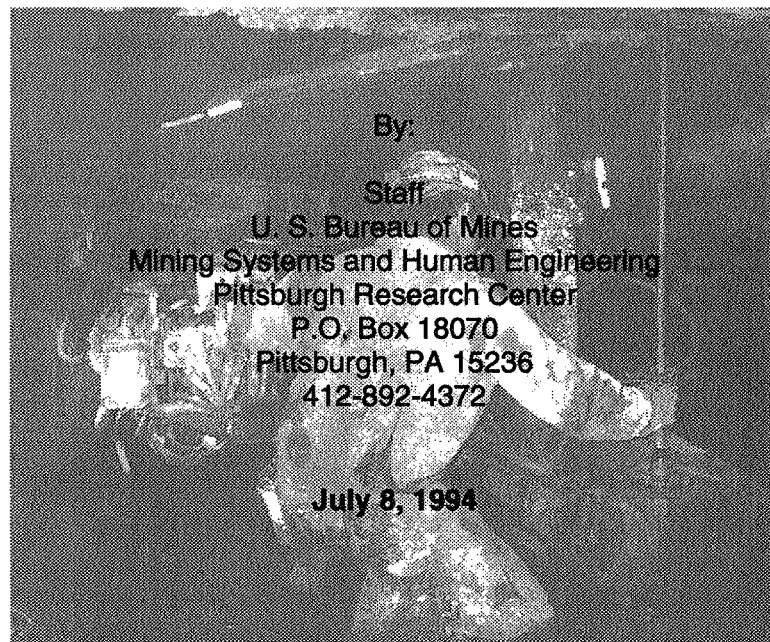


Human Factors Analysis of the Hazards Associated with Roof Drilling and Bolt Installation Procedures

Submitted to:

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SUMMARY

At the request of the West Virginia Board of Coal Mine Health and Safety, the U. S. Bureau of Mines (USBM) initiated a study of human factors issues related to roof bolting in underground coal mines. The objective of the study was to determine what hazards may be associated with roof bolting and recommend solutions to those hazards. The study focused on hazards that exist during the roof drilling and bolt installation procedures. Particular emphasis was placed on hazards associated with the fast feed lever and movement of the drill head boom or mast.

Five major categories of information collection were used to understand the types of accidents and injuries that can occur when drilling and installing bolts: (1) detailed analysis of the Mine Safety and Health Administration (MSHA) and West Virginia University (WVU) accident databases and 16 roof bolter fatal reports, (2) visits to three underground mines and interviews with 10 roof bolter operators, (3) discussions with manufacturers of roof bolting equipment, (4) interviews with three miners who have been injured during roof bolter operations, and (5) reviews of past research on roof bolter safety.

Based on the information collected, the USBM decided that the primary goal of any intervention should focus on reducing the number of accidents caused by the roof bolter operator being crushed by the boom or mast of the machine. To achieve that goal, the USBM developed a list of seven solutions which were then ranked based on their ability to protect the operator, the time needed to develop and carry out the solution, and cost. The solutions, ranked in descending order of importance, are:

1. Use an interlock device to cut off power to the controls when the operator is out of position.
2. Provide fixed barriers at pinch points and other dangerous areas.
3. Provide better control guarding.
4. Reduce the speed of the fast feed.
5. Use automatic cutoff switches for pinch points and dangerous areas.
6. Redesign the control bank to conform to accepted ergonomic principles.
7. Use resin insertion tools and resin cartridge retainers.

In addition, the USBM developed the following additional recommendations that have potential to increase the general safety of the roof bolting operation.

1. Perform an overall crewstation redesign with a greater emphasis on operator reach and visibility requirements.
2. Position personal protective equipment so it is less likely to bump or become tangled in the controls.
3. Reduce the likelihood of the drill steel jamming through better maintenance and drill shaft designs.

OBJECTIVE

At the request of the West Virginia Board of Coal Mine Health and Safety, the Mining Systems and Human Engineering group of the USBM initiated a study of human factors issues related to roof bolting in underground coal mines. The objective of the study was to determine what hazards may be associated with roof bolting and recommend solutions to those hazards. The study focused on hazards that exist during the roof drilling and bolt installation procedures. Particular emphasis was placed on tasks involving the fast feed lever and movement of the drill head boom or mast.

BACKGROUND

On October 26, 1993, USBM researchers met with the West Virginia Board of Coal Mine Health and Safety to discuss safety issues related to roof bolting in underground coal mines, particularly with respect to fast feed levers. The Board's concern resulted from their own internal report¹ that found that there were eight fatalities associated with roof bolters where the victim was caught between the drill boom and the mine roof or Automated Temporary Roof Support (ATRS). These fatalities occurred nationwide between 1983 and 1993. In all cases the victim activated a raise lever while in a hazardous location.

As a result of that meeting, the USBM began a project that looked into human factors issues related to roof bolters. The work was divided into several tasks involving interviewing bolter operators, observing roof bolting operations, contacting roof bolter manufacturers, analyzing mine accident data and reviewing past research on roof bolter safety. The project team consisted of USBM researchers with backgrounds in Engineering (Industrial, Mechanical, Mining and Civil), Physiology, Training and Safety.

Due to the coal miners strike, little field work was done until January 1994. In March, two roof bolter fatalities that occurred in early 1994 (February 15 and March 5), involving Fletcher HDDR bolters, temporarily diverted the focus of the work to studying safety issues specifically related to that machine. A third fatality involving a different style of roof bolter on March 25, 1994 prompted MSHA to organize the **Roof-Bolting Machine Committee**. Members include representatives from MSHA, the W.V. Board of Coal Mine Health and Safety, and the USBM. The committee studied roof bolting safety through mine and manufacturer visits and operator interviews. All relevant data collected as part of this project were made available to the MSHA committee.

METHOD

Data collection consisted of analysis of the MSHA and WVU accident databases, visits to underground mines and interviews with roof bolter operators, discussions with manufacturers of roof bolting equipment, interviews with miners who had been injured during roof bolter operations, and reviews of past research on roof bolter safety. After the data was analyzed, recommendations were developed and ranked using a structured technique. The data collection methods used to understand the types of accidents and injuries that can occur when drilling and installing bolts are outlined below.

Accident Database Analyses - MSHA accident files for the years 1988 through 1991 were examined to capture all roof bolter accidents that resulted in injury due to operator exposure to moving or active machinery. The search criteria used is listed in table 1.

Accident Injury Code	Search Criteria
Accident Injury Illness	Machinery or Powered Haulage
Mining Machine	Rock or Roof Bolting
Source of Injury	Underground Mining Machine or Drill Steel
Mine Worker Activity	Roof Bolter (drilling, inserting bolt, tramming and NEC) Machine Maintenance or Repair
Accident Type	Struck against Stationary Object Struck by Powered Moving Object Caught in-under-between Running or Meshing Objects Caught in-under-between a Moving and Stationary object
Degree of Injury	Injuries of all types (includes fatalities)

Table 1 - Criteria used to search the MSHA accident database.

The above data were then characterized by mine seam height, age of the victim, victim experience, and time elapsed since the beginning of the shift. Furthermore, fatality reports for roof bolting related accidents were examined for the period January 1984 through April 1994. Accidents were limited to those that took place at or near the drilling station during the bolting process or maintenance of the machine.

Additionally, WVU provided the USBM with a database that details non fatal roof bolting accidents in West Virginia coal mines from 1985 to 1990. Roof bolting accidents were defined as any accidents involving roof bolter operators and roof bolter helpers, or any accident that involved a roof bolting task. The data were derived from the West Virginia Safety Information System and consisted of 2606 accidents.

