EXTENDING MOBILE ROOF SUPPORT REACH FOR INCREASED COAL RESERVE RECOVERY

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Abstract

Ramaco Resources, LLC and J.H. Fletcher recently collaborated to solve a unique geologic situation and safely increase the reserve extraction potential of Ramaco's Rockhouse Eagle mine. The mine is located in Logan County, West Virginia and was developed as a room and pillar operation with expected normal operating heights between 60" and 108", (1.52M and 2.74M).

As mining progressed into the reserve and while Fletcher mobile roof supports, (MRS), were being procured and built, actual mining conditions varied substantially from expectations. Due to the presence of a previously undetected third split of coal in the seam, cavity heights had increased up to 22', (6.71M). The planned MRS' being built even with traditional extensions that attach to the top of the MRS roof support plate would be incapable of reaching the mine roof. A taller reach MRS was not a viable option due to the increased collapsed height as the entrance to the mine was limited to 50", (1.27M), clearance.

This paper will explain the collaboration between MSHA, Ramaco and Fletcher to develop an MRS with a tilting, mid-chassis extension designed to be installed on the machine underground to increase the range of the MRS.

Introduction

For decades, coal mining in the United States, has involved mining away from the shaft bottom or drift mouth a series of tunnels called entries. The height of the seam of coal usually determines the entry height which can be 32", (813 mm), to 20', (6.1M), or more. The width is approximately 20', (6.1M), depending on the mining method and conditions of the mine roof. Usually there are multiple parallel entries in a mine with cross cuts driven at intervals to connect the entries together so mining can proceed more efficiently. The block of coal created by the entry and cross cuts is called a pillar.

Additional pillars are developed further and further away from the mine mouth until running into a property boundary of the coal reserves or the distance becomes too great from the drift mouth or mine bottom to economically mine. This practice of driving entries and creating pillars with cross cuts is called development mining.

Once development is complete many times the pillars are removed systematically from the furthest pillar away from the mine entrance shortening the distance to the working face on advance. This is called retreat mining and is referred to as pulling pillars. This practice has been around for decades and up until the early 1990's was completed using a system of wooden timbers to hold up the roof while the pillar was being extracted. In the early 1990's mechanized roof support became common to replace installing wooden timbers for supporting the roof in retreat mining. The machines used for retreat mining are called mobile roof supports, MRS'. Typically, 4 MRS units are used with 2 in the entry and 2 in the cross cut to hold up the roof while the pillar is being mined out. Using the MRS units in pairs allows one unit to hold up the roof while the other repositions.

Figure 1. Mobile Roof Supports underground deployed in pairs.

MRS capacity is commonly 600 – 800 tons, (544-746 tonnes), nominal. The machines consist of 4 hydraulic cylinders connected to a chassis and roof support plate. Between the chassis and roof support plate is a system of lemniscate links to train the cylinders to extend to the roof in a relatively straight line and to provide horizontal support.

Figure 2. Typical Mobile Roof Support

An MRS is a radio remote controlled machine where one transmitter can control all 4 MRS units one at a time or each MRS unit can have a dedicated radio transmitter. There is an onboard hydraulic system with a pump powered by an explosion proof electric motor, commonly a 50-75 hp, (37-56 kW), motor. For power an onboard cable reel handles the cable from a power source to the four machines. The chassis is in contact with the ground using drum miner style crawlers. The cable reel, electrical enclosure and other items are protected within a plow which helps push debris out of the way during relocation of the machines. Finally, the open sides of the mobile roof support are protected from gob/goaf or other rocks rushing in under the elevated roof support plate by an interwoven mesh consisting of chain and wire rope.

There are several different retreat mining methods using MRS units but this paper won't go into detail on the differences. What is important to understand are the mechanical workings of the MRS units. The MRS units are like hydraulic cylinders, there is a collapsed length/height and stroke allowing an extended length/height to be calculated. Because some dead space is required stroke is directly related to the collapsed height.

