# LASER-CONTROLLED MACHINES FOR MICROTUNNELLING

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## ABSTRACT

Microtunnelling machines have experienced a fast technical development during the past 10 ears.

The development of mechanical and plant engineering as well as of the laser and electronics must be continued constantly in order to meet the high requirements of the jobsites.

Thanks to this successful development the microtunnelling machines have been accepted by the construction industry and are being used more and more.

Interesting construction projects are being executed with this new technique and the invitations to tender are taking it more and more into consideration.

## A. INTRODUCTION

### Research and Development of the new Micro-Tunnelling Systems AV-N and AV-T Type

#### General Remarks

Since 1982 the company Herrenknecht GmbH has been engaged in the development of tunnelling systems for non-accessible tunnels. Since it was known on the one hand that extensive projects of tunnelling sewers will have to be realized in the near future,

and on the other hand that Japanese competitors were eager to enter the German market, it was necessary to undertake intensive development work.

A research project of the Federal Ministry for Research and Technical Science, initiated by Dipl.-Ing. Bieleki, now Director of the Board of Works of the Hanseatic town Hamburg, has made it possible with its program to develop the prototype.

## B. MACHINES FOR MICROTUNNELLING

### 1. Demands on the Modern Microtunnelling Systems

Pipes are driven in non-cohesive ground, such as pebble stones, sands, brash, as well as in cohesive ground, such as clay, sandy clay, loam, marl, keuper, sandstone, coarse clay and boulder.

It is sometimes necessary to do the drivage in both dry ground and in water bearing ground.

Thus, in view of the usability and equipment of the machine, the following topics were noted.

- to be used in ground, classes 1 to 5
- to be installed rapidly
- robust, to be easily serviced
- to provide great handling ease
- continued drivage
- compact constructional design, soundproof
- operation in groundwater

## 2. Fully Mechanized Microtunnelling System

(Patens have been claimed for)

Based on its longstanding experience in jobsites and the above topics, the company Herrenknecht GmbH developed the prototype of the micromachine and drove it on jobsites in Hamburg.

As early as in 1984 this prototype with two shafts and the designation VSA-N were provided with the following perspective constructional features

1. horizontal rotary crusher, hydraulic conveyance
2. rotating cutting edge of the shield
3. wet conveyance for driving in groundwater
4. the whole equipment installed in a container (soundproof)
5. direct jacking of the drivage pipe

These five features are well-proven. The use of the crusher permits the cutting, breaking, and conveying of boulder (required power at the head 37 KW) so that it is possible to drift exactly keeping the direction given by target.

The use of wet-conveyance serves to drive without problems in groundwater.

Having installed the whole tunnelling system into a container, we solved the problem of transporting it to and from the jobsite. This prototype was used on several jobsites in Hamburg.

From the positive experience we gained there, we have the pleasure to point out three expecially favourable features of the machine: its optimum breaking effect, good controllability as well as its functionable wet-conveyance.

Thank to the promotion of the Federal Ministry of Research and Technical Science and the City of Hamburg we, the manufacturer, could enter this complex technical field.

This has provided the pre-conditions for developing the single-shaft microtunnelling system of the AV-T (Automatically controlled drivage machine with dry-conveyance by means of screw extraction); AV-N (Automatically controlled drivage machine with wet-conveyance by means of feed and supply pipes).

## 3. Design and Device of the New Micromachine AV-N, AV-T

(Patents have been claimed for)

As a result of longstanding experience with the prototype and its use on jobsites, we could operate without a second drive and a sliding center shaft, which highly influenced the total expenses of the system without limiting its operative range. The AV-T and AV-N machines, a new generation of single shaft machines, have shown the advantages proven by the prototype:

A. Crushing system
B. Short jacking carriage with an automatic fitting apparatus particularly for small starting shafts
C. The basic container is equipped so that both AV-N and the AV-T type machines may be used
D. The single shaft machine - at reasonable costs
E. System-building

## 4. AV-Type Drivage Machines for Non-Accessible Cross-Sections

The central tool is driven by an infinitely variable hydraulically actuated central shaft (power 37 KW), alternating with clockwise and counter-clockwise rotation. As to easily adapt to the given ground conditions the cutting disc may be mounted and dismounted without any difficulties. In this construction, the outer ring of the cutting edge is also rotating in order to overcut an exact profile section of the tunnel.

The machine is composed of a controllable cuttinghead, and a pipe with a measuring and guidance system and a hydraulic steering unit installed therein.