Mine Visits and Interviews - USBM personnel visited three underground coal mines to observe the bolting process and interview underground workers about roof bolter safety. Two of the mines were in western Pennsylvania and one was in southern West Virginia. Miners with bolting experience were interviewed at each mine. A questionnaire was developed to assess the miners' views about the safety issues associated with roof bolting. Issues addressed in the questionnaire included: demographic information, procedures used, training received, control layout and design of equipment, accident causes, and potential solutions. Table 2 provides the seam height, type of bolting equipment used, and the number of interviews taken for each mine:

Mine Code	Mine Location	Seam Height	Bolting Equipment	Number of Interviews
A	Western Pennsylvania	84"	Fletcher dual head bolter with a walk-thru chassis (Model HDDR),	4
B	Western Pennsylvania	52"	Three Fletcher Roof Ranger bolters and two Lee Norse TD-2 bolters	4
C	Southern West Virginia	42"	Fletcher HDDO and Fletcher Roof Rangers	2

Table 2 - General information on the mines visited to observe the bolting process.

Manufacturer Contacts - Representatives from four major roof bolter manufacturers were contacted to obtain information about their bolting machines. These manufacturers included Fletcher, Eimco, Fairchild International, and Long Airdox (Simmons Rand). Two visits were made to Fletcher and the other manufacturers were contacted by phone. The company representatives were asked to describe the models they manufacture and the layout of the controls for each model. Furthermore, they were asked if they were aware of any fatal accidents that occurred because of miners being trapped between the boom and roof or canopy. They also were asked if any design modifications were made to reduce the likelihood of such accidents.

Interviews with Injured Operators - Three miners that had experienced accidents while roof bolting were interviewed. The miners all worked at the same western Pennsylvania room and pillar mine. First, demographic data, such as age, work experience, and job classification, were recorded for each miner. Each miner then related to the interviewer the story of his/her particular accident. Next, follow-up questions were asked to get the miners' views on causes and possible solutions for roof bolting accidents, mine conditions at the time of the accident, and the training they received.

Review of Past Research - The USBM has funded several research projects in the past that looked at roof bolter design and safety. There have also been reports issued by MSHA and private companies that addressed roof bolter safety. These reports were studied for information relevant to this project. In addition, discussions about roof bolting safety have been held with

many outside experts, including officials from MSHA, the United Mine Workers of America, and mine operators.

Ranking of Recommendations - Since one of the primary objectives of this project was to recommend solutions to certain hazards associated with roof bolting, the USBM felt it was necessary to use a structured technique to rank alternative recommendations. The technique chosen is called the Analytical Hierarchy Process¹³ (AHP). AHP is a multi-criteria decision making process that was developed at the Wharton school of the University of Pennsylvania by Thomas L. Saaty. This method was selected since it provided a means for taking into account multiple criteria and objectives in determining how well the alternatives meet the goals. Because ranking alternatives becomes complex when there are multiple objectives, tradeoffs must be made among competing objectives. AHP is a tool that helps to breakdown complex decisions into manageable parts that can be effectively rated and calculates overall rankings of the alternatives under consideration.

RESULTS OF THE DATA COLLECTION

Accident Database Analyses Results - The total number of accidents identified in the MSHA data, based on the search criteria described previously was 613 (which included 5 fatalities). Ninety percent (90%) of the victims were *Caught in-under-between a Moving and Stationary Object*. Only 1.5% of the accidents occurred during equipment maintenance. Previous studies have indicated that equipment maintenance accounts for over 30 percent of lost time injuries in underground coal mining. The source of injury for 87% of the accidents was the machine, with 13% being the drill steel. The job title for 74% of the victims was Roof Bolter or Roof Bolter Helper. Over 80% of the accidents occurred in Kentucky, West Virginia, Pennsylvania and Virginia.

The above data was further characterized by mine *Seam Height, Age of the victim, Victim Experience, and Time Elapsed* since the beginning of the shift. Little significant difference could be found between the accident characteristics for the selected roof bolter accidents and accidents for all underground workers except for the category *Experience At This Mine*. For all miner injuries, frequency of injury is highest for miners with two years or less experience at the mine where the injury occurred. However, there is a recurring rise in injury frequency that is somewhat normally distributed around 12 years. For the select roof bolting injuries, the frequency of injury is highest for miners with one year or less experience. The injury frequency drops rapidly until it becomes fairly level for miners with three or more years of experience at this mine. One possibility for this observable difference, based on interviews with miners, is that roof bolter operators tend to remain roof bolter operators while other workers are more apt to change jobs after they gain seniority at a mine. Analysis of the data provided by WVU provided no additional insights into the circumstances surrounding roof bolter accidents.

Of the 16 fatality reports examined for the period January 1984 through April 1994, 11 fatalities involved the inadvertent (by the operator, roof fall, etc.) activation of a control. Equipment maintenance was the activity for 5 of the 16 fatalities. Four (4) of the 5 maintenance related fatalities involved the inadvertent activation of a control.

Of the 16 fatalities, 14 involved the moving boom. Of these, 9 resulted in the victim being crushed between the boom and the mine roof, 3 resulted in the victim being crushed between the boom and the canopy, 1 resulted in the victim being crushed between the boom and the machine frame, and 1 resulted in the victim being crushed between the boom and the ATRS. Only 1 of the accidents involved the boom lowering toward the victim. Two of the 16 fatalities involved a drill mast head and, in both cases, the victim was crushed between the drill head and the machine frame.

Finally, 12 of the 16 fatalities occurred in seam heights of 60 inches or less. For 2 of the 16 fatalities, there is evidence that the operators had to position themselves over the boom, and into a hazardous position, to see the drill steel or hole.

Mine Visit and Interview Results - Four operators of Fletcher HDDR bolters (Mine A - see table 2), four operators of Fletcher Roof Ranger bolters (Mine B) and two operators of Fletcher DDO bolters (Mine C) were interviewed during three mine visits. The interviews with Roof Ranger bolter operators were conducted with workers who had experience with both the old Roof Ranger design (straight boom and lever controls) and a new Fletcher design (offset boom and joystick control). The interviews with the DDO bolter operators included workers who had experience with and without the two-handled fast feed design. The following paragraphs summarize the major issues relevant to the fatalities as discussed in these interviews.

Accidental Actuation of Controls: Based upon the interviews conducted by the USBM, accidental actuation of controls (hitting the wrong lever or bumping controls) is a relatively common occurrence among roof bolter operators. Of the bolters interviewed, most admitted to accidentally activating controls. Those who had not done so themselves usually knew someone who had. It appeared from these interviews that choosing the wrong lever was more common than activation through accidental bumping. One miner complained that drill steels used to fall onto the controls from their storage area on top of the machine until a bracket was added to hold them in place.

Reasons Why Bolters Get Into Pinch Points: Visibility was mentioned as a possible reason bolters get into drill boom pinch points. This is a particular problem with the Roof Ranger and DDO machines working in low to medium seam heights. Operators said that they can imagine situations where the bolter might stick his head over the boom to see the drill hole. For the operators of HDDRs, the primary reason cited for entering a pinch point was retrieving a stuck drill steel. In addition, operators of both types of roof bolters said that the process of resin insertion may require the operator to get into a pinch point. The two DDO operators said that gob left by the continuous miner sometimes forced them to work closer to the boom and off-balance when bolting next to the rib.

Use of the Fast Feed Lever: Operators were asked about their use of the fast feed lever. The responses of the operators were fairly uniform, saying that the use of the fast feed lever was limited to the process of lowering drill steels and pushing the bolt up into the resin quickly. Most operators said that it was not used in any other way; however, one HDDR operator did say that some bolters drilled and bolted with the fast feed during rib pinning operations. However, the operator added that this usually was a problem because the suction could not keep up with the drilling process.

Operators were also asked whether they felt that the fast feed was necessary to do their jobs. Most operators said that they did need the feature, mainly because it allowed them to keep up with the mining cycle. Some operators also said that the feature was necessary so that bolts would not be lost due to the fast-setting resin. One operator said that the fast feed was sometimes helpful but was not absolutely necessary to do the job.

Comparison of the Old and New Roof Ranger Boom Designs: Mine B had both the old Roof Ranger design (straight boom and lever controls) and the new Roof Ranger design (offset boom and joystick control). The operators were questioned about the benefits and drawbacks of

the new design. In general, the operators felt that there was not much difference between the two, once they became familiar with the operation of the joystick. The features that the operators liked most about the new design included the better maneuverability of the drill head, the joystick control that made operation easier (less controls to operate), and the improved design of the workstation that allowed more space and a better escapeway. The negative reactions associated with the new design were that the fast feed speed was slower than the old model, that it took some time to get used to the joystick control, and that the controls were too far from the drill head. With regard to the latter, one of the operators was below average in size and had difficulty reaching the controls and the drill head.

