New Generation of Rack and Pinion Rigs for vertical and inclined SAGD Wells. Advantages of the New 360 VS Rigs. Field Testing Results.

Original solutions originate from experience.

Vasily Anishchenko

While the oil price crisis is raging around the world, most of the oil mining companies and their drilling contractors pay serious consideration to economic effectiveness of the applied drilling technologies. Every reference to a new oil mining know-how is traditionally scrutinized in the Middle East, as this is the key oil-mining region in the world. Technologies like SAGD and inclined wells with ultra-long horizontal sections have not become an exception. Most of the contractors are not willing to share their know-how with the public and they have a good reason not to do so. The purpose of this column is to throw a little light on the most tricky and interesting aspects of drilling inclined wells and applying heavy-duty rack and pinion rigs for oil and gas mining. We believe the industry can benefit from the information set forth below.

Before we lift the vail from the treasure trove of our experience, we would like to clear up a couple of definitions mentioned in the article:

1. **Mobile rig.** Most of the drilling contractors are so much used to the idea that a heavy duty rig from 150 to 500 tons hook load is a cable drilling rig which consumes several MW of power and demands a train or an army of trucks and a couple of weeks to move it from one position to another. In our paper, we are talking about mobile rack and pinion rigs with hook load ranging from 150 to 500 tons. These rigs only need three or four trucks for relocation and consume, as a rule, 30% less power than cable rigs with the same hook load. Relocation takes a day or two.
2. **SAGD** – Steam-assisted gravity drainage (SAGD) is a drilling technique that is used to extract heavy oil that is too deep or otherwise economically inefficient to mine using traditional methods. The process was originally developed by the Alberta, Canada Department of Energy as an efficient means of recovering oil reserves that are difficult to access. SAGD requires a pair of horizontal wells drilled from a central well pad. Steam generators are used to produce steam, which travels through pipelines to the wells. The steam eventually heats the heavy oil to a temperature that reduces its viscosity, allowing it to flow by gravity to a bottom well. The oil is then transferred via pipe from the producing well at the bottom to a plant where it can be treated. Application of some simple techniques including Rack and Pinion rigs allowed several drilling contractors in central and northern Russia to reduce their SAGD drilling costs down to 40% in comparison with their Canadian colleagues. Hence, in this paper we refer to the modified, cheaper version of the technology, which, in our opinion, becomes interesting against the background of the present economic necessities.

In 1990s several drilling contractors started one of the first SAGD projects in Alberta, Canada. In 2006 the technology got adopted in Russia. The depth of the Russian horizontal wells ranged between 70 and 250 meters. It soon became apparent that using ordinary vertical cable tool rigs was not productive to tu extremely small bending radius of the casings. The decision was taken to apply inclined rack and pinion rigs. Such rigs are normally used for coal bed methane mining in Australia and Russia, mine dewatering,

HDD, long-range horizontal offshore oil well drilling, underground gas storage construction and in some other applications. The technology is normally referred to as Slant Directional Drilling.

Being a supplier of drilling rigs, auxiliary equipment and adjacent technologies our company spent several years standing shoulder to shoulder with drilling contractors to work out the best and the most economically viable technological solutions and overcome the difficulties we faced on the way to successful project accomplishment. As the technology became predictable and widely used, we decided to share our experience of overcoming 10 most common problems we had to overcome on our way to high quality inclined wells.

Problem number 1. **Inclined bit rolls and will not enter the ground.** Drilling teams from vertical drilling only need the weight of the drill string to communicate axial force to the drill bit and the suspended string finds its center automatically, hence, this problem never existed in vertical drilling. As the first 45-degree inclined cable rigs started slant operations, the bit refused to enter the ground without hydraulic hammering and special drill collars. Further control of the bit load in an inclined well proved tricky without a rack and pinion mast. Rack and pinion HDD rig operators have never had that problem as the design allows total control of the bit load starting from the 1st meter of drilling. If the diameter of the first casing exceeds 300 mm, the best way to penetrate is to use step-face bits (see picture below), they are different for various ground conditions. The argument is simple: the greater the diameter of the bit is the longer it travels to the right as the rotation starts. One more important detail: in order to successfully accomplish an inclined drilling the contractor should be sure that the drill rig central shaft is properly aligned with the center of the well. The problems stemming from misalignment take a lot of time and effort to correct.

