InnoTek
SOLUTIONS FOR UNDERGROUND

"TUNNELS & TUNNELLING"

RASSEGNA STAMPA
23 novembre 2009

Casa editrice: John Carpenter House
Numero: Novembre 2009
Pag.: 44
Data: 23 novembre 2009

CONSUMABLES

At the sharp end – progress in reliability

Following rapid progress with disc cutters in the 1980-90s, cutter technology is approaching maturity, with development efforts concentrating on improved reliability and more peripheral applications. Maurice Jones checks out the current technologies and manufacturers.

There are many variables that can ensure a successful TBM drive, but the correct selection of cutters is a vital factor. Having confidence that a drive can be completed without downtime due to cutter changes removes a major worry from the project manager. TBM equipment specialist Herrenknecht refers to it as "a question of trust in lifetime, efficiency and reliability" which is important in consideration of the variable and sometimes extreme conditions to which they can be subjected and the effect of these on mechanised tunnelling project profitability. According to Herrenknecht these can include conditions such as ground temperatures of up to 50oC, rock strengths of up to 400 MPa, high water pressures, dust and abrasive sand.

When cutter changes do become necessary, they need to be completed quickly, safely, within available logistics and to the recognised machine design. An important factor in overall costs is the ease of replacement of worn or failed components on used cutters, and at what stage of the drive this needs to be carried out. The activity can be part of the supplier's service or carried out by the contractor's own trained personnel in a surface or underground workshop.

Ground conditions

The selection of cutters, and their arrangement on the cutterhead, is chiefly dictated by the expected ground conditions including not only the ground's hardness (or softness), measured as Uniaxial Compressive Strength – UCS. However it is also affected by the expected orientation of planes of weakness and their spacing, tensile strength, brittleness and abrasivity and other mineral content. The possible data on the ground conditions has to be matched by the available thrust at the TBM's cutterhead and the design of muck removal arrangements to prevent clogging and/or unnecessary energy consumption through grinding of the cut material.

Another factor greatly affecting the choice of cutters is the diameter of the tunnel and TBM, since the gauge and other outer cutters have to travel comparably great distances whilst those nearer the centre will travel less but may be subject to higher axial loading and bearing forces.

The Excavation Engineering & Rock Mechanics Institute at the Colorado School of Mines, US, under Prof. Levent Ozdemir, has carried out studies over several years into TBM performance with particular reference to ring cutters and relevant rock properties. UCS tests include an analysis of how the sample fails i.e. structurally along lines of weakness or non-structurally in an 'intact' manner. Rock tensile strength is assessed according to the Brazilian Tensile Strength (BTS) test, again with observation of the mode of failure. This gives a measure of brittleness and thus the rock cutting efficiency possible.

The more familiar Cerchar Test is used to assess abrasivity and thus to estimate cutter wear during TBM excavation with extrapolation to estimate cutter costs given the tunnel dimensions.

The effects of rock mineral content, especially how it affects abrasivity, can be limited by use of larger diameter cutters since they carry more material to wear before needing to be changed. The allowable ring wear volume before the cutter must be changed is increased by over a third in 19-in. (483-mm) cutters. Larger diameters also facilitate the use of higher capacity bearings for greater TBM thrust (and hence penetration) and torque. According to hard-rock TBM innovator The Robbins Company, 19-in. disc cutters can be operated at 311 kN load compared to the 267 kN load limit of a 17-in (432-mm) cutter, still with increased bearing life. When operated at maximum load the 19-in. cutter's bearing is only at 84% of its roller bearing load rating whereas the 17-in. cutter at maximum load is at 93% of its roller bearing load rating.

Robbins recently developed 20-in. ring cutters to give a wear volume 58% greater than that of 19-in. cutters with consequent improvements in cutter life and reduced cutter changes. Such 20-in. cutter rings are currently being used on two Robbins 10m-diameter double-shield machines on the Alimineti Madhava Reddy (AMR) project in India. This is to be the world's longest tunnel without intermediate access – at 43.5 km long.

These 20-in. cutters are also installed on the world's largest hard rock TBM, the 14.4m-diameter Robbins machine for the 10.4km-long new Niagara Tunnel in Canada.

