

CRITERIA FOR APPROVAL OF MINING EQUIPMENT INCORPORATING

ON-BOARD SWITCHING OF HIGH-VOLTAGE CIRCUITS

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Abstract - The mining industry's need for higher horsepower and the improvement in the design and manufacturing technology of high-voltage components have prompted the Mine Safety and Health Administration (MSHA) to develop criteria to modify the current regulation prohibiting on-board switching of high-voltage circuits (greater than 1000 volts a.c.). Extensive research conducted by the U.S. Bureau of Mines (USBM) and MSHA provided the basis for the development of a safe and viable criteria. Under the provisions of Title 30 Code of Federal Regulations, (30 CFR) Section 18.82, experimental permits were issued to high-voltage continuous miners and longwall systems incorporating this new technology. The information gathered from the operation of this equipment in the field along with industry concerns and recommendations were considered during the finalization of this criteria.

1. INTRODUCTION

Electrical equipment in the mines has increased in horsepower through the years. To design practical and efficient equipment, the voltages required to operate this equipment have also increased. Permissible electrical equipment operating in United States' mines must be designed to meet the requirements of 30 CFR Part 18. Until the development of this criteria, machines or systems incorporating on-board high-voltage switching were not issued an approval. The manufacturer would either design the equipment so all high-voltage switching was done remotely (outby) in fresh air or would apply for an experimental permit to temporarily use the equipment at the face. The applicable regulation was 30 CFR, 18.47(d)(3) which requires remote switching when the machine nameplate voltage exceeded 1000 volts. However, marked

improvement in the design and manufacturing technology of vacuum contractors has enabled MSHA to apply 30 CFR, 18.47(d)(6) which allows modification of the requirements to recognize improved technology.

In 1974, Eastern Associated Coal Company requested approval of a tunnel boring machine incorporating a 7200/480 volt transformer. At that time, MSHA (MESA) was concerned that the explosion-proof enclosure housing the transformer would not withstand the internal pressure generated by a short circuit phase-to-phase fault.

In 1975, tests were conducted on the enclosure at the Westinghouse High Power Laboratory. The tests were designed to determine if the enclosure would maintain its integrity during a short circuit fault. During one of the tests, the fault current ranged between 6250 to 8000 amperes (peak to peak) for 14-1/2 cycles. The enclosure lid sustained a permanent distortion of approximately three inches and fire was observed coming from the joint between the lid and the case. Testing was repeated with a new enclosure lid and a fault current of 5500 to 7500 amperes (peak to peak) was applied for 31-1/2 cycles. Five bolts on a side cover plate broke and the plate remained warped.

In 1976, a redesigned transformer enclosure was tested at the Westinghouse High Power Laboratory. Current-limiting fuses were used in an attempt to limit the energy in the transformer enclosure during a fault. The tests were designed to determine if the enclosure would contain a short circuit fault with the fuses incorporated. The enclosure contained the fault with no detectable distortion.

After successful completion of further tests, the company was issued a permit incorporating conditions of use, one of which required current-limiting fuses in each phase.

Several years later the Department of Energy issued a contract to evaluate high-voltage permissible loadcenters. Later the responsibility of the research was transferred to the USBM. There were four major phases of the program: 1) a comprehensive industry survey, literature search and state-of-the-art review; 2) development of a high energy arc testing program;

- 3) development of a recommended permissible load-center approval criteria; and
- 4) design, construction and testing of a high-voltage permissible loadcenter.

Foster-Miller, incorporated, was contracted by USBM to perform the necessary research. A test program was conducted to evaluate the pressure rise caused by a high-energy fault with and without a simultaneous methane-air explosion inside an enclosure. Foster-Miller developed a recommended set of criteria for approval of high-voltage permissible loadcenters. A loadcenter was designed according to the criteria. Brush Transformers, LTD, of the United Kingdom manufactured the loadcenter.

