AUTOMATIC DIRECTIONAL DRILLING SYSTEM

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SUMARRY

An automatic directional drilling system for vertical boreholes has been developed by Schwing Hydraulik Elektronik and Deutsche Montan Technologie (DMT) as a joint venture. This system measures the inclination continuously during the drilling process and corrects minor deviations from plumb by immediate countersteering. The actual angles and the measured values required for system monitoring are transmitted to the drilling station by an integrated data transfer system. The prompt automatic directional offset permits directional drilling with maximum accuracy.
Automatic directional drilling systems of the ZBE 3000 series have been in use worldwide since 1984 in mining, tunneling and civil engineering and have stood the test in numerous upward and downward vertical drilling operations to a maximum depth of 600 meters.

Based on this success, further development of the automatic directional drilling system for vertical deep-drilling to a depth of 4000 meters was commenced in 1988. The incentive for this development phase was the Continental Deep-Drilling Programme (KTB), sponsored by the Federal Republic of Germany, with a projected overdepth of 10 000 meters (Fig.1).

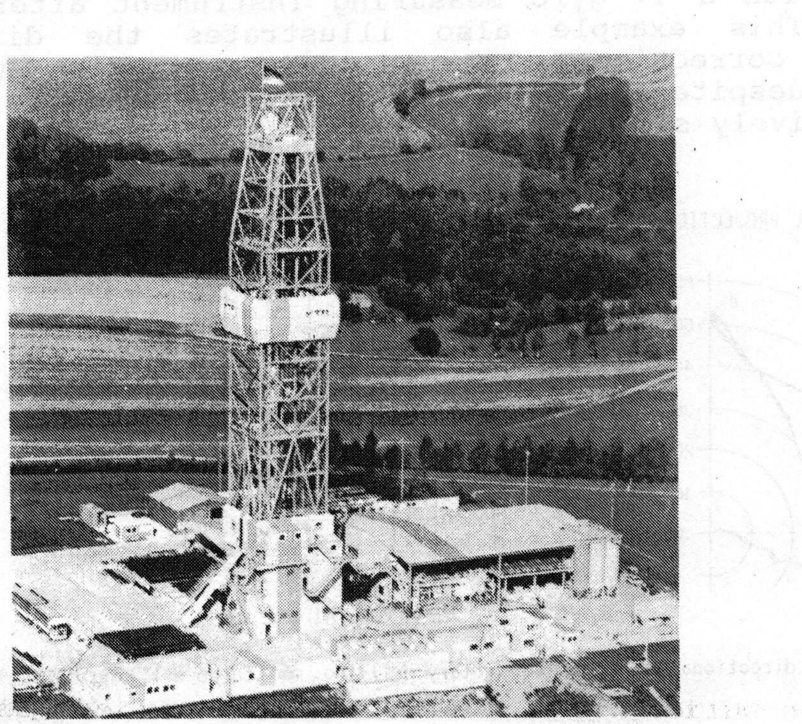


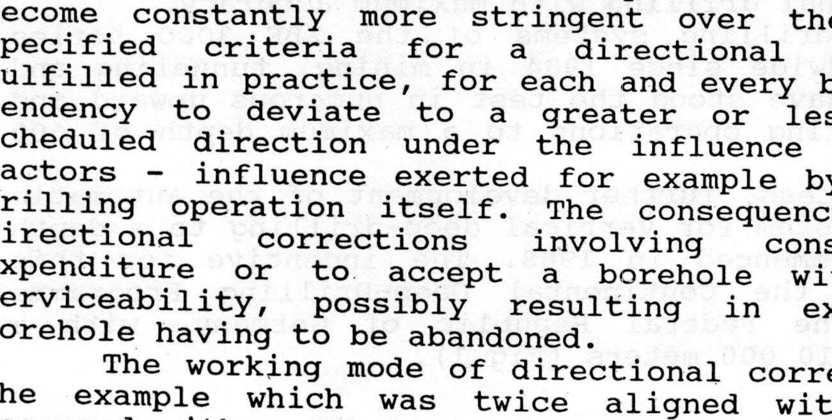
Fig.1.