Common size ranges, with some slight variations for different ground clearances, for MRS units are 32"-63", (0.8-1.6M), 42"-86", (1.1-2.2M), 50"-110", (1.3-2.8M), and 57"-144", (1.4-3.7M). For machines over 144", (3.7M), extended height it is required the machines have a side to side tilt capability of approximately 5 degrees each way. One of the reasons for this is better stability under roof loading. Another reason is because two of these side by side in a 20', (6.1M), entry is a tight fit. On uneven floor the roof plates can become entangled. For example, a 14', (4.3M), tall MRS on a 5 degree angle created by uneven bottom conditions causes the roof support plate to displace laterally approximately 2', (610mm).

Figure 3. Tilting type MRS unit

The tilting lemniscate linkage chassis addresses this problem but is an uneconomical post production machine option. It has to be built into the machine chassis by dividing the chassis into an upper and lower section connected together with a large pivot pin. A single tilt cylinder is added with anchors on each section of chassis and operator remote controlled using the transmitter. The ability to tilt the chassis is key for high reach MRS units but it has to be planned ahead of time when sourcing the MRS units.

It has been common practice to install an OEM roof support plate extension which is a steel box up to 25", (635mm), tall that is strapped with load binders to the machines roof support plate. This height is limited because of the same reason as explained for the need of a tilting lemniscate linkage system. Too much extension stacked on the top of the roof support plate can become unstable or entangled with the rib or adjacent machine. The extension is installable underground but directly adds to both collapsed and extended height of the machine the same as the height of the extension.

The Rockhouse Eagle mine is located within Ramaco's Elk Creek complex located in Logan and Wyoming Counties, West Virginia. This complex and these reserves were acquired in 2012 by Ramaco as a greenfield development. In 2016, active development of the complex was initiated with construction of a new preparation plant and loadout and development of multiple underground mines, including Rockhouse Eagle.

The Rockhouse Eagle reserve was developed as a drift mine. The bulk of the reserve to be mined was anticipated to have normal seam heights of 60"-78", (1.5-2M), with mining confined to the Eagle seam of coal with typical in-seam and out-of-seam dilution. Coredrilling had identified one area of the mine where a lower seam of coal, locally referred to as the #2 Gas Seam, would converge with the upper Eagle Seam resulting in total cavity heights up to 12', (3.7M), in height, including the interburden between seams. Due to projected favorable economics, this dual-seam mining zone was targeted for early development and mining and was expected to persist for 18-24 months in this thicker area.

The decision to acquire new MRS' which could operate in the 50"-110", (1.3-2.8M), range was made because it would allow operation at the thinner expected range of seam heights, and with extensions, would allow up to 144", (3.7M), to be mined in the dual-seam zone as long as it persisted. This sized set of MRS' also would be compatible with the seam heights at other of Ramaco's underground mines, allowing the set to be utilized at multiple locations and further justifying the capital expenditure. While not expected to be a significant amount of the reserve, areas of the dual-seam zone in excess of 12.5 feet, (3.8M), were planned to be first-mined due to the inability to safely support the roof during pillar extraction. Accordingly, and with the best information known at the time, an order for a new set of 50"-110", (1270-2794mm), MRS' was made with J.H. Fletcher with approximately a ten-month lead time.

Problem

Following the placement of the initial order mining progressed approximately as anticipated at the Rockhouse mine while material procurement and MRS construction stayed on schedule at JH Fletcher. However, in December of 2017, the mine began to encounter unforeseen geologic conditions. The convergence of the Eagle and the #2 Gas Seams occurred somewhat earlier than core drilling and gridding had projected and the seam thicknesses of both coal horizons was augmented by the addition of a thin lower coal seam, below the #2 Gas Seam which had not been modelled by the geologists. This "Lower #2 Gas Seam" added approximately 18",

(457mm), of additional seam height throughout the dual-seam zone making the average mining heights 12'-14', (3.7-4.3M), which was at or exceeded the maximum heights that the ordered MRSs could safely operate within.

