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PROCESS CONTROL IN HAZARDOUS LOCATIONS

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by

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ABSTRACT

Electrical Process Control Equipment quite often finds its way into Hazardous Locations - environments where explosive gases, vapours and dusts exist, sometimes in explosive proportions. The presentation will outline the various methods of preventing explosions due to the use of electricity in these locatons. A short history of the evolution of the various protective methods will be followed by a discussion of the state-of-the-art for these methods as it relates to process control and some recent developments in section 18 of the Canadian Electrical Code which have been made to recognize recent improvements in protective techniques.

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KEYWORDS: Process Control, Hazardous Locations, explosion-proof, intrinsic safety, dust-tight enclosure, combustible gas detection.

RÉGULATION D'UN PROCÉDÉ DANS DES LIEUX DANGEREUX

par

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RÉSUMÉ

Le matériel électrique de régulation d'un procédé est assez souvent utilisé dans des lieux dangereux, soit dans des environnements où il existe, parfois en concentrations explosives, des gaz, des vapeurs et des poussières explosifs. L'exposé comprend les diverses méthodes pour prévenir les explosions provoquées par l'utilisation de l'électricité dans ces endroits. Une brève description de l'évolution des différentes méthodes de protection sera suivie d'une discussion portant sur la technologie de pointe pour ces méthodes par rapport à la régulation d'un procédé et sur quelques modifications qui ont récemment été apportées à la section 18 du Code canadien de l'électricité afin de refléter les derniers perfectionnements des techniques de protection.

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MOTS-CLÉS: Régulation d'un procédé, lieux dangereux, antidéflagrant, sécurité intrinsèque, enceinte étanche aux poussières, détection des gaz combustibles.

HISTORY

It is well known that the first attempts to protect against atmospheric explosions were made in underground coal mines. The problem was identified early in the history of coal mining as shown in the etching on the first slide. This shows the result of not taking account of the fact that every ton of coal contains approximately 300 cubic feet of methane gas adsorbed in the pores of the coal. The coal releases the gas over a period of about one month after it is mined, rapidly at first and later tapering off to a trickle. There have even been explosions on ships carrying coal up to a month after it had been mined due to the desorption of methane.

So you can see that the early coal miners had their problems. The more coal they mined, the more gas they had to contend with. Fortunately, before the use of electricity in mines, the only problem was the use of lamps so that the miners could see to mine the coal. Some very primitive methods of methane control were used in the early days. One of these methods is shown in the second slide. Here we have what was known as the "penitent" who is lighting the methane layer before the miners go to work.

The methane would usually accumulate during the night from the previous day's mining and because it is lighter than air, it formed a layer near the roof of the mine shaft. This layer of "fire-damp" could be ignited by someone who kept near the floor and was protected by a layer of wet blankets. The man who did this rather perilous job had to be a volunteer because if the gas layer was large his life might be in danger. When they ran out of "volunteers" they recruited convicts who got a lighter sentence for performing this dangerous task. Hence the name "the penitent".

This method of gas control worked quite well because of the small amount of coal that could be mined in a day without mechanization. When electrical power was introduced into the mines, the tonnage of coal went up with a corresponding increase in the gas levels. To offset this, mechanical ventilation was also introduced which was able to clear the gas by dilution. Even today, the control of gas in a coal mine is a delicate balance between the production of coal mined and the ventilation.

In spite of all efforts to clear the gas by ventilation, explosions occured frequently early in the history of electrification of mines. Therefore, other methods of protection were developed. The earliest of these was the "flameproof" enclosure or explosion-proof enclosure as it is more commonly called in Canada.

The earliest explosion-proof enclosures were the heavy cast-iron mining motors. These were built as totally enclosed motors because of the adverse conditions and they soon discovered that the enclosure also gave them protection against the ignition of methane from the motors. This technique was soon adapted for other electrical equipment as shown in the next slide. Here we have an early manual motor starter in an explosion proof enclosure. Note that although the electrical portion of this starter is quite primitive, the enclosure is not unlike some enclosures still used today.

Another early development in coal mines was the safety lamp. This was an oil lamp surrounded by wire screens (an early form of flame arrestor). This lamp not only prevented the flame from igniting the gas, they also found that when the lamp was exposed to a weak mixture of gas, the flame became larger. This discovery led to the use of the catalytic element connected to a wheatstone bridge to detect weak gas/air mixtures; some early attempts to exploit this principle are shown in the next slide.

