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# Navigation of tunnel boring machine at Gotthard

## General

The guidance of a tunnel boring machine (TBM) is comparable with the navigation of a super-tanker: it last long time until the effect of a course-correction will be visible.

Skilled machine drivers know the performance of "their" machine in different geological conditions. Therefore a precise and reliable determination of the TBM's position is the most important information for steering control. Although the TBM moves slowly it is possible that the machine bears away the planned course and exceeds the requested precision of 100mm round the given axis. It is a real challenge to eliminate these deviations in a tunnel of such length, which can only be achieved with perfect coordination between surveying and machine driving.

All geodetic information must be carried by a polygonal process from outside the tunnel right up to the machine's cutter head. For this purpose there is normally in the machine area, along the tunnel wall a dedicated clear area or laser window available throughout the complete area of the trailing gear.

One special characteristic of the Gotthard project was also the fact that various tunnelling activities needed to be done concurrently to the advance and correspondingly the machine and trailer concept was designed accordingly. Therefore the navigation system has to be adapted to this situation too.

## Requests on the Guidance System

A guidance system is equivalent to a navigation system. It provides information for starting a control or course correction. Therefore it is indispensible that the actual position of the TBM in relation to the planned tunnel axis is continuously present and displayed. As a98% availability of TBM-position is required, continuous measurement of the TBM-position is necessary as well as the pitch and roll values of the TBM are collected and displayed. A status indication of all relevant sensor components of the guidance system is requested as well as automated direction control.

Normally the well known navigation systems are working with GPS. But in a tunnel there is no satellite reception. So the determination of position is carried out in the classic mode with the help of motorized measuring instruments.

## Characteristic of Gotthard-System

On the Gotthard tunnels two different trailer concepts were in use for the north and south sectors. To cope these circumstances different navigation systems had to be designed but using the same hardware components, including motorized total stations, inclinometer and also the software controlled shuttered prisms marking the key machine measurement points. Additionally geometric machine data (including Ram extensions) from the TBM's PLC were stored and used inthe calculation of the actual position. Concurrent to the advance, various works needed to be done: initial shotcreting, wire mess and arch-mounting and rock bolt boring which caused heavy interference of the line of sight to the machine measurement points. Therefore a standard measuring method couldn't be applied. These hardware components from total station and computer up to the shuttered prisms will all be affected by extreme vibrations.

## Navigation System in the Section Gotthard-North – Amsteg

In the North Section the first three trailers were pulled continuously during the advance over rails. The following trailer units were hanging on roller-brackets on the segment and were pulled only after the advance (see fig. 1).

