Automation and Robotics in Construction X
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The development of a drilling robot for the installation of railway tracks

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Abstract

TNO Building and Construction Research is developing an autonomous drilling robot. This robot is to be used for drilling holes for anchor bolts which fasten rails to concrete slabs. Special features of this drilling robot are: it's high precision and the relative large diameter of the holes it can drill. This paper presents the background of the project, the design of the drilling unit and robot vehicle and the experiments carried out so far.

1. INTRODUCTION

Currently a joint venture of Dutch contractors (called the "Schiphol Railway Tunnel Combination": KSS) is working on the expansion of the railway station at Amsterdam airport. This railway station is an underground station which will be doubled in capacity over the next years. One of the activities to be carried out is the drilling of approximately 20 000 holes for the fastening of the rails to the concrete slabs on the floor of the railway tunnel. Besides the drilling of the 20 000 holes for the rails, another 100 000 holes have to be drilled in the tunnel floor to insert starter bars for the concrete footpath edges at both sides of the tunnel outside the station area.

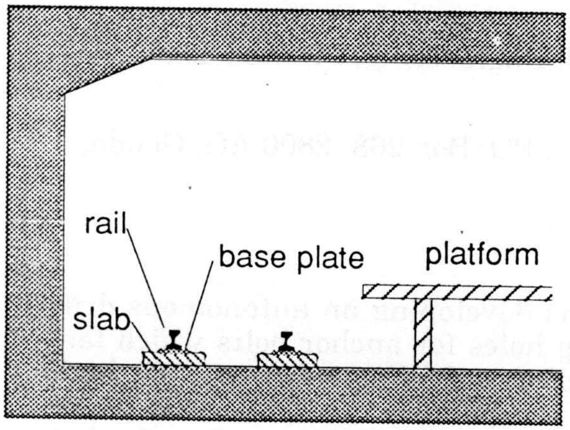
An initiative was taken to develop an autonomous drilling robot for this task. This will be discussed in more detail in section two. A special foundation called 'Robouw' was formed. The participants in this foundation are:

- HBW B.V.: a general contractor part of the HBG group, member of the KSS joint venture,
- Strukton Groep N.V.: a general contractor, specialised among other activities in rail road building; member of the KSS joint venture,
- Hilti Nederland B.V.: the Dutch sales representative of the drilling machine and mounting devices manufacturer Hilti in Liechtenstein.

The actual development of the drilling robot is carried out by TNO Building and Construction Research in co-operation with the Robouw Foundation.

1.1 The application

Most railways are built using a ballast bed system. In this system, the rails are fastened to (concrete) sleepers which are laid in a gravel bed. However, in stations this system has a drawback. The metal particles produced by the wear of the rails and wheels collect in the gravel bed and are blown around and cause rust stains in the station. Therefore, a ballast-less system, called slab track system is used. In this system the rails are fastened to concrete slabs on the tunnel floor every 60 cm using base-plates. The concrete slabs are 0.85 m wide and 3.45 m long. Figure 1a shows a cross section of the tunnel. Figure 1b shows the layout of the slabs and the base-plates in a section of the tunnel. Between the slabs there is a gap of 0.15 m in lateral direction and 0.60 m in transversal direction.



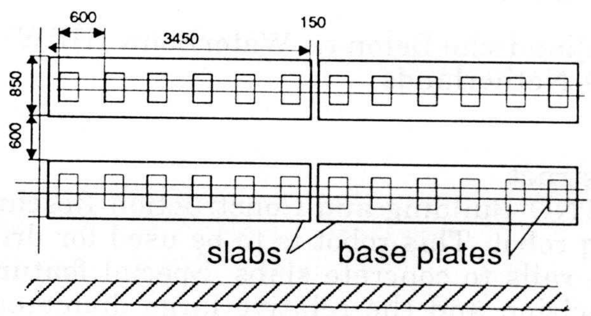


Fig.1a: Cross section of tunnel Fig.1b: Top view: Layout of slabs and base-plates

The base-plates are fastened to the slabs with two resin anchor bolts. These anchor bolts are glued into holes drilled in the concrete slabs. A pre loaded spring and nut hold the base-plate to the floor. The holes needed for anchor bolts have a diameter of 37 mm and are 130 mm deep. In total three railway tracks of each approximately 1000 m length are to be built using this system.