The importance of overall TBM design to the selection of cutters leads TBM manufacturers to emphasise the importance of integrated technology. Herrenknecht states that innovations in TBM technology and cutter tools go hand-in-hand. They see the cutter tools in the context of cutterhead design and changing procedures for the cutters. "If the cutter tools are effectively aligned, this not only simplifies the necessary maintenance work," they say, "but also positively influences profitability."

Disc cutters

Both disc cutters and roller cutters penetrate the rock face by crushing the rock in front of the cutting element as it is thrust forward. Rotation of the cutterhead with corresponding rotation of the cutter on its heavy-duty bearing ensures that the crushing action finds a different part of the face. The desired action is for the rock between these 'crush zones' to break off the face for mucking out.

Disc cutters tend to be more efficient in breaking off the rock at the face, depending on the ground conditions. According to the

Part of the Seli group, InnoTek of Rome offers three types of tools using carbide (widia) inserts. These are rippers for digging into the face and removing boulders, cutters housed on TBM blades to remove spoil dug out by rippers, and scrapers for loading out the spoil. Scrapers also guarantee correct operation of the cutter tools (gauge cutters) in the peripheral areas of the cutterhead.

CONTACT: INNOTEK S.r.l._P.zza G.Marconi 26/c_ 00144 Roma_ info@innoteksrl.com_
press office: pr@gkproject.it +39 0432 229580_Ilaria Driussi

CONSUMABLES

At the sharp end – progress in reliability

Following rapid progress with disc cutters in the 1980-90s, cutter technology is approaching maturity, with development efforts concentrating on improved reliability and more peripheral applications. Maurice Jones checks out the current technologies and manufacturers.

There are many variables that can ensure a successful TBM drive, but the correct selection of cutters is a vital factor. Having confidence that a drive can be completed without downtime due to cutter changes removes a major worry from the project manager. TBM equipment specialist Herrenknecht refers to it as "a question of trust in lifetime, efficiency and reliability" which is important in consideration of the variable and sometimes extreme conditions to which they can be subjected and the effect of these on mechanised tunnelling project profitability. According to Herrenknecht these can include conditions such as ground temperatures of up to 50oC, rock strengths of up to 400 MPa, high water pressures, dust and abrasive sand.

When cutter changes do become necessary, they need to be completed quickly, safely, within available logistics and to the recognised machine design. An important factor in overall costs is the ease of replacement of worn or failed components on used cutters, and at what stage of the drive this needs to be carried out. The activity can be part of the supplier's service or carried out by the contractor's own trained personnel in a surface or underground workshop.

Ground conditions

The selection of cutters, and their arrangement on the cutterhead, is chiefly dictated by the expected ground conditions including not only the ground's hardness (or softness), measured as Uniaxial Compressive Strength – UCS. However it is also affected by the expected orientation of planes of weakness and their spacing, tensile strength, brittleness and abrasivity and other mineral content. The possible data on the ground conditions has to be matched by the available thrust at the TBM's cutterhead and the design of muck removal arrangements to prevent clogging and/or unnecessary energy consumption through grinding of the cut material.

Another factor greatly affecting the choice of cutters is the diameter of the tunnel and TBM, since the gauge and other outer cutters have to travel comparably great distances whilst those nearer the centre will travel less but may be subject to higher axial loading and bearing forces.

The Excavation Engineering & Rock Mechanics Institute at the Colorado School of Mines, US, under Prof. Levent Ozdemir, has carried out studies over several years into TBM performance with particular reference to ring cutters and relevant rock properties. UCS tests include an analysis of how the sample fails i.e. structurally along lines of weakness or non-structurally in an 'intact' manner. Rock tensile strength is assessed according to the Brazilian Tensile Strength (BTS) test, again with observation of the mode of failure. This gives a measure of brittleness and thus the rock cutting efficiency possible.

The more familiar Cerchar Test is used to assess abrasivity and thus to estimate cutter wear during TBM excavation with extrapolation to estimate cutter costs given the tunnel dimensions.