Another significant contribution of coal mining originated as a result of two major coal mine explosions in 1912 and 1913 in the U.K. These explosions were attributed to the primitive signalling system that was used in the mines at that time. This consisted of a primitive bell, shown in the next slide, connected to a battery or step down transformer. The wiring consisted of bare wires running on insulated standoffs along the wall of the mine. To signal, the miners had only to short the two wires together with a metal tool or bar and the bell would ring. The system operated at a very low potential and current and it was assumed that for this reason that it was safe for use in a gassy environment. When they had two major explosions an investigation into these bell circuits let to the development of a safer system in which the energy was more limited. This technique was called "intrinsic safety", a technique which is very important in the field of electronic process control today.

PROTECTION BY ENCLOSURE

The first technique I will discuss is protection by enclosure. This covers both the explosion-proof enclosures and the dust tight enclosures.

Although these two techniques frequently are found in the same device, the theory of these two methods of protection are quite different. In an explosion proof enclosure, it is assumed that an explosive mixture of gas and air will get inside and the enclosure is designed to contain the explosion without damage and without transmitting the explosion to the surrounding atomosphere. In a dust tight enclosure, the enclosure is designed to exclude the dust.

There are two basic requirements which must be considered when designing an explosion proof enclosure. The first is the strength of the enclosure. It must be strong enough to withstand the pressure generated when the ideal mixture of gas or vapour and air is exploded inside. The pressures vary with the gas or vapour and also with the size and shape of the enclosure. A typical enclosure for say Class I, Group D will have to withstand an explosion pressure of about 100 psi. In addition, for a cast enclosure, there is a 4 times safety factor so the design pressure may be 400 psi. If the enclosure is being designed for one of the higher groups (Groups A, B, or C) the pressures may be somewhat higher. In addition, if the enclosure is long and narrow or has more than one compartment, "pressure piling" or "detonation" effects may drive up the pressure several times these values. Pressure piling is where one part of the gas/air mixture is precompressed (similar to the compression stroke in a gasoline engine) which gives a correspondingly higher explosion pressure. This same principle is why high compression engines produce more power. Detonation is where the precompression is so severe that the mixture ignites spontaneously like the mixture in a diesel engine. Detonation pressures can be as high as 10 times the normal pressure so steps must be taken to avoid detonation. Seals in long runs of conduit are one of the steps taken to avoid this phonomenon.

If all we had to worry about was the pressure, the job would be relatively simple. We could simply build a strong enclosure and weld it up permanently. However, it is almost always necessary to have a removeable cover for making connections and for maintenance purposes. This means that we have to introduce a joint in the enclosure which has to be tight enough to contain the explosion. Resilient seals such as gaskets and "O" rings are not considered sufficient to prevent the transmission of an explosion so a tight fitting metal-to-metal joint is required. These joints may be threaded, flat or rabbeted but they must meet the very strict tolerances given in the standards for explosion proof enclosures. The next slide is one of the tables from CSA Standard C22.2 No. 30 and it shows some typical joint widths and clearances for Class I Group D enclosures.

How do we know what clearances are suitable for these joints? These have been established by actual experiment and the values shown here are actually about 1/4 of the "maximum safe joints" determined by experiment. These clearances are for new equipment fresh from the factory. When a device has been in service for several years and it has been exposed to corrosive atmospheres and generally knocked around a bit, the joint may increase somewhat above these values. When is the enclosure considered unsafe so that must be re-machined or scrapped? The rule of thumb which is generally recongized is when the joint has opened to more than twice these values.

The theory behind the effect of an explosion passing through a machined joint may be of interest. When there is very little clearance in the joint, the amount of hot gas that can get through is very small when it reaches the outside. When it reaches the outside atmosphere, it has been cooled to such a degree that it cannot ignite the outside mixture. When we approach the maximum safe gap, another effect comes into play. It is the mixing of the hot gases with the cooler outside gases (called entrainment). This has been shown to have a significant effect on flame transmission for wider gaps. The next slide shows how this effect works. Another effect which plays a somewhat smaller part in cooling the flame is the "refridgeration" effect. The gas inside the enclosure is at a higher pressure than the surrounding atmosphere and when it passes through the joint it expands and cools in the process.