Although the drilling robot will de designed primarily as a tool for the installation of rails, reconfiguration of the robot for other drilling jobs must be possible.

2. HOW IT STARTED

Being aware of numerous experiments all over the world, the interest rose within HBW to gain experience and knowledge on the benefits and costs for construction robots. Simultaneously TNO Building and Construction Research had shown interest to develop robots for the building industry.

2.1 Suitable construction robotics projects

After the initial contacts between TNO Building and Construction Research and HBW it was decided to start a joint exercise. In a series of brainstorm sessions with designers, construction managers, site superintendents and equipment engineers of HBW, a list was made of potential applications for successful construction robots. The list had to be in-line with the interests of both parties. These interests were:

- commercially interesting
- development in co-operation with the eventual user
- in line with business activities
- preferably using the TNO developed positioning sensor called CAPSY[1] (Computer Aided Positioning SYstem)
- perspective for further development
- able to be used on other projects

Based on these requirements the interviews and brainstorms took place, gradually eliminating ideas that were not in line with the above mentioned points.

2.2 The selection of a project

The possible projects were further examined in a multi criteria analysis against a set of relevant characteristics. These characteristics were:

- the amount of repetition
- the increase in productivity when being used
- the increase in construction quality
- the possible benefits for the environment
- the improvement of health and safety for workers
- the simplicity of the project, assuring a short time realisation of a prototype

These criteria, together with the interests of the participants led to the selection of the drilling robot, for the following reasons:

- TNO's positioning system CAPSY could be used
- the automation of the drilling process is of limited complexity
- the number of holes in a railway tunnel is quite large (>100 000)
- future railway tunnels are likely to be on the market
- surveying, marking and drilling is one activity
- unmanned operation is feasible
- human handling of heavy drilling equipment is avoided
- in case of success, further developments are possible, such as:
  - * horizontal and vertical upwards drilling
  - * positioning and fixing ceiling support systems

In this stage Strukton and Hilti were asked to join HBW and form the Robouw Foundation.

3. THE PROJECT; DEVELOPMENT OF THE DRILLING ROBOT

After analysing the task of a drilling robot it was concluded that two items of the required functionality of the robot played a key role:

- the ability of the robot to position itself accurately enough to drill the holes at the required location with a tolerance of ± 2.0 mm.
- the ability of the drill unit to drill 37 mm holes automatically.

To make sure that these requirements were met, it was decided to carry out two experiments which should prove the feasibility of the required functionality be-

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[1] After the development of the concept of CAPSY by TNO, the further development was taken over by Spectra Physics Laserplane Inc. who will produce and sell CAPSY. See also [deVos93]

fore the development of the complete drilling robot. In this section the motivations behind these two experiments are described.

3.1 The accuracy of CAPSY in a railway tunnel

The positioning sensor CAPSY was expected to fulfil the required positioning accuracy. However, the special shape of the work area (long and narrow) in relation to the accuracy demands, was a concern. An experiment was planned to investigate how accurate positioning with CAPSY was in practice.

The non-linear behaviour of CAPSY's triangulation position calculation algorithm is complex. It is impossible to formulate simple accuracy behaviour rules. To investigate CAPSY's accuracy behaviour a computer simulation program was developed . This program calculates for each location within a selected area what effect angle measurement errors have on the calculated X and Y position. Figure 2 shows the accuracy behaviour in the tunnel area.