Solutions:

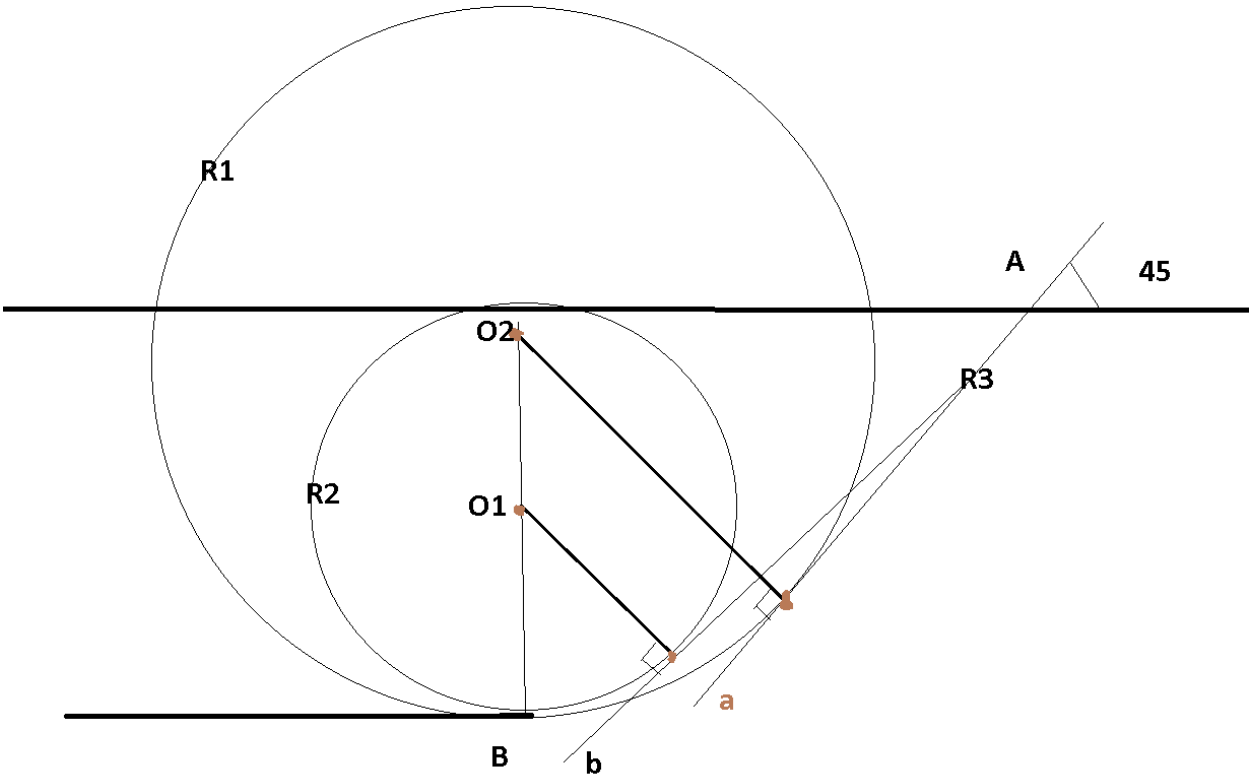
1. Use rack and pinion rigs specially designed for slant and vertical applications. They conserve energy, they are mobile and they are cheaper than cable rigs.
2. If the first casing diameter is over 300 mm, use step-face bits. They can be cone, PDC or combined bits. It is important to use proper step bits for certain ground conditions.
3. Always use high precision measuring equipment to check the alignment of the rig and the hole after the bit enters the ground. If necessary, carry out appropriate adjustments.

Problem number 2. Drilling trajectory. Standard problems with drilling trajectory come from vertical drilling where kick off should be executed gradually and it is nearly impossible to keep DLS steady, i.e. keep the same gradient intensity at every point of drilling between inclined and horizontal sections. Most of project bureaus use conventional software for inclined wells, which entails problems with precision of drilling and bending radius of installed casings

As slant directional drilling stems from two technologies: conventional oil well drilling and horizontal directional drilling, a contarctor has all chances to skim the ceam off them both. Inclined well head makes it possible to greatly decrease residual pipe steel stress. In HDD no pipeline can be bent to the radius greater than 1200 of its diameters, which is perfectly achievable in slant directional drilling. We should remember that the quality of a well without residual stress in the casings is much higher than the quality of the well where the casings are bent nearly to their yield point. There is one more argument in favor of keeping the maximum possible drill curve radius: cement is evenly distributed along the walls of the casing if there is no stress making the casings press against the walls of the well and the rotation while cementing comes in easier.

In hope that the above mentioned arguments have been pervasive, we would like to prove that the maximum casing bending radius in the well with a 45 deg. inclined well head is a circle with inalterable radius wich is a bitangent to two lines: horizontal well section and a line passing through the center of a well head:

Please, see the picture bellow:



Line a is a tangent line to circle R1, line b becomes tangent to R2 at some point. If both circles are tangent to B, the centers of both circls lie on one horizontal line perpendicular to B. this line is the center of the horizontal section of the well. Hence, R1 is bigger than R2 and if it is possible to have one radius between the point where we start bending and the point where we get horizontal, we should better consider the option very closely before deciding in favor of a standard drill curve with variable bending radius.

Solutions:

1. Use maximum bending radius while engineering the drill curve
2. Use standard software with great care
3. If possible, use RSS systems or any other systems measuring the position of the bit in every point of the drilling trajectory, not at the beginning and at the end of every drill rod.