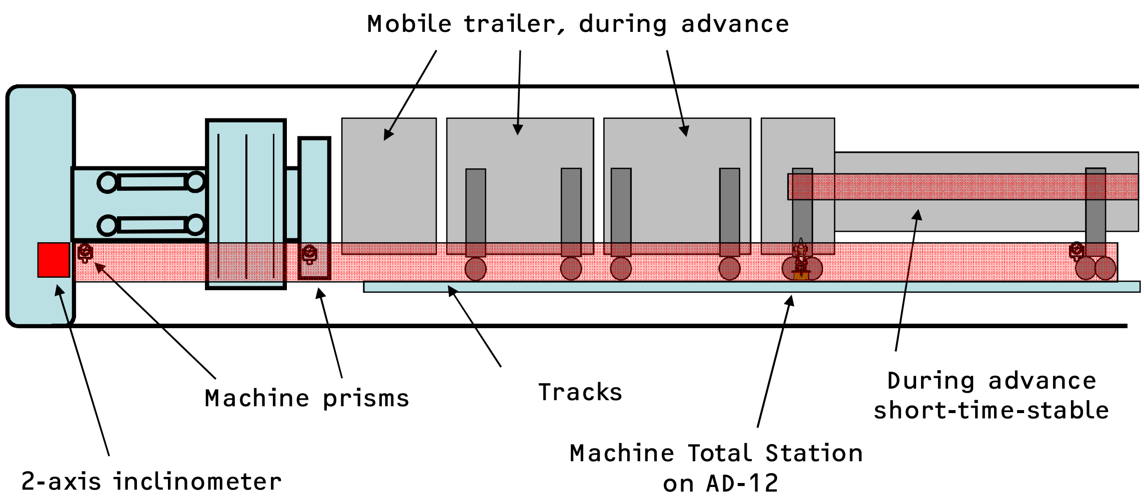


Fig. 1 Trailer concept Gotthard-North section

So this area was stable for a short-time and could be used for measuring of the cutter head - however only in the lower laser window. The coordinates and orientation for the automatic total station in the lower section had to be determined again after each advance. In this section it has been done by continuous carrying forward of key machine measuring points in the invert area. For measuring the tracks on which the first trailer section was pulled forward, these points had to be pegged out anyway. They  were also used for the automatic measuring of a "free chainage" of the total station (see fig. 2).

Fig. 2 Total station Gotthard-North

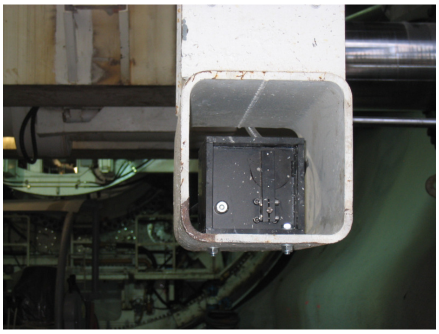

Fig. 3 Installed shuttered prisms (closed)

After each advance this trailer area was been pulled forward whereby the coordinates and the orientation of the total station changed. After the grippers were engaged again, a signal was sent to the control computer which started the automatic measuring of the total station with the present key machine measurement points. If the coordinates and the orientation of the total station were known, the TBM position could be measured by the automatic machine prism at the cutter head (see fig. 3). The total station was mounted at a self-levelling  tribrach (AD-12) which compensated for any roll and pitch of the trailer and automatically levelled the total station.



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## Navigation System in the Section Gotthard South - Bodio

In the southern section the trailer was advanced using the two walking mechanisms which were stiff during the advance. After the advance these mechanisms were contracted and moved ahead. Here the walking mechanisms could be assumed as short-time-stable construction (see fig. 4).