In summary, the operators felt that the new design was as safe or safer than the old design. The new design was considered safer in terms of the better workstation design (better controls and more room to work in), and a better head swing design. The main complaint about the new design was that it was a little slower than the old machine.

Comparison of One- and Two-Handed Fast Feed Designs: Both Mines B and C had two-handed fast feed controls. Nearly all of the miners felt that the two-handed operation was safer than the old single handed design. Although most operators felt it was safer, miners were split on their opinions of the new two-handed feature. Some did not like it as much, but others said that they actually preferred the two-handed operation over the old design. One operator felt that it slowed bolt installation and took some time getting used to.

Manufacturer Contacts Results - Manufacturer visits to J. H. Fletcher & Co. were conducted. The design engineers at Fletcher provided information on how the fast feed lever was *intended* to be used, and what safety features they were incorporating into new bolter designs (two-handed fast feed, C-rings to replace cotter pins on control linkages, rubber guards on the boom arm to serve as a pinch point warning, and offset booms to provide more work space on their Roof Ranger model). They also revealed that they had investigated the possibility of putting an automatic cutoff switch on the boom so that the switch would be activated when it contacted an object. However, they were concerned that such a switch might be disabled, unbeknownst to the operator, who might be relying on it to work. In addition, practical limitations to retrofitting these machines for safety purposes were also discussed. Fletcher engineers agreed to cooperate with any future efforts on the project and to provide engineering drawings for analysis purposes.

Other manufacturers contacted by phone included Eimco, Fairchild International, and Long Airdox (Simmons Rand). Only general information concerning the design of their machines and sales literature was obtained from each.

Injured Operator Interview Summaries - Three operators of Fletcher Roof Ranger bolters (Mine B) were interviewed. Each had been injured in the past while roof bolting. Summaries of these injuries are detailed below:

1. The bolter operator was installing a bolt in a 46" seam height. He was bending the bolt before he pushed it up in the hole when he felt pain in his lower back.

2. The operator had just completed drilling the first half of the inside bolt hole (starter) and turned around to get the finisher and pusher steels when a large piece of rock fell. The bolter operator was pinned between the boom and the rock. He suffered a dislocated hip, a cracked vertebra, torn knee cartilage, and a cracked pelvis.
3. The bolter operator was installing a 6' point anchor bolt with a coupler between the bolt sections. He was pushing the bolt up into the hole when the coupler hung up on the lip of the hole causing bolt to bow. The operator was holding the bolt so that it would not fall into the mud and reached for the fast feed lever in an attempt to drop the bolter head to realign the bolt. The rotation lever linkage was sloppy and caused the lever to overlap the fast feed lever. When the operator lifted the fast feed lever, the head dropped but the reverse rotation was also activated. Because he was holding the bolt when the reverse rotation was activated, the operator's arm was twisted around the bolt, resulting in a fractured right arm.

Only one of these injuries dealt with the primary focus of this study; hazards associated with the fast feed lever and movement of the drill head boom or mast. The cause of accident #3, inadvertent activation of a control, was also the cause of 60% of the roof bolter fatalities studied and was a recurring theme during many of the interviews with roof bolter operators. With this injury, it appears that inadequate control design or maintenance, which caused one control to activate another, led to the accident. This was also the case in two of the fatalities, and was mentioned several times as a problem by roof bolter operators.

Review of Bolter-Related Literature - The USBM has sponsored several projects since the late 1970's that looked at roof bolter safety. Those with direct relevance to this project included a study on standardized controls for roof bolters³, a study on personal protective equipment for underground coal miners², a study of accident risk during the roof bolting cycle⁹, and a study to develop Society of Automotive Engineers guidelines for underground operator compartments⁴. Other work relevant to the project includes a report by MSHA on injuries associated with roof or rib bolting⁵ and a privately published manual on how to roof bolt safely using boom style bolters¹⁰. The bibliography at the end of this report contains a brief description of these and other studies.

DEVELOPMENT OF SOLUTIONS

As a result of the mine and manufacturer visits, the operator interviews, and the reviews of past research, the project team decided that the goal of any intervention should focus on reducing the number of accidents caused by the roof bolter operator being crushed by the boom or mast of the machine. Based on this criteria, and working from a human factors perspective, the team developed a list of possible solutions:

- Perform an overall crewstation redesign with a greater emphasis on operator reach and visibility requirements.
- Provide fixed barriers at pinch points and other dangerous areas.
- Reduce the speed of the fast feed.
- Provide better control guarding.
- Use an interlock device to cut off power to the controls when the operator is out of position.
- Use automatic cutoff switches for pinch points and other dangerous areas.
- Redesign the control bank to conform to accepted ergonomic principles.
- Use resin insertion tools and resin cartridge retainers.
- Use an automatic resin insertion device.
- Reposition personal protective equipment so it is less likely to bump or become tangled in the controls.
- Reduce the likelihood of the drill steel jamming through better maintenance and drill shaft designs.

After further study, several of these solutions were determined to have low technical feasibility or would require an extended time to carry out. For these reasons they were removed from consideration as immediate solutions. The remaining solutions were ranked using the AHP process described previously.

Criteria for Ranking Solutions - The process of ranking the proposed solutions required establishing certain criteria or standards by which the solutions were to be judged. The sections that follow provide information regarding the weight given to various factors in the ranking process. The amount of weight given to the various criteria was obtained through a process of consensus by the project team. Three major categories were considered in rating the proposed solutions: (1) ability of the proposed solution to effectively protect the operator, (2) ability of the solution to be implemented in a timely fashion, and (3) the costs associated with the proposed solution in terms of installation, maintenance, and operating expense. Within each of these categories there were several criterions used to evaluate how well the proposed solutions would achieve these three major goals. Table 3 gives a breakdown of the criteria and the weight given to each in the ranking process.

Protection of the Operator - Protection of the worker received highest priority by the project team. In fact, 65% of the total score for each proposed solution was based on the ability of the solution to protect the worker from being crushed by the boom or mast. The criteria judged most important in terms of operator protection was the ability of the solution to keep the operator out of boom/mast pinch points. If an operator can be effectively removed from a pinch point, it was

reasoned, accidental activation of the controls would not have a catastrophic impact. The ability of the solution to reduce the likelihood of accidental activation of controls was rated as the second most important criteria in terms of protecting the worker. Finally, solutions were evaluated in terms of whether they might reduce or increase the mental or physiological stress (workload), thereby reducing or increasing the likelihood of accidental injury. The latter criteria received least weight.

Category	Criterion	Description
Protection (65%)		Ability of the solution to protect the operator from crushing injuries.
	Pinch points (63%)	Ability of the solution to keep operators out of pinch points.
	Accidental Activation (22%)	Ability of the solution to prevent accidental activation of roof bolter controls.
	Mental/Physiological Workload (15%)	Proposed solution will not lead to accidents or injuries due to increased mental or physiological stress.
Time (21%)		Ability of the solution to be implemented in a timely fashion.
	Hardware setup (67%)	Time necessary for development and installation of the proposed solution.
	Implementation (33%)	Time required for operator to properly learn to use proposed solution.
Cost (14%)		Cost of the solution in terms of installation, maintenance and operation.
	Installation cost (20%)	Installation cost of the proposed solution.
	Maintenance (20%)	Maintenance costs associated with the solution.
	Operational cost (60%)	Operating cost, training cost, and effect on productivity of the proposed solution.

Table 3 - Categories and criteria used to evaluate the proposed solutions.

Time - While the project team felt that the protection of the operator was the most important characteristic of the proposed solution, it also considered the time associated with carrying out the solution an important factor. Obviously, worker exposure to hazardous situations can be greatly reduced if the solution can be implemented quickly. Thus, the time necessary for full implementation of the solution was factored into the ranking process. Full implementation time consisted of both the time necessary for hardware development and setup and the time required for the operator to learn to use the proposed solution once it became operational. The time estimates were based on the knowledge and experience of the project team. This factor accounted for 21% of the total score.

