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TRENCHLESS SOLUTIONS FOR SMALL-DIAMETER PIPELINE INSTALLATIONS

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ABSTRACT: The development of sufficient pipeline capacity and the construction of sustainable power grids are the challenges for future energy supply. Due to the public environmental awareness, smart trenchless installation methods are required for fast and safe installation of pipelines and underground cables, with minimal impact on the surroundings.
For crossing obstacles along the routes, Horizontal Directional Drilling is still the preferred option, as it is an economic and industry-proven technology. In recent years, features like the jet pump, weeper subs and tooling concepts have been developed to increase safety and application range in HDD. An all-electric HDD Rig concept is a further indispensable step towards energy transition, making green energies usable in the drilling industry, while reducing emissions to a minimum.
Trenchless technologies like Auger Boring, e.g. for short crossings of railway tracks, and the Slurry MTBM based Direct Pipe and E-Power Pipe methods show their strengths on long drives in small-diameters and in permeable ground, where HDD reaches its limits. As slurry pumps are crucial components for long-distance drives, the jet pump technology has been integrated into AVN slurry microtunnelling creating the AVNS machine range.
E-Power Pipe uses the AVNS and presents a trenchless option for the two-stage installation of HDPE or steel pipes from 10” to 28”, or up to 36” with the backreaming option. Furthermore, the AVNS was implemented in the Direct Pipe technology to enable single-pass pipeline installation for long crossings down to 24” in diameter.
Today, trenchless technologies cover the entire geological spectrum, with high flexibility in terms of diameters, drive lengths and depths of the network sections to be installed. Contractors have to equip themselves with the latest technologies and equipment to be able to cover the large range of project conditions.

1. INTRODUCTION

Trenchless technologies are indispensable for the pipeline industry in order to expand existing networks, to safely install difficult crossings and landfalls for oil and gas as well as for future hydrogen transmission and power grids. New trenchless construction methods and the further development of existing technologies now offer suppliers, grid operators and construction companies a wide range of methods for project execution. Over long and short distances, over land or when crossing obstacles, economic aspects, environmental protection and the concerns of residents and landowners can be reconciled. This paper will present the latest technological solutions, in particular for small-diameter pipeline installations taking environmental and safety aspects into account. Tunneled solutions with pipe jacking and segment lining are not part of this paper.

2. TRENCHLESS TECHNOLOGIES OVERVIEW

A remarkable number of trenchless installation methods have been developed over the past 50 years. Basically, these installation methods originate from the fields of pipeline installation and tunnel construction. Successive further development in terms of diameter range, geological suitability for use, installation accuracy and the variety of pipe materials to be laid have made these techniques increasingly economical and versatile. Additional process

and technology developments such as the two-step E-Power Pipe technology were initially intended for new applications, such as the laying of underground cables, where completely new requirements were placed on the construction methods to be used from the subsequent operation of the pipelines.
Selection of the appropriate trenchless method depends largely on the specific project parameters. The pipeline can be installed directly, as it is the case with Horizontal Directional Drilling (HDD) or the Direct Pipe method. The following table provides a simplified comparison of the common methods and some key parameters.

Table 1. Overview of trenchless methods according to diameter and installation length

	Direct Pipe®	E-Power Pipe®	HDD
Installation of **Pipelines** or underground cable solution			
	one-step Pipeline/steel casing	**two-stage** Pipeline/steel casing/HDPE single casings or bundle	**multi-stage** Cable bundle or steel casing/pipeline
Diameter	**24“ – 60“**	**10“ – 28“** < 36“ with backreaming	**10“ – 60“**
Max. installation **Length**	**2,000 m**	**2,000 m**	**5,000 m**

*The information in this table is intended as an initial guideline; the parameters may vary depending on the project.

3. DIRECT PIPE®

Over the past 15 years, the Direct Pipe method developed by Herrenknecht for the trenchless installation of prefabricated steel pipelines has established itself worldwide, used in more than 200 pipeline crossings and landfall projects. It combines the advantages of Microtunnelling with the Pipe Thruster technology to enable trenchless installation of pipelines or casings in difficult ground conditions while reducing the risks typically associated with HDD. Direct Pipe allows excavating the borehole while simultaneously installing a prefabricated and already tested pipeline in one single continuous step. Typically, Direct Pipe is used to safely cross rivers or waterways, infrastructure objects, and other man-made or natural obstacles.

