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PAWEŁ NOWAK
ŁUKASZ KILAN

Sandvik Experiences with Remote Controlled Machinery

The article presents historical and current methods of controlling Sandvik machinery operating in underground mining. It indicates the direction of roadheaders development, with a special focus on various stages of introducing technical innovations that can be used in mining. The currently developed machines fit the idea of "Industry 4.0", and the solutions presented in this article allow underground plants to improve safety and productivity, making the mining branch an industrial trendsetter.

Key words: *Sandvik, roadheader, remote control*

1. INTRODUCTION

Industrial development in the twentieth century resulted in a greater demand for mineral resources required for production purposes in industry and construction. In order to achieve increasingly better results, the available machines were used for mechanical mining of rocks both in mines and tunnels. However, as users' needs and production capacities increased, the machines were differentiated according to the methods of working and size. With the development of digital technology, the first PLCs were used in the machines, then their control was extended, and finally a fully autonomous mining process was introduced, making use of the latest digital and IT developments combined with the experience gained.

This article provides a historical description of the development of roadheaders as well as the most modern approach to driving headings with the Sandvik machines.

2. SHORT HISTORY OF SANDVIK ROADHEADERS

At Sandvik, the year 1964 is considered the cornerstone and the beginning of mechanisation of mining industry thanks to the development of the F6-A machine (Fig. 1) at ÖAMG plant in Zeltweg, Austria (later Voest Alpine, now Sandvik). The machine was highly immature in terms of its structure and had many imperfections, which were constantly eliminated. Nevertheless, the first units were already operating in Austria, Italy and Morocco in 1965. With the weight of 13 tonnes, F6-A was considered heavy at that time, and the total number of produced machines was about 300 pieces [1, 2].

Fig. 1. "The most famous" photo of the F6-A in Paris [1]

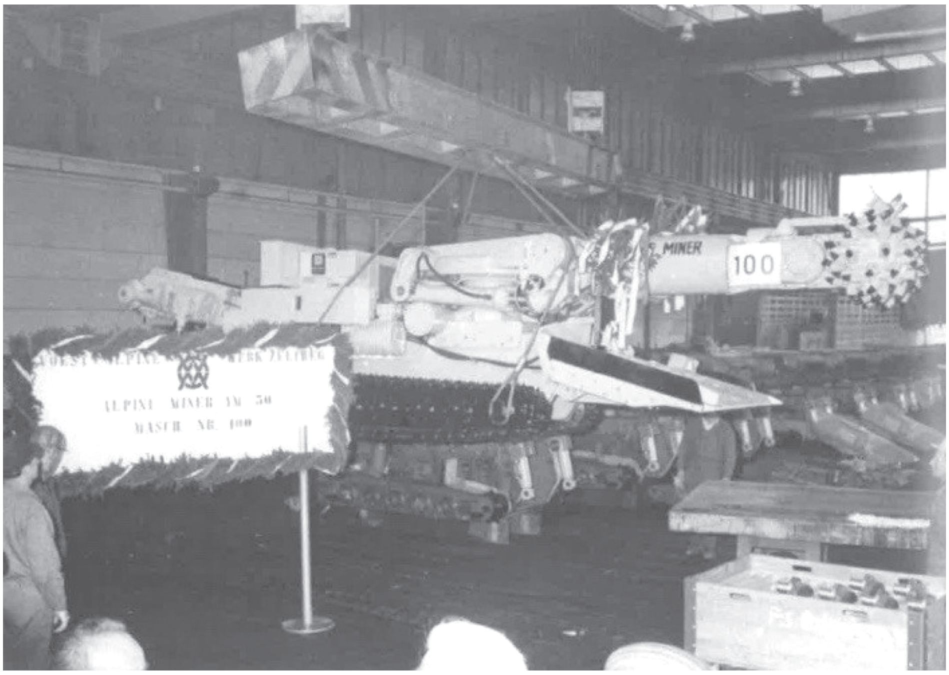

Fig. 2. Year 1979 – AM50 number 100 delivered to Poland [1]

In 1971, the roadheader changed its name to AM-50 (Fig. 2), its design was improved, and the power of the cutting head motor was increased from 30 kW through 50, 75 to 100 kW. The Zeltweg plant produced around 800 AM-50 machines [1, 2]. The machine is produced under licence until present. However, its contribution in the development of currently working roadheaders cannot be disregarded, as mentioned in the publications by Broen, Cheluszka, Dolipski, Jonak, Klich, Kotwica [3–7] and many other authors in Poland and abroad.

In 1981, the prototype AM75 roadheader developed by Voest Alpine was presented at the Dusseldorf fair (Fig. 3). In 1982, the first AM75 models were already working in German mines [1]. The machine, with numerous improvements and modifications, works to this day in many mines in Poland (Fig. 4) and around the world.

Fig. 3. Presentation of the prototype AM 75 in 1981 at the fair in Dusseldorf [1]

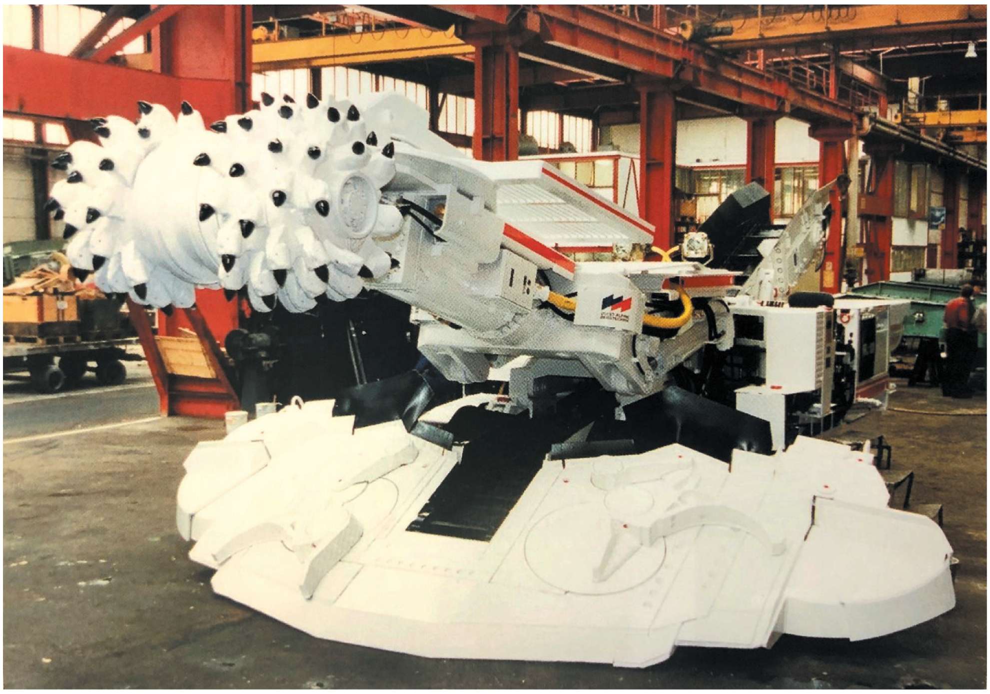

Fig. 4. AM 75 number 100 delivered to Poland in 1994 [1]

In 1998, the AM105 with the ICACUTROCK system supporting the rock mining process was presented at the BAUMA fair in Munich. Subsequent control systems of the produced machines are developed based on experiences in rock mining from all over the world [1, 2].