MSHA was also responsible for several areas in the development of the permissible loadcenters. These areas consisted of: 1) providing technical reviews and evaluating the Foster-Miller criteria; 2) designing and constructing a mobile facility for testing permissible loadcenters; and 3) testing and approving the loadcenter in accordance with the Foster-Miller criteria.

MSHA concluded that several refinements were needed to the recommended approval criteria. MSHA also decided that the criteria should be expanded to include design and testing requirements used in evaluating equipment that contain on-board high-voltage switchgear. The work carried out in these contracts lasted from about 1980 to 1986.

Near the completion of this research, MSHA evaluated equipment incorporating on-board switching of high-voltage circuits. Based on the completed research and the use of vacuum contractors, this equipment was granted experimental permits under 30 CFR, Section 18.82 for an initial period of 6 months.

The first MSHA experimental permit for high-voltage on-board switching was granted for a 2400 volt longwall system at the Jim Walter Resources No. 7 Mine on July 17, 1985. Since then, ten other 2400 volt longwall systems and two 4160 volt continuous (boring) miners have received permits enabling operation of on-board switching. The longwall systems are located in coal mines; the continuous miners are in trona mines.

## II. CRITERIA DEVELOPMENT

Based on industry's need for higher motor voltages to design machines that would provide safe, efficient and dependable operation, MSHA initiated development of an approval criteria for high-voltage equipment incorporating on-board switching of high-voltage circuitry.

The development of the criteria (see Appendix 1) was based on input from the following: 1) Foster-Miller research on the development of a high-voltage permissible loadcenter under USBM contract No. H0308093; 2) MSHA research on the development of recommended criteria and test facilities for acceptance of high-voltage permissible loadcenters and switchgear enclosures under USBM contract No. J0333909; 3) follow-up inspections on five high-voltage machines and systems operating under experimental permits; 4) MSHA internal research and engineering reports relating to explosion-proof enclosures which contain high-voltage switching; and 5) comments and input obtained from the mining community.

The main concerns can be summarized into five areas: 1) prevention of a high-voltage arc from occurring; 2) prevention of the resulting heat or flame from igniting a methane-air mixture surrounding the machine, if an arc and/or methane explosion occurred; 3) prevention of enclosure failure from an increased pressure rise, if an arc and/or methane explosion occurred within the explosion-proof enclosure; 4) prevention of pressure piling within the enclosure; and 5) personnel protection for miners working in or around the high-voltage equipment. The developed criteria addressed these concerns as discussed in the following section.

### A. Prevention of Internal High-Voltage Arcing

Machine design can have a direct impact on the possibility of arcing. The major areas that relate to arcing are: 1) electrical clearances for uninsulated conductors, 2) creepage distances, 3) control transformer construction, 4) corona protection, and 5) sealed switching.

The clearances developed for the approval criteria address possible exposure of conducting surfaces to an ionized flame front resulting from a methane/air ignition in an enclosure, as well as accounting for the effects of switching transients, altitude, and ambient air temperatures. The criteria was based on MSHA technical reports regarding adequate electrical clearance, experimental work at the Canadian Explosive Atmospheres Laboratory [1] and the USBM [2], and the Foster-Miller contract final report. A concept related to electrical clearances is creepage distances which were considered because of the environmental conditions in mines. These distances were evaluated taking into account the susceptibility of tracking between terminals on contaminated, moisture laden surfaces. The resistance of an insulator to develop arc tracks is measured by its comparative tracking index (CTI) value. The CTI value is that voltage which occurs during failure by tracking when the number of drops of a standard contaminant dropped onto the insulating material reaches 50 [3]. A safeguard against tracking is the use of an insulator whose CTI is adequate for the existing pollution conditions while setting the creepage distance for the CTI value.