The essential precondition for achieving the scheduled overall depth is a vertical borehole with virtually no deviation from plumb; this can be achieved with sufficient accuracy only with controllable equipment such as an automatic directional drilling system. The development of a new automatic directional drilling system for deep-drilling application, sponsored by the Federal Minister for Research and Technology (BMFT), was concluded in June 1990 on completion of the ZBE 5000 prototype.

1. SIGNIFICANCE OF AUTOMATIC DIRECTIONAL DRILLING

In the fields of mining, tunneling and civil engineering and in the spheres of oil and natural gas exploitation, there is an increasing demand for automatic directional drilling systems which reach their target point precisely despite any inclinations and deviate as little as possible from the scheduled direction during the drilling operation. Automatic directional drilling is of primary importance in producing freezing holes and pilot holes for shaft-sinking for the mining industry. In depth drilling, too, the demands made on the precision of the borehole have become constantly more stringent over the past few years.The specified criteria for a directional borehole are rarely fulfilled in practice, for each and every borehole has a natural tendency to deviate to a greater or lesser extent from its scheduled direction under the influence of a wide range of factors - influence exerted for example by the rock or by the drilling operation itself. The consequence is either to make directional corrections involving considerable time and expenditure or to accept a borehole with a low degree of serviceability, possibly resulting in extreme cases in the borehole having to be abandoned.

The working mode of directional correction can be seen in the example which was twice aligned with a turbo-drill and measured with a TV gyro measuring instrument after completition (Fig.2). This example also illustrates the difficulties of direction corrections, because the correction was not very reliable, despite the fact that deviations from the vertical were kept relatively slight in this case.



I and II start of directional drilling ○—○ rotary drilling ▬ turbo drilling

2. DEVELOPMENT OF THE ZBE 3000

Within the framework of worldwide endeavours to improved directional drilling technology, a number of different systems have been developed over the past few years. These are primarily passive systems designed to prevent any deviation from the scheduled drilling direction without the assistance of active control elements. Practical application has shown, however, that precise, targetted drilling cannot be achieved with adequate precision with these systems.

In order to ensure that future demands on directional drilling can be met, development work on an automatic directional drilling system began in 1979. This joint venture involving Schwing Hydraulik Elektronik and Deutsche Montan Technologie (DMT) is based on the fundamental concept of measuring even minimum deviations constantly during the drilling operation and countersteering immediately. This development marked the beginning of a change from passive to active directional drilling systems. Following a five-year development period, the ZBE 3000 automatic directional drilling system for vertical boreholes was ready to be commissioned.

3. DESCRIPTION OF THE ZBE 3000 DIRECTIONAL DRILLING SYSTEM

Fig. 3 shows a sectional drawing of the ZBE 3000 directional drilling system with its main structural and functional elements.

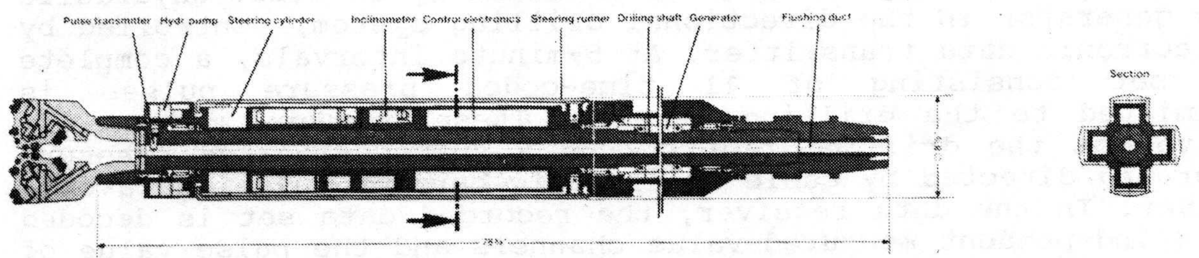


Fig.3.

The system is positioned behind the 216 mm (8½") diameter drill point and can be used with a conventional drilling rod. The mechanical construction consists essentially of an internal rotary shaft connected through bearings and shaft seals with an outer tube (external casing). The shaft transmits the rotary motion of the drilling rod through the non-rotary external casing to the drill point. Four movable control rams are mounted around the circumference of the external casing of the directional drilling system. At the front end, i.e. immediately adjacent to the drill point, a control cylinder located behind each control ram presses the ram against the wall of the borehole under hydraulic pressure. The friction resistance between the control rams and the borehole wall prevents the rams, and thus the external casing, from rotating. The space between the four control rams permits the cutting-loaded drilling fluid to be discharged. The external casing is equipped with compartments that are impermeable to pressurized water; these contain the electronic and hydraulic modules required for the measuring and control function.