In 2007, the first in Poland entirely remote-controlled AM75 roadheader number 178 was put into operation. The main objective of this project was to enable mechanical mining under conditions of increased risk of methane and rock ejection. The roadheader significantly improved both ergonomics and safety. The control panel and monitors were located about 50 metres behind the roadheader, which significantly improved the work under difficult conditions. The roadheader was equipped with a system controlling the cutting profile together with a set of cameras transmitting the image from the unit in real time. The installed equipment enabled observation of the machine's operating parameters, the position of the cutter boom and the working environment [2].

3. RADIO-CONTROLLED MACHINES

The AM75 No. 178 has been converted to a fully radio-controlled machine, where only the data and image transmission from the roadheader takes place via wire. In 2013, the fully radio-controlled roadheader MR341X number 001 was presented in Zeltweg, Austria (Fig. 5). The parameters of this roadheader were corresponding to those of AM75/MR340, but the machine was equipped with a platform with a bolting and drilling unit (Fig. 6), a support setting device with a set of platforms enabling roof support installation, and a crane (Fig. 7). The crane significantly improved the ergonomics and comfort of work because it was used for transporting the support from the arch assembly station to the roof support device located on the roadheader [2].

The machine was equipped with state-of-the-art controllers, a radio set and electro-hydraulic equipment to control all functions of both the roadheader and the platform with all the equipment located on it. The applied solutions have significantly influenced the productivity of the machine by shortening the time required for support installation, increasing safety and improving the comfort of the operators' work. The MR341X roadheader was equipped with an innovative system of data transmission to the surface – the roadheader was able to communicate with a Wi-Fi network, as well as via optical fibre and cable. Data concerning the status of the machine was received according to the OPC UA communication protocol, which was a major innovation in underground mining. Moreover, it was possible to establish a VPN connection with the machine [2].

Fig. 5. MR341/001 roadheader [2]

Fig. 6. MR341/001 roadheader with an activated remote controlled bolting and drilling unit [2]

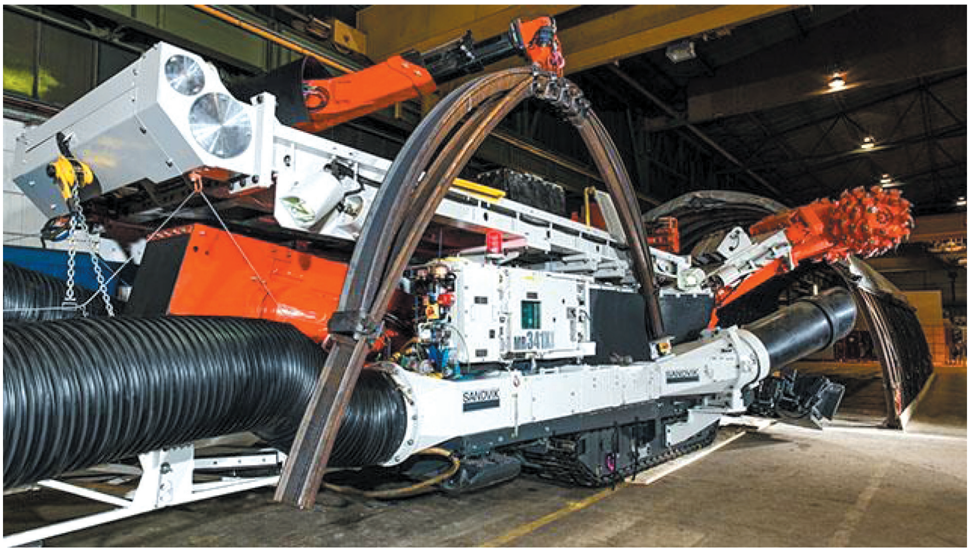

Fig. 7. MR341/001 roadheader during the transport of a support for installation [1]

4. REMOTE CONTROLLED MACHINES TODAY – SANDVIK AUTOMINE®

When the machine control system made it possible to operate and control each of the machine functions, Sandvik began to work on fully automated remote control of machines in pre-determined zones of machine automatic operation, where no people could be present. Depending on the size of a fleet of machines and the needs of the customers, there are four levels of AutoMine® service, which can be changed at any time to meet the current needs of a user. It should be added that we no longer refer to the concept of roadheaders, but to ‘machines’, as the system is able to handle the entire fleet of machines, such as roadheaders, production machines, shuttle cars, loaders, drilling machines and surface drills. AutoMine® is able to combine the work of the above mentioned machines into one process and also combine the work of many machines from more than just one excavation of a mine.

For the machines to work properly, it is necessary to have an infrastructure installed in the machines working space, an operator’s station and machine equipment that supports the Automine® system.

4.1. Overview of the AutoMine® system

An operator at the workstation has access to the plan for development of a working or a larger area (depending on the number of machines managed); he has a preview of the machine’s current parameters, video and digital monitoring of the current mining path of the roadheader and/or the loading and unloading path in the case of loaders. Machines move along a tunnel with a built-in Wi-Fi network and in the isolated zones where no people can enter. The entire mining and production process can be synchronized with the subsequent loading and hauling machines, and the role of the operator is to visually supervise the machines. In any case, the operator can take over direct control of the machine, and the machine or the set of machines can be shut down in the event of any safety risk. An important part of the system is the Wi-Fi network, which must remain uninterrupted throughout the entire operating area of the machine and the isolated zone (Fig. 8). The individual components of the AutoMine® system are discussed below.

4.2. Plan of workings

A necessary element required for the autonomous operation of a working or a tunnel is the correlation of the working development plans with the Sandvik system (Fig. 9). The Sandvik AutoMine® application is compatible with many working planning systems; therefore, using the current system does not exclude or even interacts with the installed software, so that the planned work done by the machine is updated as best as possible.

