Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Development of Exterior Wall Driving Robot for Inspection of the Insulated Pipe

Hyoung Tae Kim [a*] and Duck-Gun Park [b]
[a] *Intelligent Accident Mitigation Research Division, KAERI, Daeduk-daero 989-111, Daejeon, Korea*
[b] *AIPIT Inc., Daeduk-daero 989-111, Daejeon, Korea*
[*] *Corresponding author: kht@kaeri.re.kr*
***Keywords :** Insulated pipe, Defect, Pulsed Eddy Current (PEC) test, Exterior wall driving, Inspection robot

1. Introduction

The purpose of this research is to design and manufacture the inspection robot for the insulated piping so that defect of pipes covered with insulating materials can be measured externally without removing insulating materials.

Inspection robots inside aging underground pipes or oil pipes are being actively studied, but exterior wall driving robot for inspection of pipe outer walls has not yet been developed. In addition, pulse eddy current (PEC) technology [1,2] can measure defect of pipes covered with thermal insulation from the outside without removing thermal insulation.

Therefore, this PEC technology will be applied to an exterior wall driving inspection robot developed in this study.

2. Robot Design and Modules

In this section exterior wall driving robot [3,4] for inspection of the insulated pipe is introduced by describing the main robot modules.

2.1 Key Design Specifications

- Travelable piping external diameter (as of current design): 380 mm to 420 mm
- Driving speed: 50 mm/s or higher
- Position precision: ±5 mm / 1000 mm
- Maximum loading load: 1.5 kg
- Robot length: 1018 mm
- Robot weight: Approximately 36 kg
- Travelable pipe minimum curvature: 200 mm or more
- Power supply: Driving wirelessly powered by its own battery
- Manipulation: Wireless remote control

2.2 Robot Drive and Sensor Modules

2.2.1 Drive modules

In order to drive the robot along the pipe, the pipe is held, the roller is closely attached, and the roller is driven to drive straight, and the pipe is also rotated in the circumferential direction. Figure 1 shows the robot modules and their functions are listed in Table I. The roles of Module units 1 (Fig. 2) and 2 are the same, and only some parts have different dimensions.

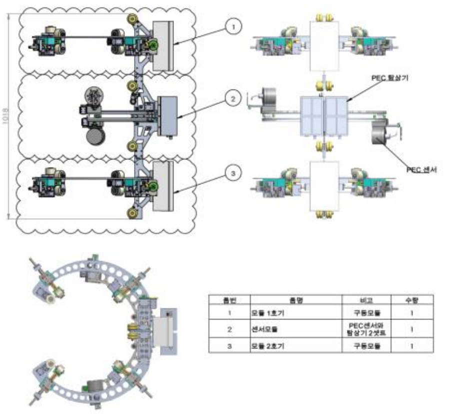

Fig. 1. Overall view of the robot drive modules: (1) Unit 1 module, (2) Sensor module, (3) Unit 2 module.

Table I: Functions of the Modules

Module	Functions
Unit 1	Responsible for forward, backward, and rotational driving of the robot
Sensor	Inspect pipe circumference using PEC sensor and detector
Unit 2	Responsible for forward, backward, and rotational driving of the robot

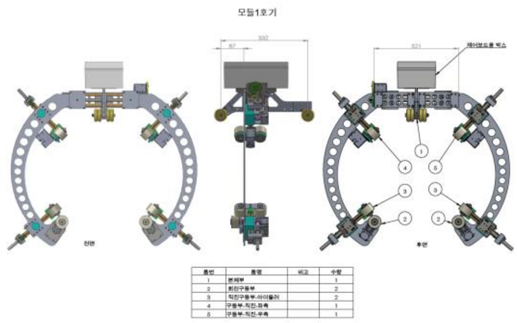

Fig. 2. Detailed view of the module unit 1.

The Drive module (for unit 1 and unit 2) consist of the main body, rotating drive, straight drive-idler, and drive-straight/left/right.

(1) Main body

The main body (Fig. 3) consists of a control board box, two grippers, and a gripper opening/closing operation. It can remove the robot from the pipe by opening and closing the gripper. The lead screw is rotated by the driving motor, and the gripper fixing block attached to the lead screw moves straight from side to side along the guide bar to open and close the gripper fixed to the gripper fixing block.