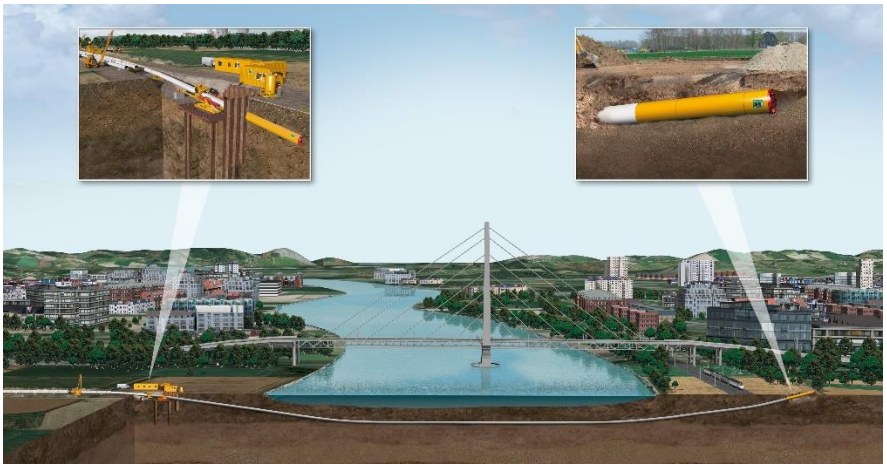

Figure 1. Functional principle of Direct Pipe for one-step pipeline installation

Thanks to further technical development and growing popularity among clients and contractors, the range of applications for Direct Pipe has steadily been expanded over the years. Today, Direct Pipe is also increasingly used for marine landfalls and/or outfalls. For these shore approaches, the Direct Pipe MTBM can (at least partly) be disconnected remotely from the pipe string at its target point on the seabed and then be recovered.
At the same time, the method has also evolved in terms of installation length and diameter. In New Zealand, in 2020 the world record was set with the installation of a 2,021 m long 48” treated-water pipeline into the open sea, after successfully completing a 1,930m long outfall two years earlier.

3.1. AVNS with jet pump for Direct Pipe

New developments in technology, such as the jet pump and the respective machine design, now make it possible to use Direct Pipe even for small-diameters starting at 24". Thus, the AVNS machine concept has recently been integrated in the Direct Pipe technology to enable one-pass installation for longer crossings smaller than 36 inches. The jet pump is essentially the same as it is used for the smaller E-Power Pipe system described below and the same principles and requirements for auxiliary equipment applies. For Direct Pipe it was field-tested on an AVN1200TB for pipe jacking, pushing a 56” steel pipe on a short 140 m railroad and road crossing near Berlin. The ground conditions were sand with some clay content and the potential for boulders, although none were encountered. Although the size ratio of the jet pump in comparison to the MTBM diameter was unfavorable, the field test showed that the jet pump intended for small-diameter Direct Pipe could even be operated on larger diameter DP-MTBM such as an 56” unit. The advance rates were up to 250 mm/min, although stable conditions were reached at around 180-200 mm/min. Ground cover was around four times pipe diameter and 5 times underneath the active railroad tracks. No settlements were detected.

Figure 2. Pipeline cross-section for 36 / 24 inches Direct Pipe

The umbilical lines supply the Direct Pipe MTBM with power, data communication, and all the other media such as slurry supply and return are redesigned for small-diameter pipes. Most notably hereby is that the high-pressure slurry lines are fully interchangeable for different pipe diameters, i.e. can be used inside 24” pipelines as well as in 60” pipelines. Only the support brackets running on rubber-coated rollers, which hold them together, must be replaced and are available in different sizes covering the full AVNS range from 24” to 36”. Machines from 42” to 60” use a different style support bracket allowing better access.