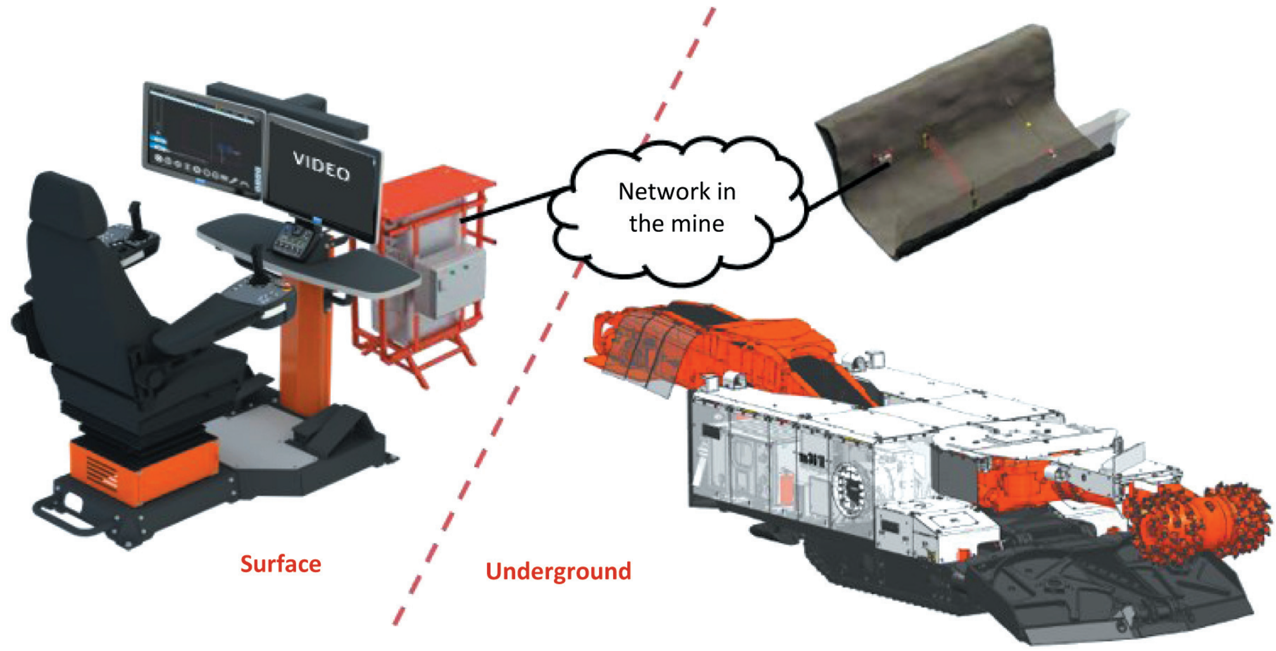

Fig. 8. The AutoMine system concept [2]

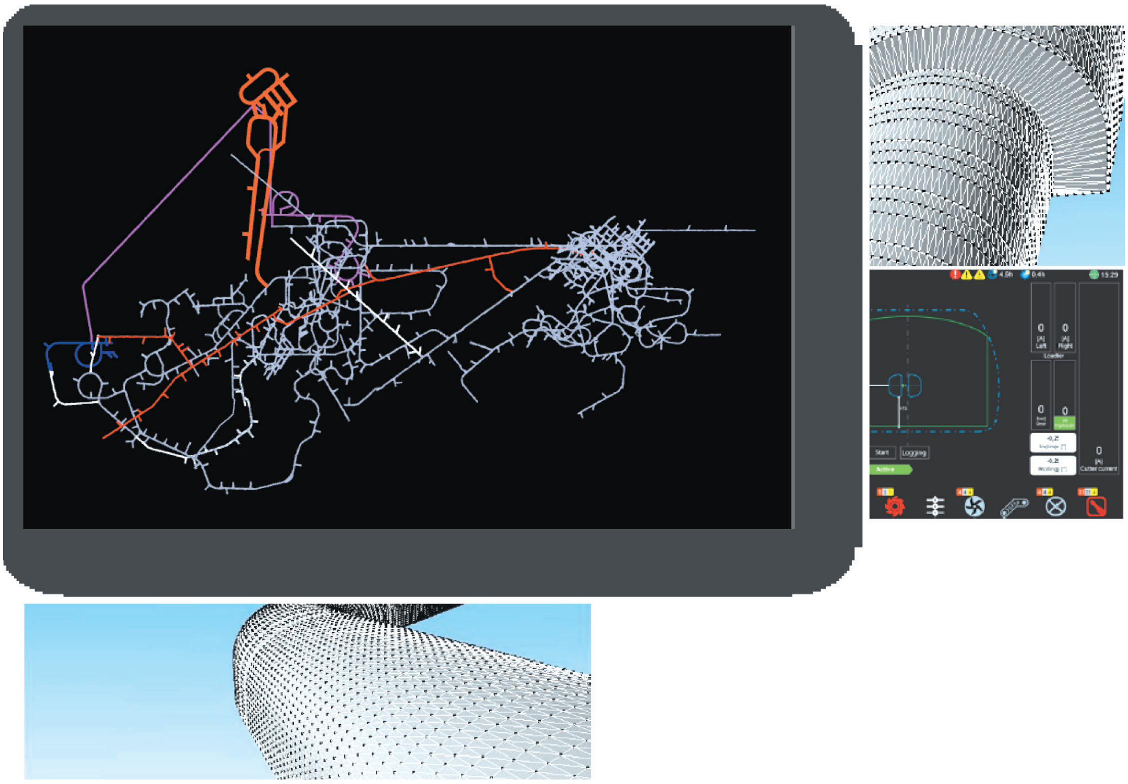

Fig. 9. Integration of the mine working planning system with Sandvik systems [2]

The current mine working plan is sent to the machine and updated in real time. The machine controller in the tracking mode selects subsequent working paths so that the excavation is in line with the imposed working plan, which can also be changed in real time, and then the machine will make the appropriate corrections. At this stage, the following systems will cooperate: the working planning systems (external software of the user), the AutoMine® system and the system for visualization of the cutting profile with automatic mining.

4.3. Isolated zones of machine operation and connection with the Wi-Fi network

In order to be able to move autonomously in the working site, it is imperative that the machine or a set of machines is isolated from the people moving around (Fig. 10). It is therefore necessary to build an infrastructure which will enable creation of isolated autonomous operation zones and a network infrastructure which will allow the machine to remain on-line.