Another engineering study dealt with control transformers. On a high-voltage machine, a control transformer is used to convert high-voltage to control voltage ( $\leq 120$  volts). On these transformers, transient voltages can be transmitted through the transformer's primary-to-secondary capacitance, where the transmission ratio value could be approximately unity. The study determined that this problem could be minimized by assuring that the ratio between the secondary-to-ground capacitance and the primary-to-secondary capacitance is large [ $\geq 10$ ] or that the transformer is equipped with electrostatic (faraday) shielding.

One danger inherent with high-voltage equipment is that excessive electrical stress can cause premature breakdown of insulating materials. It was determined that corona does not present a problem on 2400 volt systems, but may effect 4160 volt systems. Adequately and properly prepared corona protection minimizes the stresses placed on insulation and acts to reduce stress related insulation failures. The corona requirement was based on Foster-Miller's recommendations .

High-voltage load switching devices must preclude exposure of arcs to the atmosphere surrounding the switch assembly. This has been accomplished by using vacuum contractors. The arcing current produced by the making and breaking of contacts under load is contained in a vacuum bottle (one bottle per phase) and cannot ignite methane that may be present inside an explosion proof enclosure.

B. Prevention of Ignition of Methane Surrounding the Machine

Protective measures to prevent the heat or flame from an arc and/or methane explosion in an explosion-proof enclosure from igniting a methane-air mixture surrounding a machine would include minimum free distances and designs to prevent ignitions by expelled particles. An MSHA technical investigation determined that, if phase-to-phase arcing occurred, there may "be adequate arc energy to heat the walls of the enclosure beyond the safe working temperature. Distances between the wall/cover of an enclosure and bare electrical conductors inside the enclosure were established to prevent wall/cover damage due to phase-to-phase arcing.

When a short circuit occurs between two electrodes, particles of the conductor material (usually copper) are "thrown" into the surrounding area. If a short circuit in an explosion-proof enclosure is accompanied by a pressure rise, some of these particles may be expelled through the flange gap and, if an explosive atmosphere is present, cause an ignition [4]. Based on work done in conjunction with the Foster-Miller contract, a solution to this would be to not locate conductors in the same plane as the flange flame-path. This would not be necessary on a step (combination), labyrinth, or threaded type flame-path fit.

c. Prevention of Exceeding Enclosure Design Pressure

Foster-Miller conducted high-energy arc testing to assess the hazards of pressure increase caused by a high-energy arcing fault, with and without a simultaneous methane-air explosion. Depending on parameters (arc

characteristics, fault location, available energy, enclosure volume, presence of methane, etc.), it would be possible to exceed the 150 psig design pressure of a standard explosion-proof enclosure if a fault occurred. Therefore, the criteria requires a means of safely limiting the pressure rise within the enclosure to .83 times the enclosure design pressure. The high-voltage equipment which is presently operating under experimental permits use fast acting circuit protective devices which would clear a high-voltage arc before a significant pressure developed due to the arc. An MSHA technical investigation has resulted in a method for safeguarding against high-energy arcing faults using the trailing cable electrical protective device. This is one acceptable means of safely limiting the pressure rise within an enclosure. Other protective methods can be accepted by MSHA provided they demonstrate an equally high level of safety.

MSHA is concerned about the specified design pressure of an enclosure. Presently, an enclosure that is designed for 150 psig is tested with a methane/air explosion. Normally, these pressures do not exceed 100 psi. Since the protective method to prevent overpressurization is directly related to the design pressure, MSHA wants to insure each enclosure design is capable of withstanding its design pressure. Therefore, static pressure testing on each enclosure prototype is required.

Dynamic pressure testing is also required. In addition to the standard explosion tests of 30 CFR Part 18, tests in methane/air ignited by guncotton are required on enclosures accepted on the basis of a design pressure greater than 150 psi.