While the guidance system for Direct Pipe in 36” to 60” comprises of a gyro compass and water hose levelling system, the small-diameter Direct Pipe system initially used the same technology as E-Power Pipe, a recently developed combination of gyro and magnetic field detection from the surface (TUnIS Navigation MT$^{\text{GyroEMS}}$). Whereas, the latter is introduced to Direct Pipe because of the difficulty to perform control surveys in or through small-diameter pipelines, while replacing the traditional hydro level system at the same time. However, the specialists at VMT have since developed another solution to complement the gyro navigation through an onboard control measurement feature, thus eliminating the issues associated to magnetic field detection systems. Depending on a project’s requirements, all these navigation solutions may be deployed simultaneously or in part only.

Furthermore, Herrenknecht’s new small-diameter AVN rock series for traditional microtunnelling is also being incorporated into the AVNS Direct Pipe concept. A new range of small-diameter Direct Pipe systems is emerging to cover rock conditions with strengths of up to 200 MPa depending on the diameter – with a single jet pump for discharge over 1,000 meters.

3.2. Small Direct Pipe Reference Project

The world premiere for Direct Pipe in 2007 was the installation of a 48” steel pipeline to bundle cables and a water pipeline crossing Germany’s largest river, the Rhine. Since then, Direct Pipe has been used on more than 200 crossings worldwide, in particular for crossing key sections along the route of pipelines. 90 percent of them are below rivers or other bodies of water, but some of them were under infrastructures and trafficways.

Figure 3. 28” Direct Pipe jobsite installation for 342 m long river crossing in Poland

In Poland, the first small-diameter Direct Pipe project was on its way two years ago, using jet pump technology. A 28” AVNS 600 DP in conjunction with an HK500PT Pipe Thruster was working on two crossings for the Gas Interconnector between Poland and Lithuania (GIPL). The first river crossing of 342 metres (Czarna Hancza) has been completed successfully by installing one single prefabricated pipe string (gas pipeline, coated inside & outside). The anticipated ground conditions were sand, silt, clay, some peat, and some small-size gravel (pebbles). The encountered ground conditions shortly after launch were heavy gravel and some boulders, which soon triggered the decision to switch from a soft to mixed ground cutting wheel.
Shortly after, the 28” Direct Pipe unit was on its second challenge (River Narew crossing): 880 metres (two pipe strings) in the initially anticipated ground conditions (sand, silt, some clay, some light gravel). Meanwhile, this system is on its second project in Poland, having completed half of the scheduled crossings already.

Future references are coming from Italy where two small-diameter Direct Pipe crossings are scheduled for 2023, and the United States of America and Thailand potentially, which shows a great interest in this technology. All these countries, amongst some others, are using Direct Pipe for many years already and are primary contributors to its success, with completion of 50 % of the total number of crossings.
Also other countries in Europe are already looking at smaller diameters around 32” and below, and the jet pump technology has spawned interest for larger diameters such as 42” on an impressive windfarm project in the United States.

4. E-POWER PIPE®

4.1. The E-Power Pipe method

E-Power Pipe is used for the trenchless installation of small-diameter product pipes. Over long distances of more than one kilometre, both pressure-resistant and non-pressure-resistant product pipes can be installed. The two-stage process integrates aspects of the proven Horizontal Directional Drilling (HDD) technology and of pipe jacking (microtunnelling). The broad spectrum of applications ranges from the installation of cable protection pipes for underground cables to pipelines for gas supply, district heating or the transport of hydrogen.
For the two-stage E-Power Pipe installation process, a jacking frame is installed in the launch shaft. In a first step the AVNS machine and the reusable, temporary steel jacking pipes especially developed for E-Power Pipe are pushed through the ground along the specified alignment. After breakthrough at the target point, the MTBM is separated from the jacking pipe string. In the target pit a pull head is then attached to the jacking pipe string. The prefabricated product pipe already prepared for installation is connected. As the jacking pipes are pulled back by the jacking frame, the product pipe is successively pulled in. The borehole thus remains mechanically supported the whole time. During insertion, the product pipe can be connected to the ground with the addition of backfill material.
Minimal earthmoving, no heavy equipment between launch and target pits, thus less noise and exhaust emissions, with less impact on the surface are the main benefits of the E-Power Pipe method. These are of special interest when concerns of landowners and environmental protection play a key role for the project to be realized.