The effects of rock mineral content, especially how it affects abrasivity, can be limited by use of larger diameter cutters since they carry more material to wear before needing to be changed. The allowable ring wear volume before the cutter must be changed is increased by over a third in 19-in. (483-mm) cutters. Larger diameters also facilitate the use of higher capacity bearings for greater TBM thrust (and hence penetration) and torque. According to hard-rock TBM innovator The Robbins Company, 19-in. disc cutters can be operated at 311 kN load compared to the 267 kN load limit of a 17-in (432-mm) cutter, still with increased bearing life. When operated at maximum load the 19-in. cutter's bearing is only at 84% of its roller bearing load rating whereas the 17-in. cutter at maximum load is at 93% of its roller bearing load rating.

Robbins recently developed 20-in. ring cutters to give a wear volume 58% greater than that of 19-in. cutters with consequent improvements in cutter life and reduced cutter changes. Such 20-in. cutter rings are currently being used on two Robbins 10m-diameter double-shield machines on the Alimineti Madhava Reddy (AMR) project in India. This is to be the world's longest tunnel without intermediate access – at 43.5 km long.

These 20-in. cutters are also installed on the world's largest hard rock TBM, the 14.4m-diameter Robbins machine for the 10.4km-long new Niagara Tunnel in Canada.

The importance of overall TBM design to the selection of cutters leads TBM manufacturers to emphasise the importance of integrated technology. Herrenknecht states that innovations in TBM technology and cutter tools go hand-in-hand. They see the cutter tools in the context of cutterhead design and changing procedures for the cutters. "If the cutter tools are effectively aligned, this not only simplifies the necessary maintenance work," they say, "but also positively influences profitability."

Disc cutters

Both disc cutters and roller cutters penetrate the rock face by crushing the rock in front of the cutting element as it is thrust forward. Rotation of the cutterhead with corresponding rotation of the cutter on its heavy-duty bearing ensures that the crushing action finds a different part of the face. The desired action is for the rock between these 'crush zones' to break off the face for mucking out.

Disc cutters tend to be more efficient in breaking off the rock at the face, depending on the ground conditions. According to the

Robbins disc cutters are made to bore through any type of material that can be fractured with no set maximum rock hardness other than the economic limit of slower progress.

Of course it is not a simple matter of being able to expect greater progress in softer rock, even when the structure is taken into consideration. Robbins warns that since cutters will penetrate deeper into soft rock a potential situation may result that the TBM may not have enough power to turn the cutterhead. In harder rock the cutter capacity may limit progress rather than the machine power.

Increasing demands

Although the pace of technical development in cutters has not been so rapid of late, the increasing demands placed on TBM systems have, in turn, placed more demands on the cutters employed. One such demand is the higher pressures experienced at the face in some projects. Herrenknecht says that tools can be expected to work under ambient pressures up to 20 bar. The company's answer in current development is pressure-compensated disc cutters. Disc cutter bearings work in a chamber sealed from ambient conditions. The seal sets can usually accomplish a differential pressure of 3-4 bar so, consequently, under ambient pressure greater than 4 bar pressure compensation of the bearing chamber of the disc cutters is necessary. This can be done by a membrane construction that allows for a pressure transfer from the ambient medium to the oil in the cutter bearing chamber.

Another Herrenknecht development is the narrow single-disc cutter, which allows narrower spacing between cutters on the cutterhead. The company says that many current and future projects require cutterheads with cutter spacing of only 70-80 mm, thus allowing a much higher face opening ratio of 30-35% for better muck flow, especially for mixed face conditions. Such faces can include soft soils as well as very hard rock at the same time, such as in residual soils overlying fresh bedrock. This type of ground needs a large number of disc cutters (and their holders) with small spacing, but this contradicts a high opening ratio. The new development allows for a cutterhead design with disc cutters arranged in rows on the arms, allowing for comparatively large apertures between them.

As demonstrated by the Palmieri range, disc cutters are available in single, double and triple-disc designs with single housing or as a twin-disc centre cutter with double housing. Palmieri cutters are now manufactured and supplied by a separate company within the Palmieri group in Gaggio Montano (Bologna), with other tunnelling equipment, including cutterheads, being supplied by Palmieri Tunnelling-Drilling of Venturnia (Livorno). Palmieri claims the widest range of sizes from 6 to 20 in. (150-500 mm) diameter to cover microtunnelling systems as well as large-diameter TBMs. The cutters are equipped with high-temperature-resistant seals to minimise bearing contamination at water or air pressures up to eight bar.