Problem number 3. Stability of a long horizontal hole and high filtration rates

We have published several articles devoted to polyacrylamide and cement solutions against losing drill mud in fissured formation. We have also mentioned inflatable packers, which are necessary to carry out successful cementing operations along inclined and horizontal sections of a drilling hole. The purpose is is to distribute cementing agent in the formation evenly around the mud loss area, not just cementing the bottom of the horizontal hole and go on losing mud via the top layers, which the cement cannot penetrate due to gravity.

Most of the contractors in the central part of Russia do not have financial opportunity to use drilling fluids with proper rheology to prevent mud losses. Some of them drill with water. But water is not always accessible. The problem of losing mud is exacerbated by the loss of formation stability in the hole. If the formation in the loss area does not get sealed, the contractor will almost certainly get problems with cementing the casings and the general contractor will not accept such a hole. Most of the contractors in the area where our rack and pinion rigs were involved use polyacrylamides. Some of them still go on losing money, as they do not use inflatable packers.

The most important issue in the process of applying inflatable packers is controlling down hole pressure. We normally advise to follow the guidelines bellow:

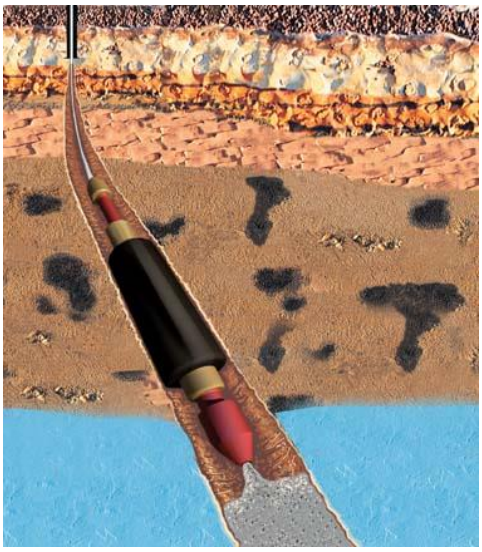
- If the mud loss gets too far, it is still necessary to drill a short distance past the filtration area. If necessary, improve rheology and use any filtration additives. After making sure you have drilled past the filtration zone, lift the drill string.
- One or two inflatable packers are installed in proper places on the drill string and the string is run-in-hole operation continues till the packers are installed in proper places relative to filtration are.
- The packer should be positioned in such a way that no cement gets past it into the cle an section of the hole. If necessary, pump drill mud via the well mouth to keep the hole stable. If the cement gets past the installed packer into the hole, the hole might be lost. Such cementing is called suicide.
- Please, follow all producer's manuals and prescriptions while installing the packer.
- Centralizers are often used before and after the packers to drive them safely into position down the hole. (please, make sure you use proper centralizers and do not use gauge rings or reamers)

The operational sequence in this case looks as follows:

- Preparing cementing agent or polyacrylamide. Pumping the cementing agent down the holw.
- If cement is used, pump it in small portions go on pumping until proper pressure is achieved. If you use polyacrylamide, mind that in most cases you pump the whole batch down the hole and wait for one hour until you can check the pressure. Repeat operation until you can achieve proper pressure.
- Cleaning the packer should be carried out with great care. It is important to properly calculate the weight of the cleaning fluid. Heavy fluid goes below the cement, light fluid goes on top.
- Checking the quality of plugging and pressuring the hole. After solidification of the cementing or plugging agent try to apply maximum possible pressure of the pump. Make sure you do not frack the formation.
- After pressurizing is complete and successful, pull out the string.

Inflatable packer should only be used under professional supervision.

In one of horizontal holes we had to repeat the procedure several times.

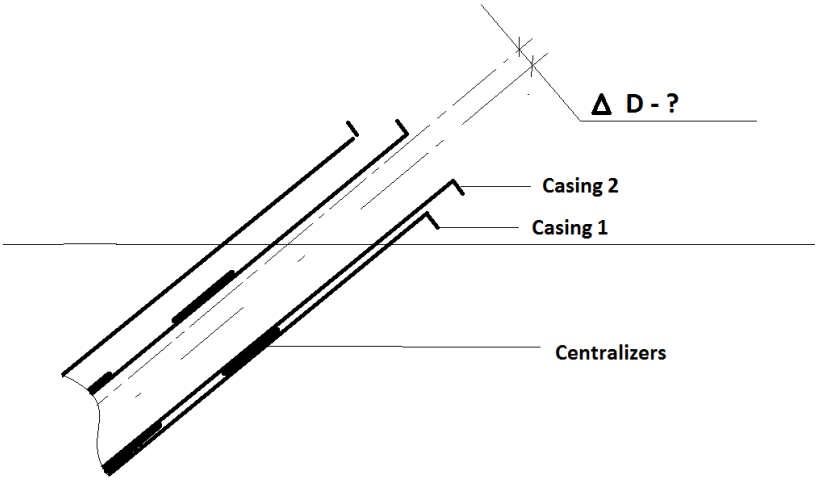


Solutions:

1. Use polyacrylamides or plugging agents
2. Use inflatable packers along horizontal sections
3. Make sure the rig can control the pull-and push force with enough precision

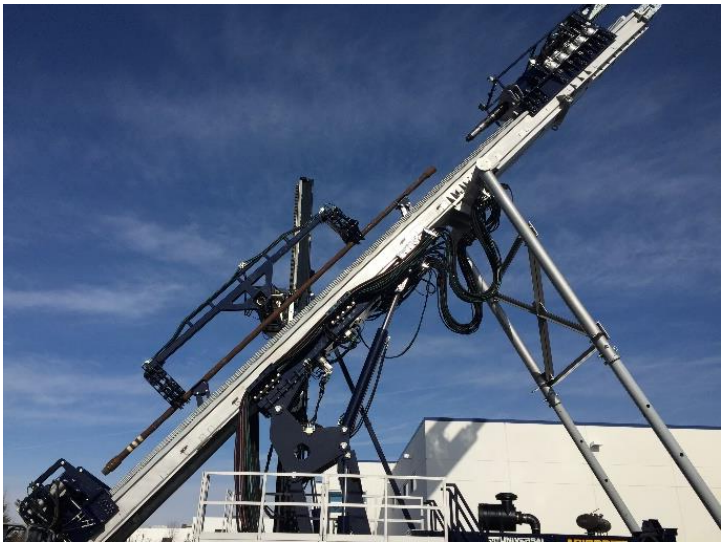
Problem number 5. Axis misalignment between the rig's central shaft and the drill line

As the contractors started using inclined rack and pinion systems, most of the solutions were found, but as the old HDD rigs were adapted for 45 degree operations one more serious problem emerged. Casings in vertical drilling operations are self-centered as they are suspended from a top drive like a pendulum. In inclined position casings of smaller diameters rest against the groove of a previous large diameter casing. The rig in most cases is rigidly welded to the anchors, which is required by safety regulations. The picture bellow manifests the problem:



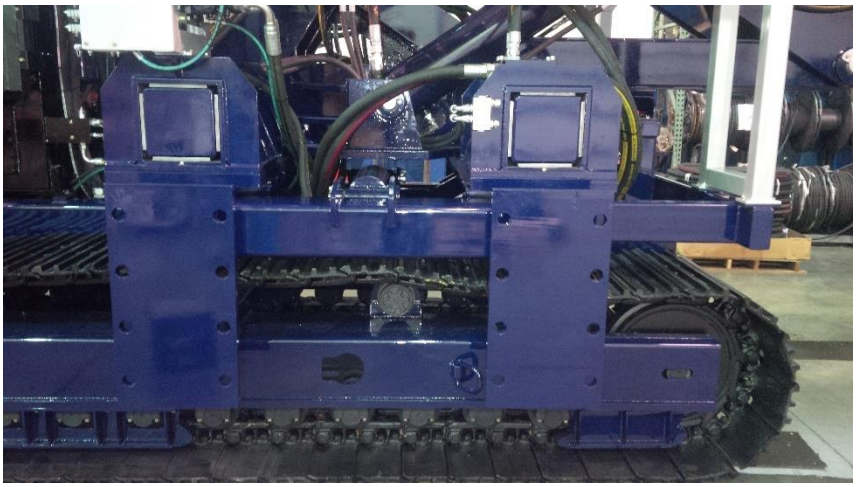
Having spent several years in the inclined drill fields our specialists found the solution, which was implemented in ADI 360 VS. The rig can adjust the mast axis without being detached from its anchors. Another solution for existing rigs of older generation is a flexible sub patented by ADI. Please, see picture of the new generation rig bellow:

In inclined position:

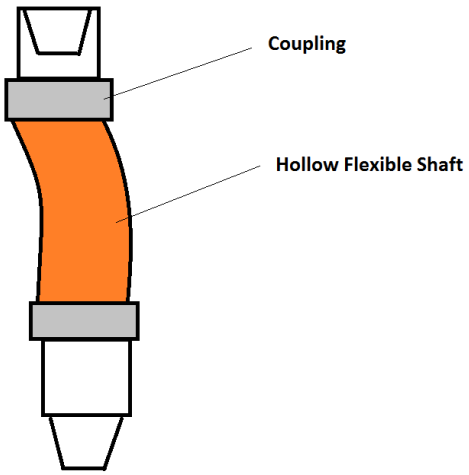


In vertical position:

The mobile ADI 360 VS with its 150 ton hook load and 70 kNm is not only capable of aligning its mast up and down using parallelogram under the mast, it moves the mast on the existing well head 300 mm left and right using powerful guides and unique sidelong anchors as shown in the picture bellow:



Flexible sub is capable of transmitting rotation between two slightly misaligned shafts.