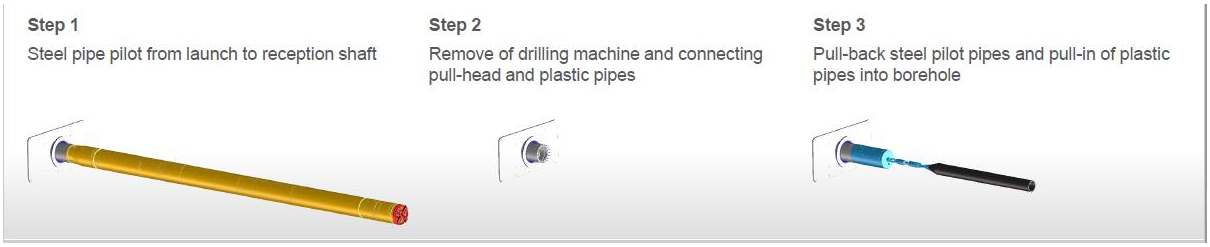

Figure 4. Overview of E-Power Pipe installation steps

4.2. AVNS Slurry MTBM with jet pump

The AVNS350XB tunnel boring machine with an excavation diameter of 505 mm is the key component of the E-Power Pipe method. The AVNS tunnelling machine uses the jet pump as single slurry pump. The jet pump is integrated into the MTBM and enables a high conveying capacity while requiring very little space. The hydraulic powerpack for the supply of the cutting wheel and the steering cylinders is integrated inside the MTBM. This eliminates connection of hydraulic lines otherwise typical in pipe jacking procedures at this construction size.
With the integration of the jet pump into the well-known technologies of Slurry Pipe Jacking (AVNS) and HDD, the feasible application range of these trenchless technologies has been expanded again by going longer with smaller diameter pipes and pipelines and by lowering the frac-out risk in HDD significantly. The new AVNS slurry machine concept featuring the jet pump presents a milestone in slurry microtunneling pushing the boundaries towards the feasibility of longer drives in smaller diameters. Thus, several applications and technologies benefit from the development of one single tool.
The specially designed cutting wheel is equipped with robust cutting tools. A cone crusher located behind the cutting wheel crushes boulders, rock or other materials to a pumpable grain size. TUnIS Navigation MT^{Gyro}, a modern gyro compass based navigation system allows ongoing position determination and high-precision control known from microtunnelling in the non-accessible diameter range. Combined either with a magnetic field and a corresponding sensor, or the newly developed TUnIS.pipelight, an assistance system enabling automated control measurements, long distances can be excavated precisely.

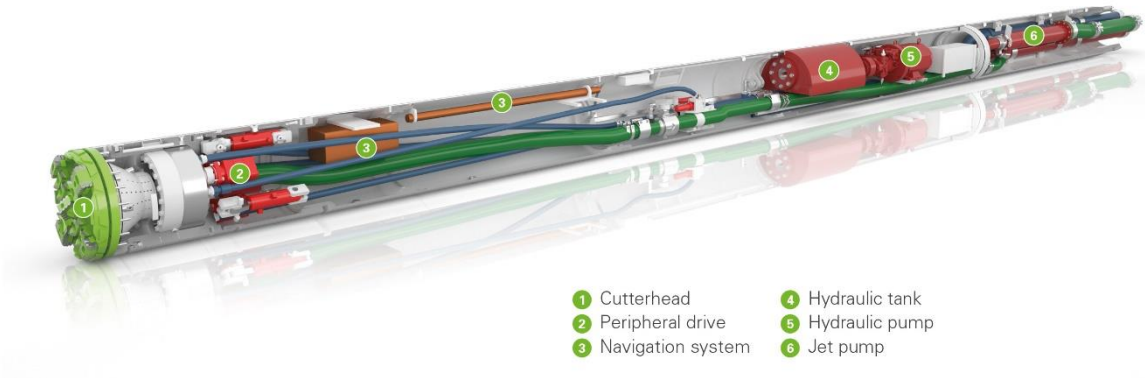

Figure 5. AVNS 350 XB with its components

The first AVNS of its type, an AVNS 350 XB, is used in the two-stage E-Power Pipe technology and is designed for an excavation diameter of 20 inches. It can cover a geological spectrum from loose soils to soft rock of up to 30 MPa, while handling grain sizes of up to 100 millimeters. In the past, even quartzite layers with compressive strengths of up to 100 MPa have been overcome successfully.