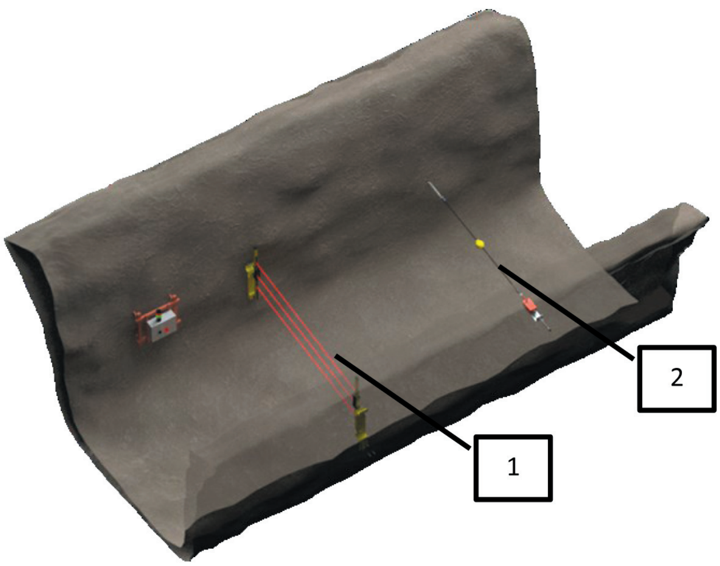

Fig. 10. Activated barrier that defines the machine working area: 1 – laser barrier, 2 – line barrier [2]

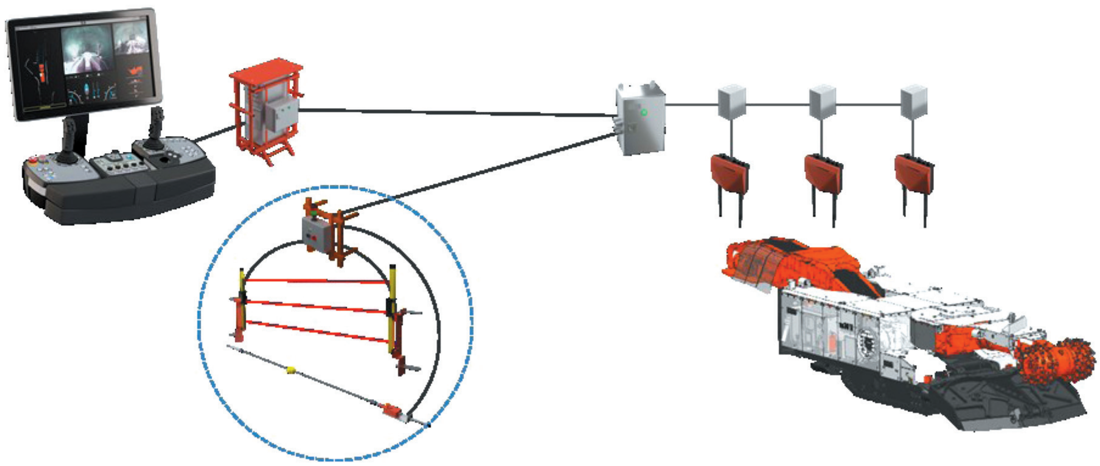

Fig. 11. Machine connection with the Wi-Fi network, the barrier and the operator's station [2]

The areas are built using physical barriers and laser barriers that prevent crossing, which are repeated several times at a distance of several meters. The last person leaving the working area of the machine activates the zone, which is then confirmed by an operator at the workstation. From that moment, crossing of any of the barriers will cause immediate shutdown of the machine. The same will take place in case of loss of connection or when a safety button is pressed. Communication of the machine with the barriers and the operator's workstation takes place through the Wi-Fi network antennas installed along the heading (Fig. 11). This way, the operator is informed about the status and alarms on both the machine and the zone barriers. The Wi-Fi network and the installed routers along the heading can be connected by means of both optical fibres and a dedicated network cable. The barriers have been designed in accordance with PN-EN ISO 13849-1/-2.

4.4. Automatic mining

The automatic mining system cooperates on an ongoing basis with the PLC system of the machine, with the sensors installed in the working, with the working development plan from the mine and with the vision system that recognizes the face revealed following every movement of the cutter (Fig. 12).

Only a minimal configuration is required to start automatic mining, yet the operator can have influence on the mining parameters or take over the full control in manual mode. The cutting path visualised on the operator's screen (Fig. 13) can be continuously checked or changed by the operator, after which it is sent to the machine's PLC.

The cutter's position is indicated by colours depending on the force pressing it to the rock; the longitudinal and transverse inclination of the machine is also included in the profile. Position of the cutter near the edge of the profile is signalled to the operator, and when the cutter moves outside the profile, a red signal is displayed (which usually happens in manual mode, when the operator deliberately moves the cutter outside the edge of the cutting profile).

Sandvik has been developing the cutting profile visualization for many years, allowing the mechanical mining process to be carried autonomously.

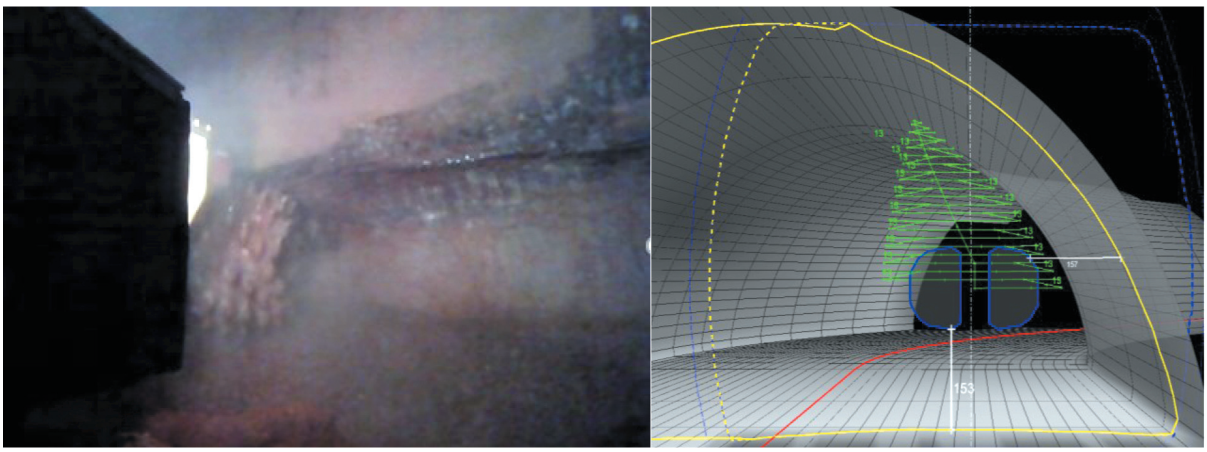

Fig. 12. Machine vision system and a digitally shown mining path [2]