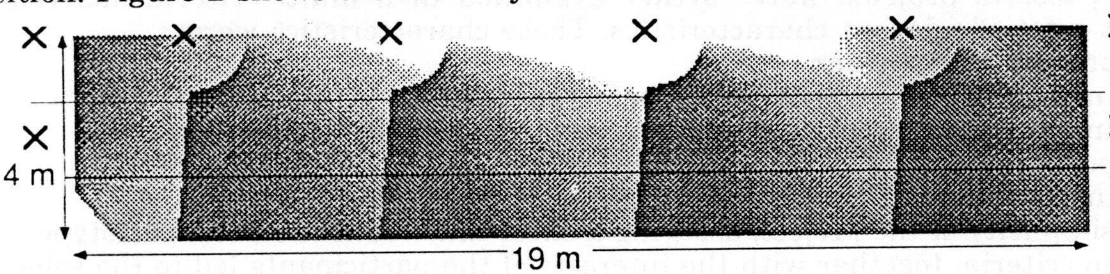

Fig. 2: Accuracy behaviour of CAPSY in tunnel (white = low accuracy)

After the verification of a number of possible reflector locations an experiment was carried out to investigate the accuracy in practice. Section 5.2 describes this experiment and its results.

3.2 The development of an automatic drilling unit

For drilling holes in concrete two systems can be used. A hammer drill is normally used for small diameter holes. For holes with a larger diameter a core diamond drill is used. This drill is cooled with water. For the drilling of the 37 mm holes both systems can be used. A major disadvantage of the core drilling process is that after the drilling the concrete core needs to be broken off and removed. This is a very difficult process to automate. Another disadvantage is that water needs to be supplied and (if possible) removed. A major drawback of using a hammer drill is that it generates vibrations. Eventually it was decided to use a hammer drill due to it's low price, reliability and simplicity. A test drilling unit has been built to get a better insight into the automatic (computer controlled) drilling process using a hammer drill.

4. THE DESIGN OF THE DRILLING ROBOT

This chapter presents the construction of the test drilling unit and the conceptual design of the robot vehicle. After the completion of the experiments with the test drilling unit, a new drilling unit will be designed which will accommodate two drills. This design will be optimised using the experience gained with the test unit.

The main components of the drilling robot are:
- the drilling unit
- the robot vehicle
- the position measuring system (CAPSY)
- a control and monitoring system
- a reinforcement detector
- auxiliary support equipment such as: vacuum cleaner, air compressor etc.

The next two paragraphs explain the design of the test drilling unit and the robot vehicle.

4.1 The test drilling unit

The picture in figure 3 shows the test version of the drilling unit. It consist of the following components:
- a hammer drill, Hilti Model TE 74
- a vertical guidance mechanism
- a pneumatic cylinder to control the vertical drive of the drill
- a pneumatic safety break
- a dust suction nozzle

The drilling process is controlled by sensors:
- a (vertical) drill position sensor
- a pressure difference sensor
- a power consumption sensor connected to the hammer drill.

The hammer drill is mounted on the drilling frame and is guided in the vertical direction along two cylindrical columns. The vertical motion of the drilling machine is activated