A dust-tight enclosure simply has to have joints small enough to exclude the dust. This requirement can often be met by an explosion proof enclosure without any further modification although there are some explosion-proof joints which do not meet this requirment. An example is the shaft joint on an explosion proof motor. For this reason a "dual rated" motor must often have a second "dust tight" joint on the shaft outside of the bearing. Because a dust tight joint does not have to stop an explosion, gaskets may be used. Therefore it is possible to build a dust tight enclosure which is not necessarily exposion proof. In addition, if the enclosure is reasonably rigid, it can be built of sheet metal because it does not have to have the strength to resist an internal explosion.

Another form of protection by enclosure is pressurizing. This technique involves a reasonably tight enclosure or even a complete room which is maintained at a slight positive pressure to prevent the entry of an explosive gas or vapour. The pressurizing medium is usually air drawn from a clean safe source but in some cases an inert gas may be used. The pressures involved are quite low - in the order of a few inches of water so that no particular strength is required for the enclosure.

Pressurization requires three basic things: (1) a safe source of clean air or inert gas, (2) a timed purge at startup to ensure that all of the original atmosphere (which may have been hazardous) has been displaced by the purge gas, and (3) a warning device and/or a shutdown switch operates when the pressure falls below the design limits.

PROTECTION BY ELECTRICAL DESIGN

Protection by electrical design involves designing the equipment for use in hazardous locations from the start. The above forms of protection normally involve taking a standard electrical or electronic device and putting it in a special enclosure. On the other hand, if a device, particularly a signal or process control device, is designed specifically for use in a hazardous location, a technique called intrinsic safety can be used. Like the signal bell referred to above, particular attention must be paid to the electrical parameters including the voltage, current, inductance and capacitance in the circuit.

There are no magic numbers that you can give for these parameters which automatically make it safe because they are all inter-dependent. As examples: the higher the voltage of a circuit, the lower the capacitance must be and the higher the current, the lower the inductance must be.

In addition, the levels vary with different gas groups and also with frequency. Non-linear circuits, such as voltage regulators, which try to maintain a given potential regardless of the load, present special problems of analysis. The next slide shows a typical set of curves for current vs. inductance plotted on log-log paper. Note that if the inductance is iron-cored, saturation effects may come into play at the higher current levels making the curves invalid. In that case, you may have no option but to test the circuit.

Testing of intrinsically safe circuits has almost gone out of style in recent years because of the availability of very reliable curves such as the one shown in the slide. These curves were obtained using the apparatus shown in the next slide. This apparatus is standard equipment for any laboratory certifying intrinsically safe equipment as it is still needed for unusual cases. My motto has always been "when in doubt - test".

This apparatus consists of a cadmium disc with two slots machined in it and four tungsten wires 11mm long on an electrode holder. The disk revolves in one direction while the tungsten electrodes revolve in the opposite direction. This ensures even wear on the disc and a random pattern of scraping and snapping across the grooves and off the edge of the disc. This apparatus is just about the most efficient spark generation apparatus ever developed! Even the metals were specially picked for their propensity to spark! Therefore, it has a built in safety factor. For this reason, the curves are now used just as they are, with no safety factor included.

Not that intrinsic safety is without safety factors! The safety factors are in the "faults" that are imposed on the circuit in the analysis stage. These include any two independent faults liable to occur in service - at the same time, except for certain special components which have a very high reliability rating. In addition, because the wiring method is not specified, any external circuits are assumed to short together, short to ground or open circuit (whichever gives the worst result) and these are not counted as faults!

Another technique which uses electrical design to ensure safety rather than an "add-on" enclosure is called "increased safety". The best analogy I can think of for this technique is that it is similar to "double insulation". If you take an electric drill and to safeguard the operator from electric shock, you add a ground wire, this is similar to adding a special enclosure. But if you add an additional insulation system, you have improved the electrical design so that the likelihood of electical shock is reduced to the point that a ground wire is not necessary. This is similar to the principle of "increased safety" - the equipment is built to such high electrical standards that the likelihood of electrical breakdown (and subsequently causing an ignition of the flammable atmoshpere) is very unlikely.

Before you rush out and start specifying increased safety for your hazardous locations, I feel that I must caution you that this is a technique which is not generally recognized in North America. It originated in Germany and is recognized by the International Electrotechnical Commission (IEC) but you will not find it mentioned in the Canadian Electrical Code. The problem is that because it is not used in Canada, nobody knows how to install and maintain it and for this reason, the inspection authorities are reluctant to allow its use. Something of a chicken and egg situation!

