

The development and testing of a mobile drilling robot

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ABSTRACT

A mobile drilling robot has been developed by TNO Building and Construction Research in cooperation with Dutch industries. This robot will be used for drilling holes for, among others, anchor bolts for fastening railway tracks to a concrete foundation or holes for starter bars. One of the design criteria was the high level of accuracy of the location of the holes: ± 2 mm, which is extraordinary for a construction site.

In this paper a comprehensive description of the drilling robot is presented, including the structure with its components and the control systems. Laboratory results and the on site tests in an underground railway station at Amsterdam airport are also presented.

1. INTRODUCTION

Hollandsche Beton- en Waterbouw (HBW), a subsidiary of the HBG Group, and TNO Building and Construction Research initiated research, development and implementation of a drilling robot. Together with Strukton Group and Hilti Nederland a foundation, called Robouw, was formed.

HBW and Strukton are working on the doubling of the railway tunnel and underground station at Amsterdam airport. Approximately 20,000 holes, with a diameter of 37 mm and a depth of 130 mm, have to be drilled for the fastening of the rails to the concrete

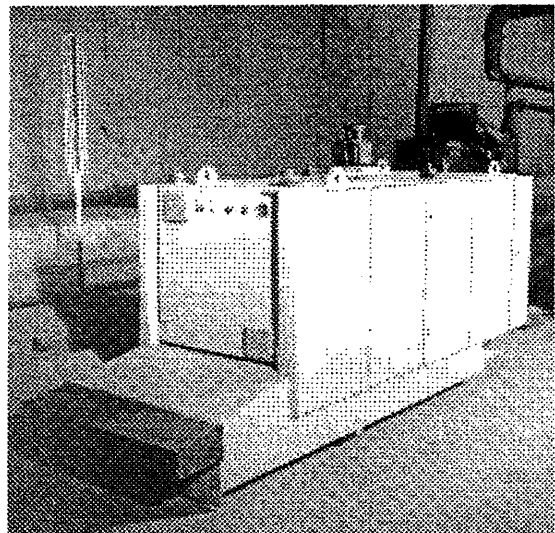


Figure 1. Drilling robot.

slabs by anchor bolts on the floor of the railway tunnel with high accuracy requirements. Another 100,000 holes, with a diameter of 20 mm and a depth of 350 mm, have to be drilled in the tunnel floor to insert starter bars for concrete footpath edges. This drilling is hard and unhealthy work.

The most important benefits of the use of the drilling robot are:

- the elimination of the hard and unhealthy manual drilling work,
- the automation of the labour intensive surveying work required for the positioning of the rails (minimizes the possibility of mistakes),
- the combination of surveying and drilling in one machine.

The actual research and development of the drilling robot has been carried out by TNO Building and Construction Research in cooperation with the Robouw foundation. After analysing the tasks of the drilling robot in 1991/1992, two experiments were carried out successfully [1].

- On site testing of TNO's positioning sensor Capsy [2, 3] to find out whether or not this sensor would be accurate enough for the rail fastening application.
- The development and testing of an automated test drilling unit.

The prototype drilling robot, including the control systems, was developed and built in 1992/1993. Laboratory tests at TNO Building and Construction Research were carried out with promising results. In November and December 1993 on site experiments were carried out in the railway tunnel at Amsterdam airport.

2. DRILLING ROBOT

The main components of the drilling robot are the robot vehicle, the drilling unit, the reinforcement detector, the positioning sensor (Capsy) and the auxiliary equipment (see figure 2).

2.1. Robot vehicle

The robot vehicle integrates all components within a rigid frame. The only connection with the environment is an electric power supply cable of 380 volt.

Figure 1 shows a picture of the drilling robot. The overall dimensions of the vehicle are 2.3 m long, 0.9 m wide and 1.4 m high, the total weight is approximately 1000 kg. The prototype robot vehicle is robustly designed for use on a construction site.

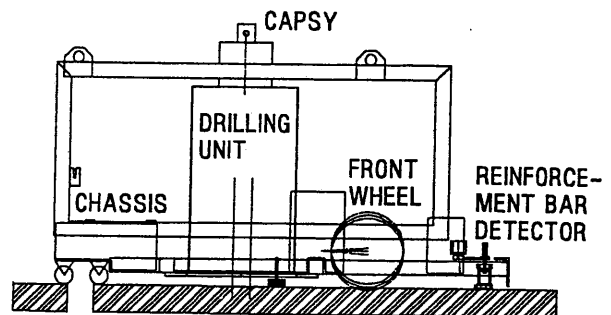


Figure 2. Outline of the robot vehicle.