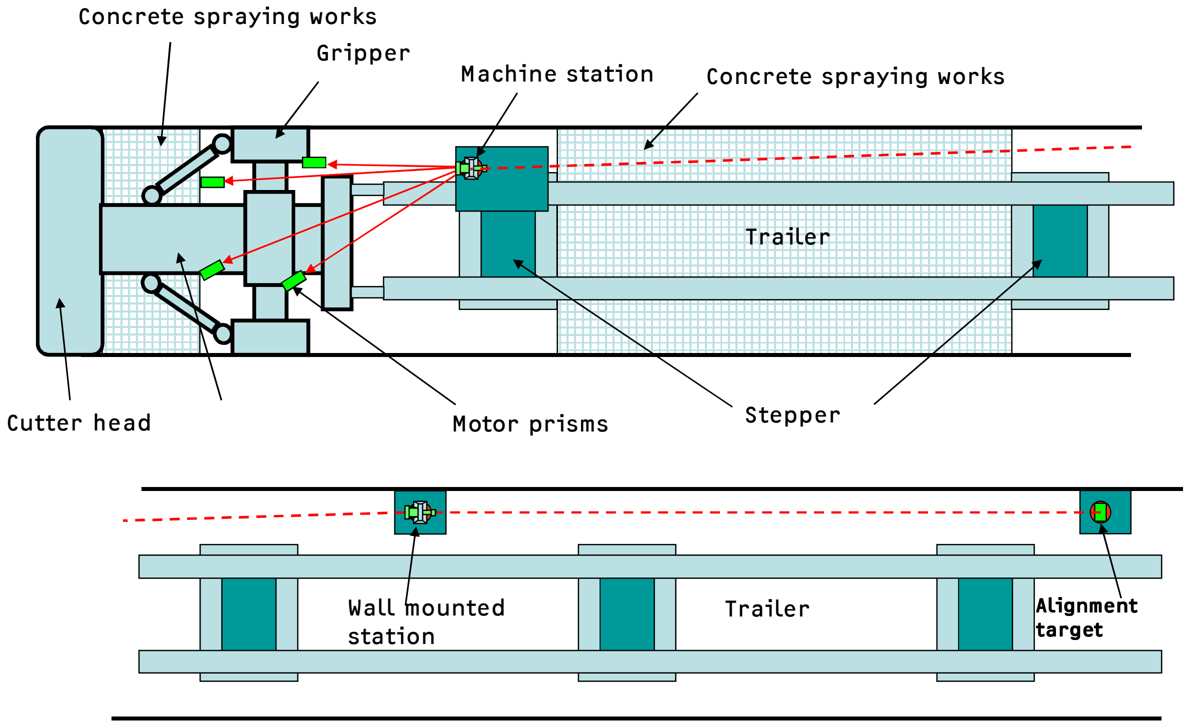


Fig. 4 Trailer concept Gotthard-South section



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Four motorized shuttered prisms (machine prisms) were mounted on the machine frame (see fig. 5) and measured on the machine axis. This "local" co-ordinate system was incorporated into the computer calculations. During the advance the machine framework moves forward.

The machine station (motorized total station on an automatic tribrach AD-12) was mounted on a divert frame which was connected to the frontal walking mechanism and independent from the trailer (see fig. 6).

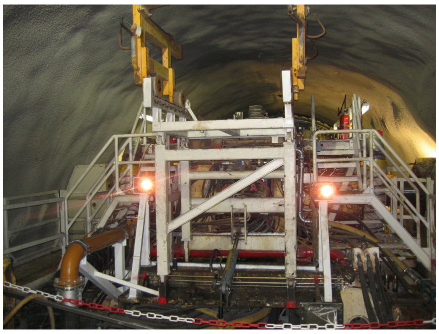

Fig. 5 Shuttered prisms on machine frame

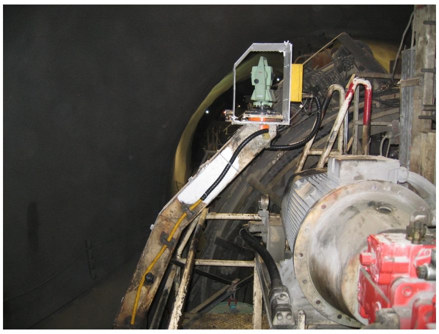

Fig. 6 Divert frame with machine station

During the advance this mechanism does not move. It was only pulled forward after the advance. With the short-time-stable machine station the motorized prisms were measured and the global coordinates calculated during the measurement cycle and the TBM's position was determined by a special transformation (see fig. 7). As the TBM stays in advance mode within these measuring cycles, a track correction is added to the measurements of the motor prisms (dynamic transformation).

As with the Gotthard-North system the coordinates and orientation of the machine station were only short-time-stable. This means they changed with each advance. When an advance was made, the grippers were contracted, moved forward and afterwards extended again on the tunnel wall. A signal was then given by the TBM to the control computer which started the measuring of the machine station from the wall-station mounted in the rear. The measuring operation took about 2 minutes. Afterwards the shotcrete work in the backup area could continue.



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## Display of TBM Position

On the monitor (see fig. 7) all for the control relevant data are displayed for the machine driver. Beside the deviations of the planned axis (horizontal and vertical) the roll and pitch were also shown. The indication of operating state of the connected sensor system is displayed as well as the station and the advance number. Out of this display the direction control and also the display of the last (historical) shield drive could be activated. The latter acts first of all for identification the performance of the TBM, which influenced directly the control.