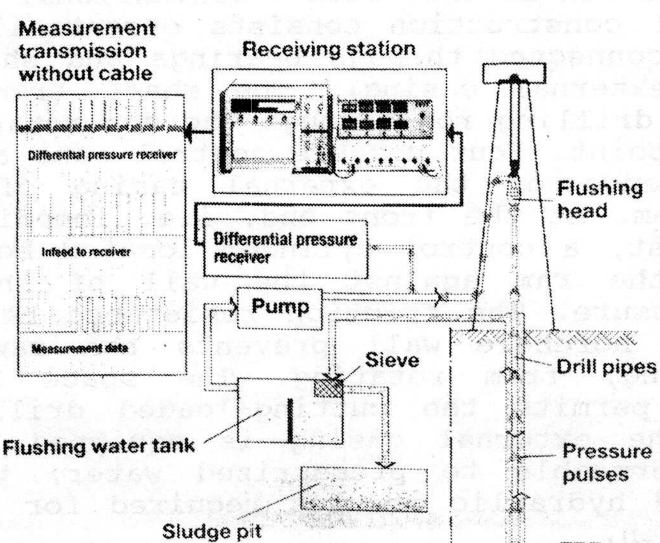
One important control component is the inclination measuring system, consisting of two inclinometers set at right angles to each other, and the corresponding evaluation and control electronics. The inclination of the borehole is measured in the positive and negative x or y direction with the inclination sensors. The inclination measuring system has a resolution of 1 angular minute with a fixed measuring range of 120 angular minutes.

When a deviation from plumb is registered, an offset signal is transmitted from the evaluating to the control electronics. This triggers solenoid valves assigned to the four directions of inclination. The solenoid valves open the hydraulic circuit and activate the control ram assigned to the direction of inclination. Retraction of the control ram induces a control force with which the system is restored to plumb position.

The control operates with a correction window of 6 angular minutes, i.e. the control is activated at +3 / -3 angular minutes' deviation from plumb. Incipient borehole inclinations are detected from the very outset and corrected immediately with corresponding counter-steering measures by this control process, which operates continuously in all directions of inclination.

A cable-free transmission system for the measured data has been developed for system monitoring and transfer of recorded inclination values during the drilling operation. The system operates by the pressure pulse method, in which a pressure rise in the form of a short pressure pulse is generated in the drilling fluid within the drilling rod by narrowing the discharge section. The discharge section is narrowed by an electrohydraulic pulse generator in the directional drilling system, controlled by an electronic data transmitter. At 5-minute intervals, a complete data set consisting of 11 time-coded pressure pulses is transmitted to the drilling station. These pressure pulses are received at the drilling facility by a surface-located pressure sensor and directed by cable as electric current pulses to a data receiver. In the data receiver, the recorded data set is decoded into 8 independent measured-value channels and the pulse value of these channels is displayed on a monitor. (Fig.4.)

Transmission of check data



The directional drilling system operates without an external power supply. The energy required for the measuring and control elements is fed to the system by the rotary motion during the drilling operation (relative motion between the rotating shaft and the non-rotating external casing) and converted into electric and hydraulic energy.

The hydraulic system has a system pressure of ca. 100 bars, provided by 4 piston pumps. These pumps are located at the front end of the directional drilling system and are driven by eccentric cams mounted in bearings on the rotary shaft. The electric energy is generated by an alternator installed in the rear section of the directional drilling system. The stator winding of the alternator is embedded in the tube of the stationary external casing and encloses the shaft-mounted rotor consisting of two half-shells fitted with permanent magnets. With the relatively low rod speed of ca. 60 rpm, the required service voltage of 24 volts is generated with a supplied electric power of 55 watts.