Cost - The cost associated with the solutions was also recognized as an important factor to consider in the evaluation process. As shown in Table 3, the project team considered the costs associated with installation and maintenance, as well as the operational costs of the alternatives. The cost factor comprised 14% of the total score in ranking of the solutions. The costs of the proposed alternative on operating costs (or cycle costs) received the greatest weight in this category (60% of the cost factor), followed by maintenance costs (20%) and installation costs (20%). The cost estimates were based on the knowledge and experience of the project team.

Once the weights of the criteria were developed, the alternative solutions were compared in a pair-wise fashion with respect to only one criterion at a time. For example, two proposed solutions would be compared, considering only how each resolves keeping the operator out of pinch points. The project team decided by what factor one solution outperformed the other according to this criterion. Comparisons continued until all combinations of alternatives were exhausted. Next, the alternatives were compared two at a time with respect to inadvertent actuation of the controls, and so on. Calculations were then made to derive overall priorities for each proposed solution. A relative weight was given to each proposed solution based on the calculations, where the weights of all the alternatives summed to unity. The final ranked solutions are listed in Table 4.

Rank	Solution	Weight
1	Use an interlock device to cut off power to the controls when the operator is out of position	0.239
2	Provide fixed barriers at pinch points and other dangerous areas	0.166
3	Provide better control guarding	0.153
4	Reduce the speed of the fast feed	0.127
5	Use automatic cutoff switches for pinch points and other dangerous areas	0.125
6	Redesign the control bank to conform to accepted ergonomic principles	0.112
7	Use resin insertion tools and resin cartridge retainers	0.077

Table 4 - Solutions ranked using the AHP process.

The next section discusses the ranked solutions of the USBM for reducing the number of accidents caused by the roof bolter operator being crushed by the boom or mast of the machine. Note that any design change made to roof bolters based on these recommendations need to be evaluated to (1) make sure it is effective, and (2) to make sure there are no new hazards created.

DISCUSSION OF SOLUTIONS

In addition to the seven ranked solutions discussed on the following pages, the USBM feels that it is important to increase the miners' awareness of the hazards of roof bolting through additional task specific operator training. Such training needs to be given for each phase of the roof bolting cycle. Should any roof bolters be modified based on the recommendations in this report, the operators need to be retrained to do their jobs on the retrofitted equipment.

Solution 1: Use an interlock device to cut off power to the controls when the operator is out of position

To reduce the risk of the operator being crushed, an interlock device that would prevent the movement of the boom or drill mast when the operator has left the designated operating area should be installed on all roof bolters. An interlock device is a common safety feature used to ensure that an event does not occur inadvertently while a certain condition exists. There are two general categories: those which must be activated in order for motion or action to occur (dead man controls) and those which upon activation will stop motion or action (automatic cutoff switches - discussed later in this report). One form of dead man interlock that may effectively prevent the operator from accidentally engaging the fast feed lever is a two-handed control mechanism. Requiring a two-handed fast feed would also help to keep the operator within the

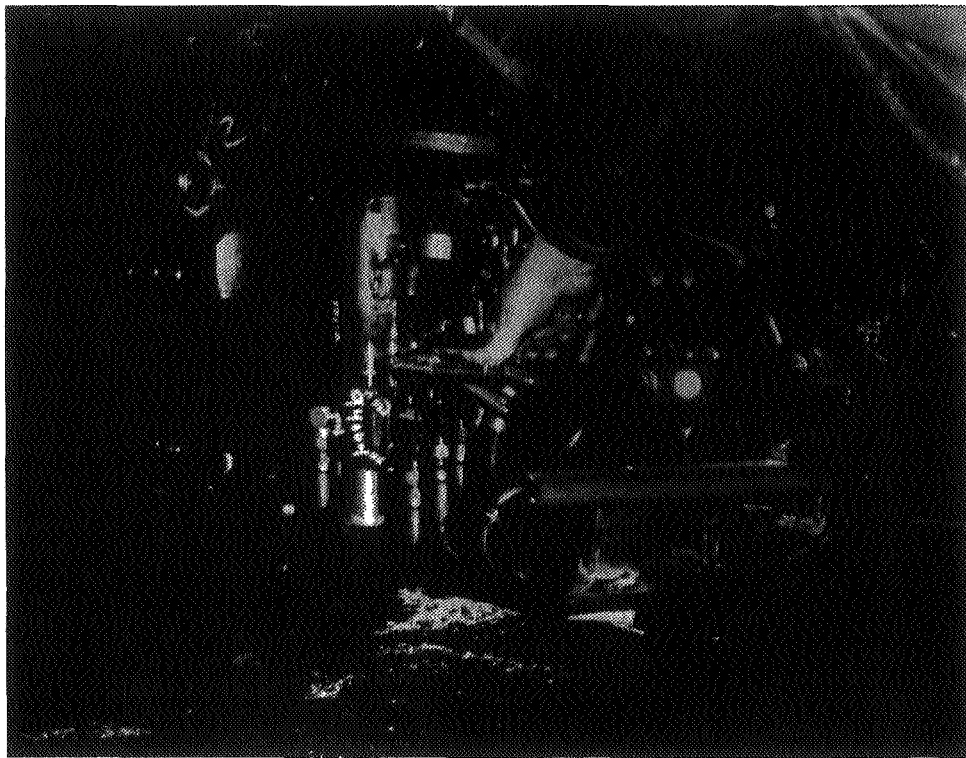


Figure 1 - Positioning the dead man switch too close to the fast feed lever allows the operator to activate both with only one hand.

safe work area and away from the drill boom while it is in motion. Careful consideration must go into the design and use of this system to ensure that the two-handed control cannot be overridden casually by the operator (figure 1). This may include disabling other drill functions, such as drill rotation, while the fast feed is engaged. Also, there must be confirmation that the operator still can complete the required tasks effectively while using both hands for the fast feed. (Note: An official from J. H. Fletcher and Co. has stated that all their new machines will use a two-handed fast feed and that retrofit kits will be available for machines already in use.)

Setting up a general dead man to control the drill head motion functions would be another way to ensure that the operator is within a designated safe area when operating the roof bolter. Possible devices include a foot pedal, a weight-sensitive platform, or a rail to which the operator must apply light pressure to activate the motion functions of the machine. Again, care must be taken in designing a dead man device to ensure that no new hazards are introduced and that the operator can still effectively perform the job.. One item that must be addressed is ensuring that the device will not fatigue the operator because of any awkward body position required to keep the dead man switch engaged.

Solution 2: Fixed barriers at pinch points and other dangerous areas

By their nature, roof bolters have many moving parts that create many pinch points. (Note: all pinch points on the machine should be marked with reflective warning labels. The labels need to be cleaned regularly so they are always visible.) A possibly very effective and inexpensive way to protect the operator from being caught in one of these pinch points is to place a stationary obstruction between the worker and the hazard (figure 2). The design of these fixed barriers must be thought out carefully so that the operators do not expose themselves to other hazards while attempting to work around the barrier. The barriers must be difficult for the operator to circumvent, i.e., fasteners for the fixed barriers should be of a type not easily removed, and the barriers themselves should be made as rugged as possible. The barrier should not cause the operator to assume awkward postures, and it should not further restrict visibility. Finally, it should not force the operator into another pinch point area to perform the task.

Solution 3: Provide better control guarding

A simple and inexpensive way to help prevent the inadvertent activation of a control is to provide better control guarding. A guard is a barrier that prevents any part of the body from inadvertently entering the control area. For roof bolters, it should also prevent falls of the roof or rib or other objects (tools, drill steels, resin boxes, etc.) from activating a control (figure 3). A well designed control guard for roof bolters must have certain characteristics. First, it must impose no new restrictions, discomforts, or difficulties for the worker. It must automatically move into or be fixed in place. If adjustable, it must not move out of alignment easily. It should be designed specifically for the machine, the type of operations to be conducted, and the hazards which are present. It should in no way restrict the access to emergency shut-offs. Finally, it should be easy to inspect and maintain.