This technique would be especially useful for very large motors. These motors are very expensive to build as explosion-proof units. If they were built to increased safety standards and contained no slip-rings or other arcing parts, they could be open ventilated machines.

Another technique of interest which is gaining wider acceptance in the field of process control is the non-incendive circuit. Simply stated, the non-incendive circuit is a Division 2 version of intrinsic safety. By eliminating the rigid fault criteria of the intrinsic safety analysis, we arrive at a circuit which under all normal conditions of use and abuse (the faulting of the field wiring is still considered) will not cause an ignition of the explosive atmosphere. A new rule and an addition to appendix F have recently been approved by the Part I rule and the accompanying appendix material puts non-incendive circuits on the same basis as intrinsic safety, limited of course to Class I Division 2 Hazardous Locations.

PROTECTION BY IMMERSION

There are a number of other, little used protection techniques where the electrical parts are immersed or encapsulated. These include oil immersion, sand filled and encapsulation.

Oil immersion is a very old technique but it has recently fallen from favour in most countries. It relied on the electrical equipment, including normally arcing parts, being totally immersed in an insulating oil. In this way, the electrical parts were never exposed to the explosive gases or vapours.

Sand filling is a French technique, recognized by the IEC but not used in North America. For obvious reasons it is not used for any equipment containing any moving parts. Its use seems to be limited to static devices such as transformers, reactors, etc.

Encapsulation is a relatively new method of protection for equipment for use in hazardous locations. It has limited use in North America but there is a definite interest in the technique here. In Europe, there is even more interest in this subject. They already have a standard for this technique in Yugoslavia and recently Technical Committee 31 of the IEC set up a new Subcommittee to prepare a standard for this form of protection. While a piece of static equipment can readily be encapsulated, some other form of protection must be provided for any moving parts and for line connections.

INSTALLATION REQUIREMENTS

The installation of explosion-proof enclosures is very well documented in the Canadian Electrical Code, Part I. When it comes to intrinsic safety and non-incendive circuits, the Code seems to leave installation practices up to the installer. The reason for this is that most of these circuits are safer than Class 2 signal circuits and therefore it does not really matter how the wiring is run. Appendix material such as Appendix F is recommended and not theoretically mandatory practice. I say theoretically because it does become mandatory if the local inspector wants it installed that way.

There is guidance elsewhere on the recommended method of installing intrinsic safety and non-incendive circuits. The first place to look is in the manufacturer's instructions or "control drawing" as it is sometimes called. This may give you the limitations of the circuit which is very important - particularly when there are a number of possible combinations. Another place where you can find guidance is in ISA RP 12.6 (currently under revision). This Recommended Standard has some very good advice and guidance for anyone who is installing one of these circuits for the first time.

For example, if the circuit contains an intrinsically safe barrier, it is often permissible to use any "simple apparatus" such as a thermocouple, light emitting diode, switch or resistance temperature detector in the circuit without it being specifically mentioned in the approval documents. The latest draft of ISA RP 12.6 defines "simple apparatus" as a discrete device which will not generate or store more than 1.2v, 0.1A, 125mW or 20 uJ.

If the equipment "control drawing" gives the electrical parameters of the devices which can be connected to the intrinsically safe circuit rather than the actual catalogue numbers of these components, it has been approved under the "entity concept". What this means is that the user has more freedom to choose the components he wants to use rather than using only the components which were actually tested with the apparatus. In Canada, this concept is used to a limited extent but I expect that it will be used to a greater degree in the future. It was the introduction of the Zener barrier that made this concept possible.

There has been a lot of controversy about the use of Zener barriers and computers recently. The reason for this is that these barriers are the only practical way to connect a computer to an intrinsically safe circuit. The problem is that most barriers are only rated for 250V rms whereas most computers contain a video tube with approximately 12,000V on the power supply. This means that theoretically, if the power supply for the Video circuit were to short to the barrier input, the high voltage might destroy the barrier and cause the circuit to become unsafe. This has not actually happened to my knowledge and people who have tried to artificially produce this condition tell me that it is very difficult to damage a barrier this way. There are several factors working in favour of the barrier. They are:

(1) The power supply for a video tube is very limited in its current output.

