Development of Climbing Testing Machine for Concrete Wall Using Impact Acoustics

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Abstract
We developed a remote-controlled testing machine for vertical concrete walls. This testing machine adheres to the concrete wall by two sets of suction cups, and climbs the concrete wall by the alternating motion of the two sets of suction cups. The impact acoustic method is used in this testing machine. This testing machine has a tapping mechanism and a microphone for the acquisition of the impact sound. The impact sound is converted into an electrical signal and transmitted to a computer through electrical cables. The weight and the dimensions of the testing machine are about 19 kg and 1.0 m by 0.8 m, respectively. This testing machine climbs the concrete wall at a speed of one meter per minute. The effectiveness of the system of the impact acoustic was tested by applying the system to an inspection of a specimen with an artificial circular void defect. A circular void defect with a diameter of 200 mm at a depth of 25 mm was able to be detected.

Keywords: Impact Acoustic Method, Remote Control, Testing Machine, Concrete, Non-Destructive Test

1. Introduction

A lot of concrete structures are deteriorating to dangerous levels throughout Japan. These concrete structures need to be inspected regularly to be sure that they are safe enough to be used. The inspection method of these concrete structures is typically the impact acoustic method. In the impact acoustic method the worker taps the concrete on the surface with hammer. So it is necessary to set up scaffolding to access vertical structures for inspection. However, setting up of high scaffolding is not economical in time and money. Moreover setting up scaffolding is difficult on very high concrete walls.

So we develop a remote-controlled testing machine for vertical concrete walls as shown in Fig. 1. This testing machine adheres to the concrete wall by two sets of suction cups, and climbs the concrete wall by the alternating motion of the two sets of suction cups. The impact acoustic method is used in this testing machine.

Figure 1. Wall-climbing machine
The advantage of this climbing testing machine is that scaffolding is not necessary. It takes a lot of time and effort to set up scaffolding. The machine dramatically improves the speed and cost of concrete wall inspection. The machine is also able to make inspections at height. Recently high concrete structures have been constructed such as 50 m high bridge piers. There are piers of bridges with a 100 m height above ground. It is unrealistic for workers to inspect such inaccessible places.

2. Climbing testing machine

The climbing testing machine has an adhesion mechanism, a climbing mechanism and a tapping mechanism. The dimensions of the climbing testing machine are 104 cm length, 80 cm width and 24 cm height. The weight is 19 kg.

2.1 Adhesion mechanism

In literature one can find multiple kinds of propulsion and adhesion mechanisms and systems for climbing robots. Common and well-known methods are, e.g. passive suction cups [1-3], molecular adhesion [4, 5], magnetic adhesion [6, 7], and claws [8-10]. The adhesion technologies of molecular adhesion, magnetic adhesion, and claws are not suitable for inspecting vertical concrete structures. Using the molecular adhesion and claws, it is difficult to obtain enough adhesion force. Especially because there are counter forces generated when using the tapping mechanism. Therefore, relatively strong adhesion forces are needed. Using the magnetic adhesion, the adhesion isn't able to obtain enough adhesion force because concrete is not a magnetic substance. Therefore, we adopted the passive suction cup method.

2.2 Architecture of the climbing testing machine

Figure 2 shows the architecture of the climbing testing machine we have developed. This machine has eight suction cups, and strongly adheres to concrete wall. Four suction cups A and C or four suction cups B and D are connected to each other. The two sets of suction cups move in relation to each other to create rotational motions by one rotary actuator and linear motions by two linear actuators. The power is supplied through electrical cables from ground.

![Figure 2. The architecture of the climbing testing machine](image)
This climbing testing machine uses a tapping mechanism for the impact acoustic method. The mechanism consists of two rotating steel ball with a diameter of 16 mm and two reduction geared motors. A reduction geared motor drives the mechanism so that two steel balls tap the wall four times a second. The reduction geared motor with the two tapping steel balls swings like a pendulum at an angle of 70 degrees. The swing frequency is 0.5 Hz.