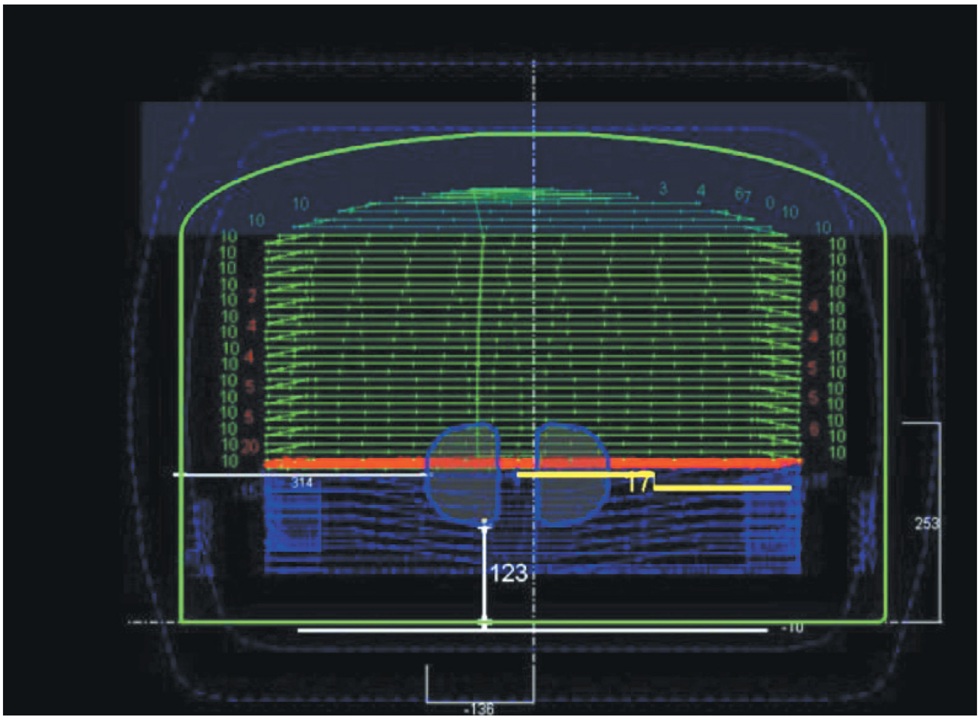

Fig. 13. Example of dynamic mining cycle with a path set at 10 cm [2]

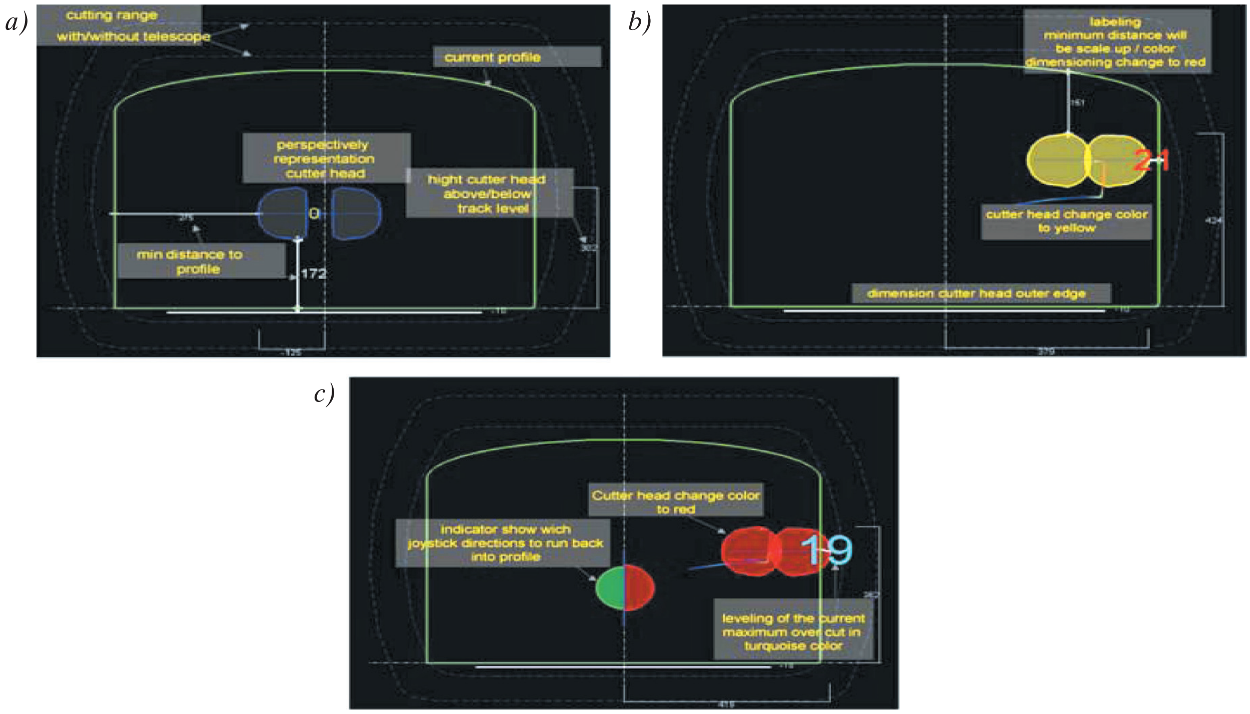

Fig. 14. Visualisation of the cutter's position in relation to the cutting profile: a) central; b) at the edge; c) outside the outline [2]

The system is also installed on machines where, by increasing the ergonomics of the operator's work, it enables manual control of the machine in dusty conditions or whenever visibility is limited due to other factors.

Diversity of the existing mining profiles is not a problem, because it is possible to select the required cutting profile predefined by the user at any time. The machine is also equipped with algorithms protecting machine components that are most susceptible to wear during the cutting process, such as the protection of the cutter gear, by reducing the rotation speed when the motor current of the cutter gear increases.

4.5. Remote guidance

The previously created digital profile of the working is transferred on-line to the working development system, the AutoMine® system and to the reporting system. The entire operation is combined with automatic machine guidance within the space of the mine driving project. The guidance system consisting of internally located inclinometers and an independent theodolite allows for continuous monitoring of the machine's position in relation to the planned working, as shown in Figure 15.