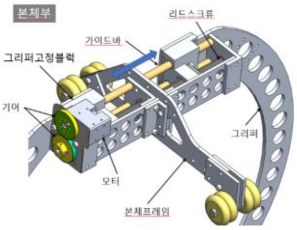

Fig. 3. Main body.

(2) Rotating drive

The rotating drive (Fig. 4) is 2 sets per module, consisting of a rotating motor and roller, responsible for rotating the robot in the circumferential direction of the pipe.

The gear rotates by the driving motor and the connected roller rotates, rotating the entire robot in the circumferential direction. The pipe adhesion of the rotation driving unit is operated by the gripper opening/closing operation unit of the main body.

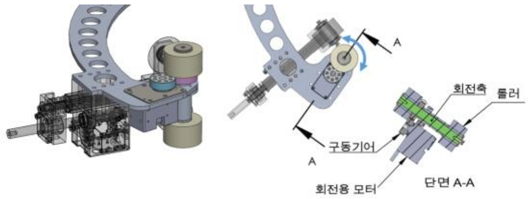

Fig. 4. Rotating drive.

(3) Drive-Straight/Left/Right

The drive-straight/left/right (Fig. 5) is 2 sets per module and consists of a pusher that drives the roller up-down and a motor that drives the roller. When the robot is running before and after, the motor operates to rotate the roller, so the robot moves.

The rotation of the robot by rotating the roller in close contact with the pipe. The lead screw is rotated by the wheel up/down motor, and the guide bar attached to it is up/down to attach the roller to the pipe (Pusher device). When the roller adheres to the pipe, the wheel drive motor rotates the roller through the gear to create the robot's forward and backward movement.

(4) Straight drive-idler

The straight drive-idler is 2 sets per module, consisting of a pusher that lifts and lowers the roller which hold the pipe so that the robot runs before and after. The roller is not for drive, but there is no roller drive motor

Parts related to the wheel drive motor are excluded from the straight driving part, and the roller is closely attached to the pipe when driving straight, so that the robot does not deviate from the pipe, and the roller is not directly driven. The driving of the robot is carried out by a wheel-driven motor in the driving part-straight forward part, and this part serves to guide the robot while it is in close contact with the pipe by a pusher.

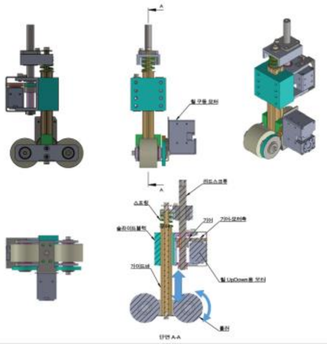

Fig. 5. Drive-Straight/Left/Right.

2.2.2 Sensor Module

The sensor module (Fig. 6) rotates the PEC sensor and measures it by closely attaching it to the pipe, and modules 1 and 2 are connected back and forth, so they move according to the driving of modules 1 and 2.

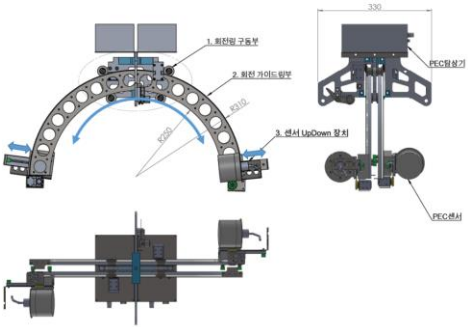

Fig. 6. Sensor module.

(1) Rotating ring drive

The rotating guide ring is supported by a guide roller so that the rotating ring to which the sensor is attached moves along the arc. Since the 2 sets of rotating rings must be supported, 8 guide rollers are attached to the front and rear of the driving unit.

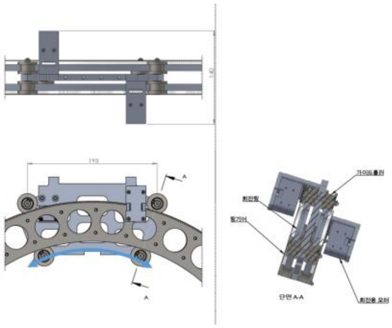

Fig. 7. Rotating ring drive.