At the back of the robot vehicle a number of simple wheels (only rotatable as wheels) are mounted. At the front of the vehicle a single, electric driven wheel is mounted for traction and steering. A special steering mechanism has been used, designed for operation of the robot vehicle in nearly straight lines. Except for the rotation of the wheel itself, the front wheel has two degrees of freedom: it can be moved sideways (left/right) and vertically (raised/lowered). The wheel cannot rotate about a vertical axis. Together with the back wheels, this mechanism has a double function: it can turn the robot vehicle to the required orientation (heading) and it can adjust the position of the drilling unit in transverse direction (left/right). With the front wheel in lowered position the front of the vehicle can move 40 mm to the left or to the right. Consequently the orientation (heading) and position of the vehicle changes. When the required orientation/position of the robot vehicle has been reached the wheel is raised, set in the centre position and lowered again. This cycle can be repeated as often as necessary to get the right orientation or position. During the drilling the front wheel is raised and the vehicle rests on its back wheels and two fixed supports near the drilling unit.

2.2. Drilling unit

The drilling unit is placed in the centre of the vehicle. The unit contains two hammer drills which can drill two holes simultaneously. The hammer drills are set in position corresponding to the distance between the holes in the base-plates which fasten the rails to the concrete floor. Each hammer drill has its own guidance and control system. The cladding of the drilling unit reduces the noise level and provides stability for the drill guidance mechanism.

Figure 3 shows a picture of the drilling unit with the two hammer drills. It consists of the following main components:

- hammer drill, Hilti model TE 74,
- vertical guidance mechanism,
- pneumatic cylinder for vertical movement of the hammer drill,
- pneumatic safety brake.

The drilling process is controlled by a personal computer. It activates the drill and controls the drilling forces. The power consumption and the vertical position are measured.

The complete drilling unit can be rotated about a vertical axis and fixed on the robot vehicle at any required angle. For more details see [1].

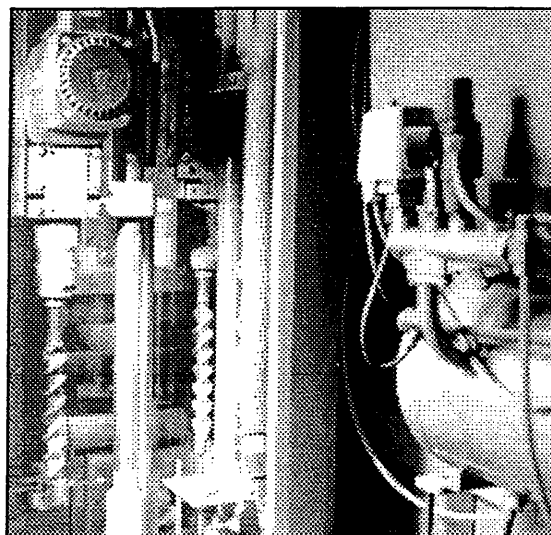


Figure 3. Drilling unit.

2.3. Reinforcement detector

A reinforcement detector is placed at the front of the vehicle in order to avoid damage to the drilling bits due to possible collision with the reinforcement bars. Moreover, any electrical contact between the rails, when mounted, and the reinforcement bars must be avoided. If necessary, the positions of the holes to be drilled will be changed (see also section 3.3.). During the drilling of a certain set of holes the measurements are carried out for the determination of the position of the reinforcement bars for the next holes. Figure 4 shows a picture of the reinforcement detector.

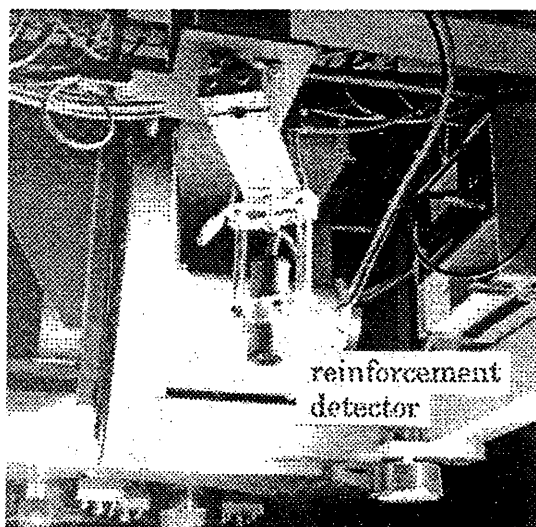


Figure 4. Reinforcement detector (bottom view).