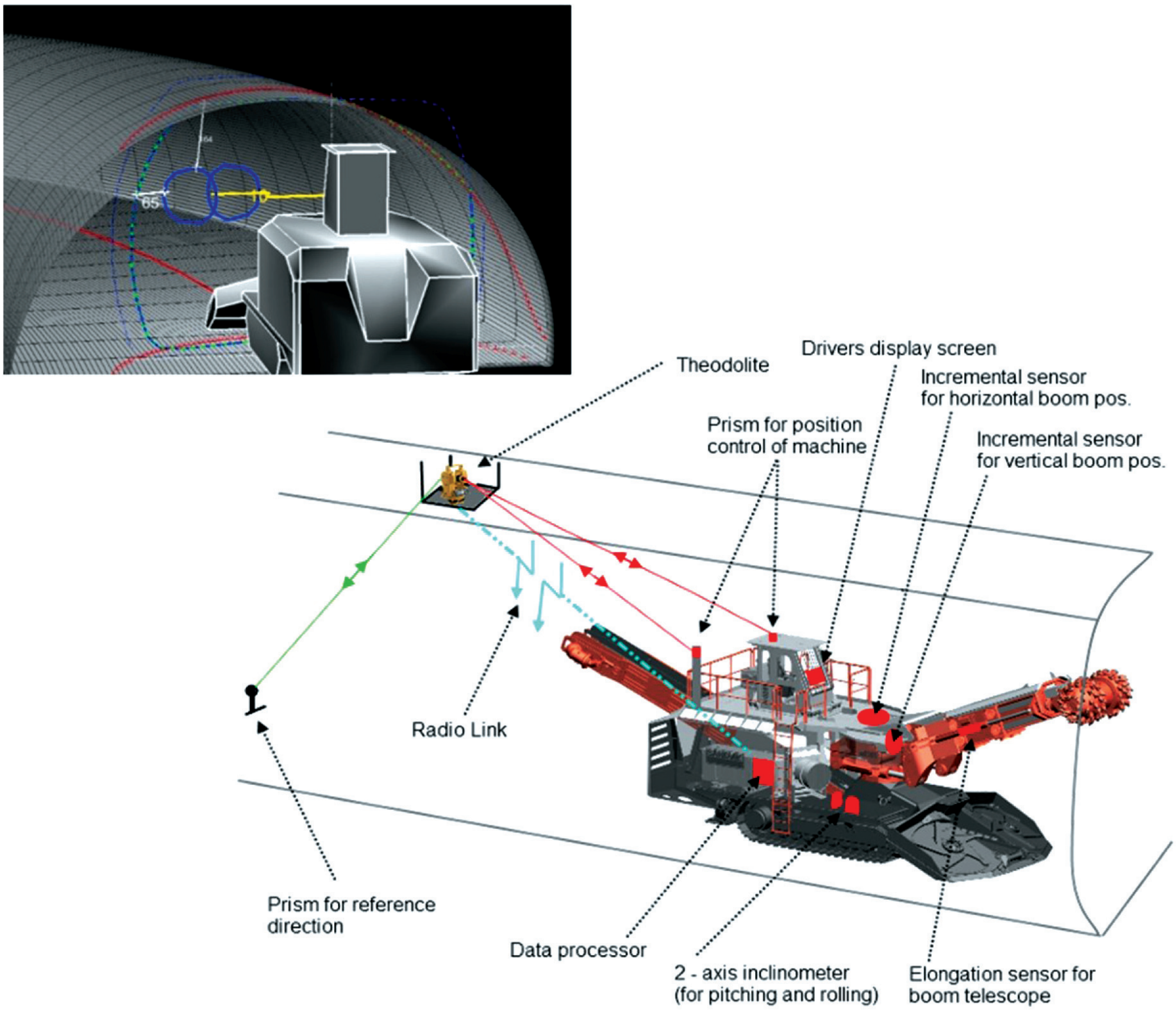

Fig. 15. Measurement of the current position of the machine in the working [2]

4.6. Operator's Station

The control or supervision of the machine operation can be carried out on a specially constructed operator's station which is adapted to the needs of the user, the machines to be managed and the size of the fleet (Fig. 16).

In addition, the operator's station can be located in different areas of the user's plant. It may be located in the nearest safe place at a certain distance from the machine, but outside the working area, so that the operator is not exposed to harsh and dangerous conditions during mining, but stays close to the machine – a solution applied in very difficult conditions or in the case of a small fleet of machines without a common link between the machines. This station greatly increases both the safety and comfort of work, keeping the operator away from the dangerous factors.

The operator's station can be located at a long distance from the machines, but it can be extended to manage multiple machines when they work together as part of the process and when the isolated zone is large. As part of a larger fleet, the operator's station may also be placed on the surface in a dedicated room. In addition to the safety and comfort of work, we increase the productivity of the fleet, particularly over a large area of the mine, and the time it takes to change operators is the time needed to log on again.

Fig. 16. Types of operator's stations [2]

The operator's interface and the layout of each screen are defined by the operator. Each operator has his own profile. The machine can only be controlled from a logged profile. Having a profile allows one to generate shift reports, forward messages to subsequent operators and send messages or commands to other users on the shift.

4.7. Maintenance

Periodic service and maintenance activities on the machines must be carried out by qualified personnel only. Despite the use of self-lubricating devices and many sensors connected to the warning and locking system, the presence of technicians is required in the maintenance process.

However, the process of maintenance must be planned and carried out in the conditions of machine shutdown, in a safe place and without direct exposure to dangerous conditions present during mining; the maintenance works also include extending the range of Wi-Fi network, checking the position of the theodolite or performing ongoing repairs on the machine according to the maintenance plan.

The inspection and replacement of picks on the cutter head also require manual handling by the employees responsible for respective activities.

5. MACHINES READY FOR THE FUTURE

The described system of autonomous working development operates and is prepared for use with the MH620 and MR341 type machines (Fig. 17). These are proven machines which can work in different workings. Your local Sandvik representative will assist you in selecting the right machine. MR341 roadheader will be presented below.

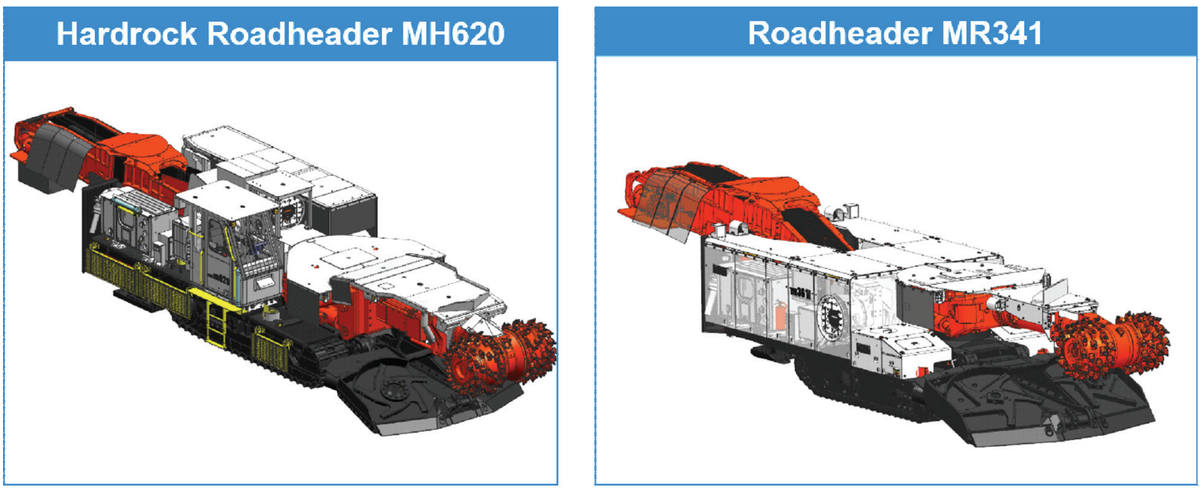

Fig. 17. MH621 and MR341 type roadheaders [2]

5.1. MR341 roadheader

The MR341 roadheader can be manufactured in a configuration tailored to the needs and prevailing conditions in the indicated workings; both the total power and the maximum cutting profile (Fig. 18) are adapted to the user's needs.