Solutions:

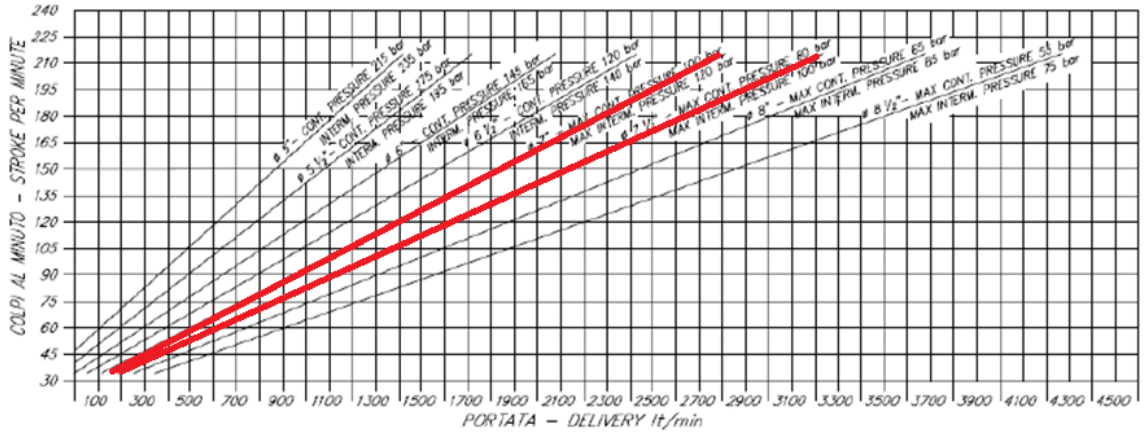
1. Use new generation drilling rigs with alignment system for the mast
2. Use flexible subs to rotate two slightly misaligned shafts
3. Always check the rig for proper alignment
4. Be very careful with fine threading of the casings. The thread always gets broken in case of misalignment.

Problem number 6. Choosing proper pumps and adjusting pumping pressure.

On one hand the mud motor should rotate, on the other hand the formation at 100 meter depth should not be broken even after 2 km. It is a rule that all pumps used in slant drilling operations and in horizontal drilling operations are to be adjustable. The diameter of an HDD hole ranges between 6 and 80 inches, and the diameter of a slant hole can range between 6 and 12 inches at relatively shallow depth. It is possible to use HDD rigs modified in a special way for SDD operations. But special care should be taken when choosing the pump and relating it to the existing mud motor. The specification of the pump should be agreed with the mud motor or vice versa. Some reckless contractors fail to do so and keep their pump load at 95 per cent from the maximum possible limit, which makes the life of such pumps very short. Most of the general contractors and field operator demand that their drilling contractors keep two HP pumps at each rig. They have a very good reason to do so.

Solution:

According to our experience of drilling between 100 and 300 meters to the length of up to 1,6 km it is reasonable to use two pumps marked red in the diagram below. Do not use smaller pumps, it is dangerous. All pumps should be adjustable:



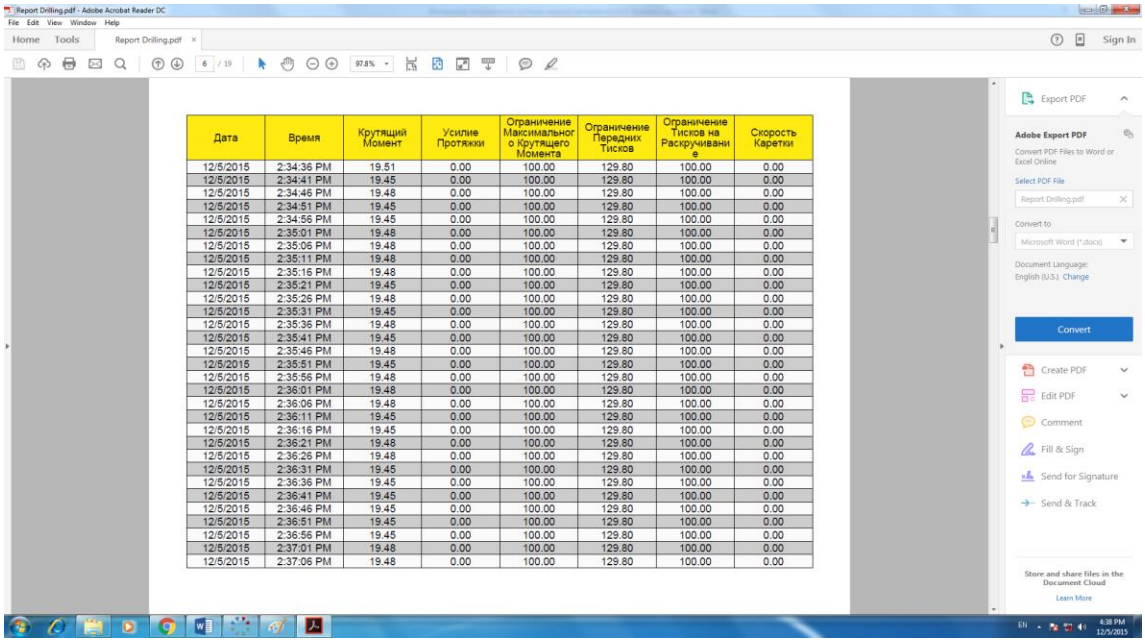
Problem number 7. Control of all drilling parameters.