4.3. E-Power Pipe reference project

The efficiency of the E-Power Pipe method has already been demonstrated in practical use in several projects. Following the successful pilot project in 2017, the E-Power Pipe method was used in further construction projects for the expansion of the grid in Germany. With its remarkable advance rates, high planning reliability and environmentally friendly construction, E-Power Pipe scores well with grid operators, contractors and landowners. The current record installation length of 2,000 m has been achieved beginning of 2022 in the Netherlands, where a HDPE pipe bundle for underground cables has been pulled in a 20” borehole.

Figure 6. Breakthrough of AVNS machine after pilot drill and pullback of protection pipe bundle of 2,000 m

5. HORIZONTAL DIRECTIONAL DRILLING

5.1. General trends in HDD

For many years, the trend in HDD went for longer and larger crossings to meet the requirements along the main pipeline routes. In this context, high-torque HDD Rigs have been developed and auxiliary equipment, such as the Pipe Thruster for flexible power reserve to support challenging crossings is available. Nowadays, with a rising number of HDD projects for the installation of underground cables, smaller installation diameters are required. This leads to a rising potential for smaller rig sizes, which cause lower emissions and save resources at the same time.

As is the case in the automotive industry, downsizing is a preferred solution for new HDD Rigs in the market. The pull force of the rig, which defines the rig size, remains the same or often is being reduced, while simultaneously the torque is being increased. It is not uncommon to see 100 to 150 ton Rigs with a torque drive of a former 250 or even 400 ton Rig. Today´s precision in drilling is so high, that the pull forces during pipe pull-in are more controllable. Thus, large rigs are only needed on special projects to be on the safe side. Torque is the key nowadays.

5.2. Sustainability and CO_2-Footprint

In the context of climate change, aspects of sustainability are coming into focus of planners, operators, and contractors. This not only concerns the pipeline industry but also power grid companies, which face the same challenges along their installation routes.

For HDD operations, the range of aspects includes fuel consumption and emissions, water and bentonite consumption, disposal of drilling fluids and excavated muck, jobsite footprint, and fluid release. A corresponding obligation to provide evidence on the part of the contractor will play an increasingly important role in the awarding process of future construction projects.

The worldwide focus on CO_2 reduction and the steadily growing awareness of environmental protection is pushing the equipment manufactures to new solutions. One of these is the electrification of the complete jobsite. Running the jobsite only on electricity, including the HDD Rig itself, gives the contractor the possibility to run the jobsite with considerably reduced CO_2 emissions.

Even producing the electricity with generators is improving the environmental jobsite footprint. The engines inside the generators are running continuously at an optimum revolution range. Furthermore, they are often better maintained. With an intelligent control system, several generators can even be connected to each other and are only turned on when a certain amount of power is needed.

5.3. Digitalization

Digitalization also finds its way to the pipeline industry. In order to ensure the communication between all components, the jobsite equipment has to be connected intelligently. This is the basis for a good performance, facilitates remote access and allows continuous data recording and evaluation. With an increasing degree of automation, less manual interference is needed on drilling process or pipe handling for example. In future, even the separation system and mud mixing could adapt automatically to the geology.

5.4. History of electrified drilling

A prefered way to start a new concept is to keep as close as possible to the existing design and convert only single parts into the new technology. Therefore, in a first step, the “problematic” diesel engines have been swapped with electric motors, which is until today a common and reasonable thing to do. As with all technical transitions, the industry first had to get used to the new practices. Even if drilling itself did not change that much with a simple exchange of motors, the equipment still kept their hydraulic system creating the so-called Hybrid HDD Rig range.

The Hybrid Rig and the complete jobsite spread can now be operated both directly from the grid or by generators. An overview on the electrified range of drill rigs and components is shown in Figure 7.