The minimum height of the profile in the vertical position is 3.3 m, and the maximum height 5.05 m, whereas in the horizontal position the minimum width reaches 4.2 m, and the maximum – 7.6 m, allowing for a very versatile use of the machine in workings.

The total maximum installed motor power of 382 kW (1000 V power supply) and the total weight of the machine of approx. 67 make the machine suitable for the mining of different types of rock.

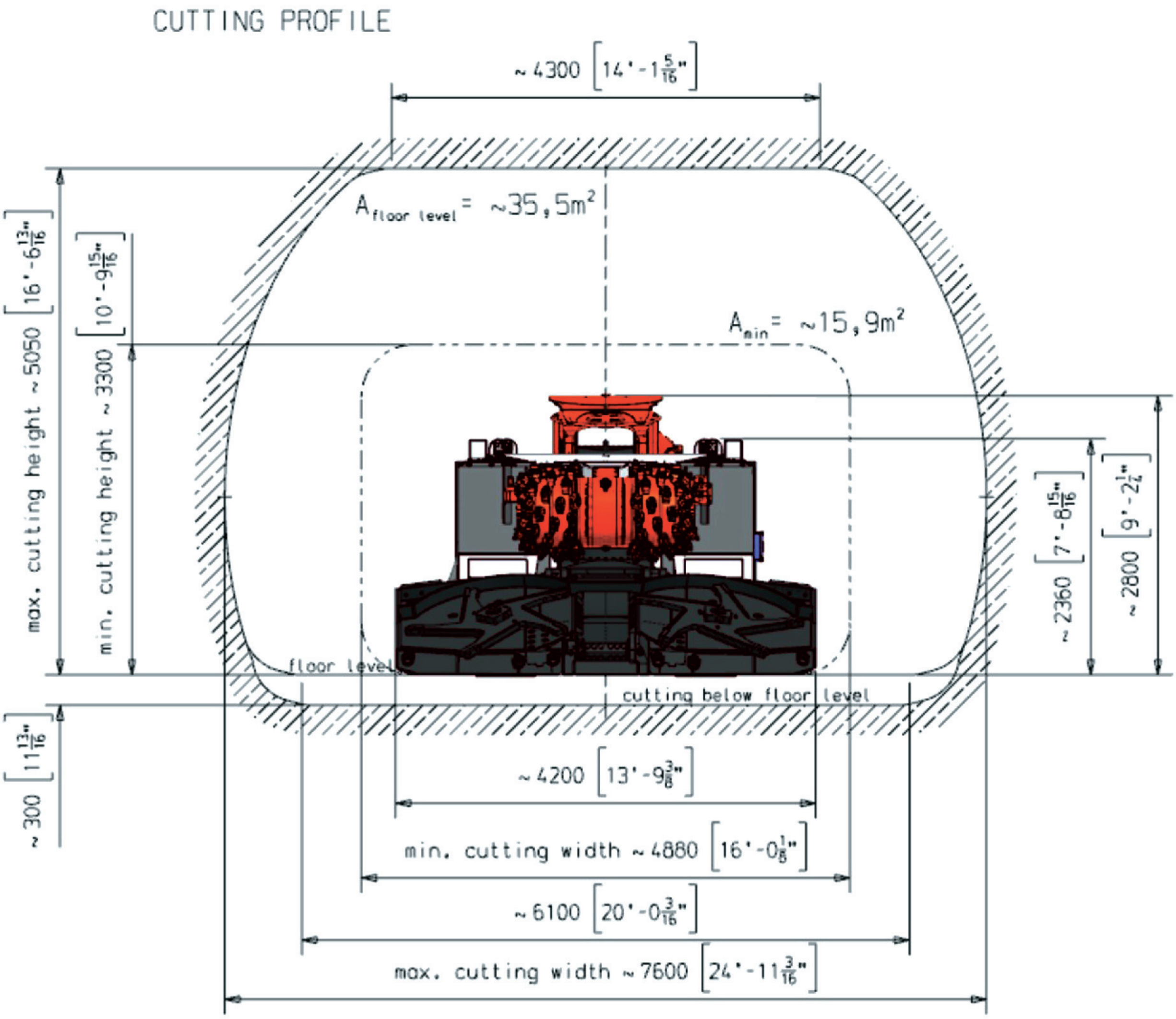

Fig. 18. Possible maximum and minimum cutting profile of the MR341 roadheader [2]

5.2. Cutter unit

The MR341 is equipped with a cutting unit (Fig. 19) consisting of a turret, a cutter motor and a cutter gear.

The unique geared turret ensures constant and stable working conditions; it is driven by a 230 kW electric motor, and the cutter gear generates approx. 52 000 Nm of cutting torque. The control and position of the turret are fully monitored, and the cutting gear is equipped with the innovative OMFCS II oil monitoring and cooling system.

In addition, the cutting unit is secured against excessive wearing by the software controlling the motor current of the cutting unit, the turret pivoting and other parameters that extend the life of all cutting components.

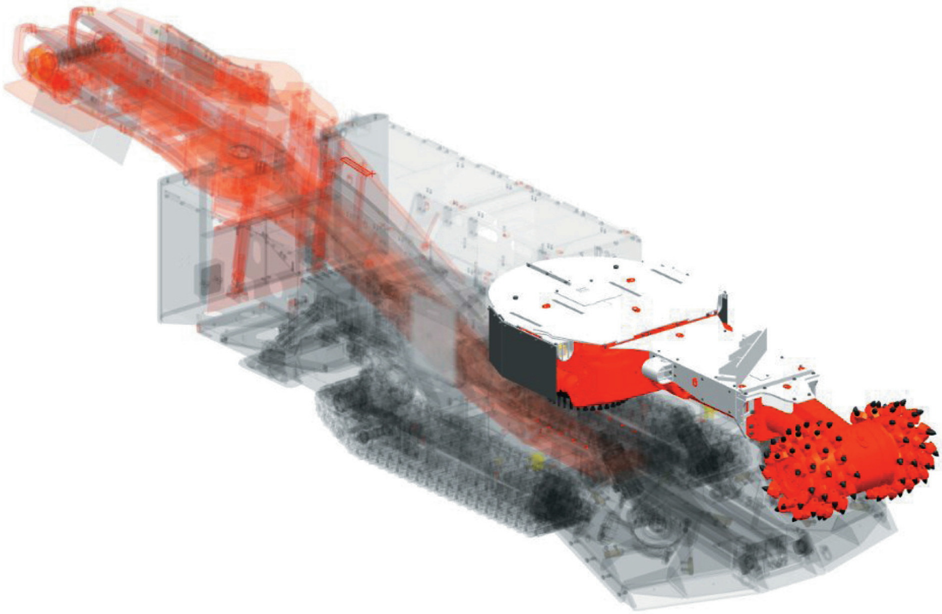

Fig. 19. Cutter unit of the MR341 roadheader [2]

5.3. Loading system

The system has been designed to ensure high cutting performance, hence, among others, triple bearing of the conveyor, wear-resistant sheathing and variable speed hydraulic conveyor motor with a capacity up to 205 m^3/h were applied. Loading table with extensions that increase the loading width of the mined rock.