Another concern leading to overpressurization can be the decomposition of insulating materials due to tracking. Tracking can allow a low level, normally undetectable current to flow in and across the surface layer of the insulator. This current can produce heat and possibly gas which may jointly over-pressurize the enclosure. As previously discussed, using insulators with an adequate CTI rating can prevent tracking.



l). Prevention of Pressure Piling

Pressure piling is a complex phenomenon that can occur when gas in a portion of an explosion-proof enclosure is compressed before being ignited. The resulting pressure rise may be much greater than would normally be expected from a methane/air ignition. Subdividing enclosures into compartments connected by narrow passages, either intentionally or inadvertently by component placement, can result in pressure piling and must be avoided as required by 30 CFR Part 18.

E. Personnel Protection

There is a need for additional safety requirements for the high-voltage equipment. Barriers or partitions between the high-voltage and low-voltage circuits must be provided to prevent accidental contact. Cover interlock switches to automatically de-energize any enclosure containing high-voltage uninsulated conductors must be provided. Switches of the plunger or shaft operated type are required to have two per cover minimum. This requirement is a result of the follow-up inspections performed on the high-voltage equipment operating under experimental permits which revealed sticking cover interlock switches on three of the five machines inspected. Visible main disconnects are required on-board electric face equipment incorporating power components located on separate frames. If ground wire monitors or grounded phase protection devices are located on-board the machine or system, test circuits must be provided to check their condition without exposing personnel to energized circuits. The last requirement for personnel protection is that of ground fault protection. All of these requirements are intended to improve the safety of the persons working on and around this high-voltage equipment.

### III. CONCLUSION

The criteria, developed after extensive research and testing, is a safe and practical approach to approving equipment with on-board high-voltage switchgear. This criteria provides the mining industry with the capability of safely utilizing equipment with potentially higher productivity. In addition to the protective methods specified in Appendix A, there are alternative methods that may provide equal protection, such as pressure switches or special pressure release devices. Designs of this type have not yet been incorporated in mining equipment; however, they will be given future consideration.

## APPENDIX I

APPROVAL CRITERIA FOR HIGH VOLTAGE EQUIPMENT  
CONTAINING ON-BOARD SWITCHING OF HIGH VOLTAGE CIRCUITRY

## 1. Purpose

The purpose of these criteria is to establish technical requirements to be used by MSHA in evaluating for approval high-voltage equipment containing on-board switching of high voltage circuits. This criteria is to supplement the existing requirements of Title 30 Code of Federal Regulations (30 CFR) Part 18, all of which apply unless specifically amended or replaced by parts of this criteria. These requirements do not amend or supersede the requirements of 30 CFR, Part 57 and 75. The intent is to define and expand Section 18.47(d)(6) which states "MSHA reserves the right to require additional safeguards for high-voltage equipment or modify the requirements to recognize improved technology." All of these requirements must be met in order for the equipment to be approved.

## 2. Definitions

- a. Comparative tracking index (CTI) - an index for electrical insulating materials determined by the American Society for Testing and Materials Standard D3638-85.
- b. Corona extinction voltage - the maximum voltage at which corona ceases as the applied voltage is gradually decreased.
- c. Creepage distance (electrical) - the shortest distance between two uninsulated conducting parts measured along the surface and joints of the insulating material between them.

a. High-voltage - nominal voltage in excess of 1000 volts AC up to and including 4160 volts AC.

e. Internal free volume - the volume in an explosion-proof enclosure not occupied by components.

f. Load switching device - any two-state apparatus designed to operate within energized circuits which in one state precludes and in the other state transfers electrical power to power-transducing mechanisms, typically motors and transformers.

g. Minimum free distance - the minimum unimpeded distance between an arc across uninsulated high-voltage conductors and an enclosure wall or cover which will prevent the arc heat from raising the wall or cover temperature above the working temperature of the material.

h. Pressure piling - a condition resulting from ignition of pre-compressed gases in compartments or subdivisions other than those in which ignition was initiated.

i. Sealed switching - switching devices designed to preclude exposure of arcs to the atmosphere surrounding the switch assembly.

j. Tracking - the progressive formation of conducting paths, on the surface of a solid insulating material, due to the combined effects of electric stress and electrolytic contamination.

k. Working temperature - the allowable temperature of a material before its short-time tensile properties are significantly diminished.