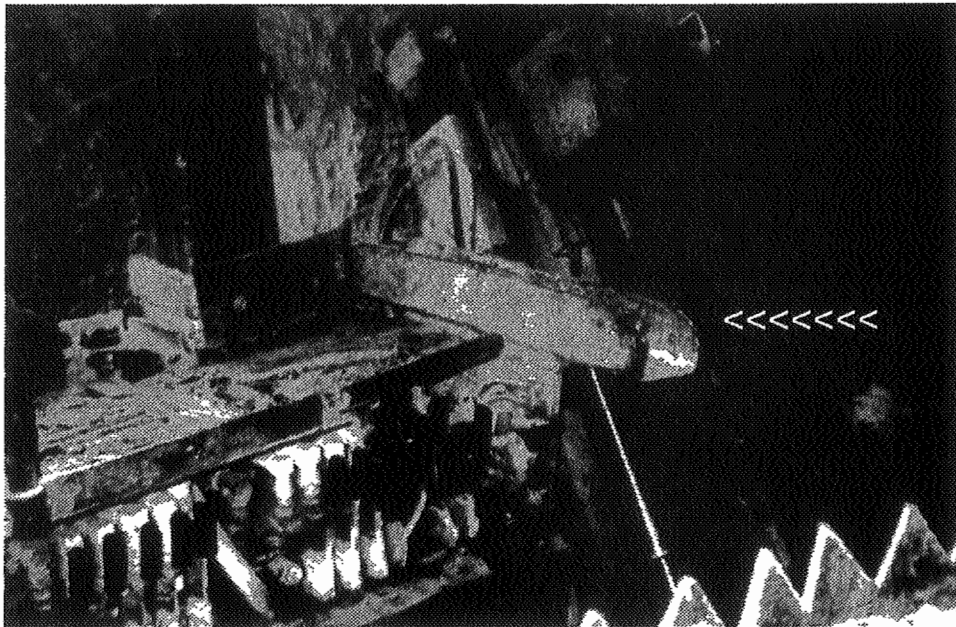


Figure 2 - The heavy steel tool tray welded onto this HDDR bolter by mine personnel provides a fixed barrier to the mast pinch point.

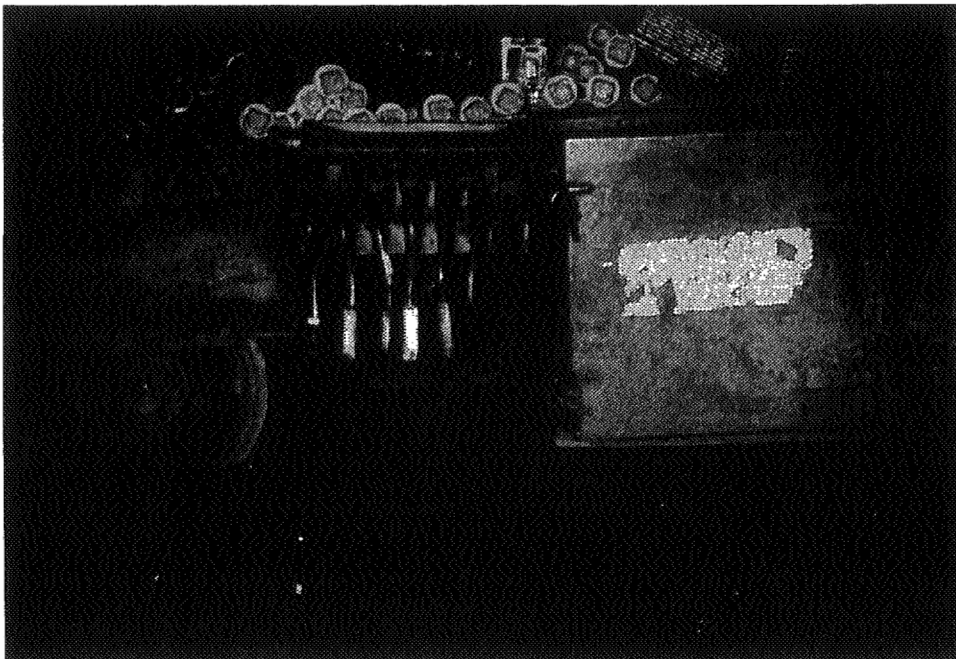


Figure 3 - Unguarded controls are more likely to be activated by roof or rib falls.

Solution 4: Reduce the speed of the fast feed

The fast feed is a feature that bolter operators use primarily when installing resin bolts to prevent the resin from setting up before the bolt has been completely inserted into the hole. However, many roof bolter operators speed up the bolting process by using it to lower the boom quickly when extracting drill steels and after installing the bolt.

Figure 4 compares the fast and slow feed speeds for roof bolters from an unpublished informal survey conducted in West Virginia. The chart shows a wide variation in fast feed speeds, with some roof bolter models having no fast feed feature at all.

When the necessary time for operators to remove themselves from boom or mast pinch points is considered, these fast feed speeds may be excessive, particularly in low seam heights where there is less room to maneuver. Unfortunately, it is difficult to determine what is a safe fast feed speed. It depends on many variables, such as the machine configuration, the operator's work space, and the ability of the operator to react in an emergency situation.

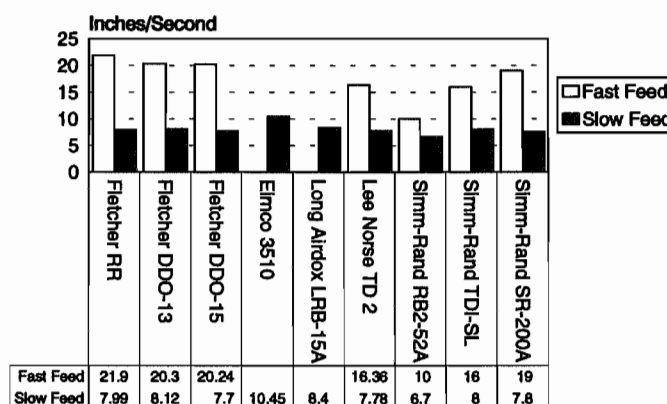


Figure 4 - Average fast and slow feed speeds for roof bolters. Source: MSHA Roof-Bolting Machine Committee

Until further research can be done to determine "safe" fast feed speeds, or other measures are taken to insure that roof bolter operators cannot become pinched by the boom or mast of the roof bolter, it would be prudent to limit the fast feed speed on roof bolters. Since the slow feed speed is limited by factors related to bit life and the hardness of the overhead strata, it may be reasonable to limit the fast feed speed to some multiple of the slow feed speed. As an example, table 5 illustrates the effect of limiting the fast feed speed to two times the slow feed speed. Another alternative would be for individual mines to do their own time studies to determine the impact of lowering the fast feed speed and using a slower acting resin on their productivity.

Note: This solution does nothing to keep the operator out of the pinch points created by the boom or mast, or prevent the inadvertent actuation of controls. However, it may increase their chances of escaping a hazard once they become aware of it.

Roof Bolter	Current Fast Feed	Current Slow Feed	New Fast Feed Limits	% Diff.
Fletcher RR	21.90	7.99	15.98	-27.03
Fletcher DDO-13	20.30	8.12	16.24	-20.00
Fletcher DDO-15	20.24	7.70	15.40	-23.91
Eimco 3510	N/A	10.45	N/A	N/A
Long Airdox LRB-15A	N/A	8.40	N/A	N/A
Lee Norse TD 2	16.36	7.78	15.56	-4.89
Simm-Rand RB2-52A	10.00	6.70	13.40	34.00
Simm-Rand TDI-SL	16.00	8.00	16.00	0.00
Simm-Rand SR-200A	19.00	7.60	15.20	-20.00
Average	17.69	8.08	15.40	-12.94

Table 5 - The effects of limiting the fast feed speed on roof bolters to two times the slow feed speed.

Solution 5: Use automatic cutoff switches for pinch points and dangerous areas

An automatic cutoff switch is another form of the interlock devices discussed earlier. In contrast to the dead man control, the automatic cutoff will stop motion or action only upon its activation.