Cost balance

In costing the use of a TBM any saving in the purchase of cutters needs to be balanced against the cost of TBM standstill (lack of availability) and the costs of unplanned tool changing.

Quality of manufacture and control directly affects the strength or weakness of cutters, especially in the metallurgical process. Cheap cutters are available which may differ little from more expensive versions in superficial terms but which could tend to wear out quicker or fail when put the use, especially under harsh conditions.

Robbins says that one of the problems in incorrect cutter choice is lack of experience amongst some contractors, causing them to base cutter decisions purely on purchase price. "Rings made of 'less developed' materials are often used on project with the intent to cut costs, but with the consequence that cutter life and penetration can be compromised. Using cutter rings that optimise cutter life and penetration will ultimately benefit the contractor in the long run," says Robbins.

Although known mainly for hard-rock work, Robbins confirms that disc cutters are being manufactured for more varied conditions, and longer and larger diameter tunnels.

Red Horn Engineering of Singapore has been manufacturing Black Diamond cutters at its factory in Shanghai since early this year following its acquisition of the range from Pacific Tunnelling of Australia. Albert Per of Red Horn points out that, whilst basic ring cutter design has changed little, there are more demands on performance of the cutter ring itself for the same cost. However, "the necessary material available at reasonable cost is very much limited," he says.

This cost pressure from customers has led some suppliers to offer lower price cutters

Below left: Assembling a larger diameter (19-20-in.) disc cutter for higher capacity loading and wear; Below right: Robbins 20-in. diameter disc cutters and backloading holders installed on the 14.4m-diameter hard-rock TBM cutterhead used for the current Niagara Tunnel project

with different material,claims Per. “Most of the time,” he continues, “the cutter cost skyrocketed because everyone is rushing and pushing the limit resulting in unpredicted wear and faulty cutters.” This includes such things are cracked rings and failed bearings.

With mixed ground additional possible performance failures include increased torque (possible cutterhead stall), cracked rings and bearing failure such as from a bent shaft. On hard, homogeneous tunnel faces the loading is shared more equally amongst the cutters but in mixed ground penetration can tend to be different between cutters, resulting in increased impact from hard inclusions. Per also cites the case of a mixed faced with a band of very soft ground that can stop a disc cutter from turning, creating uneven wear. Uneven wear of the discs will deter the normal rolling action, even when returning to hard ground, resulting in more uneven wear to the disc and perhaps the holder body too.

The correct material is also important is such conditions. “Just remember,” points out Per, “that a really hard cutter can reduce wear, but only for hard rock. It will crack easily when in mixed ground as it will be more brittle. For hard ground a thinner tip and standard rolling toque is recommended, and for mixed ground a wider tip (cutting edge) and lower rolling torque.”

According Per bearing seal failure is not a common fault and is usually due to incorrect set up. “Most of the time a seal failure is due to improper installation or an unclean (assembly) environment. The seal face is machined almost perfectly flat, thus any foreign particles can result in leaking. One cutter failed the pressure test and a strand of hair was found on the seal face. The cutter passed the test once the hair was removed.”

A recent Black Diamond development is a patented single-bearing cutter with a 2-cup bearing in a single cone designed by NTN for Red Horn. It eliminates the need for torque adjustment. There is an even pressure on the bearing to create the rolling torque over a longer bearing life. “Our seals sit perfectly on the bearing and when the cup is tightened a resistance is created from the seal and bearing to create the rolling torque.” For lower torque a shim plate is added between the bearing to push out the cup and release the contact pressure between the cup and cone.

All Black Diamond cutters have the torque set after assembly, but if a lower torque is required a shim plate can be added. Per says, “These improve the speed for maintenance and repair, and also eliminate the possibility of over or under torque, which can result in unforeseen failure of the cuter.”