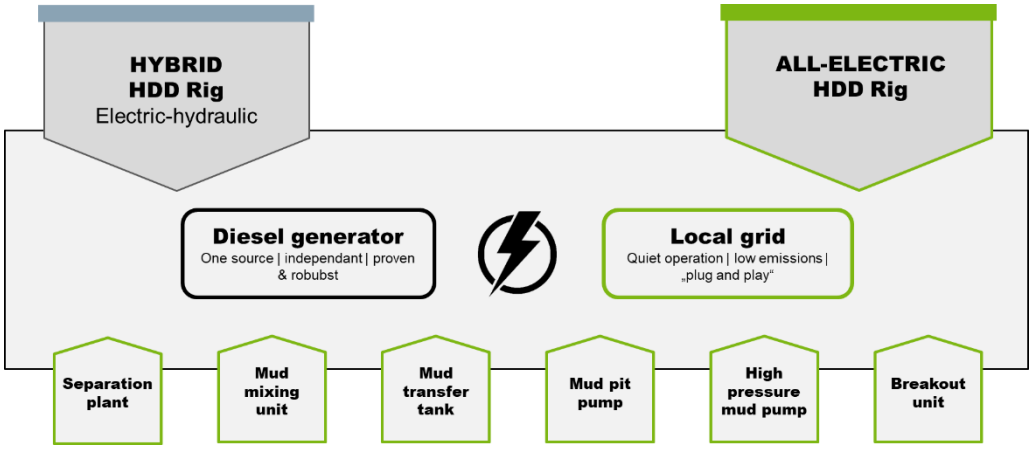

Figure 7. The basis of Electrified HDD with all jobsite components

5.5. Hybrid HDD Rig HK80CK

In order to cope with the requirements of drilling in urban areas and to make the use of green energy effective in the long run, Herrenknecht has developed a very compact Hybrid Rig HK80CK on a crawler base. This Rig is able to push or pull 80 t and has a torque of 60,000 Nm powered by a 250 kW electric engine. Several design features have been implemented to achieve a small footprint on site and high mobility for relocation of the Rig. At the same time, the compact Hybrid Rig considerably reduces noise and exhaust emissions for operation in urban areas. The unit is autonomous and runs all equipment from one electrical source. The electrical power can come either directly from the grid or from a separate generator. This generator is able to run not only the rig, but also the recycling system, transfer or mixing tanks, breakout wrenches and even the high-pressure mud pumps. All accessories are available in electrical versions, so the Hybrid Rig is simply getting in line with all of the existing electric-driven equipment.

Figure 8. Herrenknecht Hybrid Rig HK80CK in operation on jobsite in France

5.6. All-Electric HDD Rig HK300TE

An all-electric HDD Rig is on the way as a further indispensable step towards energy transition, making green energies usable in the drilling industry. A directly electrically driven Rig allows the use of green electricity and assures higher efficiency without the losses associated with the hydraulic system. Once developed and tested, the principle can be transferred to all Rig sizes creating a new generation of all-electric HDD Rigs.

Former electrified drill Rigs, so-called Hybrid Rigs described above, exchanged the diesel engine with a three-phase induction motor which was powering the hydraulic system. Relatively simple, but it enabled the driller to power the Rig purely electrically, while simultaneously keeping the hydraulic system. Consequently, the driller did not experience any difference for Rig operation, it felt like any other conventional Rig. Besides these positive aspects, the efficiency rate was not at its best. The conversion to the hydraulic system is always connected to power losses.

Efficiency
In order to improve the efficiency, the hydraulics have now been removed from the system. This means, that the electric motors, now permanent magnet synchronous motors, are directly installed on the carriage on the gearboxes. This increases the efficiency drastically.
In conjunction with the efficiency improvement, a reduction of emissions follows. If a grid is possible as a power source for the electricity and the grid gets its power out of a green source such as a wind turbine, hydropower or solar panels, the CO2 emission gets close to zero.
And even if a generator with a diesel engine as power source is used, those engines are made to run continuously in the best possible revolution range to have the best power output. In combination with the high efficiency rate of the direct electric drives, the diesel consumption can be reduced massively.