Dependant on the length of the pipe the tunnel may be thrusted through a shaft having a diameter of 3,0 m by pipe jacking where the pipes have a diameter of 2 m, or in case of as shaft having a diameter of 2 m where have a diameter of 1 m.

The following machines are marketable:

- AV-N 300 (which means a 300 mm internal diameter of the tube)
- AV-N 500
- AV-N 600
- AV-N 700

- AV-N 800
- AV-N 1000
- AV-N 1200
- AV-T 250/200
- AV-T 400
- AV-T 500
- AV-T 600/700

The jacking carriage may easily be adapted to any shaft. The pressure ring is automatically replaced which permits thrusting of a drivage pipe within three strokes. As a result, we have only a short nonproductive time during the thrust. An adjustable pressure ring serves for driving pipes of variable diameter.

### 5. Container

The equipment will be delivered completely mounted in a container of 20" which on request may me provided soundproof. In this arrangement the working area is separated from the hydraulic and electric by a pressure wall.

The control board is designed both for hydraulic and screw conveyance and is located in the working area. By means of a lifting gear - a crane having a lifting capacity of 3,2 to. - the machine, jacking carriage and starting seal, are positioned inside the starting shaft. The drivage pipes are received by the craneway having a free end protruding beyond the shaft, and are tansferred within the shaft. The container further contains a computer unit for evaluating the measurements of the guidance system.

## C. LASER CONTROLLED GUIDANCE SYSTEM

### 1. Surveying

With the prototype 6 years ago three systems were used and only the laser guided system finally was approved and is now world-wide in use.

The three guidance systems were:

a. electro-optical
b. Gyro compass
c. Laser guidance

## 2. Laser Controlled Guidance System

### Concept of the MH-Laser Controlled Guidance System

The complete system is made up of the following components:

a. Laser Target
b. Computer and Keyboard
c. Monitor
d. Rotary Encoder
e. Various pressure sensors (in hydraulic system)
f. Printer

### Laser Target

The laser target is rigidly fixed within the tunnelling machine, it's make-up being:

1. Sensor plate with light sensitive photo-electric transducers
2. Microprocessor system with analog/digital convertor
3. 2 Inclinometers to measure level and roll of the machine
4. Serial interface for data transfer

The laser target can be supplied in three sizes

50 mm high x 80 mm wide
100 mm high x 160 mm wide
200 mm high x 200 mm wide

The laser target housing is 100 % watertight. The data transfer between laser target and computer is in digital format via a control cable. The resolution of the sensor plate is 1 mm in both the X and Y direction. The resolution of the inclinometers is 1 mm/me.

## Sensor Plate Operation

The sensor plate is equipped with light sensitive photo electric transducers which transmit a signal when the laser is in contact with them. Via the known geometric pattern of the photo electric transducers, those sensing light from the laser can hence define the position of the machine.

Several transducers are alwayss illuminated at the same time meaning that the centre of the illuminated area can be calculated via the distribution of light over a wide area. This enables an accuracy of position within 1 mm to be achieved. The same applies with an unstable laser spot (for example. the spot is not round or the spot is bigger than 30 mm), the same accuracy of position is possible.

## Computer Evaluation

The computer is built into the operators control panel. It reads the signals from the laser target and external pressure sensors and stores the data. In the event of power failure or switching off the equipment, the data is permanently stored by saving it to disk.

The data is displayed both graphically and numerically on the monitor and can be produced as hard copy in the form of a printed driving record. If the machine, and thus the target, is rolling, the program recalculates the X and Y co-ordinates automatically thus transforming the laser axis, so that the user is always looking at the true position of the machine.

During the tunnelling operation, any comments or events can be recorded and later printed as part of the driving record.

## Printer

During the tunnelling operation, the driving record is automatically produced by the printer at the chosen interval of tunnel advance. The following detail is included in the driving record:

- Time
- Date
- Pipe Number
- Distance
- Deviation in level
- Deviation in line
- Roll
- Horizontal angle of machine
- Vertical angle of machine
- Steering cylinder stroke
- Jacking force in tonnes
- Cutting wheel torque
- System error messages
- User inserted comments

The printer can also produce a graphical interpretation of line/level of the tunnel drive.

## Further possibilities

The MH-guidance system can be equipped to measure other parameters by the use of more sensors and could therefore be used for fully automatic steering of the tunnelling machine.

## Summary

The MH-guidance system is used at present predominantly for the remote control of microtunnelling machines for the installation of pipelines 250 mm to 1000 mm bore.