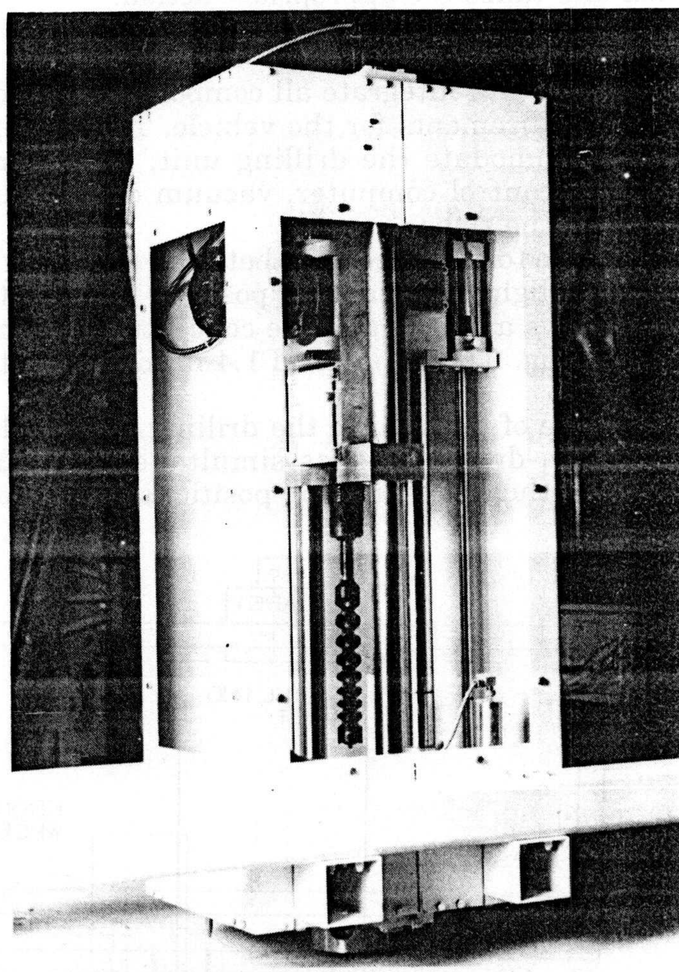

Fig. 3: Test drilling unit

and controlled by a pneumatic cylinder. One of the main reasons for using a pneumatic cylinder is that it absorbs the vibrations generated by the percussion mechanism in the hammer drill. During the drilling process the pressure difference (i.e. the drilling force) in the upper and lower half of the cylinder is controlled. A drilling jig is used to guide the drill during the initial stage of drilling the hole. The bore dust is removed by a suction nozzle connected to a vacuum cleaner. The drilling force (i.e. air pressure), the consumed (electric) power and the vertical position are measured in order to control and to monitor the drilling process.

A sensor measures the vertical position of the drill. In case of any calamity, the air pressure in the pneumatic safety break is released, activating the brake and the drill is instantly held at its current position.

A personal computer is used to control the drilling unit. A special interface card controls the air pressure valves and activates the drill and vacuum cleaner and reads the sensor values for air pressure, power consumption and vertical position and takes the appropriate action.

4.2 The robot vehicle

The robot vehicle will integrate all components into one drilling robot. There are a number of requirements for the vehicle. These are:

- it must accommodate the drilling unit, CAPSY, reinforcement bar detector, control unit, control computer, vacuum cleaner and air compressor.
- it must fit on the slabs
- it must be able to cross the gaps between the slabs
- it must be as light and small as possible to make transportation simple

Figure 4 shows a drawing of the conceptual design of the vehicle. The vehicle will be 2.3 m long, 0.9 m wide and 1.4 m high. The total weight will be approximately 750 kg.

In the middle of the vehicle the drilling unit is placed. The unit contains two drills which can drill two holes simultaneously. The relative positions of the drills are set to the corresponding positions of the holes in the base-plates. Each

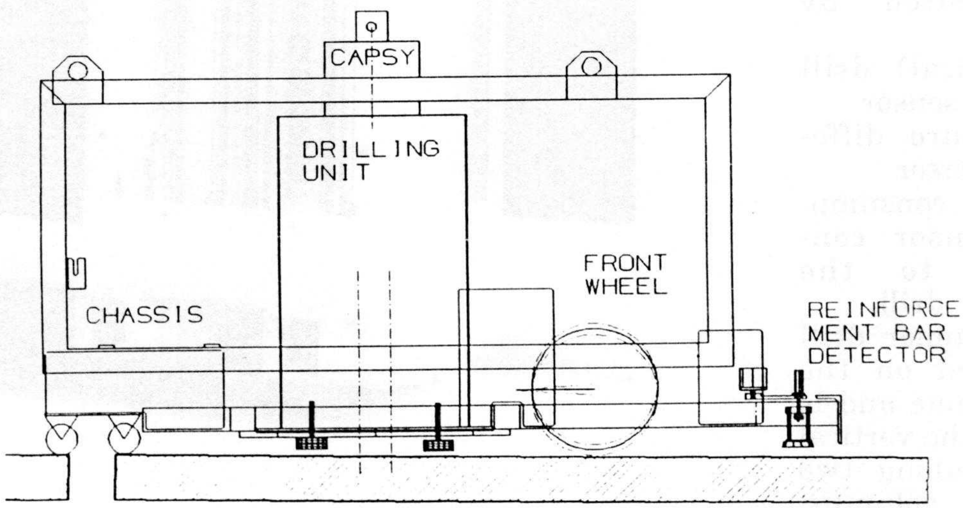

Fig. 4: Side view on vehicle

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 construction.