Noise emissions
The hydraulic motors were a main source of noise. With the new electric drives, the noise level was reduced by 10 dB. To humans, with a non-linear sense of amplitude, this represents a halving of perceived noise. The HDD jobsite noise level is now driven by surrounding equipment like the shakers on the separation system instead of the Rig itself. Noise reduction is a side effect of electrification, but most recognized and highly appreciated by the jobsite personnel. Furthermore, lowering the noise level contributes its part to jobsite safety, as a constantly high noise level affects concentration and can lead to an increased risk of accidents.

Electronic components
There is a certain insecurity for the susceptibility to errors for complex electronic systems, this is partly true, the more complex a system gets, the more the probability can be for failures, that is just part of the digitalization. To reduce the risk of failure and ensure a high reliability of the equipment, the most sensitive electronic parts are taken off the rig and transferred in a separate power module. This module is disconnected from all vibrations and other disturbances from the drill rig, and the drill string itself or external sources. With creating this protected capsuled environment for e.g. the frequency converters, they are not affected by any disorders which normally cause failures.

Field tested
First field testing of the new all-electric HDD Rig HK300TE proved, that all considerations Herrenknecht have carried out were successful and no major errors occurred. The contracting crew and the Herrenknecht engineers are very satisfied with the results.

Figure 9. HK300TE: Herrenknecht´s first all-electric HDD Trailer Rig with 300 ton pull force

5.7. Reducing Frac-Out Risk in HDD

Weeper Subs
When looking at the drilling process itself, the Herrenknecht Weeper Sub in particular with longer drilling distances reduces the risk of frac-outs significantly by gradually increasing the volume flow in the borehole. Less drilling fluid is required at the drill bit.

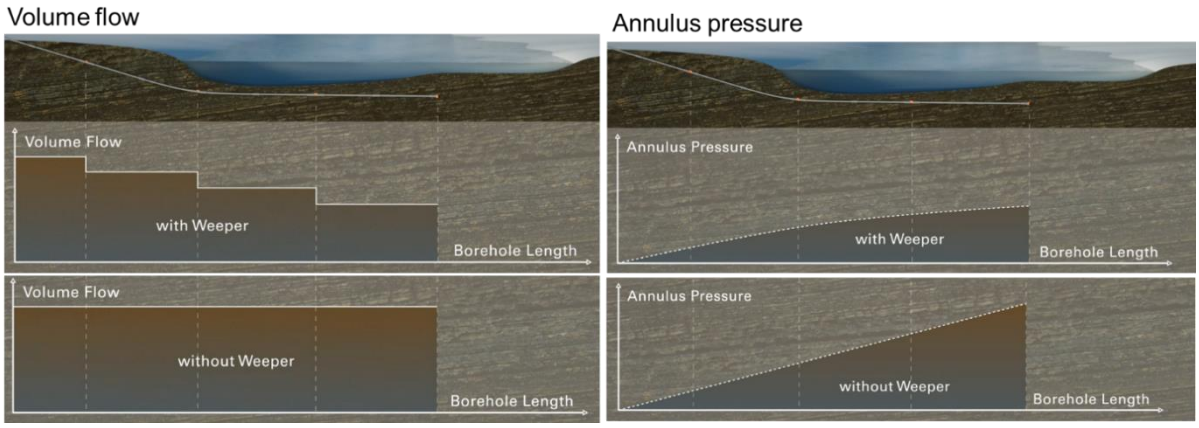

Figure 10. Volume flow and annulus pressure during pilot bore, with and without Weeper

During the drilling process, part of the drilling fluid from the drill string is actively directed into the mud return flow via an extraction nozzle system. This improves the material flow in the annulus and the removal of settled cuttings. Multiple Weeper Subs are installed at intervals along the drill string. With their help, the volume flow in the borehole is gradually increased and therefore the required amount of drilling fluid at the drill bit decreases. Thus, the risk of frac-outs is significantly reduced.

Jet Pump

The jet pump system was developed for HDD operations to reduce the risk of inadvertent fluid returns to the surface (frac-outs). As in HDD the open borehole is normally used for returning the cuttings created by the reamer or hole opener, several mechanisms can lead to over-pressurizing the surrounding formation (e.g. clogged borehole) and thus establishing a potential frac-out risk. The jet pump solution seeks to overcome the above-mentioned problems. There is only one (high-pressure) surface pump which is feeding drilling fluid (mud) to the reamer and from there back to the surface. This is pressurizing the unlined borehole to create returns flow. The longer and deeper the borehole gets, the higher the pressures will have to be.