2.4. Positioning sensor

For the positioning of the drilling robot the Capsy positioning sensor is used (Capsy stands for Computer Aided Positioning SYstem). This sensor has been developed by TNO-Building and Construction Research and is based on a triangulation measurement by means of a rotating laser beam [2, 3]. The sensor uses reference reflectors. For the locations of the reflectors reference is made to [1]. The positions of these reflectors are to be measured before operation of the robot vehicle. In spite of the difficult shape of the working area (long and narrow) the Capsy sensor fulfilled the requirements.

Capsy is mounted on top of the robot vehicle (see also figure 1 and 2). Corrections are made for roll and pitch angles of the robot vehicle due to unevenness or inclination of the concrete slabs. An algorithm calculates the corrections in lateral and transverse directions measured by a tilt sensor on the base of the robot vehicle.

2.5. Auxiliary equipment

The drilling robot is equipped with:

- a vacuum cleaner to exhaust and collect the bore dust,
- a low noise air compressor for the drill feed and vertical movement,
- a tilt sensor for roll and pitch angles of the robot vehicle,
- several safety devices, such as:
 - light and noise warning signals,
 - emergency buttons,
 - safety bumpers with tactile sensors.

3. CONTROL SYSTEMS

The control systems of the drilling robot consist of the overall control system, the drilling process, the reinforcement detection process and the path planner.

3.1. Overall control system

In order to commence operation the drilling robot must know both the coordinates of the holes to be drilled and the coordinates of the reflectors (for the positioning sensor).

The overall process is controlled and monitored by a personal computer. The drilling process cycle consists of the following steps:

1. fetching of the locations of the next holes (position, orientation and depth),
2. measurement of the current position of the drilling robot,
3. path planning (section 3.4.),
4. movements of the drilling robot,
5. verification of the new position (is it close enough to the desired position; if not the process restarts with step 2),
6. lowering of the drills, drilling of the holes and retracting of the drills; during this process drilling data is collected (section 3.2.),
7. measurements with the reinforcement detector (simultaneously with the drilling step 6, section 3.3),
8. logging of the drilling process data.

3.2. Drilling process

The control scheme of the drilling process is shown in figure 5. If the machine is not drilling, the vertical motion is position controlled. During the actual drilling of the hole, the vertical movement (drill feed) is force controlled.

3.3. Reinforcement detection process

The reinforcement detector at the front of the vehicle takes samples, along a circular path with a diameter of ± 290 mm, every 10 degrees. From the collected data the position of the rectangular reinforcement bars is determined.

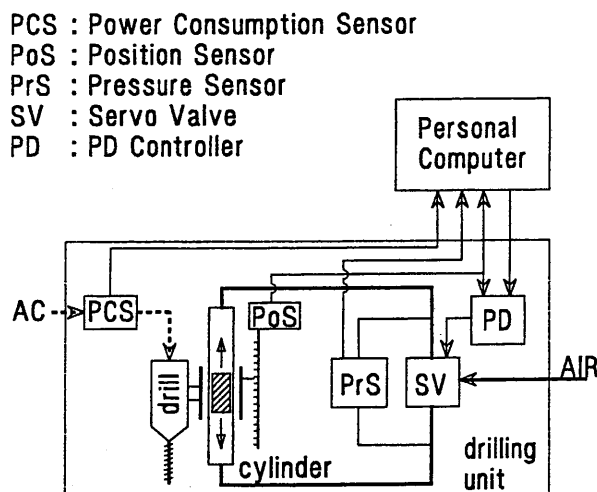


Figure 5. Control of the drilling process.

The detector algorithm is based on a periodical grid with unknown pitches in x- and y-direction (see figure 6). Relative to this grid, the centre of rotation of the detector can be expressed with an unknown offset in x- and y-direction. With about 36 measurements the four unknown quantities (two pitches and two offsets) are calculated using the 'least square' method.

If reinforcement steel is present at the hole locations to be drilled the necessary offset is determined and it is checked whether or not this offset is within defined limits.

3.4. Path planner

Because the drilling robot is equipped with two drills working simultaneously both the horizontal position (x, y) and the orientation (heading) of the drilling robot must be correct. This is achieved by means of a path planner (see figure 7). First the orientation of the robot vehicle is adjusted by a transverse displacement (section 2.1.) of the front wheel (a), then the vehicle is moved in the forward direction (b) and finally the orientation of the vehicle is adjusted again by a transverse displacement of the front wheel (c). Following this strategy a correct position and orientation of the drilling robot is achieved.

If, due to the limited manoeuvrability of the robot in transverse direction, the desired position cannot be reached in one manoeuvre, then the robot will, after the last orientation adjustment (c), be moved in astern direction.

