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7. Emission free mining jumbo concept in increasing productivity and reducing costs in deep level underground development

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Abstract

Environment, Health and Safety topics are often first on the agenda for today's underground mining houses and contractors to provide sound working environment for all personnel underground. One of the key focus areas in the future will be to reduce or even eliminate the emissions generated by the diesel combustion engines used in various areas during the mine production wherever any personnel are being exposed to these conditions.

In the coming years several mines will be declining deeper along with their new production areas. These deep mine conditions will set challenges for the technologies being used of today to keep the ventilation capacity and ventilation costs at an acceptable level. In addition to this comes the exposure of increased ambient temperatures caused by ground thermal heat.

Deeper production levels also sets harder requirements to keep the cost of development under control as additional over break in drilling and blasting means additional rock to be hoisted up from deeper underground and at higher costs per each tunnel meter of development.

From the mining equipment OEM perspective this calls for higher level of automation and emission free solutions in drilling, loading and hauling to help customers in overcoming the challenges listed above.

The subject of this paper is to introduce new ways and share practical experiences to gain better drilling results and eliminate emissions in underground face drilling. The paper introduces the new concept of highly automated mining jumbo with electric driveline system, its main features and corresponding benefits through practical case stories on using the equipment in various mines mainly in Northern Europe.

Introduction

Increased awareness of various health concerns associated with underground combustion engines have forced mining industry to look various ways to reduce the expose of their workers onto the emissions being produced, like Diesel Particulate Matters (DPM's), carbon dioxides (CO_2) and Nitrogen Oxides (NOx). For example the most widely used method to control diesel particulate matters at the

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underground ambient is ventilation as doubling of the airflow into a working face results in a 50% reduction in the DPM concentration at that face [1]. On the other hand the costs of ventilation are considered as one of the main contributing factor for operational expenses associated when running the underground operations and the effect of this cost factor becomes even larger the deeper the underground activities are declining.

Rather than putting excessive investments solely on increasing the ventilation capacity there are other ways to reduce or even eliminate the concentration of various emissions right at the source on where they are being produced. This sets requirements for the Original Equipment Manufacturers (OEM) to provide safer, cleaner and environmentally friendlier solutions for various mining activities, like drilling, loading and hauling.

This paper introduces new underground development drilling jumbo that uses electric driveline technologies providing completely emission free drilling concept helping to reduce underground emissions at the mines. On the other hand there are various side features coming along within this concept providing added benefits like increased health & safety, reduced heat load onto the ambient, less operating costs, better drilling productivity and savings through energy efficiency.

Main features of the drill rig

This modern technology underground mining jumbo (see the figure below) consists of several subsystems that each has their own contributing factor to provide value adding benefits in face drilling. These systems can be for instance, highly fast

Figure 1: Modern technology underground mining jumbo contains several advanced drilling features along with electric driveline that is used for moving the drill rig between headings.

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and precise drilling control system (including rock drill), boom controls, ergonomic operator environment and wide range of automatic drilling features.

Driveline system is also one of the subsystems of the unit which main purpose is to move the rig between different working locations in the safest and efficient possible way. Conventional drivelines are taking their energy from on board diesel combustions engines when moving the jumbo underground. The new underground mining jumbo is based on electric driveline, where diesel engine has been taken off and being replaced by electric motor drive and onboard battery package giving all the energy needed for tramming when not being connected onto external sources of energy, i.e. mine electricity.

Architecture

The architecture of the driveline system contains some key components and the concept is illustrated within the figure below.