By late January of 2018, an additional problem/opportunity presented itself. From the roof, a fourth mineable seam of coal had locally presented itself. This seam, referred to as the Eagle Rider, was not present in previously drilled coreholes, outcrop measurements taken, or adjacent underground mining in the area. However, the seam converged with the other three horizons with an interburden of in-seam rock of 18"-36", (457-914mm), and coal thickness of 12"-24", (305-610mm). The addition of this coal and in-seam rock brought typical mining heights to between 16'-17', (4.9-5.2M), with locally higher cavity heights up to a maximum of 22', (6.7M).

Due to the extreme seam heights and the presence of multiple seam interaction from underground mining in seams above at approximately 120', (3.7M), 300', (91M), and 600', (183M), pillar dimensions were extremely large, as much as 72' x 122', (22-37M), in one area of the mine. Due to height to width ratios, the pillars were similarly largely sized whether first or second mining was considered. Ramaco determined that it was economically desirable to retreat mine in the high cavity areas if the work could be done with MRSs and if it could be done safely.

While consideration was given to ordering a larger set of MRSs which were capable of reaching mine heights of 16'-20', (4.9-6.1M), this was quickly discarded as a viable option for a number of reasons. First, the lead-time to build the new, larger set would not have met the mine development timeline required and there were concerns that ground conditions could deteriorate if these tall pillars were mined and then allowed to sit an additional 10-12 months while bigger equipment was procured. Secondly and perhaps most importantly, the collapsed height of the larger machines would not fit inside the drift openings of the Eagle mine where the single bench Eagle seam was mined. Typical mining heights in this area were 50", (1.3M), although a single entry had been mined at 66", (1.7M), initially to allow the anticipated higher seam continuous miners, roof bolters and shuttle cars to be brought into the mine. The larger MRS units had a collapsed height of 92", (2.4M), and would not fit into the mine.

Figure 4. MRS Extension, (OEM and mine supplied wood layer), located adjacent to Rockhouse Eagle Face-up and Coal Outcrop

Finally, the economic justification of a larger set of MRS' which at that time only had a projected useful area of approximately 120-130 pillars could not be justified.

Ramaco endeavored to validate that mining in this high seam area could be completed in a manner that was safe for the employees and also did not endanger the structural integrity of the overall mine (i.e. pillar stresses causing rides or pillar failures). Prior to engaging in further design consultation with JH Fletcher, Ramaco engaged a third-party mining engineering company to perform a boundary element analysis on the mine, taking into account seam heights, multiple seam overmining (including pillar workings in overmining) and overburden stress. The LaModel software package was utilized for this work. The results of this analysis showing a mining sequence that keep stress levels at acceptable levels and was incorporated into the mining plans.

At this time, convinced that pillaring could be done safely if a machine could be developed to reach the roof, Ramaco and JH Fletcher began meetings to design a unique machine that was able to be used in lower seam heights, while still reaching the full seam heights anticipated at the Rockhouse Eagle mine while also not abandoning the progress made on the originally ordered MRSs.

Solution

During the time the tilting chassis extension concept was being considered by Ramaco the MRS units were progressing toward final assembly. Once the tilting chassis extension idea was accepted the design proceeded. A solution was arrived at during discussions between

Ramaco and Fletcher of adding a chassis extension that incorporated the tilting mechanism and increasing the reach once installed. In combination with the extension on top of the roof support plate the reach could be around 17', (5.2M). A machine of this reach would be over 10', (3.0M), height collapsed.

The solution allowed the use of the existing raise cylinders, lower chassis, roof support plate, lower lemniscate link, upper lemniscate link, caving shield, control link, hydraulic tank, crawlers, plow, electrics, hydraulics and chain curtain. The new items required for the tilting chassis extension were a lower tilting chassis, upper tilting chassis, pins, tilt cylinder, new electric motor, new control valve, chain curtain extension and hose extension kit.

Design

The MRS chassis is a high strength steel structure between two special heavy duty miner type crawlers meant to take a nominal load of 800 tons of external load onto the roof support plate. Smaller horizontal loads are also transmitted to the crawlers and chassis through the lemniscate linkages that ensure nearly vertical travel of the roof support plate from collapsed to extended. The roof load onto the chassis varies slightly depending on the height of the MRS units due to the change of the angle of the main support cylinders.