### 3. Design Pressure of Explosion-Proof Enclosures

a. All explosion-proof enclosures shall have a minimum internal design pressure of 150 pounds per square inch gage.

b. Explosion-proof enclosures containing high-voltage switchgear shall have a means of safely limiting the maximum pressure rise within the enclosure to .83 times the design pressure. See Appendix A for one means of satisfying this requirement.

#### 4. Component Placement/Pressure Piling

a. Partitions subdividing Single enclosures shall be designed such that pressure piling is not created.

b. Internal components shall be arranged so as not to effectively divide the interior of the enclosure into separate compartments joined by restricted passages that creates pressure piling.

c. High voltage electrical components located in high-voltage explosion-proof enclosures shall not be coplanar with a single plane flame-arresting path.

#### 5. Minimum Free Distance

High-voltage explosion-proof enclosures shall be designed to establish the minimum free distance listed in Table 1.

Table 1 - High-Voltage Minimum Free Distances (MFD)

Wall/Cover Thickness (in)	Steel MFD (in)		Aluminum MFD (in)	
	A	B	A	B
3/8	1.8	3.9	8.6	18.1
1/2	1.2*	2.7	6.5	13.0
5/8	.9*	2.1	5.1	10.4
3/4	.6*	1.6	4.1	8.6
1	.3*	1.0*	2.9	6.2

Column A specifies the MFD for enclosures that have available 3 phase bolted short circuit currents of 10,000 amperes rms or less, Column B specifies the MFD for enclosures that have a maximum available 3 phase bolted short circuit currents greater than 10,000 and less than or equal to 20,000 amperes rms.

a. When the adjacent wall area is the top of the enclosure, the minimum free distance shall be increased by 1.5 inches for 4160 volt systems and 0.7 inches for 2400 volt systems.

b. Minimum free distances may be reduced if a grounded 1/4" thick steel shield is used between the area of potential arcing and the adjacent wallcover area\*.

\*The minimum electrical clearances must still be maintained.

#### 6. Electrical Clearances for Uninsulated Conductors

Minimum clearances between exposed electrical conductor surfaces, or between uninsulated conductor surfaces and grounded metal surfaces, within enclosures shall be as listed in the following table.

Table 2 - Minimum Clearances Between Uninsulated Conductors

Phase-to-Phase Voltage (rms)	Clearances (inches)	
	Phase-to-Phase	Phase-to-Ground or Control Circuit
2400	1.4	0.6
4160	3.0	1.4

a. When case lining insulation is used, it shall be rated for the phase-to-phase voltage and the uninsulated part to insulation clearance shall not be less than 2/3 of the phase-to-ground clearance listed in Table 2.

b. Bus bars shall be supported to prevent movement which would decrease the required clearances.

c. Devices connected to bus bars shall be independently supported.

## 7. Creepage Distances

a. Rigid insulation between high-voltage terminals or high-voltage terminals and ground shall be designed with creepage distances in accordance with Table 3.

b. Comparative tracking indices referenced in Table 3 shall be made based on American Society for Testing and Materials Standard D3638-85.

Table 3 – Minimum Creepage Distances

Phase-to-Phase Voltage	Points of Measure	Minimum Creepage Distances (inches) for			
		CTI Range*			
		CTI $\geq$ 500	380 $\leq$ CTI < 500	175 $\leq$ CTI < 380	CTI < 175
2400	0-0	1.50	1.95	2.40	2.90
	0-G	1.00	1.25	1.55	1.85
4160	0-0	2.40	3.15	3.90	4.65
	0 G	1.50	1.95	2.40	2.90

\*Assumes that all insulation is rated for the applied voltage or higher.

Appendix B shall be used as a guide for determining measurement of creepage distances.