The MH-guidance system is suitable for use with a variety of tunnelling machines and can be equipped to record the many different parameters relevant to the particular machine or operation.

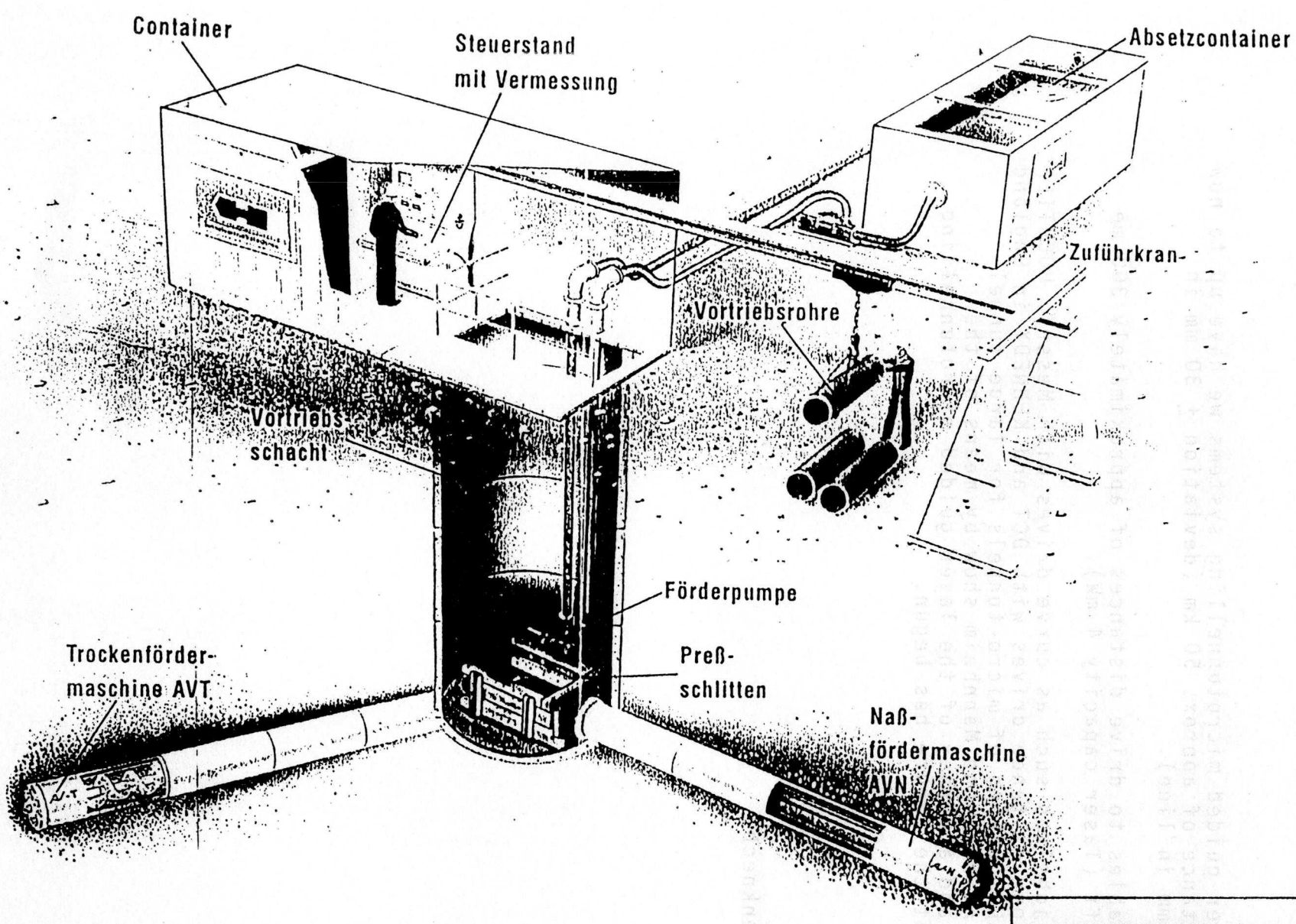
D. SUMMARY

With the laser guided microtunnelling systems we have up to now driven a distance of approx. 50 km (deviation ± 30 mm in level, ± 50 mm in line).

The laser enables to drive distances of approximately 300 me from one shaft (laser capacity 4 mW).

Spectacular jobsites such as curve drives with Messrs. HOCHTIEF in Berlin, long distance drives with DCT and KENNEDY in England as well as the driving of micro-tunnels for large tunnel profiles in Atlanta and Mannheim show by means of the reliability and accuracy of the laser guided microtunnelling machines that the future has begun.