4. PRACTICAL EXPERIENCE GAINED WITH THE ZBE 3000 DIRECTIONAL DRILLING SYSTEM

ZBE 3000 automatic directional drilling systems have been in use worldwide since 1984 for vertical directional drilling operations in mining, tunneling and civil engineering. A total of 51 boreholes have been produced to date, with the longest vertical down hole measuring 600 meters. Good results have been achieved with the ZBE 3000 for pilot boreholes for sinking shafts and for exploratory boreholes in concrete dams. All these boreholes were as planned and straight-lined, some of them with a deviation of only 0.1 %. An impressive example of the result of a directional drilling operation carried out with the ZBE system is shown in Fig.5. The pilot borehole shown here has a length of 191 meters and shows its absolutely vertical path by means of a laser. The opportunities presented to drilling technology by a directional drilling system are demonstrated by the parallel paths of two boreholes 72 meters long and only 200 millimeters apart (Fig.6).

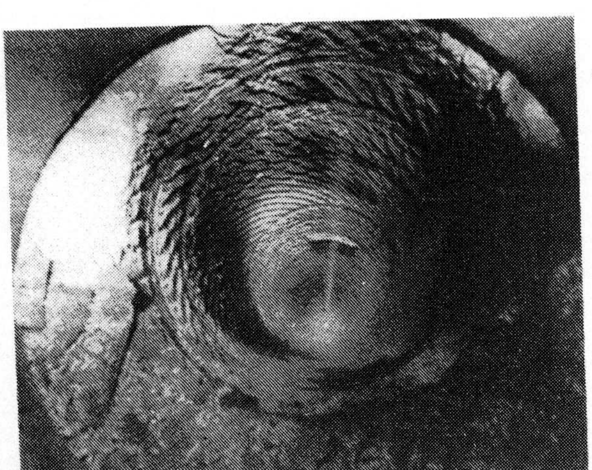


Fig.5.

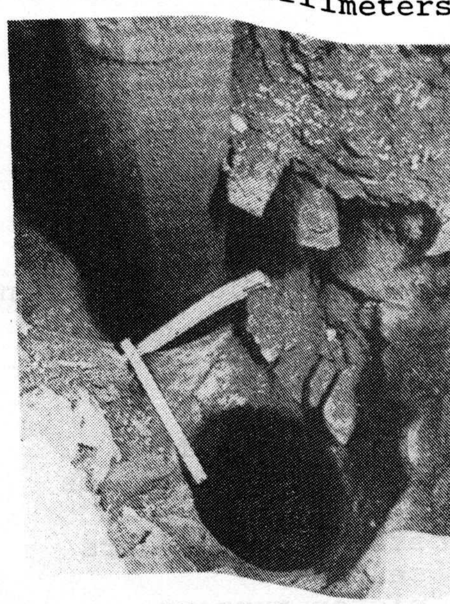


Fig.6.

5. FURTHER DEVELOPMENT FOR THE CONTINENTAL DEEP-DRILLING PROGRAMME

Drilling work for a 10 000 meter deep borehole got under way on 6th October 1990 at Windischeschenbach in the Upper Palatinate region of Germany. This was the start of the main phase of the Continental Deep-Drilling Programme (KTB), a major geoscientific research project sponsored in recent years by the Federal Republic of Germany to a total sum of 500 million deutschmarks.

This planned drilling depth of 10 000 meters is essential if research carried out there into the principles of geochemical and geophysical processes is to be of scientific relevance. The envisaged depth makes it essential to keep the path of the borehole as close as possible to the vertical. In view of the geological conditions to be expected at this location, conventional drilling systems have very limited opportunities for adhering to the required verticality of the borehole, so that the use of automatically controlled systems is a high-priority feature in the drilling concept behind the KTB.

Experience gained in the field with the ZBE 3000 system gave rise to further development of the directional drilling system for the Continental Deep-Drilling Programme; this was sponsored by the Federal Minister for Research and Technology (BMFT). In view of the high temperatures to be expected, the directional drilling system is to be used to a depth of 4000 meters. Following a two-year development period, the ZBE 5000 prototype was completed in June 1990 (Fig.7).