The lifting cylinders rest into four bowls placed on the bottom plate of the chassis. Trunnions on the cylinders allow movement but prevent the cylinders from becoming dislodged from the bowls. The tops of the cylinders have a ball and socket connection to the roof support plate to allow for uneven roof, front to back or side to side.

The bowls on the chassis were used to provide a locational function, they defined the correct location of the lower tilting chassis extension to be attached to the chassis. The bowl was a known location for supporting the loads placed on the machine from the roof. Since the bowls were known to support the loads it saved time in the design since known loads were similar from cylinders or the lower half of the chassis extension.

The pins and bushings used in the chassis extension pivot was the same components used in the already existing high reach MRS units, these did not need reinvented since the loads were very similar.

The upper chassis extension likewise used previous design knowledge to shorten the design process of figuring out structure, materials, pins, bushings, bowls, tilt cylinder and lemniscate connections. Chain curtain extension pieces were added by simply using shackles to connect curtains together. Jumper hoses was added to all hoses that were required to run from the original location to an elevated location on the upper tilting chassis extension half. Most of these were the raise cylinder hoses. The total tilting chassis extension height added to the MRS units was 60", (1524mm).

While the design solution was unique a lot of tried and true designs were incorporated together. To increase the reach even further a traditional roof support plate extension was added on top of the roof support plate using load binders and chains to secure them in place. The maximum OEM roof support plate height is 25", (300mm).

The mine worked with MSHA to add another 18", (457mm), of hardwood blocking on top of the OEM roof support plate. This wooden extension was also chained into place. See Figure 4.

Total extension height added to the 50"/110", (1.3—2.8M), machine was 60", (1524mm), from the tilting chassis plus 25", (300mm), from OEM roof support plate extension plus 18", (457mm), of mine installed hardwood for a total of 103", (2616mm), of extension. This changed the collapsed and extended height to 153"/213", (3.9-5.4M), almost 18', (5.5M), total reach.

The MRS delivery was delayed only a few months to allow the tilting chassis extension to be fitted to try to head off any unforeseen problems that may occur trying to install the extension underground.

Underground Installation

A well thought out plan was put in place to make sure the assembly and disassembly of the machine went safe and smooth. The MRS units were delivered to the mine and taken underground inby the lower clearance part of the mine. In a 12', (3.7M), seam height section of the mine, I-beams was roof bolted in place crossways in the mine entry approximately 7', (2.1M), apart. These I-beams were approximately 16', (4.9M), long almost reaching from rib to rib. Under the ends of the I-beams vertical posts were added to augment the strength provided by the roof bolts connecting the I-beam to the roof. Approximately 10 I-beams were placed parallel down this work area entry.

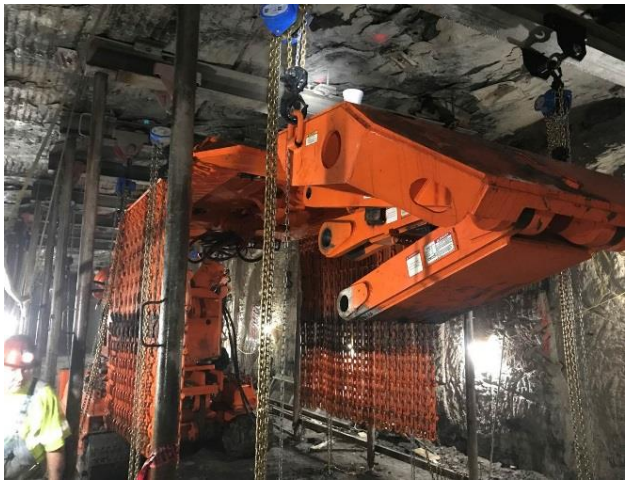

Figure 5. Suspending Roof Support Plate, Chain Side Curtains, Caving Shield and Lemniscate linkages.