![Diagram of tapping mechanism](image)

**Figure 3.** A tapping mechanism for the impact acoustic method

### 2.3 Mechanism of climbing walls

Figure 4 shows the configuration of the machine to climb up. Figure 4 (a) shows the configuration of the machine when the suction cups A and C are in operation to support the main body of the machine. In the next stage in Fig. 4 (b), the suction cups B and D are lifted up. The suction cups B and D are in operation, and the suction cups A and C are out of operation as shown in Fig. 4 (c). Finally, the main body of the machine is lifted up by the two linear actuators. Repeating these operations, the climbing testing machine is able to climb up walls. The inverse operation lets the climbing testing machine climb down walls.

Figure 5 shows the configuration of the machine to climb diagonally. Figure 5 (a) shows the configuration of the machine when the suction cups A and C are in operation to support the main body of the machine, and the set of suction cups B and D is put at an angle. In the next stage in Fig. 5 (b), the suction cups B and D are lifted up diagonally. The suction cups B and D are in operation, and the suction cups A and C are out of operation as shown in Fig. 5 (c). Finally, the main body of the machine is lifted up diagonally by the two linear actuators. Repeating these operations, the climbing testing machine is able to climb up walls diagonally. This machine is not able to move in the horizontal direction. One set of climbing up and down with the counter angles allows the machine to move in the horizontal direction.
(a) Sanction A&C ON and B&D OFF

(b) Sanction B&D UP

(c) Sanction B&D ON and A-C OFF

(d) Sanction A&C UP
diagonally

Figure 4. Mechanism of climbing up

(a) Sanction A&C ON and B&D OFF

(b) Sanction B&D UP diagonally

(c) Sanction B&D ON and A-C OFF

(d) Sanction A&C UP diagonally
diagonally

Figure 5. Mechanism of side movement
3. Experiment

3.1 Climbing walls

We tested the ability of the climbing of the testing machine and the tapping mechanism. The circumstances of the climbing are shown in Fig. 1. The speed of the climbing was about one meter per minute in comparison with the linear actuator speed of three meters per minute. This deference comes from manual operations. As mentioned above the one step of climbing up needs four operations as shown in Figs. 4 and 5. The switching takes a long time.

3.2 The impact acoustic method

We applied the tapping mechanism to two types of walls. One has no defect, the other a circular void defect. Figure 6 shows the wall having a circular void defect with a diameter of 200 mm. The depth of defect is 25 mm.

![Concrete wall with a circular void defect](image)

Figure 6. Burst elastic waves

The surfaces of the walls were tapped on by the steel balls and the tapping sound was acquired by a microphone. The sound pressure signals in the time domain were converted into the frequency domain signal by the Fourier transformation (FFT). Figure 7 shows the FFT results of a wall without a defect. We can see there is no dominant peak in the frequency spectrum. This means there is no defect.

![Frequency spectrum of a surface without a defect](image)

Figure 7. Frequency spectrum of a surface without a defect
Figure 8 shows the FFT results of a wall with a circular void defect. We can see there is a sharp peak at 2.6 kHz. This peak shows there is a defect. The vibration of this peak is the flexural vibration of the disk between the specimen surface and the circular void defect.

![Figure 8. Frequency spectrum of a surface with a defect of 200 mm diameter at 25 mm depth](image)

6. Conclusion

We have developed a climbing testing machine for concrete structures. The machine is able to adhere and climb up vertical concrete walls at a speed of one meter per minute. It has a tapping mechanism so that is able to detect defects by using the impact acoustic method.

However, the machine has some problems. One problem is its low speed. Another problem is the heavy weight of power cables. The reliability of the adhesion is also a problem. Therefore in the next prototype we aim to

1. Automate the movement of the climbing testing machine. That is, we will turn the machine into a robot. This improvement will improve the speed to over two meters per minute.
2. Make the body and the power cables lighter. Specifically, we will use lighter actuators and the amount of cables will be reduced. Our final target will be to remove the power cables altogether and replace them with a remote power transmission such as microwave or lazer transmission technologies.
3. Mount pressure sensors on the suction cups to improve the reliability of the adhesion.

References