Two recent fatal accidents involving roof bolting machines occurred on the Fletcher HDDR "Walk-Through" model. In these accidents, the operators placed themselves over the mast in an attempt to retrieve a drill steel that had become jammed in the rib. While in this position, the fast feed lever on the control bank was apparently activated, causing the drill pod to raise. They were crushed between the advancing drill pod and the frame of the machine. Because of these accidents, Fletcher has designed an automatic cutoff switch for the HDDR roof bolter. It consists of a bar extending the entire length of the control bank and through to the pinch point between the drill head mast and the machine frame. If the operator leans on the bar it immediately deactivates the hydraulic controls, stopping all motion of the drill head (figure 5).

Installing such an automatic cutoff is a relatively simple task on the HDDR roof bolter due to the straightforward design of its operator station. Unfortunately, other roof bolting machines, such

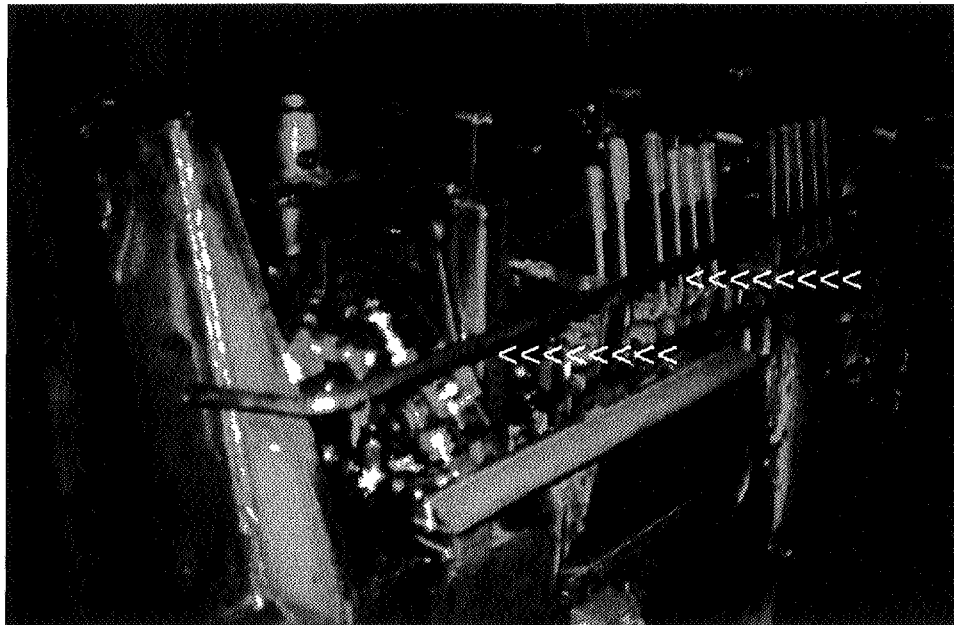


Figure 5 - Automatic cutoff switch for the HDDR roof bolter.

as the Fletcher Roof Ranger, do not have fixed operator platforms. These machines typically have the drill head mounted on the end of a boom that raises and lowers. With no convenient locations to mount a cutoff switch, the feasibility of applying this solution to these types of machines is questionable. A significant human factors and mechanical design effort would be necessary to develop mechanical cutoff switches for boom style machines. Some issues that would need to be considered include making sure the switch is fail safe, designing the switch to minimize inadvertent activations (otherwise, the operator may disable it), and insuring that the switch does not interfere with other controls.

One idea for an automatic cutoff that may warrant further research is to place infrared sender and receiver proximity switches along the drill boom. These switches would be set up to disable the boom raise whenever the beam was broken. An infrared switch consists of two parts: a sender unit and a receiver unit. The sender unit sends out a beam of infrared light. The receiver unit "sees" this beam and sends out a signal accordingly. The signal would be used to control the hydraulic oil reaching the boom raise cylinder. If any part of the operator's body would come close to the boom and break the infrared beam (while installing resin, retrieving a stuck drill steel, etc.), the boom would not move even if the controls were activated.

Of course, this equipment would have to be rugged and capable of surviving in the underground environment. Furthermore, all electronics would have to be intrinsically safe and MSHA approved. Thus, setting up of this system may best be completed at the manufacturing level, rather than retrofitted in the field.

Solution 6: Redesign the control bank to conform to accepted ergonomic principles

There has been a significant amount of research done on the design of controls for mobile equipment^{6,7,8}, and at least one study that looked specifically at the design of controls for roof bolters³. Some general findings from that previous work that applies to controls at the drilling station are listed below:

- Controls should be coded according to their sequence, location and shape (figures 6 and 7). They should be labeled. Coding according to color is not considered practical in the underground mine environment.
- Whether it is correct to mirror image controls for dual boom bolters (figure 8) is still being debated. One study reports that either mirror image or place arrangement is acceptable. However, another study suggests that when the operator on the left side operates the controls with the right hand, and the operator on the right side uses the left hand, the mirror image arrangement decreases the time the operator needs to adjust to a switch in sides.
- The direction of control movement should be according to control movement stereotypes (table 6).
- Where practical, the number of controls should be reduced by combining control functions into one control. (Fletcher now offers a Joystick control option on its Roof Ranger model that combines drill rotation with drill feed).
- Optimum control pressure is approximately 10-15 lbs. for controls operated with full arm motion and the hand.

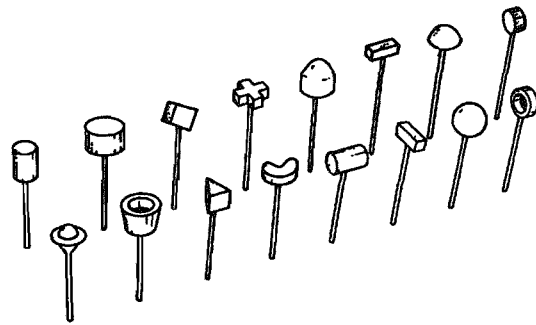


Figure 6 - Knob shapes that can be recognized by touch by operators who wear gloves³.

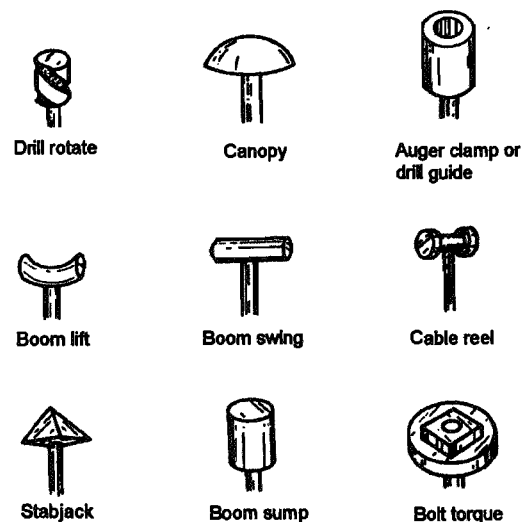


Figure 7 - Suggested knob shapes for roof bolters that relate to the function being controlled³.

- For controls operated with the forearm and hand only, the minimum resistance is 5 lbs, and for hand operated controls the minimum resistance is 2 lbs.

In addition to the above, control layouts for the same model of roof bolting machine should be identical on a per mine basis to avoid problems related to adjusting to different control layouts.

Another important aspect of control design is maintenance and maintainability. Sloppy control linkages have been implicated in many injuries and several fatalities. Control linkages should be inspected before every shift, and loose or broken linkages should be repaired immediately. Controls should be designed to allow easy visual inspection and should use components that can withstand the mine environment. The bibliography at the end of this report contains many references related to control design. Finally, should any roof bolters controls be modified based on the recommendations in this report, the operators need to be retrained on the retrofitted equipment.