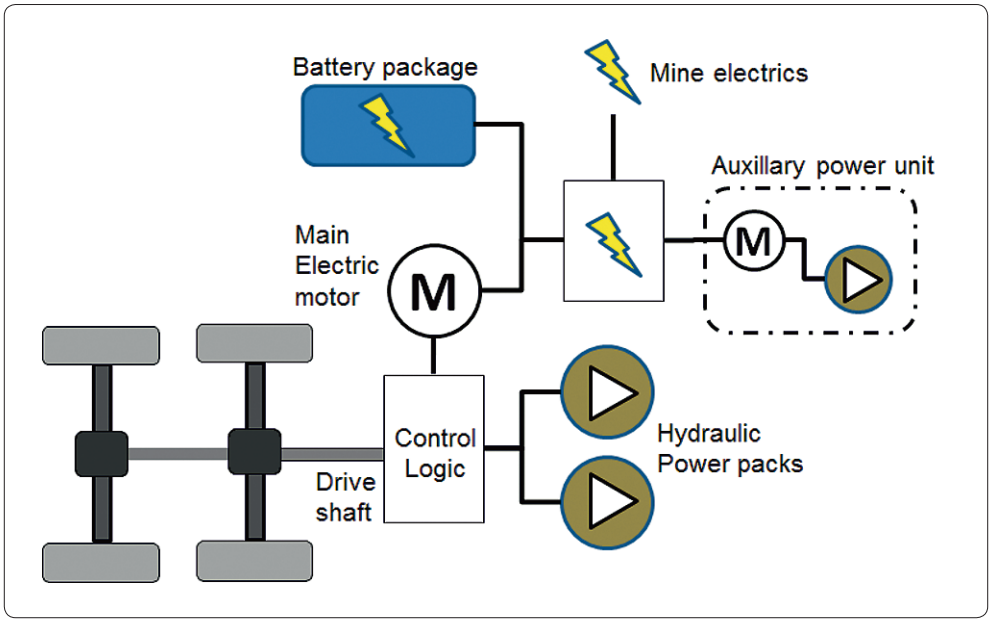

Figure 2. Electric driveline system main components and architecture.

The battery package of the unit contains all needed energy to move the drill rig between the headings. The chemistry of the battery is based on Sodium Nickel Chloride (SoNick) - based technology. This chemistry is optimal for various underground drilling applications, where rig is being connected onto mine electricity while drilling and tramming is the only function where unit is isolated from the mine's supporting infrastructure. Another selection criteria's that support given battery chemistry are safety and reliability, which are basic requirements for any underground equipment and technologies introduced onto the industry. On the

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other hand, selected architecture illustrated above is not dependent on the battery technology in case new options for electric energy storage are becoming available.

The purpose of the main electric motor is to convert the electric energy stored in the batteries to tractive force moving the drill rig at the mine. The speed of the motor is controlled via traction inverter. This ensures high precision and torque available even in low speed ensuring optimum user experience where precision in tramming is needed. During drilling this inverter is used to charge up the batteries and the same electric motor is used to power the hydraulic power packs from the mine electric grid. This allows keeping the technical concept as simple as possible by utilizing selected componentry onto multiple different functions.

Drill rig's control logic defines from where the energy is taken and to where it is distributed based on current operating mode of the unit, i.e. drilling or tramming. During drilling the unit utilizes mine electricity to run the main electric motor and the energy is distributed to hydraulic power packs. During tramming the battery electrical energy is converted in the same electric motor onto tractive effort for moving the drill rig via driveshaft.

Auxiliary power unit contains electric motor that is connected onto hydraulic pump. The purpose of this component is to provide needed hydraulic power while moving the drill rig. This contains e.g. controls for the central articulation valve, boom movements and hydraulic jacks.

Value proposition

The electric driveline concept introduced above offers various benefits in underground face drilling. One of the main values for the end users among comes along with increased health and safety for underground operating personnel. First of all the rig doesn't produce any underground emissions as there is no combustion engines associated. Also the ambient heat load generated by the rig is much less compared to diesel engine. This brings significant comfort for the people working along with the rig. Also noise levels are lower during tramming and engine idle. As there are no more diesel engine related hot surfaces e.g. turbo chargers associated where oil and diesel fuel may be spilled on the risk of fire can also be reduced. Finally, the operator cabin is built onto highest possible standards for bringing comfort for the operator helping them to work more consistently for longer periods of time. This means increased visibility for both drilling and tramming, reduced noise and dust levels inside along with more ergonomic and adjustable controls for all the rig functions.