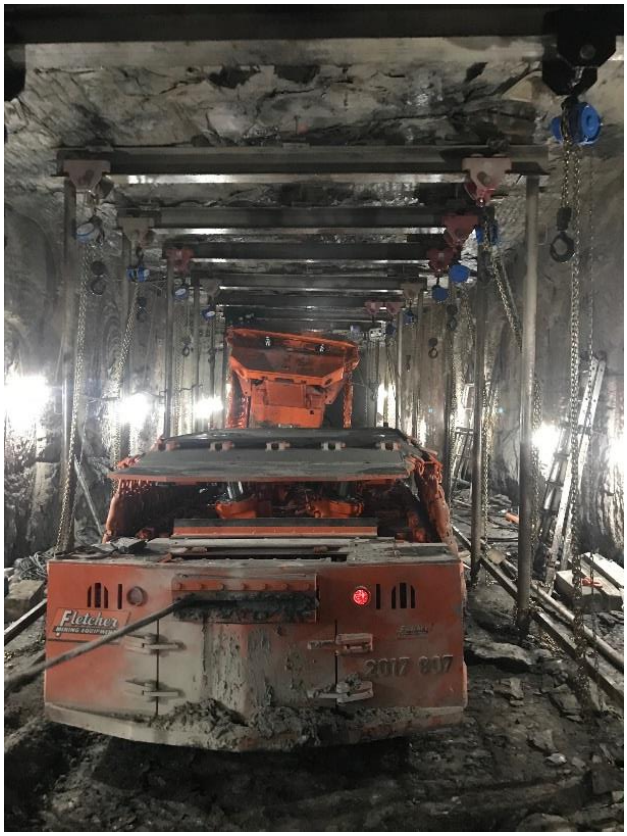

Figure 6. Mobile Roof Support Disassembly and Assembly Area

The I-beams allowed connection of chain falls and winches to lift the loads required for assembly and disassembly of the machine components.

Under one set of I-beams the roof support plate was removed from an MRS and left suspended. The machine was trammed forward to the next set of I-beams so the 4 raise cylinders, caving shield and lemniscate linkages, could be removed and also left suspended. Note, the lemniscate linkages and caving shield were tack welded together to make them lift as a single unit instead of three individual components.

Down the assembly line of additional I-beams the tilting chassis lower half was hauled into place and suspended. Next came the upper tilting chassis half which was also suspended from I-beams.

To begin reassembly of the MRS, the stripped chassis was trammed into place under the lower tilting chassis extension half. This tilting chassis extension half was lowered into the MRS chassis and bolted into place using previously located connection points. The bowls in the chassis help locate these large components together.

Next step was to tram the machine again to a location under the upper tilting chassis half. This component was lowered and the upper and lower tilting chassis halves were pinned together. The tilt cylinder was added, marrying the two halves together allowing +/-5 degrees of tilt for the machine above the tilt cylinder pin.

The machine was reversed down the assembly line until it was located under the four raise cylinders, caving shield and lemniscate linkages. Lowering these components onto and connecting took a large amount of time because of not only the many pin connections but hose extensions had to be added.

Once the next step of the process was ready to proceed it required another relocation to locate the machine under the suspended roof support plate. Once this was lowered and pinned in place, extensions for the chain curtains were added.

Figure 7. Fully Assembled Mobile Roof Support Underground, (except roof plate extensions)

The total amount of suspended weight removed from the machine before adding the tilting chassis extension, was approximately 21,000 lbs, (9525 kg).

Using the I-beams where the tilting chassis halves were suspended the OEM roof support plate extension and mine supplied wooden extension were hoisted to the roof allowing the MRS to tram underneath so these components could be added making the final machine ready to go into the retreat mining workings.

The new extension components added to the machine was approximately 19,000 lbs, (8618 kg).

