# Light at the end of the tunnel

**by Norbert Benecke, Volker Schäpe and Volker Schultheiss**

**Across the globe, more and more tunnels (and longer tunnels) are being built. Currently, the longest tunnel in the world is the 57 km (35 mi) long Gotthard Base Tunnel in Switzerland, but this could change in the decades to come with the planned 123 km (76 mi) under-sea tunnel to be built between the Chinese cities of Dalian and Yantai. Every tunnel project is a multi-million dollar investment, and the level of accuracy required for tunnel measurement increases continually. When trains are expected to travel through at a speed of up to 300 kph (186 mph), the planned tunnel's axis has to be maintained with maximum precision. In the case of tunnel construction in ground water such as with the Elb Tunnel in Hamburg, the giant tunnel boring machine has to be driven into a special water-sealed target construction with centimetre precision when finished. The smallest directional error in the heading can lead to considerable technical problems and financial risks when working on critical projects of this magnitude.**

The tunnel surveyor plays a crucial role in making sure that the breakthrough of the tunnel occurs precisely at the specified target point. The challenge is to guide both sides of the tunnel in the right direction. The measurements for directional transmission occur using elongated traverse lines, which can only be connected to a control network of a known point at the tunnel's entrance. There is no way to check the directional accuracy of the advancing opposite end of the tunnel. As tunnel length increases, configuring both ends for the correctness of proper tunnel direction result in considerable risks and uncertainties.

## Surveying under difficult conditions

Many tunnel tubes have entry starting shafts. From these starting shafts, fixed-point coordinates are transfered down to the tunnel's level so that the tunnel can be bored correctly and navigated toward its target, this being the other end of the advancing tunnel. This process, known as plumbing, always involves an element of risk, when transferring fixed reference points in such small and narrow shafts. If the measured data is so much as a millimetre inaccurate, this inaccuracy compounds itself and leads to


considerable deviations in the lateral traversing line of the tunnel's many curves and its direction.

The measuring risks in the tunnel itself occur when the line of sight is diverted and subject to refractive influences such as temperature differences, humidity or dust. These make measuring angles and reliable measurements difficult and errors unavoidable. This applies even more due to the fact that in most tunnels the surveying points cannot be situated in the centre of the tunnel for logistical reasons and must therefore be located at the tunnel walls. Targeting close to the wall increases the risk of refraction even further. Tunnel courses with numerous (and tight) curves also require maximum accuracy.

As the tunnel length increases, errors from plumbing and refraction can add up to as much as several meters, making breakthrough at a desired position impossible. A considerable amount of additional work is then often required in such cases.

### The solution is a "toy"

Previously, miners and tunnel builders solved this problem using compasses. In the modern tunnels of today, however, this is not possible due to the considerable amount of iron and steel used. Initial developments in solving this problem using gyroscopes came about in the early 1950s.

Just about everyone is familiar with gyroscopes from childhood, when playing with a spinning top. We are constantly using the underlying physical principle of precession in our daily lives, for example, when we take our hands off a bicycle's handlebars while riding and continue going straight as if by magic.

Precession is the directional change of the axis of a rotating body (a gyroscope) when external forces apply torque to it. If such a gyroscope is built into a measuring device which is positioned somewhere on the Earth for a certain period of time, the Earth's gravity will act on this gyroscope as the external force during this time. The gyroscope tries to counteract this external force and to remain in its original position. If it then manages to measure these values, such a gyroscope can be used to determine the direction to the Earth's axis (cartographic north).

## DMT and Leica Geosystems – 20 years of close cooperation

For the Gyromat from DMT to work, it requires a fixed connection to a high-performance theodolite. Once the gyroscopic measurement has taken place in the Gyromat, the direction is transferred to surveying points in the tunnel network via the theodolite. DMT made the decision to work closely together with Leica Geosystems over 20 years ago. Current Leica Geosystems instruments fit the DMT Gyromat perfectly and are reliable and rugged for use under difficult tunnel conditions. Data transfer functions flawlessly, and thanks to the outstanding cooperation between the development engineers at Leica Geosystems and DMT, model changes are also easy to manage.

The ability to outfit theodolites or total stations individually enables their use in geodetic applications and control tasks in unlimited ways. The Gyromat 5000 is compatible with the high-accuracy total stations from Leica Geosystems, including of course current models such as the Leica Viva TS11 and TS15, Leica TS30, TM30 and TM6100A and the new Nova TS50 and MS50 MultiStation.

DMT (Deutsche Montan Technologie) developed one of the first high-precision surveying gyroscopes for the German coal mining industry. The Gyromat was subsequently further developed for a variety of tasks, e.g. tunnel construction and ship building. The current model is the Gyromat 5000, which is by far the world's most accurate surveying gyroscope, thanks to its angular precision of 0.8 mgon, corresponding to an arc deviation of about 1.2 cm (0.5 in) over 1 kilometre (0.62 mi).

### The Gyromat in use around the world

Gyroscope-based traverse line measurement for safeguarding the heading direction experienced its breakthrough in guiding the heading of the Channel Tunnel between England and France. When the tunnel breakthrough occurred in 1990, a lateral deviation of just 35 mm (1.4 in) over a total tunnel length of 55 km (34 mi) was achieved. This was only possible due to the use of the then-current Gyromat 2000, with which DMT carried out independent check measurements on the English and French sides.

Since then, DMT experts have successfully carried out more than 3,500 gyroscope campaigns across the globe using high-accuracy Gyromats and Leica Geosystems total stations. Whether it's the CERN particle accelerator in Geneva, hydroelectric plant construction in Lesotho or Iceland, the Gotthard and Brenner base tunnel projects and similar projects in the Indian Himalayas, US waste water tunnels or the world's current largest waste water project (the Emscher conversion) in the Ruhr region of Germany, DMT experts equipped with the Gyromat and Leica Geosystems total stations are there to independently check the tunnel direction and, if necessary, make corrections. DMT surveyors also participated in the construction of the infrastructure for the Winter Olympic Games in Sochi and in subway construction in a number of cities on every continent.

DMT surveyor Volker Schultheiss comments: "Thanks to our independent check measuring, we are able


**Camels attentively watch Volker Schultheiss during calibration measurements on-site in Abu Dhabi.**


to assure the owners and the construction company carrying out the work that the tunnel is heading exactly where it's supposed to. With minimal financial outlay, we are able to safeguard a multi-million Dollar investment. In roughly 70% of measurements, we can confirm that the heading is moving within the permissible tolerances, but in about 30% of cases, corrections need to be made based on our measurement results. In one extreme case, a correction of over 3 metres (9.8ft) was necessary. Thanks to corrections like this, considerable additional expenses can be avoided."

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DMT

DMT GmbH & Co. KG is a company of the "TÜV Nord Group" and an internationally active, independent engineering and consulting company focusing on raw material exploration, other exploration, mining and coke oven technology, construction and infrastructure, product testing, building safety and industrial testing and measurement technology. A special strength of DMT is the development of innovative geodetic, geotechnical and geophysical measuring devices for special tasks based on its own practical experience with special customer requirements.

In addition to tunnel construction services, Leica Geosystems partner, DMT, also sells the combination Gyromat/Leica Geosystems theodolite to customers, primarily in the areas of tunnel construction, ship building, military applications and the production of fiberoptic gyroscopes (the Gyromat is used to calibrate the gyroscopes produced). The Gyromat is sold directly by DMT and is also available through the Leica Geosystems worldwide dealer network.