The adoption of the rig and the driveline technology is easily available for any underground operations utilizing conventional mine electricity supply for drilling. The drill rig charges the batteries during normal drilling cycle to ensure they are filled up at the completion of the drilling and thus the unit is ready to be moved to the next face. This means that the system doesn't require any additional investments for separated charging stations, big power line cabling, swapping areas of the batteries etc. The electric power intake from the mine grid can be preset to a

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certain value and the rig ensures this limit will not be exceeded while charging the batteries during drilling.

The electric driveline has also potential to offer increased drilling productivity by using same onboard batteries to maintain the drilling power even there is limited electricity available from the grid. This feature is called active power compensation and it is based on similar presettable current limit value as used in charge while drilling feature. This limit value can be adjusted based on available capacity at the mine's electric infrastructure. In case the rig needs more power from what is available, e.g. during peak loads in drilling, the unit draws reserve power from the onboard batteries ensuring that the predefined limit value in electric power intake towards mine's infrastructure is not exceeded (see figure below).

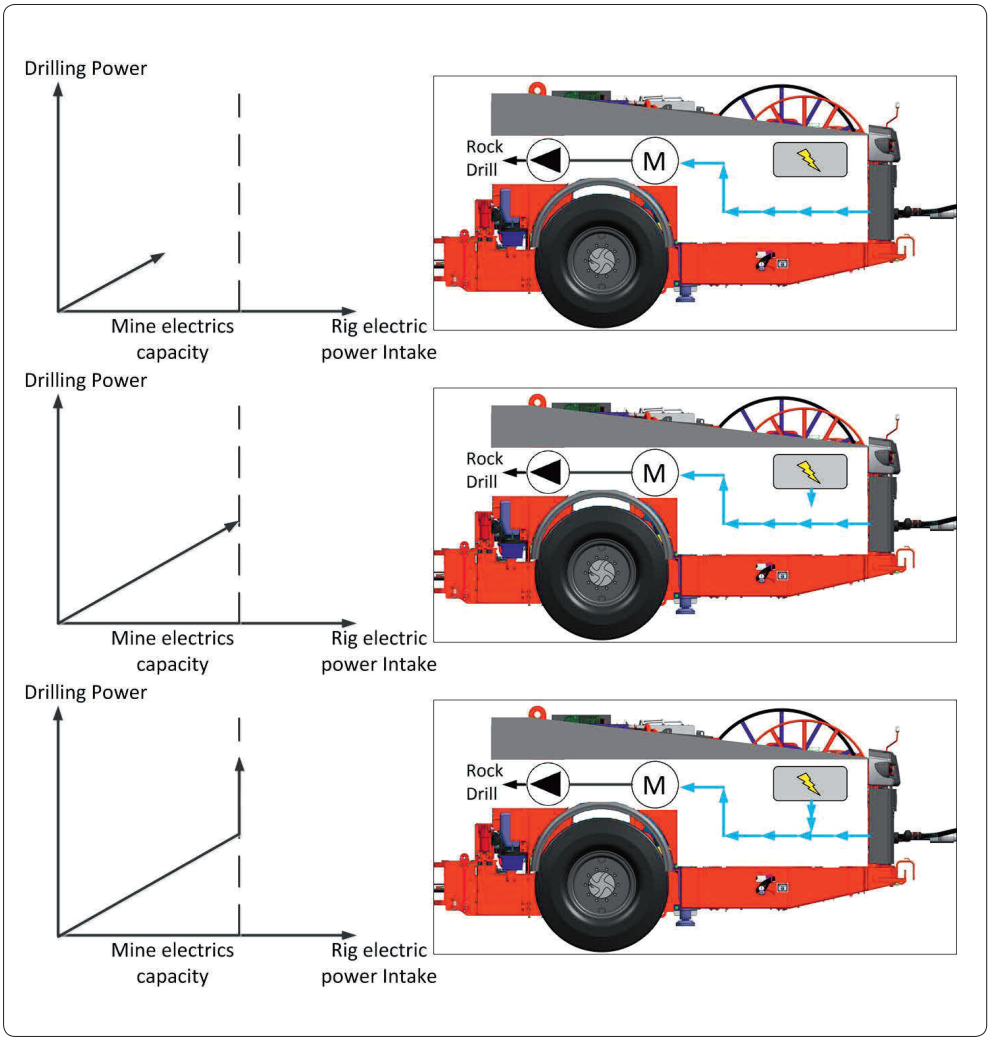

Figure 3. Active power compensation system draws reserve power from the batteries during drilling.