In order to set an example we would like to give an account of the disaster, which happened at one of the rigs and resulted from meager experience of a drill rig operator and connivance of a site manager. The situation unfolded very quickly. The operator could not push the next consecutive 9' casing into the hole and applied 20 tons to “do it”. According to the calculation of our supervisor, the string of casings should have been going down under its own weight at that stage. The operator pushed on it as if nothing happened and kept silence. The rig was old and its LWD systems needed a PDF print out of several hundred pages just to analyze one shift period. If a site manager is not a superman, he is not able to analyze so much data within half an hour of the shift change. The hole had to be plugged and abandoned after a failed attempt to cement it. A small radius dog leg in the hole and sand dunes at its bottom “squeezed” the casing and successful cementing became impossible. Had the site manager a chance to analyze the data within a short time at the end of the shift, not after the accident, the disaster could have been prevented.

Our drilling experts together with the best IT specialists form the US designed a brand new LWD system, which allows the analysis of the most important drilling parameters within minutes. A site manager should only study two pages for each parameter to find out the extreme figures. The new generation of rigs made it possible to check all parameter measured at the rig within minutes.

MWD and LWD systems of ADI360 VS give an operator the opportunity to produce a detailed understandable report of measured rotation torque, pull and push forces, make up and break out torque, RPM of the engine, fuel consumption, pressure from all pressure transducers etc. It possible to choose a time period from the log and a measured parameter. After study the report can be printed. It means pring only a couple of A4 pages to have a clear picture like the one shown below:

In the form of a table:



Дата	Время	Крутящий Момент	Усилие Протяжки	Ограничение Максимальног о Крутящего Момента	Ограничение Передних Тисков	Ограничение Тисков на Раскручивани е	Скорость Каретки
12/5/2015	2:34:36 PM	19.51	0.00	100.00	129.80	100.00	0.00
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12/5/2015	2:36:16 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:21 PM	19.48	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:26 PM	19.48	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:31 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:36 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:41 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:46 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:51 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:36:56 PM	19.45	0.00	100.00	129.80	100.00	0.00
12/5/2015	2:37:01 PM	19.48	0.00	100.00	129.80	100.00	0.00
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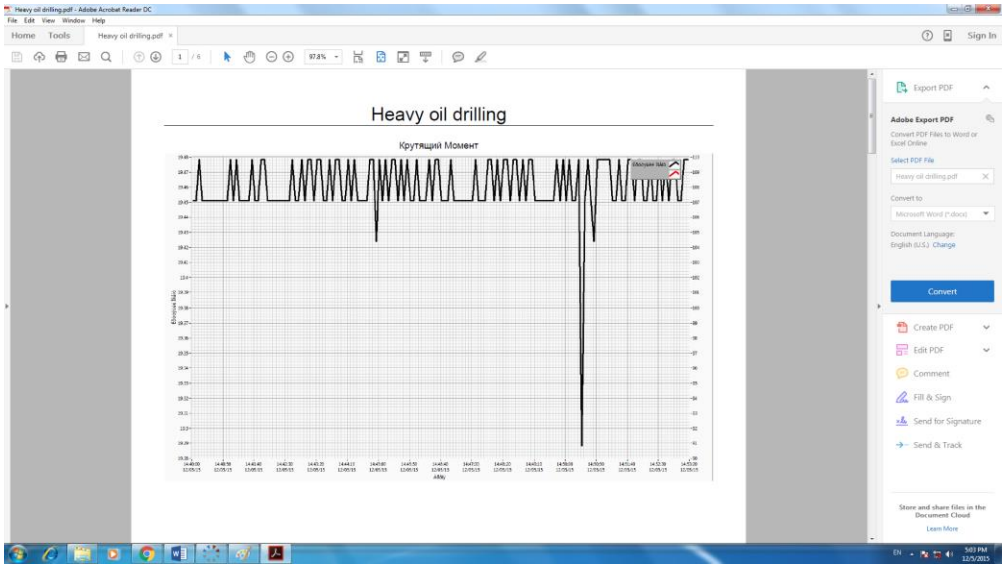
Or in the form of a diagram:



Solutions:

1. Use only LWD systems which are simple to analyze and can be deciphered within 5 minutes by the rig operator or a site manager
2. Always observe a drilling plan and make sure you have a good plan with calculations for all applicable forces
3. Make sure you install proper limitations to the parameters and use rigs which allow to limit the force of absolutely all functions applied to the drill string

Problem number 8. Precision of navigational systems.

The operational margins of most existing hydro pulse and electromagnetic systems do not allow their operators to measure the inclination with such precision as to peep the maximum permissible deviation of 0,5 m per 1.5 km. This is necessary for successful SAGD installations. If the distance between the two wells in the pair deviates from the project requirements, the steam chamber will not perform effectively and the production rate will not rich its plan. Some companies use inductive pipes or magnetic joints, this technology is limited to it's owner and is extremely expensive for those who is willing to purchase.