Roller cutters

Prior to the development of ring cutters, the hardest ground was tackled by cone- or frustum-shaped cutters set with rows of carbide inserts that could penetrate the rock face under the required pressure and grind it for removal. Whilst ring cutters are more efficient for most sizes of TBM, roller cutters, originally developed for large-diameter rotary drilling, are still found in tunnelling applications of smaller diameter such as raiseborers and microtunnellers, and also for shaft drilling.

Well known for its long expertise in carbide element design, manufacture and applications, Sandvik produces tricone bits and roller cutters for raiseboring in the Sandvik Mining & Construction range.

Meanwhile the development of small ring cutters for smaller diameter tunnel and microtunnelling drives continues amongst specialist manufacturers.

Picks and scrapers

Tunneltec, which makes a wide range of ripper and scraper tools for use in medium-to-soft ground, emphasises the importance of the cutting material that comes into contact with the ground. Managing director Friedhelm Allwicher and marketing manager Stefan Jansen report that there has been a trend to using more tungsten carbide (often known central Europe as ‘widia’) in the composition of the tool, with corresponding less use of hard facing. The Tunneltec product range does not use hard facing in any case, replacing it with carbide buttons.

In mixed ground picks and related tools tend to be subjected to shock loading more often than in homogeneous ground, or that experienced by rolling cutters. Therefore the static cutters have to be designed to cope with this type of loading. Jansen mentions that in a recent tunnelling project TunnelTec employed different compositions of tungsten carbide and different types of brazing to handle shock loading.

As mentioned earlier, the outer cutters, especially gauge cutters, have a comparatively hard life throughout a drive but their durability must be assured. Jansen comments, “One important issue (with cost) is to cut the gauge area to avoid big problems with melting over-cut.” Efficient gauge cutters are needed to provide the space for forward movement and steering, but since they are set at an angle to the TBM axis, they need to be constructed to withstand high forces across their own axes.

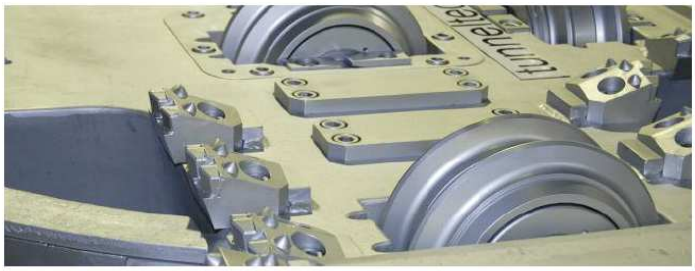
Part of the Seli group, InnoTek of Rome offers three types of tools using carbide (widia) inserts. These are rippers for digging into the face and removing boulders, cutters housed on TBM blades to remove spoil dug out by rippers, and scrapers for loading out the spoil. Scrapers also guarantee correct operation of the cutter tools (gauge cutters) in the peripheral areas of the cutterhead.

Bewarder of Germany offers a very wide range of cutters including static and ring cutter types for all standard BM types. Types include various shapes of pick and scraper cutters, reamers, centre cutters, copy cutters and the aforementioned discs. Bewarder claims that careful selection of carbide insert quality and the use of heat-treated steel optimises wear protection, and helps to produce a very good cost-performance ratio. Inductive brazing with temperature-resistant solder is used for bonding between the carbide and tool body material.

Changing

Even though backloading of cutters is now commonplace, it can still be a tricky and time-consuming procedure. This is especially so in soft ground in consideration of the medium used to support the open ground (compressed air, pressurised slurry, etc.). If mid-drive cutter changes can be avoided it improves both

Right: **Part of a dual-function 2,26m-diameter TunnelTec rock cutterhead delivered last year to contractor Dibco of Toronto. It features both fixed and disc cutters and can be converted to soft-ground use. Its first project was for a siphon sewer in Calgary.**



Above left: Breakthrough of an 8.16-m Wirth EPB TBM equipped with TunnelTec tools on the Castellanza metro project, Italy. The cutterhead is equipped with both static rippers and scrapers and disc cutters with carbide bullet inserts. Right: Disc cutters shown on the cutterhead of a 9.90m-diameter NFM Technologies TBM on completion of 1140m in a single month for the Madrid-Gijon high-speed railway route

safety and scheduling.