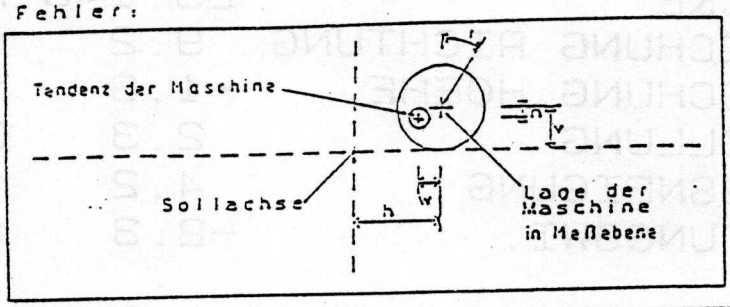
Martin Herrenknecht



# LASER GUIDANCE DATA

| | | | |
|---|---|---|---|
| Station | 25.16 m | 24.10.89 | 15:32 |
| Horizontal | 22 mm | Druck 125 to | |
| Vertikal | 12 mm | Drehm. 65 bar | |
| Verrollung | 7 Grad | | |
| Neigung | -6 mm/m | | |
| Richtungswi. | -8 mm/m | | |
| Zylinder | 10 mm | | |
| | 8 mm | 12 mm | |

Fehler:




r = Verrollung
y = Vertikalabweichung
h = Horizontalabweichung
n = Laengsneigung
w = Richtungswinkel

Betriebsprotokoll ausgedruckt am: 26.08.90 11:41:23

Erklaerung der Abkuerzungen:
HO = horizontale Abweichung in mm
VE = vertikale Abweichung in mm
RO = Verrollung in Grad
NE = Laengsneigung in mm/m
RW = Richtungswinkel in mm/m
ZL = Steuerzylinderhub links in mm
ZO = '' oben in mm
ZR = '' rechts in mm
PR = Vortriebspressendruck in to
DR = Drehmoment des Schneidrades in Bar

Vortriebsprotokoll ausgedruckt am: 26.08.90 11:41:23
ARGE Fahrlachtunnel Haltung n Seite: 1

| Datum | Zeit | Station m | HO mm | VE mm | RO Grad | NE %o | RW %o | ZL mm | ZO mm | ZR mm | PR to | DR Bar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25.08.90 | 05:57 | 0.10 | 0 | 5 | -2 | -2 | 0 | 40 | 39 | 42 | 63 | 57 |
| 25.08.90 | 06:09 | 0.20 | 0 | 5 | -2 | -4 | 0 | 40 | 37 | 42 | 2 | 45 |
| 25.08.90 | 06:09 | 0.30 | 0 | 6 | -2 | -4 | 0 | 40 | 37 | 42 | 1 | 44 |
| 25.08.90 | 06:09 | 0.40 | 0 | 6 | -2 | -4 | 0 | 40 | 37 | 42 | 5 | 66 |
| 25.08.90 | 06:09 | 0.50 | 3 | 5 | -1 | -4 | 4 | 40 | 37 | 42 | 2 | 53 |
| 25.08.90 | 06:10 | 0.60 | 2 | 5 | -1 | -4 | 5 | 40 | 37 | 42 | 4 | 76 |
| 25.08.90 | 06:10 | 0.70 | 1 | 6 | -1 | -3 | 5 | 40 | 37 | 42 | 5 | 107 |
| 25.08.90 | 06:10 | 0.80 | 3 | 5 | 0 | -3 | 6 | 40 | 37 | 42 | 7 | 117 |
| 25.08.90 | 06:11 | 0.90 | 2 | 5 | 0 | -2 | 0 | 40 | 37 | 42 | 7 | 113 |
| 25.08.90 | 06:11 | 1.00 | 2 | 5 | 0 | -2 | 2 | 40 | 37 | 42 | 9 | 122 |
| 25.08.90 | 06:12 | 1.10 | 2 | 5 | 0 | 0 | 0 | 40 | 39 | 42 | 6 | 99 |
| 25.08.90 | 06:12 | 1.20 | 3 | 5 | 0 | -1 | 1 | 40 | 39 | 42 | 7 | 69 |
| 25.08.90 | 06:12 | 1.30 | 3 | 5 | 0 | -1 | 1 | 40 | 39 | 41 | 11 | 119 |
| 25.08.90 | 06:13 | 1.40 | 3 | 5 | 0 | -2 | 1 | 40 | 39 | 42 | 9 | 111 |
| 25.08.90 | 06:13 | 1.50 | 3 | 5 | 0 | -2 | 1 | 40 | 37 | 41 | 10 | 112 |
| 25.08.90 | 06:13 | 1.60 | 3 | 5 | 0 | -3 | 1 | 38 | 37 | 41 | 8 | 101 |
| 25.08.90 | 06:13 | 1.70 | 3 | 3 | 0 | -4 | 1 | 38 | 36 | 41 | 11 | 114 |
| 25.08.90 | 06:17 | 1.80 | 3 | 3 | 0 | -5 | 1 | 40 | 36 | 42 | 8 | 121 |
| 25.08.90 | 06:17 | 1.90 | 1 | 3 | -2 | -4 | -2 | 40 | 36 | 42 | 0 | 42 |
| 25.08.90 | 06:18 | 2.00 | 0 | 3 | -3 | -4 | -6 | 40 | 36 | 42 | 9 | 141 |
| 25.08.90 | 06:18 | 2.10 | 0 | 3 | -1 | -4 | -8 | 40 | 36 | 42 | 7 | 120 |