## 8. Control Transformers

Transformers with high-voltage primary windings that supply control voltages in high-voltage explosion-proof enclosures shall:

- a. Be connected line-to-line on the primary side.
- b. Incorporate grounded electrostatic (Faraday) shielding between the primary and secondary windings or be constructed such that the secondary capacitance to ground is at least 10 times the capacitance between the transformers primary and secondary.
- c. Supply a maximum nominal voltage of 120 volts line-to-line.

## 9. Corona Protection

Safeguards against corona shall be provided on all 4160 volt circuits in explosion-proof enclosures. The 60 hertz corona extinction voltages for cables and insulation shall not be less than 5000 volts rms.

## 10. Switching Devices

High-voltage switching devices shall be only of the sealed switching type.

## 11. Overcurrent Protection

Overcurrent protection shall be provided on all cables supplying power to enclosures containing high-voltage switchgear. This protection shall consist of instantaneous short-circuit protection and inverse current/time protection for the purpose of limiting electrical fault energy.

## 12. Personnel Protection

- a. High-voltage and low-voltage circuits, shall be separated by location, barriers or partitions to prevent exposure to energized high-voltage conductors or parts. Metal barriers or partitions shall be grounded.



b. The cover(s) of any compartment in the high-voltage switchgear enclosure containing uninsulated high-voltage components shall be fitted with interlock switches arranged to automatically de-energize the exposed high-voltage components within that compartment when the cover is removed. Switches of the plunger operated type will require 2 per cover minimum installed such that operation of either will de-energize the high-voltage enclosure.

c. Visible main disconnects shall be required on-board electric face equipment incorporating power components located on separate frames.

d. Test circuits shall be provided for checking the condition of ground wire monitors and grounded-phase protection without exposing personnel to energized circuits, if such devices are located on-board the machine or system.

e. Ground fault current shall be limited by a neutral grounding resistor to not more than 6.5 amperes for a 2400 volt system or 3.75 amperes for a 4160 volt system. The tripping current for the ground fault protection device shall not exceed 40% of the maximum fault current.

### 13. Static Pressure Test Requirements

The following static pressure test shall be performed on each prototype design of explosion-proof enclosure housing high-voltage switchgear prior to the explosion tests. The test shall also be performed as a routine test on every explosion-proof enclosure housing high-voltage switchgear, at the time of manufacture, unless the manufacturer uses an MSHA accepted quality assurance procedure covering welding and inspection of the enclosures.

#### a. Test Procedure.

1. Seal the enclosure to allow pressurization.
2. Internally pressurize the enclosure to the design pressure +3% psi, maintaining the pressure for a minimum of 10 seconds.

3. Following the pressure hold, the pressure shall be removed and the pressurizing agent removed from the enclosure.

b. Acceptance Performance.

1. The enclosure, during pressurization, shall not exhibit leakage through welds or casting.

2. The enclosure, following removal of the pressurizing agent, shall not exhibit visible cracks in welds or permanent deformation.

#### 14. Dynamic Pressure Test Requirements

In addition to the standard explosion tests of 30 CFR Part 18, the following test shall be performed on any explosion-proof enclosure housing high-voltage switchgear being accepted on the basis of a design pressure greater than 150 psi.

a. The enclosure shall be tested empty, without components or dummies representing components.

For three tests the explosion shall be a 9.4 to 9.8 by volume per centum methane in air ignited by centrally located gun-cotton. The quantity of guncotton shall be such to produce in a standard test vessel a pressure of  $(.83) (pd) - pet$  where  $Pd$  is the design pressure of the enclosure and  $Pet$  is the maximum recorded pressure from the standard explosion tests or 100 psi, whichever is less.

b. Performance of tests shall be evaluated in accordance with 30 CFR Section 18.62(b).

APPENDIX A

One acceptable means of safely limiting the pressure rise within an enclosure is through the use of the trailing cable electrical protective devices to limit the electrical energy released by a high-voltage arc.