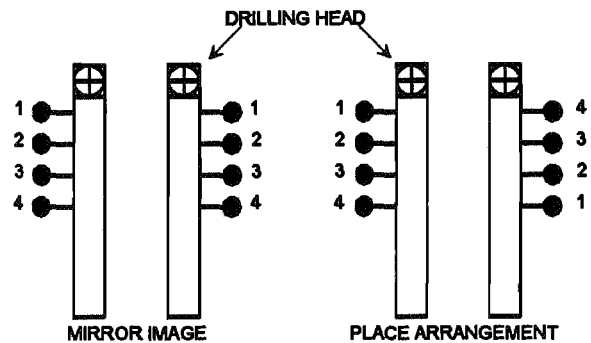


Figure 8 - Two dual boom bolter layouts illustrating Mirror Image and Place Arrangement of controls³.

Function	Direction of Movement
On	Up, Right, Forward, Clockwise, Pull
Off	Down, Left, Rearward, Counterclockwise, Push
Right	Clockwise, Right
Left	Counterclockwise, Left
Raise	Up, Back
Lower	Down, Forward
Retract	Up, Rearward, Pull
Extend	Down, Forward, Push
Increase	Forward, Up, Right, Clockwise
Decrease	Rearward, Down, Left, Counterclockwise

Table 6 - Typical control movement stereotypes¹¹.

Solution 7: Use resin insertion tools and resin cartridge retainers

Operators of both boom and mast type roof bolters have indicated difficulty installing resin cartridge(s) into the hole, particularly in higher seams. Consequently, they are compelled to climb out onto the mast or boom to reach the hole. There have also been instances of operators riding the boom up to the roof to install resin.

The use of resin insertion tools is one alternative for reducing the tendency of bolter operators to position themselves in hazardous locations or to perform unsafe acts. During this effort, the USBM learned of two insertion tools. One, a resin and bolt insertion device, was designed by the Birmingham Bolt Company for use in truss bolting with expansion-shell type bolts (figure 9). It consists of a variable length PVC pipe with a slot cut through its entire length. The pipe's inside diameter is determined by the diameter of the expansion-shell. The slot width is determined by the diameter of the bolt being used. The pipe is snug fit over the expansion shell and holds the resin while it is inserted into the pre-drilled hole. The bolt then acts as a plunger, forcing the resin into the hole. When the expansion shell enters the hole, the PVC pipe section drops off so it can be recovered and reused.

The other insertion tool was designed by J. H. Fletcher & Company (figure 10). It consists of a variable-length (3-10 feet) PVC pipe with a slot cut in it that allows a hinged handle (used as a plunger) to push a tube(s) of resin into a pre-drilled bolt hole.

Any resin insertion device like those mentioned above must be inexpensive so it will be practical to have it available at the section. They must also be easy to use and provide a definite advantage over climbing out onto the mast or boom to reach the hole.

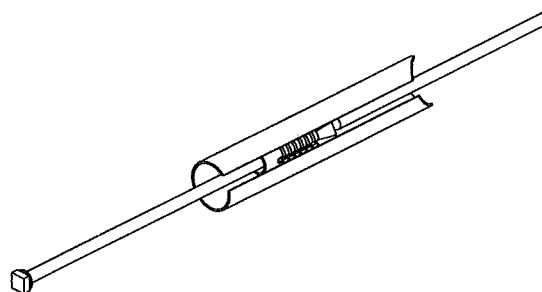


Figure 9 - Resin and bolt inserter by Birmingham Bolt Company.

Regarding in-hole retaining devices for tubes of resin, the USBM has learned of two that are available from resin manufacturers - the "clip" and the "parachute" (figure 11). The clip (made by Celtite) is a .94 inch square piece of plastic, .08 inch thick, with a .83 inch hole in the middle. The (daisy) parachute made by DuPont resembles a badminton cock; it is 2.04 inches long and 1.1 inches in diameter. Both are used almost exclusively in non-coal mining, particularly hard rock mining in Canada. The parachute is designed specifically for the pneumatic, semi-automatic insertion feature of Eimco-Secoma bolting machines. The clips and parachutes come pre-assembled on the resin cartridges, although the manufacturer will provide them separately if the

customer desires. The extra cost of using the clips and parachutes is approximately 15% and 20-25 % of the cost of the resin, respectively.

Ultimately, the hazards associated with resin insertion are best handled by eliminating the task altogether. Although there are now no known fully automatic methods of resin insertion, semiautomatic insertion methods do exist. Two are made by Fletcher and Eimco-Secoma for roof bolters used predominantly in non-coal, hard rock mining operations. With the Eimco-Secoma machine, the bolter operator feeds tubes of resin into an injection hose from the operator compartment to the pre-drilled hole by compressed air. The Fletcher roof bolters, also described as "roof-referenced double-extending mast machines," are being used by mines in the northern West Virginia-Maryland area. These machines insert resin tubes semiautomatically and remotely using a mechanical mechanism. A basic requirement of using these machines, however, is sufficient working height. (Note: The Fletcher machine uses a resin retainer that resembles the plastic cap commonly used to protect the ends of pipe. Fletcher says these are relatively inexpensive, e.g., several thousand for under a \$100. The retainers are assembled by the bolter operator, not by the resin manufacturer.)

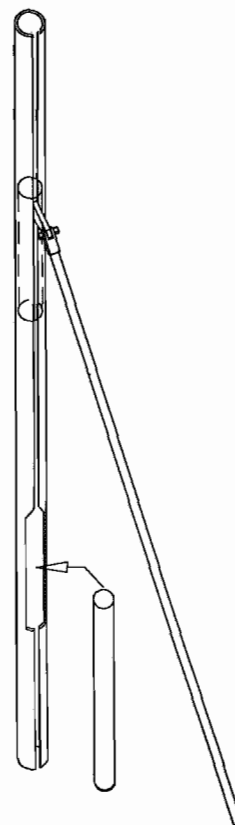


Figure 10 - Resin insertion assist from J. H. Fletcher & Co.

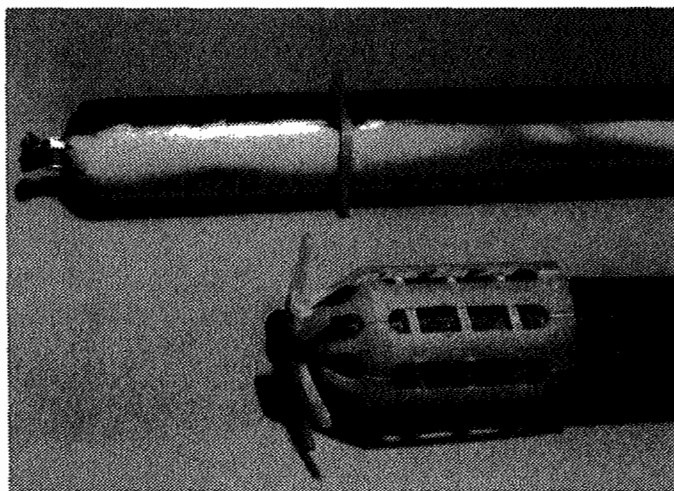


Figure 11 - Resin retaining devices: clip (top) and parachute.

Additional Solutions

The following unranked solutions would require considerable additional research to develop and are not considered immediate answers to the problems of roof bolter safety. However, evidence indicates that the ideas discussed below have great potential to increase the general safety of the roof bolting operation.

Perform an overall crewstation redesign with a greater emphasis on operator reach and visibility requirements

Based on the mine and manufacturer visits, it appears that many of the crewstations for roof bolters have been designed with production considerations foremost. The operators' needs have been met only after the basic layout of the machine has been completed. Thus, the operator has to lean over the control panel to retrieve a drill steel, or position himself or herself over the boom to insert a drill steel.

The best solution to this problem is to perform a thorough analysis of the roof bolting task to determine the true needs of the operator so they can complete the task safely and efficiently. Some factors that need further study (through literature reviews, laboratory experimentation or task analysis) include:

- | | |
|-------------------------------|--|
| Visibility and illumination - | What does the roof bolter operator need to see (drill head, hole, controls) and in what detail? |
| Noise and communication - | Who does the operator need to communicate with while bolting (other bolters), and what information must be transferred? |
| Postural analysis - | What postures are best for a given seam height and work load (sitting, kneeling, prone)? |
| Reach accommodation - | What controls need to be handled and at what frequency, what tools need to be handled, what needs to be reached from the crewstation (mine roof, rib) to perform the task? |

Once there is a thorough understanding of the task and the operator needs, it is possible to begin to design a crewstation and machine that meet those requirements. It is likely that many of the more hazardous operator requirements can be designed out of the system once the engineers have a better understanding of what their machine needs to do. For instance, design engineers have to understand the potential hazards associated with removing a jammed drill steel. They need to consider the force required to remove the steel, the frequency of its occurring, and the tendency for operators to take the easiest path to the steel (over the controls).