In order not to use the borehole as a return line, except during pilot bore, and not to use the mud pump on the surface as discharge pump, the downhole jet pump has been developed. It is positioned directly behind the reamer, or hole opener, to collect the cuttings right after they have been excavated and transport them through the drill string (in the case of HDD) to the surface.

The type of pumps which can be used downhole are rare in HDD. It must be a simple and robust pump, which also can transfer torque together with push or pull forces. Furthermore, the pump must be capable of producing a sufficient pumping head. Its power supply must be trouble free and run in wet, submersed, subterranean conditions. The pump itself must fit at least in a 26-inch borehole. Traditionally, there are not many pump types that can handle such requirements. The jet pump is simple in that it has no moving parts, but can be considered complex in terms of the theory behind its operation.

The down hole jet pump for HDD absorbs cuttings from the bottom of the borehole and pumps them through the drill string behind the reamer to the exit side to surface. The power supply for the jet pump is generated by a high-pressure flow of a conventional HDD high-pressure mud pump on the entry side. The jet pump system is applicable in HDD to borehole sizes from 26 inches and larger.

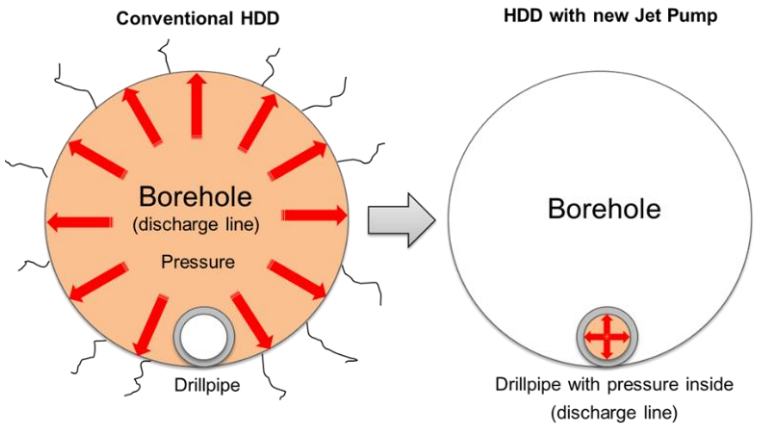

Figure 11. Discharge in HDD, with and without jet pump

6. CONCLUSION

Horizontal Directional Drilling is more than ever important to meet the demands of today's construction projects for pipeline networks and power grids. Besides its main industry, the pipeline construction, which will not disappear, will shift from oil and gas to alternative green fuels like hydrogen. HDD will further gain a wider application range. New developments enable the technology to be used in cable installation, fiber optic or gravity sewage lines. The simplicity of the method in comparison to other mechanized tunnelling methods for example, is more and more appreciated and plays a bigger role for projects where time and money is important, as long as the ground conditions allow a safe drilling process.

In highly permeable ground conditions, where HDD is not applicable, E-Power Pipe and Direct Pipe represent a safe alternative, depending on diameter, installation length and depth and the final type of pipeline to be installed. In both Slurry MTBM-based trenchless technologies, the new AVNS slurry machine concept with jet pump presents a milestone pushing the boundaries towards the feasibility for longer drives in the small-diameter pipeline range. Consequently, several applications and technologies benefit from the development of this one single tool. E-Power Pipe with AVNS and jet pump at the core presents a new trenchless alternative for the installation of small-diameter pipelines and HDPE pipes, e.g. for cable protective pipes in power grid expansions. In a further development, the jet pump for Direct Pipe extends the range towards smaller diameters down to 24” for installing steel pipes in a single pass safely and economically.

Further developments in navigation technology by Herrenknecht’s partner VMT have raised the bar for state-of-the-art-technology by eliminating the use of magnetic-field detection guidance systems that were initially used for small-diameter Direct Pipe systems. Thus, making these systems even more reliable, simpler, and more versatile in terms of their application range.