At the front of the vehicle a reinforcement bar detector is placed. This detector is placed 1.20 m in front of the centre of the drill unit and is protected by a metal bumper. The detector verifies that no reinforcement bars will be hit during the drilling. Although the concrete slabs are designed so that no reinforcement is present at the locations of the base-plates, presence of any reinforcement bars must be verified because electrical contact between the rails and the reinforcement bars is strictly forbidden.

At the front of the vehicle, behind the reinforcement bar detector, a single front wheel is placed. This front wheel is driven by an electric motor and is mounted in a special suspension which has two degrees of freedom. A special characteristic of the applications for which the drilling robot is being designed is that the holes to be drilled are in (nearly) straight lines. Therefore, the front wheel is fixed in a 'straight ahead' direction. Instead, the wheel can be raised and lowered and be moved to the left or to the right. During drilling the drive wheel is raised and the vehicle will lower itself and rest on the back wheels and the two pads near the drilling unit (see fig 4). When the front wheel is lowered and the pads are off the ground, the front of the frame can move 40 mm to the left or 40 mm to the right. This way the vehicle can turn itself ±1.3° to the left or to the right. When the required direction has been reached, the wheel is retracted, is set in the centre position and lowered again. This steering mechanism can also be used to adjust the position of drill unit in transverse direction.

At the back of the chassis a double wheel system is mounted which enables the vehicle to cross the gaps between the slabs.

5. EXPERIMENTAL RESULTS

At this stage two experiments have been carried out. Paragraph one describes the positioning verification tests. Paragraph two describes the experiences with the test drilling unit.

5.1 Experiments with CAPSY

The most important criteria for the placement of the base-plates are the gauge and alignment of the rails. Therefore the allowed accuracy of the positions in transverse direction must be within ±2.0 mm. In longitudinal direction a lower accuracy of the base-plate positions is acceptable.

As described in section 3.1, an experiment was carried out to verify the accuracy of CAPSY in practice. In a section of the railway tunnel a surveying team marked 36 locations of base-plates using traditional techniques. They also marked eight locations for the reflectors. In the experiment the pre marked locations of base-plates on six slabs were measured using CAPSY. At the time the experiment was carried out with a July(1991)-prototype version of CAPSY.

The measurements of the pre marked locations with CAPSY showed only small differences. The maximum measured differences in transverse direction of the base-plate locations were within the allowed limit of ±2.0 mm. The average difference was 1.1 mm. The expected performance enhancements of the production version of CAPSY and potential increase in accuracy by changing the reflector set-up promise further improvements in CAPSY's positioning accuracy.

5.2 Experiments with the drilling unit

The aim of the development of the test drilling unit is to obtain experience with automated hammer drilling in concrete and verify the design of the test drilling unit. Currently test drillings are carried out to obtain measurements of the pressure difference sensor, electrical power sensor and position sensor are registered and evaluated to obtain the control parameters for the drilling process.

The vibrations caused by the percussion mechanism are absorbed by the pneumatic cylinder. Nearly no vibrations are noticeable in the drilling unit. The first experiments with the test drilling unit showed that automated drilling in concrete with a hammer drill is feasible.

6. CONCLUDING REMARKS

The experiments carried out until now show the feasibility of the development of an autonomous drilling robot. The position measurements of CAPSY are accurate enough for the application. The test drilling unit drills holes smoothly without producing much dust or vibrations. The development of the complete drilling robot has started.

7. REFERENCES

[deVos93] de Vos, L.B.C., Hasara, B. "Field applications with CAPSY", Proceedings 10th ISARC, Houston, May 1993.