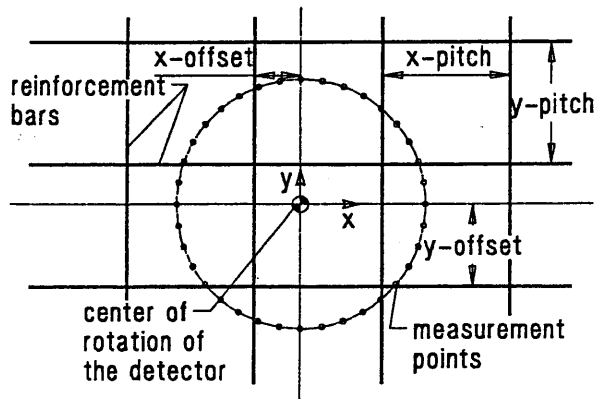


Figure 6. Principle of the reinforcement detection.

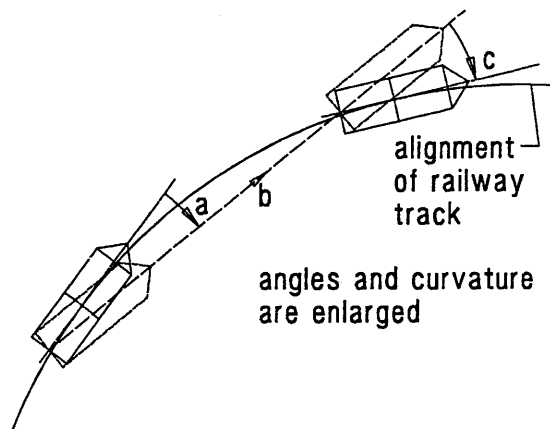


Figure 7. Path planner.

4. EXPERIMENTAL RESULTS

The first tests of the drilling robot were carried out at the laboratory of TNO in a simulated tunnel environment. The total working cycle of the robot vehicle with its positioning sensor was evaluated.

After finishing these tests with promising results, experiments were started on the construction site at Amsterdam airport. A special straight part of the tunnel was prepared, consisting of three sections, with a total length of approximately 60 m. In this test set-up eight reference reflectors were used, four located at the end of the rails of a section and four beside the section distributed over its length [1]. A surveyor marked the positions of the reflectors using a standard theodolite. In this way about 400 holes (diameter 37 mm) were drilled by the drilling robot.

The accuracy of the position of the drilled holes within a certain reflector set-up is ± 1 mm in transverse and ± 4 mm in lateral direction of the rails. The reproducibility of the position of the system within a reflector set-up is ± 0.5 mm. This turned out better than expected. Notably, the accuracy in transverse direction is the most important, because this determines the alignment of the railway track. It appeared that the transversal position is best determined using only the four reflectors placed at the ends of the sections. For the determination of the lateral position also the four reflectors beside the section are used.

The total time for one complete drilling cycle (section 3.1.) is about 4.5 minutes; ± 1.5 minutes for moving and positioning the drilling robot and ± 3 minutes for the drilling of two holes depending on the wear of the drilling bit. After the movement of the drilling robot to the next location on the concrete slabs generally one adjustment cycle appeared to be sufficient to reach the desired position.

In the beginning of 1994 the rails will be mounted to the drilled holes. The complete rail installation procedure from the positioning of the reflectors until the mounting of the rails will then be evaluated.

CONCLUSION

The following can be concluded.

- Automated drilling of relatively large diameter holes in concrete floors with a hammer drill is possible. Hard and unhealthy manual drilling work can be eliminated.
- The positioning sensor Capsy is suitable for moving and positioning an Automated Guided Vehicle (in this application a mobile drilling robot) on a construction site.
- Within a certain reflector set-up in a narrow tunnel environment (typically 4 m width) a desired position can be reached with an accuracy of ± 1 mm in transverse and ± 4 mm in lateral direction. The reproducibility is ± 0.5 mm. The

difference in accuracy between transverse and lateral direction is due to the restrictions of the reflector set-up in a narrow tunnel.

- The labour intensive surveying work can be partly automated because the drilling robot is able to position itself. The tasks of the surveyor in this application have been changed. They now position the reference reflectors of the Capsy positioning sensor and provide the drilling robot with these locations and the locations of the holes to be drilled. An approach to provide these locations using CAD data is presented in [4].

The following further developments/activities are mentioned.

- Testing of the drilling robot in curved alignment sections.
- Improvements of the reflector set-up; e.g. longer sections (40 m to 60 m) and/or less reflectors per section.
- Recognition of undesirable situations such as fractured or worn drilling bits.

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