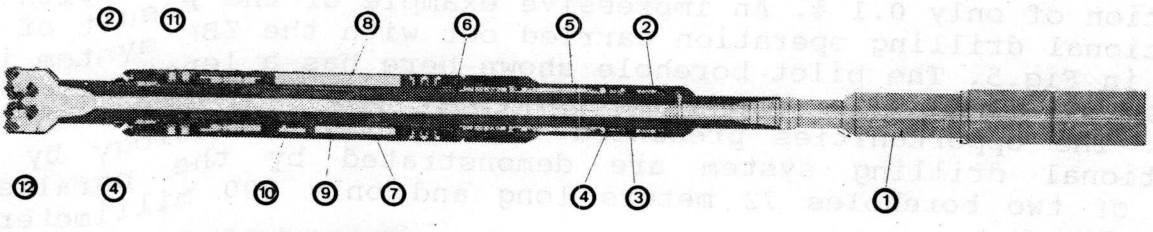


Fig.7.

1. measurement pulse transmitter
2. shaft seal
3. flushing hole
4. bearing
5. generator
6. drilling shaft
7. control electronics
8. hydraulic pump
9. steering cylinders
10. sensors
11. piston runners
12. boring head

The basic structure and the mode of operation of the existing ZBE 3000 directional drilling system were taken extensively into account in the development of the new system. However, a number of developments had to be made on the functional detail components to ensure that the directional drilling system can be used under the extreme conditions encountered in a deep borehole.

One important influencing factor is the high ambient temperature - about 120° at a depth of 4000 meters. In the ZBE 5000 system, all electronic components, sensors and control instruments are designed to withstand this temperature range.

At 400 bars, the hydrostatic pressure of the drilling fluid in the section down to 4000 meters makes high demands on the mechanical construction and the sealing elements of the directional drilling system. Sealing systems generating constant pressure compensation between the interior space of the system and the external static pressure of the drilling fluid have been developed for the ZBE 5000 system. In the case of dynamic shaft seals, the pressure compensation prevents unbalanced strain on the sealing elements, prolonging their service life many times over.

The influence of high vibrations generated during the drilling operation by the intervention of the drilling bit and increased by the drilling rod was also taken into account in the development of the ZBE 5000 system. The vibrations occurring affect the sensitive inclination-measuring system of the ZBE, impairing the control characteristics. Special inclination sensors, designed to eliminate the disturbances of the vibrations in conjunction with electronic filters, are used in the ZBE 5000 system.

The planned use of a directional drilling system at a depth of 4000 meters necessitated the development of a new transmission system for the measured data. The time-coded pressure pulse transmission in the ZBE 3000 system implies the reception of steep-edged pressure pulses in the well fluid system. The pressure rise generated at a depth of 4000 meters is, however, received only as a gradually rising, low-amplitude pressure wave at the surface-located drilling facility because of the long transmission route. This is aggravated by the pressure waves generated by the piston pumps of the well fluid system which, as a constant interference level, restrict registration of the data pulses.

The newly developed data transmission system of the ZBE 5000 transfers the recorded measured values into specific code words formed from the generated pressure pulses. As in the digital system, the opportunity offered by binary terms for representation is exploited in transmitting the measured values. The "logical states" one and zero imply in this case the presence or absence of pressure pulses. Pulse telegrams are generated by a microprocessor-controlled data transmitter. The status-coded pressure pulses are received at the drilling station via a high-grade filter circuit from the base level of the well fluid system and then decoded. Besides being displayed on a monitor, the measured values are transferred via a serial interface to a personal computer, where they are evaluated by means of purpose-developed software programmes.

The extensive development work directed towards using a directional drilling system in deep-drilling operations has been successfully concluded. This has been confirmed by operations already carried out with three ZBE 5000 directional drilling systems in the KTB well, with a vertical path being produced in each case.

6. CONCLUSION

The use of directional drilling systems is paving the way to new techniques not feasible with conventional drilling methods. Automatic correction of the drilling direction permits high-precision directional drilling operations. Maximum reliability is assured by cable-free transmission of the measured values and by the associated continuous function-monitoring during the drilling operation. Further development of the directional drilling system for deep-drilling application has shown that an active drilling system with integrated electronic assemblies and hydraulic driving elements can be used even under extreme conditions.

Besides application of the directional drilling system in vertical drilling operations, further development in the future will concentrate on its application in horizontal and inclined drilling operations.