The loading system (Fig. 20) is integrated with the cutter unit, and the changes in the loading capacity are controlled by constantly evaluating the amount of mined rock, which extends the maintenance periods and the life of the entire loading system and allows for adaptation to the haulage capacity.

5.4. Frame and crawler assembly

A heavy frame with two hydraulically-lowered rear stabilizers and pins with increased diameters have been used to extend the life of the components. The compact crawler track assembly with a power of 120,000 Nm enables movement at the speed of 8.8 m/min. The hydraulically driven crawler track assembly allows for changing the width of the crawler plates.

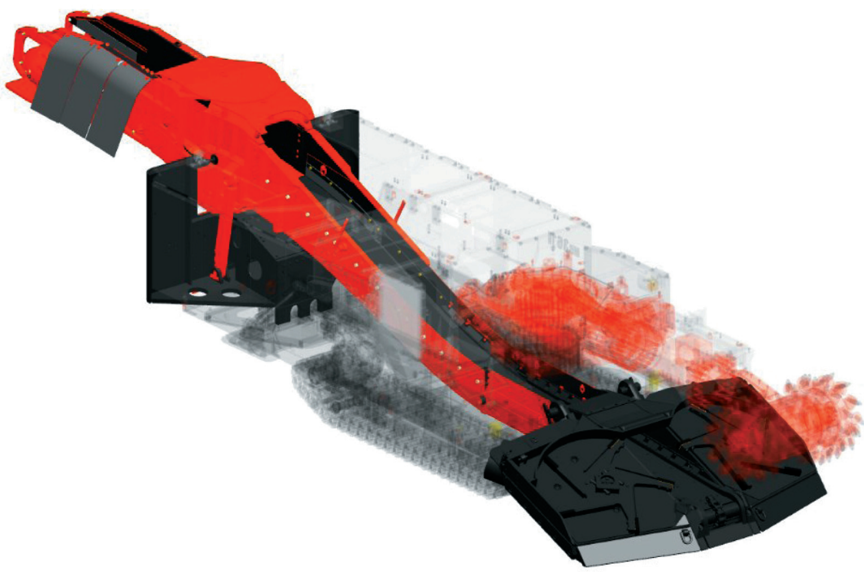

Fig. 20. Loading system of the MR341 roadheader [2]

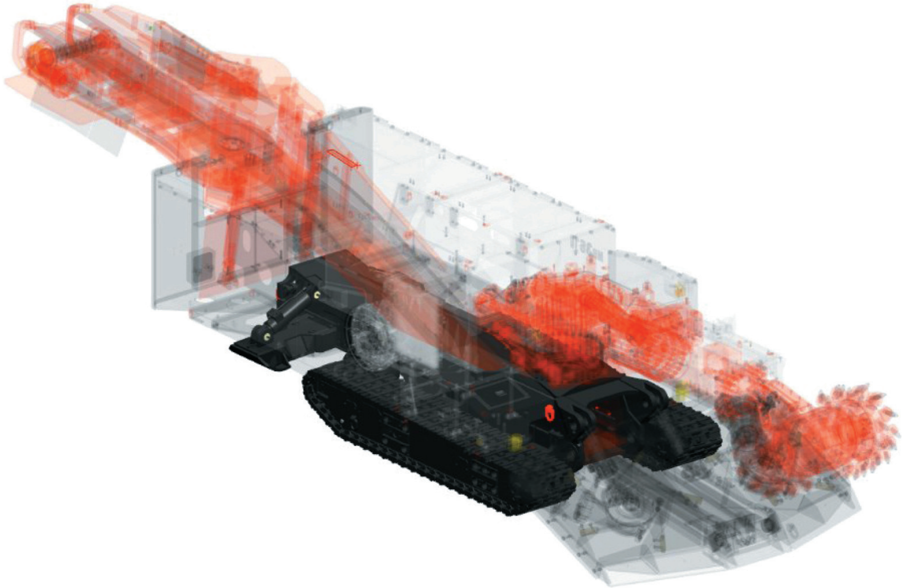

Fig. 21. Frame and the crawler assembly of the MR341 roadheader [2]

5.5. Electric system

The MR341 roadheader is equipped with an electric box designed for autonomous mining operation. Supervision over the control of the machine functions is carried out by the latest PLC produced by B&R, combined with other PLCs that supervise the spraying, safety, positioning and data transmission systems. Direct control is affected by means of dedicated proportional solenoid valves that allow very precise control of the cylinders, hydraulic motors and other hydraulic components with the appropriate feedback.

The roadheader's electric system allows for predictive estimates of component wear and preventive maintenance. All the information concerning the wear of individual components based on time and working conditions as well as monitoring of current parameters can be displayed in the operator's, dispatcher's and maintenance panel. In line with the assumptions of 'Industry 4.0' concept, the operator is constantly informed of the need to replace consumable fluids or other consumable parts. All information is correlated in order to reduce the machine maintenance costs and increase its productivity.

6. SUMMARY

Many years of global experience in the development of machinery designed for mining industry has allowed for the introduction of autonomous machines that help to protect the highest value – life and health – in places where human work can be very dangerous or even impossible. At the same time, striving to maintain productivity at a profitable level results in looking for new opportunities in the extraction of deposits that have been previously unavailable.

Sandvik's semi-automatic, automatic or autonomous machine systems significantly improve the safety and comfort of the crew, reduce their exposure to harmful conditions and hazards, reduce maintenance costs and breakdown times, extend the life of the machine and components, and reduce the risk of damaging the machine or components. The machine's productivity is additionally influenced by reducing the time necessary to reach the machine by changing operators, which now takes place at a remote operator's station instead of the place where the machine works.

All these new functionalities have a positive impact on the TCO (Total Costs of Ownership), an extremely important parameter in modern companies promoting sustainable development.

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PAWEŁ NOWAK, M.Sc., Eng.
ŁUKASZ KILAN, M.Sc., Eng.
Sandvik Polska Sp. z o.o.
ul. Strefowa 10, 43-100 Tychy, Poland
{*pawel.nowak, lukasz.kilan*}*@sandvik.com*