(2) Rotating guide ring

It is a rotating ring with a PEC sensor at the end and is powered by a motor so that the 2 sets move symmetrically. The rotating ring has stoppers at both ends, limiting the range of rotation.

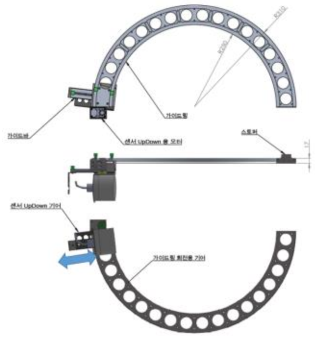

Fig. 8. Rotating guide ring.

(3) Sensor up/down device

When measuring, the sensor is brought into contact with the pipe, and when moving, it is raised. The guide bar with the sensor is moved by the motor and rack gear.

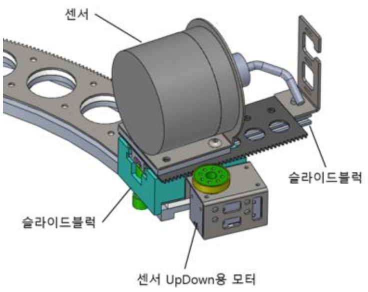

Fig. 8. Rotating guide ring.

2.3 Prototype of Exterior Wall Driving Robot

A prototype of exterior wall driving robot was manufactured and has been tested in test mockup (Fig. 9) for the insulated pipe line including a vertical, curved, and horizontal sections.

Fig. 9. A prototype of robot mounted on the exterior wall of pipe.

3. Conclusions

The previous version of robot driving is a step-by-step operation with three modules and six grippers, so it has to take several steps to complete a cycle, so the speed is inevitably slow. In addition, during the forward and backward process, a step of releasing the gripper that was holding the pipe is essential, and as soon as the gripper is released, the module sags slightly downward. In addition, when the gripper is released and moved back and forth, the roller at the end of the gripper hits the pipe and interferes with driving, making the module more inclined, causing the robot to become unstable. In a word, most driving problems occur in the process of loosening and tightening the gripper, so the fundamental solution is to remove the loosening and tightening motion. Therefore, for its fundamental improvement, the method of driving by direct rotation of the wheel has been switched from a step-by-step operation method of loosening and holding the gripper.

This method eliminates the process of loosening and tightening the gripper because the wheel continues to hold and drive the pipe. Instead, the direction of the wheel is different when the robot goes straight and rotates, so only one of the two must be attached to the pipe, so a pusher device that adheres and detaches the wheel to and from the pipe is required.

Therefore, in the new model of the wheel drive method, a pusher device was added to create two types of wheel sets for straight and rotating and attach them to and from the pipe. Two sets of wheels for straight driving, two sets for straight children, and two sets for rotation were added per module, increasing the overall weight and number of parts.

As a result of the test, the speed has increased considerably compared to the previous one because the wheel is rotated, and the driving performance of the curved pipe has also improved compared to the previous one. However, since the wheel must be driven and the wheel set must always be in close contact with the pipe, the number of motors operated at the same time increases, causing a battery power capacity problem, which is one of the challenges to be solved in the future.

REFERENCES

[1] H.T. Kim and D.G. Park, Development of a Deep-Learning-Based Flaw Detection Algorithm for Analysis of Pulsed Eddy Current Nondestructive Test Data, Proceedings of Korea Nuclear Society KNS Autumn Meeting, Oct.20-21, 2022, Changwon, Korea.

[2] A. Sophian, G. Tian, and M. Fan, Pulsed Eddy Current Non-destructive Testing and Evaluation: A Review, Chin. J. Mech. Eng. 2017.

[3] A. Nayak and S.K. Pradhan, Design of New In-Pipe Inspection Robot, Procedia Engineering, Vol.97, p. 2081, 2014.

[4] J. Lin, Z. Ren, and X. Hong, A new type of vertical wall-climbing robot, J. of Physics Conference Series, Vol2366, 2022.