LASER GUIDANCE DATA

**Die Anzeige der Messwerte**

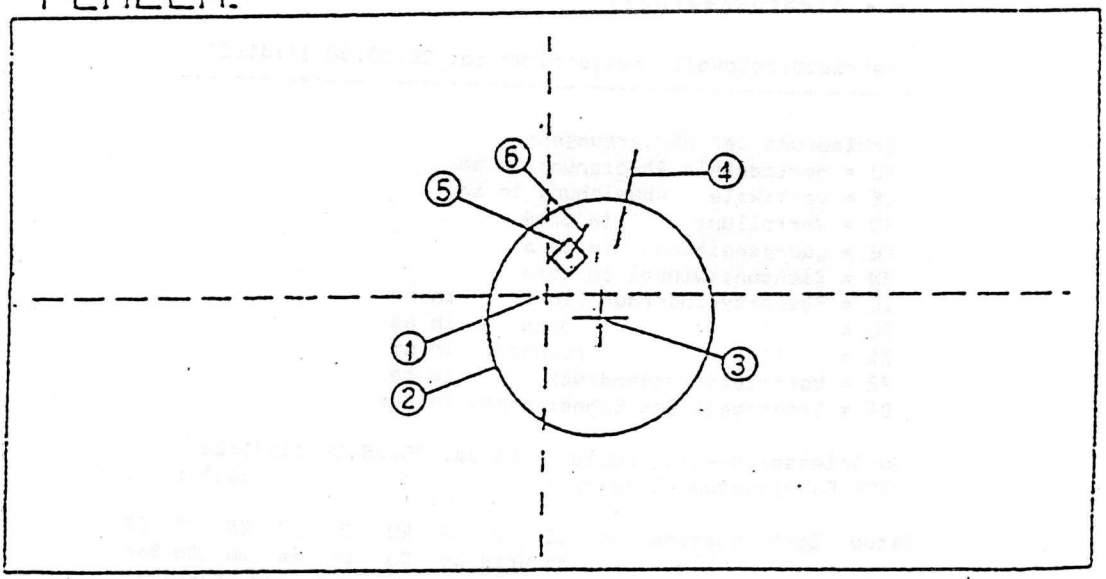
MESSUNG ZIELTAFEL SN: 003

| | | |
|---|---|---|
| STRECKE | 25.148 | m |
| ABWEICHUNG RICHTUNG | 9.2 | mm |
| ABWEICHUNG HOEHE | -1.6 | mm |
| VERROLLUNG | 2.3 | Grad |
| LAENGSNEIGUNG | 4.2 | mm/m |
| RICHTUNGSWI. | -2.3 | mm/m |

ZYLINDER 11mm

5mm 7mm

FEHLER:




1. Sollachse des Tunnels (parallel zum Laser)
2. Istlage der Vortriebsmaschine zur Sollachse (im Beispiel rechts/tief)
3. Rollachse und Mittelpunkt der Vortriebsmaschine
4. Zeiger der Verrollung der Vortriebsmaschine (im Beispiel leicht rechts)
5. Zeiger des horizontalen und vertikalen Richtungswinkels der Vortriebsmaschine (zeigt die Tendenz, in die sich die Vortriebsmaschine bewegt, hier nach links oben)
6. Zeiger der Tendenz der Richtungswinkel