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The same reserve power from the batteries can also be used to provide more balanced electricity to supply other units operating on the same area at the mine. During low power loads (e.g. moving a rock drill between the holes) the unit charges the same batteries ensuring they are loaded at the completion of the round and the unit is ready to be moved onto next heading without any separated waiting times to charge the batteries up.

There are possibilities to reduce both direct and indirect operating costs by utilizing the electric driveline technologies. The electric motor has less moving parts and in general fewer areas that require service and maintenance compared to standard diesel combustion engine. In principle the only service item is the filter at the battery pack air cooling circuit that needs to be replaced once every 1000hrs of tramming. This results direct savings in parts costs and service hours compared to diesel drivelines. On the other hand the biggest cost saving potential lies on the indirect savings side. For example diesel fuel logistics are no longer needed since all the energy for moving the rig is taken from the mine electrics infrastructure that already exists at the production and service areas. Potentially the biggest savings are related to mine ventilation. This is of course provided that the fleet of units having electric drivelines is large enough and there are possibilities to consider this when the ventilation capacities are being sized up, e.g. during feasibility studies of greenfield mine projects or when planning new production areas before the actual development takes place. Again all the cost impacts listed above are being emphasized more heavily the deeper the mine operations are declining over time.

Electric drivelines, when built along with concept described above, offers also better efficiencies of using energy. When moving the unit downwards of a decline the same electric motor can be used to charge the batteries by utilizing a braking energy generated. In general the energy efficiency of electric motor is ~95% that is well above average power efficiency associated with diesel engines. Finally, direct mechanical link between the electric motor and the drive shaft ensures that the limited tramming energy is being utilized within the most optimum way and not losing any efficiency onto torque converter or hydraulics in between.

Battery package contains enough energy to drill 7–8 holes without any connection to mine electrics. This allows keeping up the production some time even if the mine electric supply is off for whatever reason. On the other hand few holes can also be drilled in the areas where no electric connections, like gate end boxes are available, e.g. secondary blasting holes.

Finally, system architecture illustrated above allows to design the concept to be compliant with multiple different mine voltages and frequencies at once. This can bring various benefits to mine contractors, who operates in different mines and electric systems as the rig can easily be moved between the mine sites where needed without extensive changes in the unit electrics.

All the benefits and features associated with electric drivelines can be combined with highly automatic drilling features that help mining houses and contractors to optimize their quality of charging and blasting results. This can be achieved with comprehensive office tools to create optimum pattern for holes including analyses

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tools of the data collected from the unit. During drilling the torque optimized drilling control system minimizes dilution of holes and automatic boom movements between the holes ensure consistent and predictable drilling results round after round. By utilizing these features there is great potential to reduce over break, increase pull out and gain consistency in drilling resulting additional costs savings and better productivity per each blast.

Case studies

Sandvik has made a product release of DD422iE that is a highly automatic underground mining jumbo based on electric driveline technology introduced in this paper. Prior the release took place there were various trials conducted to validate the concept in real underground mining conditions. The observations and outcomes of these trials are introduced within this chapter.

Pampalo Gold Mine (Endomines AB)

Pampalo Gold Mine (owned by Endomines AB) is located in the eastern part of Finland, approximately 45km north north-east from the township of Ilomantsi. The deposit was discovered in 1990 following by a trial production between 1996 and 1999. Endomines bought the mineral rights in 2006 and commenced production in 2011. Nowadays the annual production is ~150 000 tonnes with a grade of 3 g/t Au.