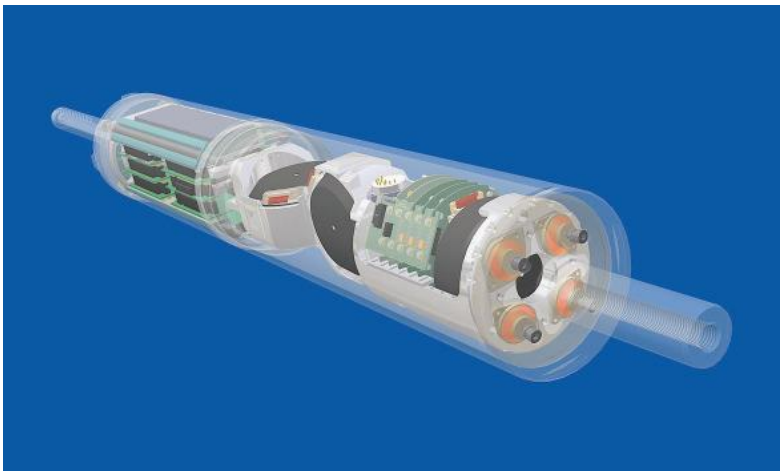
Magnetic appliances and electromagnetic data transfer cannot be used in conductive coal layers, hence, standard nagivational systems cannot be applied in coal seam gas projects. High frequency gyro nativational systems are widely used in Europe (see picture bellow), the systems can be installed into drill rods of 3 ½ and 6 5/8.

The problem of precision cannot be solved with navigational devices only. A systematic approach should be practiced to make the drill string more predictable and simple to calculate. For example, if a project company applied polynomic equations to drilling curves: one $y=kx^n+ds+c$-type could be used for profile, where n is an even degree like 2, 4 or 8. And $y=k^n\sqrt{x}$-type could be overprinted onto a plan of the future well. A single radius for the curves described in previous chapters is also an option. It would simplify the measuring process and make it possible to measure and check the position not just at the beginning and at the end of every drill rod, but to measure the position at every single point of the line. If this technology is combined with RSS systems, the "A" mark for precision can be guaranteed irrespective of the electro conductive soil conditions or the length of the string.

Solution:

1. Use new gyro systems for electro conductive coal layers
2. Use predictable curves to measure them in every point
3. Use RSS systems to make the hole smooth and keep it stable

The picture of a gyro system is shown bellow:



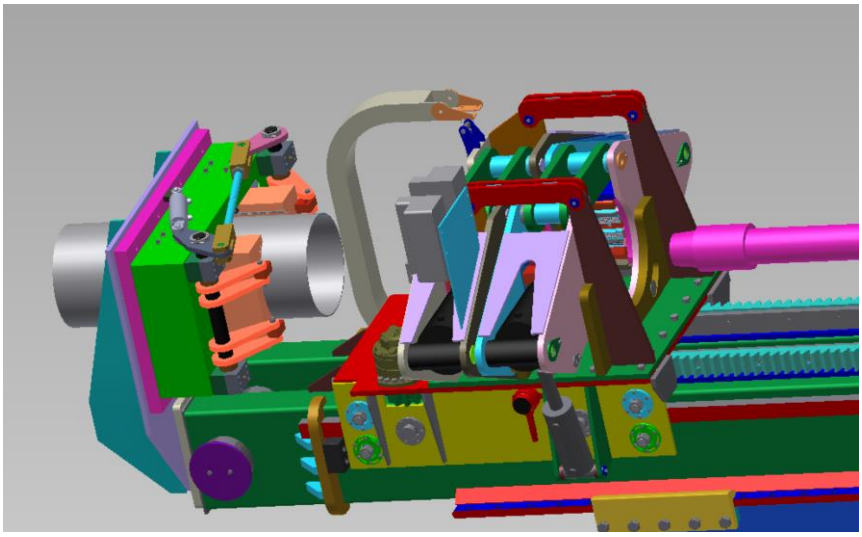
Problem number 9. **Keeping the drill rods and casings from sliding into the hole**.

Normally HDD operations do not normally require a special slip to keep the string from falling into the hole as the inclination of a mega rig normally kept lower than 10 degrees. Conventional oil well drilling cannot do without one. Standard “Vertical slips” cause problems in inclined positions:

- The upper wedges touch the rods and casings and scratch them even in open position
- The upper wedges do not get fully opened
- It is nearly impossible to center standard slips against an inclined mast
- If a modified HDD rig is used, the slip should be installed on a frame inside a pit 2.5 x 2.5 x 2.5 meters. It is dangerous to operate the device from the pit.