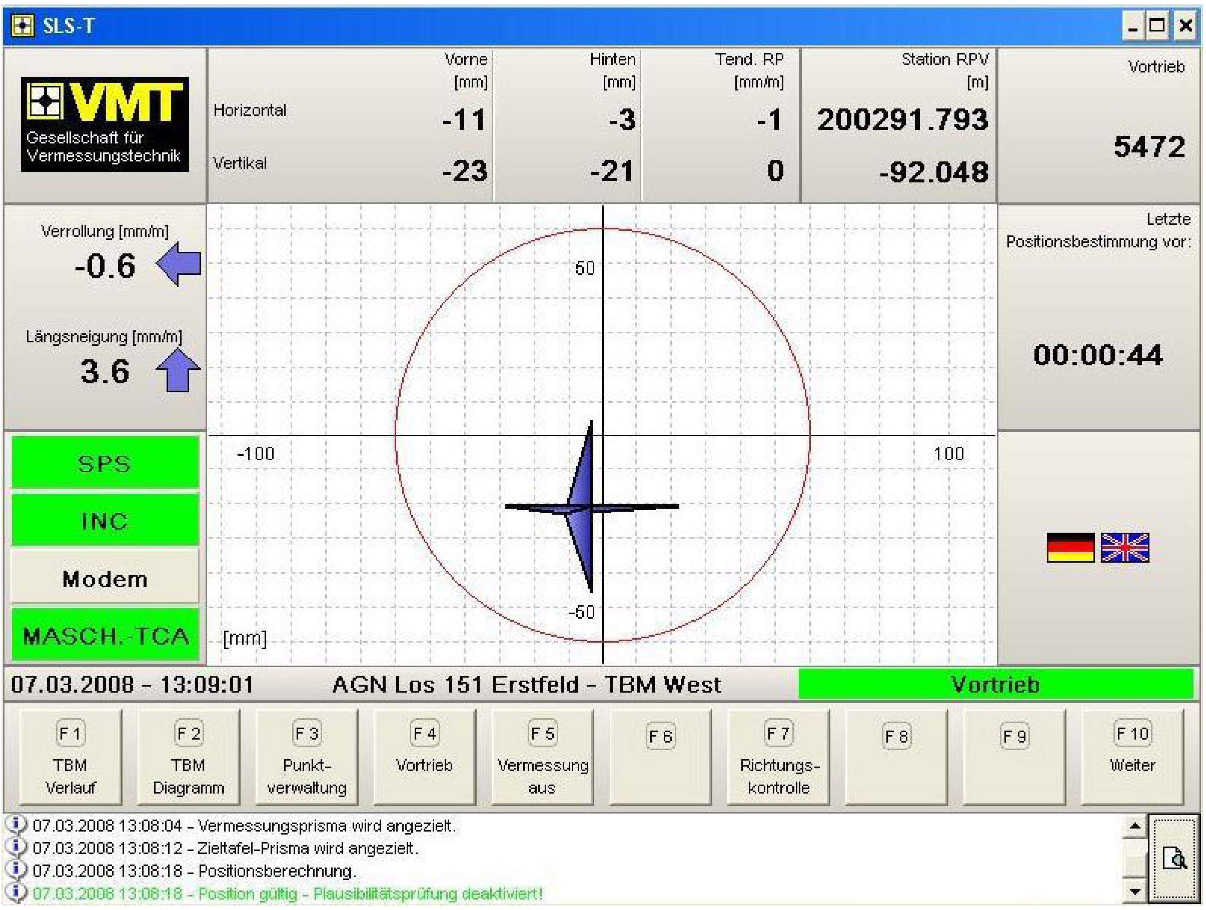


Fig. 7 TBM position in relation to the planned tunnel axis, calculated by transformation



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Abstract:

The adaptation of the navigation system to the special drive-operations was doubtless a big technical challenge. The components used and materials were subject to very problematic conditions such as vibration, dust and heat. The operating mode of the navigation system has to be fully orientated to these drive operations as the driving process should be in no way affected. Several times during the advance not only geometric system adaptations were necessary but also changes in some hardware components. For example the controller unit (data conversion and network) has to be cooled with compressed air as well as conforming to at least the IP62 protection category.

The use of similar hardware components and a modular software system was beneficial as all the necessary adaptations could be done with relative low effort.

Things didn't always flow smoothly – therefore sincere thanks are given to all parties involved, for their patience and understanding during the set up of the system and the necessary revisionary phases.

All things considered, this project has account in many aspects for the enhancements of technique and methods whereof many future projects will benefit from.



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