The trial of the new electric driveline system took place during the second quarter of 2015. The unit was a prototype machine where electric driveline was integrated with simple hydraulic controls for drilling. There was no instrumentation or automatic drilling features integrated onto the unit as main purpose and KPI's for the trial was to validate some of the listed benefits associated with the new electric driveline technology only as follows:

- Adequate battery capacity to move the drill rig between the headings
- Concept adaptability to existing work schedule of the mine with minimum changes and without additional investments (other than training of operating personnel) from the mine
- Additional drilling productivity by using the active power compensation functionality
- General availability of the unit and concept suitability for underground mine conditions

Majority of the drilling took place between levels 375–555 m. There was well enough battery capacity available to move the unit between the headings and charge while drill feature ensured that the battery charge level was high enough to move the rig onto the next face. No recorded cases occurred where battery capacity would have compromised the normal working plan for the mine. Also no abnormal breakdowns were experienced during the tests.

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Active power compensation system was utilized during the trial. Previously the mine had some limitations on how much drilling power can be drawn from their current electric infrastructure: For example 55kw electric motors were the maximum size allowed to be used for a twin boom mining jumbo. At the beginning of the trial the current limit of the unit during drilling was set to 250A as per mine's requirements. Within the rock drills being used with the test unit this would have limit the maximum percussion pressure onto 180–185bars. Active power compensation system allowed drawing reserve power from the batteries and the percussion pressure was possible to increase up to 210bars. This resulted roughly 22% faster drilling time per hole without increasing the current intake from the mine network. At the completion of the round the battery charge level was still reaching needed capacity to move the unit onto the next face even when active power compensation system was being utilized.

Summary of the tests:

- Total tramming distance: 16.4 km (forward), 17.2 km (reverse)
- Sub-levels (during normal operation): 375 m–555 m
- Amount of drilling: about 13 rounds + some sets of 15–30 holes

All in all the trial indicated that electric driveline technology is robust enough for mine conditions and can bring several benefits particularly in conditions where limited amount of electric power is available for drilling. The test outcomes allowed the design team to continue onto next phase establishing a first commercialized unit model utilizing this technology.

Kylylahti mine (New Boliden AB)

Kylylahti mine (owned by Boliden) is copper-gold and zinc mine located within the historic Outokumpu mining district in Finland. The underground operations are based on long hole open stoping with voids filled with a mixture of waste rock and cemented waste rock.

The first commercialized unit model, DD422iE was taken onto the mine for a trial. This model has the electric driveline combined with new cabin, drilling- and boom control system and all the automatic drilling features included. The tests took place from August to October 2016 and the main KPI's were as follows:

- Adequate battery capacity to move the drill rig between the headings
- Unit adaptability to existing work schedule of the mine with minimum changes and without additional investments (other than training of operating personnel) from the mine
- Unit availability
- Feedback of the unit suitability for underground mining operations from operators, shift supervisors and mine management perspectives

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Most of the time the drilling with the unit took place between levels 200 and 730 m below the surface. The deepest level was 810m and service bay was located at 225 m below surface. As the decline at the mine was 1:7 this meant that the unit maximum tramming distance on an incline (~3 km) was not enough to cover the worst possible scenario where the unit needs to be moved for service in the lowest possible level. However the shift supervisors at the mine were able to find a workaround for this limitation by planning the work areas and work orders so that the unit maximum distance did not become an issue. The average charge level of the battery was varying between 20% and 90% from the maximum capacity (see example from the figure below). No recorded cases were made where the battery charge level would have emptied prematurely during tramming.