(2) Barriers are by nature very rugged electrically. The zeners normally short circuit when they fail and this causes the fuse to blow, disconnecting the barrier from the supply. The next figure illustrates a typical barrier circuit from which you can see how it protects the circuit from electrical surges.

(3) The output of the Video power supply is usually quite remote from any signal circuit and will normally short to ground through another internal component before it reaches the barrier. Bear in mind that these terminals are full of integrated circuits with spacings to

ground that will short out at a few hundred volts and consequently will not carry 12,000 volts beyond the first component.

Although nobody will come out and say that there is no problem, these combinations are in use in many installations and nobody is getting very excited about it. To investigate all video terminals for connection to intrinsically safe circuits or to design and test a barrier for 12,000 volts is just too much trouble.

RECENT CHANGES IN SECTION 18

Installations for use in explosive atmospheres (hazardous locations) are governed in the Canadian Code by section 18. Recent changes to this section have made possible the use of some new products and wiring methods. These include the use of cable wiring systems, the deletion of the word explosion proof form some clauses, the rewriting of the Class I Division 2 sub-section and the recognition of Combustible Gas Detection Instruments as a method of protection.

As a result of the completion of CSA Standard C22.2 No. 174 "Cables and Cable Glands for use in Hazardous Locations" cables together with their glands are now recognized as an alternative to rigid conduit in all hazardous locations. The only question remaining to be resolved is whether non-metal sheathed or armoured cables may be used in Class I Divison 1 Hazardous Locations. Although the present wording of the Code seems to permit any cable approved to Spec. 174, the regulatory authorities in Canada have so far opposed this. In spite of this little problem, the use of cables in hazardous locations in Canada has increased dramatically in the last few years because of the ease of installation and the economies of using cables instead of rigid conduit.

When we are asked to approve a new product, using a new or different method of protection in Canada, it often requires a change of the code to recognize this special form of protection. The U.S.A. National Electrical Code is full of such clauses allowing a certain form of protection for a certain application. An example is a product used for pumping liquified natural gas. This is a special pump with an encapsulated winding which is immersed in the liquid methane at a pressure of about 1300 psi. The motor is not explosion-proof because it is both encapsulated and immersed in the product it is pumping. It is also built so that it cannot operate when there is no liquid in the tank. The connection box is outside of the tank and is of explosion-proof construction. Because the motor, while quite safe from causing an explosion, was not explosion-proof, it was not recognized by the Code. Rather than putting in a special clause for this device, we opted to delete the word explosion-proof from this and a number of other clauses in section 18 to avoid having to make code changes every time a new product came on the market. The product must still pass through CSA and be certified by them and approved by the regulatory authorities committee but we do not have to take the extra step to change the Code.

The fourteenth edition and previous editions of the Code contained many rules pertaining to equipment for Class I Division 2. These rules contained requirements for such things as surface temperatures and arcing and sparking parts which could not be properly addressed by an inspector in the field. Obviously surface temperatures of components cannot be conveniently measured by a field inspector - that is a laboratory job! In addition, many sparking parts did not give off enough energy to cause an ignition but how could a field inspector tell that? By re-writing this sub-section we were able to correct these problems and in addition we introduced the new concept of non-incendive field wired circuits mentioned earlier.

A very recent change approved for inclusion in the next edition at the last meeting of the Part I Committee is the use of Combustible Gas Detection Instruments as a form of protection. While limited to equipment for which other methods of protection is not practical, this method will make it easier to use special analyser equipment not built to explosion-proof requirements, in hazardous locations if it is protected by a gas detector. The system is similar in many respects to the purging method in that the equipment must be disconnected from the supply as soon as the detector sees a high gas condition. There are also some fail safe requirements in the new rules and a new appendix has been prepared describing the recommended installation practice. It allows equipment suitable for use in Class I Division 2 to be used in a Division 1 location if it is protected by a gas detector and ordinary location equipment to be used in a Division 2 location if it is so protected.

The Committees and Subcommittees responsible for the Code and the Standards for electrical equipment are trying very hard to keep up with new technology. You can help by providing your input. Appendix C of the Code gives the procedure to be followed for people who wish to propose a change or ask for an official interpretation. Rather than complaining about a rule which you think needs changing, wouldn't it be more constructive to propose a change?