Reposition personal protective equipment so it is less likely to bump or become tangled in the controls

In tight quarters, personal protective equipment is more likely to bump or become tangled in the roof bolter controls, possibly causing an inadvertent activation. One solution is to provide designated areas on the bolter for storing the operator's Person Wearable Self Contained Self Rescuer (PWSCSR) so that it need not be carried at all times. This could be expedited by using a carrying harness that simplifies attaching and detaching the PWSCSR to the miner's belt. The storage area would have to be designed to provide quick and easy access to the PWSCSR. Another alternative is to develop a carrying harness that positions the PWSCSR so that it no longer interferes with roof bolter controls.

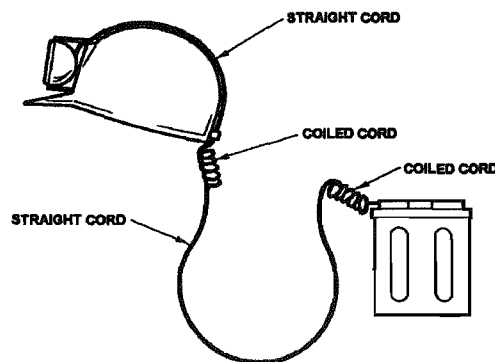


Figure 12 - USBM Coiled Cap Lamp Cord concept.

A possibility for reducing the chances that a control will be activated if it is snagged by the cap lamp cord is to use the coiled cord concept² developed by the USBM (figure 12). A more extreme idea (that would require further study) would be to improve the lighting systems on bolters (spot and area lighting) so that personal cap lamps are not necessary for bolter operation. Designated areas would be provided on the bolter for storing a cap lamp so the operator need not carry it at all times. As with the PWSCSR, a carrying harness that simplifies attaching the lamp battery pack to the miners' belt would be a possibility.

Miners today still wear a wide range of outer garments, ranging from old street clothes to expensive coveralls, that have not been tailored to the mine environment or mining tasks. Few mines regulate the work clothes worn by their miners beyond requiring a snug fit around the ankles. In one of the most hazardous work environments known, a miner may be permitted at the work site in blue jeans and a T-shirt. There appears to be less effort spent on the development of protective clothing for miners than for nearly any recreational sports activity. Perhaps bolter operators need clothing that minimizes the chance of snagging a control, such as tighter fitting coveralls or jackets.

Also related to personal protective equipment, lower seam roof bolter operators spend a large percentage of their time on their knees. In high production sections (extended cut), where there is pressure for the bolter to keep pace with the continuous miner, roof bolter operators have less opportunity to stretch and rest their legs. There is some anecdotal evidence that one of the major problems for lower seam bolter operators is damage to the knees (there were 64 accidents involving roof bolter operators injuring their knees in 1993). Uncomfortable postures may lead

some operators to assume positions that relieve the pain in their legs but expose them to pinch point hazards.

Due to the need to reach bolts and tools, insert resin, and adjust the position of the machine, it may be impractical to construct a crewstation that allows the operator to sit while bolting in low seams. However, it should be possible to provide bolter operators with knee pads that take advantage of new cushioning materials that are more suited to the bolting task. Also, an adaptation of a device used by carpet layers (a combination knee pad/stool) may work in low seam mines.

Reduce the likelihood of the drill steel jamming through better maintenance and drill shaft designs.

During drilling operations, drill steels can become caught in the hole. There are many reasons why this could happen: the bolter operator may not be drilling a straight hole, the strata could be moving and could bind the drill steel, there could be water that could cause dust clogging, or the dust vacuum is inadequate. In any event, the bolter operator must retrieve the drill steels, often forcing the operator to get in a position considered unsafe (such as crawling out onto the boom, reaching or leaning out beyond the protective canopy) to retrieve the steel.

Initial misalignment is probably the main reason drill steels are difficult to retract. Using a deep chuck and drill guide may help improve the initial alignment. Unfortunately, drill guides are in a vulnerable location and are high maintenance items. Since they are not critical to the drilling cycle, they are often not repaired when damaged. A disadvantage of using deep chucks is that, unless the initial alignment is correct (difficult to do unless the floor is horizontal), the steel will bind in the hole unless the roof bolter is repositioned³ (figure 13).

One possible solution investigated was to make the drill steel shaft smaller than the bit. This would cause the hole to be slightly larger than the shaft, making it less likely to jam. However, after checking with several ground control experts, it was decided that this solution is limited by current technology. The smallest diameter of drill steel needed to maintain strength is approximately 7/8 inch. For a one inch hole, this is the smallest diameter for the drill steel.

Better maintenance procedures may reduce the jamming problem. If the dust bins and filters are not cleaned out regularly, there may be a decrease in the suction power. The maximum vacuum can be maintained if the dust bins and filters are checked and cleaned

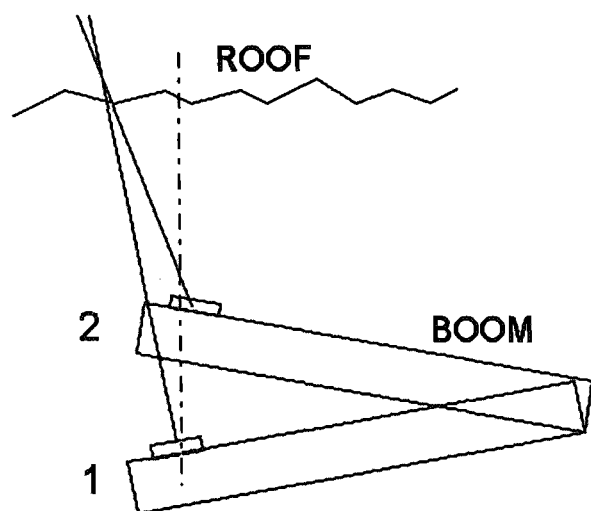


Figure 13 - The misalignment increases when the boom goes from position 1 to position 2 unless the roof bolter is moved forward³.

regularly as part of the normal pre-shift inspection. Suction hoses also need to be inspected regularly for cuts and excessive wear. Switching to water dust suppression systems may help to eliminate the dust clogging. Unfortunately, water drilling is messy and many roof bolter operators do not like it.

RECOMMENDATIONS

The implementation of the following recommendations could significantly reduce roof bolting related injuries.

1. Implement as many of the following ranked solutions as possible. Those at the top of the list have a higher potential to reduce the chances that a roof bolter operator will be crushed by the boom or mast. After any modifications are made to the roof bolting equipment the operators must be retrained to do their jobs on the retrofitted equipment.
 1. Use an interlock device to cut off power to the controls when the operator is out of position.
 2. Provide fixed barriers at pinch points and other dangerous areas.
 3. Provide better control guarding.
 4. Reduce the speed of the fast feed.
 5. Use automatic cutoff switches for pinch points and other dangerous areas.
 6. Redesign the control bank to conform to accepted ergonomic principles.
 7. Use resin insertion tools and resin cartridge retainers.
2. Increase the miners' awareness of the hazards of roof bolting through additional task specific operator training.
3. Perform a study to determine the maximum safe speed for equipment appendages (booms, conveyors, stab jacks, etc.) in the underground workplace.
4. Perform a study on the possibilities for positioning or redesigning personal protective equipment so that it is less likely to bump or become tangled in the controls.

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A Bureau of Mines contract phase report that makes recommendations for the modification of controls on roof bolters using human engineering principles to increase safety and efficiency. The report also analyzes roof bolter accident data, looks at the deficiencies in the design of roof bolters and roof bolter controls, and reviews human factors criteria for control design.

4. Research Support for the Development of Guidelines for Underground Operator Compartments, Final Report, August 1990, USBM Contract H0308110.

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