An analysis undertaken to derive a simplified method for safeguarding against high energy arcing faults resulted in the following equation.

$$t_{\text{trip}} = R \frac{P_a \text{ (vol)}}{(I_{\text{sc}})_{\text{max}}}$$

where  $t_{\text{trip}}$  = maximum clearing time of the outby short circuit protection device (ins)

$$R = \begin{array}{ll} 1.4 \text{ for 2300 volt system} & \frac{(\text{ms})(\text{Amp})}{(\text{lb})(\text{in})} \\ 0.76 \text{ for 4160 volt system} & \end{array}$$

$P_a$  = the pressure attributed to the high-voltage arc

$$P_a = \frac{\text{nominal maximum design pressure} - \text{methane pressure}}{2} \text{ (psi) also } P_a \leq (.83) (p_d) - p_{\text{et}}$$

$p_d$  = the design pressure of the enclosure (psi)

$$P_a = \frac{\text{design pressure} - 100}{2}$$

$p_{\text{et}}$  = the maximum recorded explosion test pressure (psi)

note: normal maximum methane pressure is 100 psi

vol = internal free volume of the enclosure (in<sup>3</sup>)

$(I_{\text{sc}})_{\text{max}}$  = maximum three phase bolted short circuit current (Arms)

The corresponding maximum trip current setting ( $I_{\text{trip}}$ ) is determined by:

$$I_{\text{trip}} = 0.7 (I_{\text{sc}})_{\text{min}} \quad (A_{\text{rms}})$$

where  $(I_{\text{sc}})_{\text{min}}$  = minimum 3 phase bolted short circuit current ( $A_{\text{rms}}$ )

Normally the manufacturer will not know the available short circuit current when applying for MSHA approval. Therefore, the preceding equations are solved for the minimum and maximum short circuit currents.

$$(I_{sc})_{\max} = R \frac{P_a \text{ (vol)}}{t_{\text{trip}}} \quad (\text{Arms})$$

$$(I_{sc})_{\min} = \frac{I_{\text{trip}}}{0.7} \quad (\text{Arms})$$

These last two equations shall be used to limit the allowable maximum and minimum 3 phase bolted short circuit currents available at the enclosure's high-voltage terminals. This condition of use will be made part of the approval. The allowable short circuit range will be stamped on the machine's approval plate, along with the outby short circuit protective device's maximum current setting and maximum clearance time.