The desirability of completing a tunnel drive without tool changing is more important with metro construction, especially in urban areas. This avoids any increased tendency to subsidence in a particular but unplanned location. According to Jansen one solution is to have more tools per track, thus sharing the load. Another is to work with different heights of tools so that well-working, virtually fresh, tools are available over the complete drive.

Changing ground conditions present an extra challenge especially when trying to avoid cutter changes mid-drive. Jansen says that to meet both these requirements, "Geological analysis is essential in order to realise (or modify) the cutterhead layout and to arrange the tools including types, placement, height and quantity. At one job-site in the north of Italy using an earth-pressure balance (EPB) machine, the cutterhead has been assembled with Tunneltec cutters and tools to manage sand and gravel at the beginning of the drive followed by limestone, and then sand and gravel again at the end."

Customisation & compatibility

It might be thought that there was little scope for customisation in supplying a 'consumable' product ranges such as cutters but Stefan Jansen of Tunneltec has identified a trend for customisation of cutterheads and tool layouts as a factor in the increase of TBM supply with a 'buy back' option for use in later projects. The cutterhead invariably needs customised cutter arrangements to meet the expected new excavation conditions when they become known, as this is unlikely to be known at the time of TBM design. Repeat customisation may be necessary from job to job to suit the aim of the project and complete it successfully.

"We see that customers want more and more standard TBMs in order to have less different spare parts," comments Jansen, "but on the other side, they want a cutterhead (as the important part to dig out the material) that is optimised for the related project. Thus we will have more and more different cutterhead layouts around the world."

Durability development

Even with previous experience of similar tunnelling conditions, it can be difficult to predict the life of cutters, although, whether through better products or better planning, this is increasing. In a recent 11.38m-diameter NFM EPB TBM application in Wuhan under the Yangtze River, China, for rail tunnels Tunneltec tools (face scrapers, face rippers and bucket (mucking port) scraper all lasted for 2700m without changing, and were still not worn out. The cutterhead was equipped with 250 face picks and 16 bucket scrapers. Geology comprised sand layers, gravel and shale with face pressures up to 7 bar, which would have made any tool changes risky and expensive.

In the more difficult geology of a 9.18m-diameter Metrobus Brescia (Italy) project that included abrasive material, cobbles and limestone layers, TunnelTec tools lasted for 1467m without changing compared to 80m for the tools previously used. A Herrenknecht TBM was fitted with scrapers, welded-on rippers, replaceable rippers and a nose cone ripper.

Stefan Jansen emphasises the importance of comparing the circumstances of each project in comparing tool life, since simple longevity figures can be misleading.

According to Robbins improved materials have surfaced to meet the demands for increased cutter life and loading. For example, cutters that are made for high-load situations consist of a material that keeps it properties at a higher temperature, and is therefore tougher and more resistant to chipping than standard cutters. Both variations of cutter, says Robbins, are equally resistant to abrasive wear. Robbins cutters using purer and tougher materials have been available since 1998. These cutters, of generally longer life, have been used successfully on project such as the Manapouri Hydroelectric Project in New Zealand and La Malata Land Outfall in Ferrol, Spain.

Service

In addition to the support of customers with product advice, manufacturers usually need to provide job-site support such as in the form of cutter stocks and refurbishment facilities in a workshop such as the mobile unit Red Horn provides. At the end of tunnelling the cutter consignment balance will be returned to Red Horn within an agreed time frame and the contractor charged for whatever is used.

Tunneltec relies on staff site visits whenever required due to contractor problems, advising whatever the tools that are used.

Herrenknecht's range of practical customer services includes a cutter database as a management tool. The data relates to experience of wear rates and cutter exchange strategies gathered during a number of projects. Database users can develop economic project strategies for cutter disc exchange and refurbishment. The database also records the cutter type as well as the time, place and reason for the exchange or refurbishment. The database can, therefore, deliver a complete history of each cutter disc, reports on the respective costs incurred during the last excavation and permits the forecasting of favourable maintenance intervals including cutter exchanges. The database software is available to in multiple languages. T&T