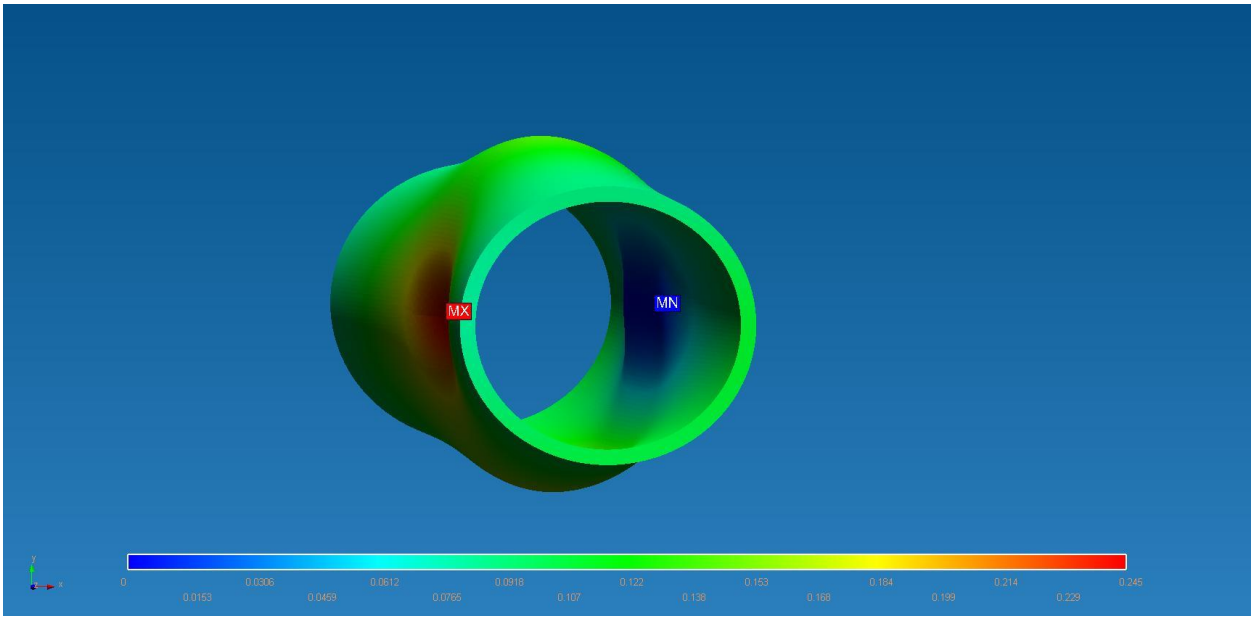
Solution:

1. The slip should be installed on the rack of a rack and pinion mast for proper alignment
2. The slip should work both in vertical and in inclined position. See pictures bellow:



Problem number 10. Control of forces applied to all pipes:

The picture below gives the strength calculation of a 168 mm filter pipe. Our special software shows that 4 tons are enough to break the pipe:



The break out unit should be adjusted to the safe limit. Otherwise a pipe can be easily broken.

Solution:

1. Modern drill rigs are capable of tender approach to pipes, rods and casings. Care should be taken when choosing a rig.

2. But in the process of project preparation should inevitably include finite element analysis of all casings and pipes.

New technologies greatly increase opportunities of oil and gas drilling contractors. However, wider horizons open new challenges. Several years ago, an HDD contractor had to hit the bull's eye to get the pilot drill done. Today a Slant Directional Rig operator has to hit the bull's eye every meter of drilling. The solutions need better consideration and responsibility of choosing the right equipment and materials has far greater boundaries than it ever had due to the reduced viability of most oil well drilling projects. Our specialists are always there at your disposal when it comes to complicated projects in vertical and inclined drilling.

Bellow you can find the technical parameters of ADI 360 VS Rigs:

Description	ADI (Made in USA)
Name of the rig	ADI 360VS
Possible inclination of the mast, degrees	8-90
Pull-push force, ton	150
Carriage speed, m/min	55!
Rotary force, kNm	70
Rotation speed, RPM	90
Way of communicating the force to the bit	Double sided rack and pinion mast
Maximum length of casings and rods, m	12
Temperature range	-40/+45°
EX proof	API, Russian EX Proof certificate
Clamp of the break our unit open, mm	102-477
Automatic Rod Loading System	+
Type of transportation	Chain Trucks
Rotary table	+
Slip	+
Transportation and assembly type	Modular
Dimensions, m	20,9 x 2,5 x 3,2 м Can be disambled
Weight of the biggest part, ton	30
Power pack	Aboard a mobile rig
Engine	John Deer
Power	600 kW

In conclusion, it is necessary to say that rack and pinion rigs have proved their effectiveness for slant directional drilling. The new generation of these rigs can allow their owners carry our projects in such industries as:

- Coal bed methane
- Dewatering of mines
- Traditional HDD

- Traditional oil well drilling (this type of rigs is normally much cheaper, although it can work only with 12 m rods and not with 24)
- Branching
- Extremely long wells including off shore applications (special type of the rigs not supplied to Russia)
- Work over operations

We hope that our experience can help other companies improve their financial effectiveness and build profitable businesses in the present day non-stable oil drilling market environment.