#### EXAMPLE CALCULATION

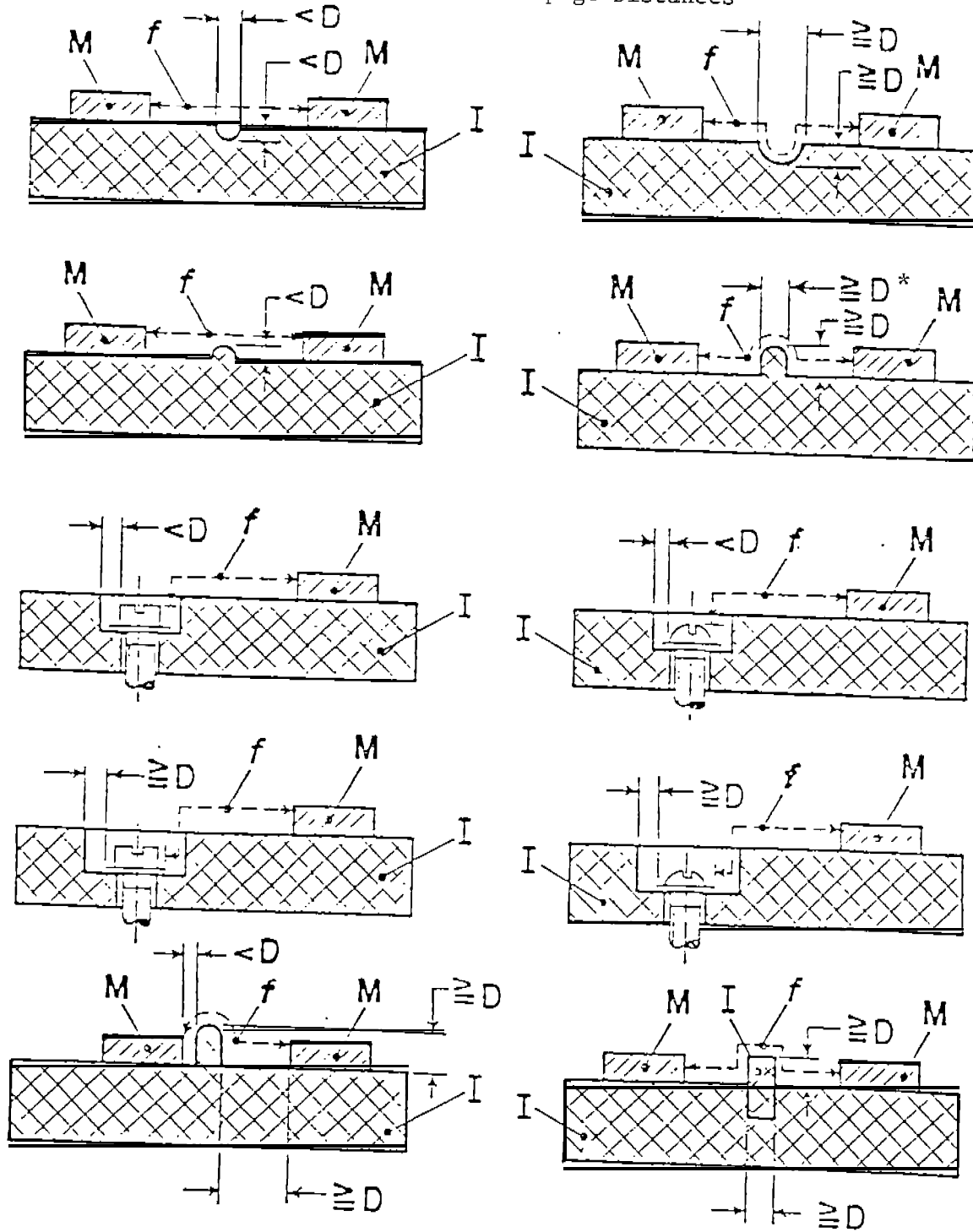
On-board a 2400 volt continuous miner, the enclosure which houses the high-voltage switchgear has an internal free volume of 20,000 in<sup>3</sup> and is designed to withstand 150 psi. The maximum recorded test pressure was 90 psi. The outby short circuit protective device is set to trip at 2500 amperes and it has a clearing time of 90 ms.

$$\begin{aligned} (I_{sc})_{\max} &= R \frac{P_a \text{ (vol)}}{t_{\text{trip}}} & P_a &= \frac{150-100}{2} = 25 < \begin{matrix} (.83)(150)-90 \\ < 34.5 \end{matrix} \\ &= 1.4 \frac{\left(\frac{150-100}{2}\right) (20,000)}{90} \\ &= 7778 \text{ A}_{\text{rms}} \end{aligned}$$

$$\begin{aligned} (I_{sc})_{\min} &= \frac{I_{\text{trip}}}{0.7} \\ &= \frac{2500}{0.7} \\ &= 3571 \text{ A}_{\text{rms}} \end{aligned}$$

Therefore, the machine can be used only with electrical systems that deliver no less than 3571 amperes and no more than 7778 amperes 3 phase bolted short circuit current to the machine enclosure.

Appendix B - Examples of Creepage Distances



$f$  = creepage distance

M = metal

I = insulation material

D = 0.118 inches (3 millimeters)

\*If the ribs on the surface of insulating parts are at least .118" high and their width is appropriate to the mechanical strength of the material, then the minimum width may be reduced to .039" and still be considered in calculating the creepage distances.

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