 mm |
| 3. DEFECT DETECTABILITY | ARTIFICIAL DEFECTS CONTAINED IN THE MOCK UP WERE DEFECTED |