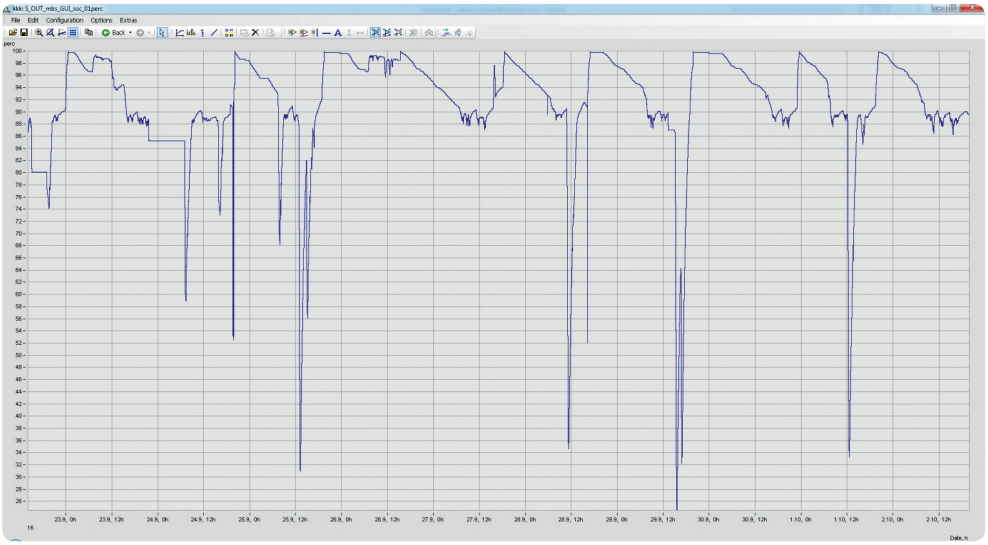

Figure 4. An example of DD422iE battery charge level graph taken from 1.5 weeks period during a trial at Kylylahti mine.

On the other hand charge while drill feature was a good tool to increase a tramming distance without losing any time. This meant that when the unit was moved from the bottom level to service, it was moved onto levels in between to drill a round. The batteries were charged up while drilling and the unit was able to continue all the way to service without losing any time to load the batteries separately. This was a feature that was embraced by both shift supervisors and mine management.

Some feedbacks received from the mine personnel:

"*I got familiar with the rig within one day*" – Jarkko Väisänen, Drill Rig Operator

"*Enough tramming speed on an incline, almost too much on flat*" – Jarkko Väisänen, Drill Rig Operator

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”*Charging while drilling the face gives enough energy for batteries at the completion of the cut, no separate charging phase needed anymore*“ – Kimmo Turunen, Shift Supervisor

“*Drilling a cut in between is a good way to increase the tramming distance*” – Kimmo Turunen, Shift Supervisor

“*I would surely prefer this than a diesel operated unit*” – Kimmo Turunen, Shift Supervisor

”*In my opinion this type of technology suits very well with underground drills*” – Jaakko Kilponen, Manager of Mining

Despite the electric driveline was the main area of interest during the trial, some remarks were also made in regards to drilling. The torque optimized drilling control system reduced or some cases even eliminated jams that are fairly typical within the rock conditions at the mine. On the other hand the automatic and semiautomatic boom (i.e. position automatically to the closest hole) movements were seen beneficial when drilling burn and easer holes as it allowed operator to focus on the other boom while other one was being moved by the rig. This helped operator workload for not spending excessive amount of time to manually align the feed as per given plan as the unit was able to do it quicker and more precisely. Also cabin ergonomics with increased visibility, reduced noise and optimized dust control was well received by the operators.

Summary of the tests:

- Total drilled meters: 45000drm
- Total tramming hrs: 51h
- Total tramming distancies: 104km (forward), 101km (reverse)
- Unit availability: Aligned with current fleet reference at the mine

All in all the test results and feedback from the trial indicated that the technology is ready for a commercialisation and is well built to sustain underground mining conditions shown via good availability rates achieved with the unit during the trial.

Conclusions

The case studies listed above shows that technology for electric drivelines is ready and mature enough to bring commercialized mining equipment onto the markets that can help mining industry to reduce their underground emissions. Along with better emission control there are some added benefits with this concept that can help mining houses and contractors to achieve better productivity, reduce their operating costs and bring better care for their operating personnel.

The OEM’s should design their products such a way that the adaptation of this kind of technology is made as easy as possible and the electric drivelines can be

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used side by side along with current diesel operated fleet. This is to avoid mining houses to make any additional investments other than normal capital and operational expenses of the equipment and being able to gradually increase the amount of electric units rather than replacing their whole fleet at once.

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