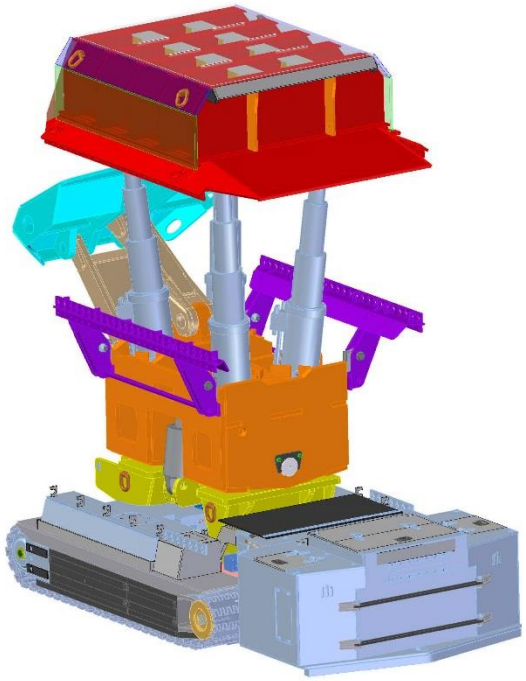

Figure 8. Cad model of MRS with tilting chassis and Roof Support Plate Extensions, (chain side curtains not shown).

Results

Once the MRSs were fully assembled they were commissioned and put into service almost immediately and with their highest reach required. Although there were typical start-up issues that would be expected with any new machine, the MRSs worked as designed, provided the required ground stability and allowed a much higher reserve extraction ratio.

The collaborative effort helped Ramaco not only to mine a higher percentage of its reserves, but also reduced the capital expenditures that otherwise would have been required if a stand-alone high-seam set of MRS' were purchased and constructed and installed underground at the Eagle Mine. At the time that the purchasing decision was being made, the mine only expected to recover 125 of these high seam pillars. While these pillars contained over 200,000 clean tons, (181,437 tonnes), of metallurgical coal that could be extracted using MRS' that would otherwise be stranded, this would have created a marginal return on investment for specially built set of MRS' just for this projected use. Furthermore, without any similarly sized reserves in Ramaco's current portfolio, the prospects for

leasing or selling these scarcely used assets would likely have been limited to a select group of international miners.

By designing the removable chassis extensions, the incremental capital costs were reduced by 70% from new high-seam machines, and Ramaco retained an extra set of mid-seam machines for use in other locations throughout the Eagle mine as well as other mines and reserves that they own. It will also allow the operational flexibility to adapt to changing seam conditions if other multiple seam mining presents itself at this mine or others in the future.

As mining continued at this mine, the extent of the actual high seam areas continued to be delineated. An additional unexplored property to the south of the reserve was acquired by lease, where these high seam conditions persisted. There are now six pillar panels which are projected to have mining cavity heights in excess of 13', (4.0M), which will require the chassis extension MRS' in order to reach the roof. Where initially 125 pillars of extractions were anticipated and was used to justify the expense and effort of retrofitting the machines, there have now been 209 pillars between 13' – 19', (4.0-5.8M), which have been extracted, with an additional 228 pillars expected to be retreated.

Discussion

The idea of assembling a tilt chassis extension into the MRS units was a success as higher reserves were mined that otherwise would have been lost. There were no safety risks to the operation of the machines. From a machine design point of view this has been a success, but disassembly/assembly was very challenging. Early on manual chain falls were used and it was soon realized this method was not only physically draining but slow. Electric hoists were obtained which helped not only speed up the lifting process but made it less physically challenging.

A mobile gantry crane type machine may make sense for future assembly/disassembly efforts? It would have to be decided by the mine using the cost/benefit of the current system versus what a purpose-built machine would provide. This would be a specialty machine and would be a design challenge in itself but could potentially pay for itself if the mid-chassis extensions were needing to be installed on a frequent basis.

Each chassis modification required multiple mechanics working several shifts on each machine to make the change. The work was strenuous and technical enough that a determination was made to alter the mine plan of the mine to ensure mining all high seam reserves, prior to mining or retreating any mid-seam reserves, to limit the amount of machine changes that had to be made.

The larger 75 hp, (56 kW), motor was determined to be an absolute necessity. Without the larger motors, the machines would have struggled to quickly tram forward between lifts in the pillar line, particularly when soft floor conditons were encountered.

Conclusion

Design modifications to allow the working height of MRS to be extended from 110", (2.8M), to 213", (5.4M), was a success. The safety and functionality of the MRS was maintained and coal reserves were mined that otherwise would have been lost forever.

Figure 9. Mobile Roof Support Working