THE APPLICATION OF FIBER OPTICS TECHNOLOGY TO THE DESIGN OF MINE LIGHTING SYSTEMS

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ABSTRACT

This paper describes the Bureau of Mines efforts in the research and development of a new and innovative mine lighting system which is based on fiber optics technology. The new lighting concept offers significant advantages over conventional systems in the areas of both safety and long-term maintenance costs. An overview of Bureau research into the problems and limitations of present-day mine lighting systems is also presented.

INTRODUCTION

Congress recognized the essential need for better lighting in the mining workplace in the Federal Coal Mine Health and Safety Acts of 1969 and 1977. Today, 85 percent of required underground coal mining machinery is equipped with an approved lighting system, representing one of the most evolutionary changes to the mining environment in the last decade. Although considerable progress has been made towards providing better lighting and consequently increased visibility and safety in mining environments, many problems and areas of investigation remain.

OVERVIEW OF MINE LIGHTING PROBLEMS

Conceptually, the notion of providing lighting in underground coal mines appears simple, but its implementation is filled with subtle and complex problems. Recent efforts of the United Mine Workers of America/ Bituminous Coal Operator Association (UMWA/BCOA) Joint Industry Health and Safety Committee in cooperation with Mine Safety and Health Administration (MSHA) personnel have involved surveys [1] of illumination complaints and problems in low and high seam coal mines. Results of the surveys revealed that a large portion of the miners have complaints about the performance and design of existing lighting systems. Most of the complaints are caused by vision impedance (discomfort glare, disability glare, veiling reflections, and after images) from the light sources. In many cases the complaints are so severe (particularly in low-seam coal mines) that a large proportion of the miners prefer that the lighting systems be removed. Followup studies by the Bureau of the glare tolerance levels of miners [2] have shown that the level of glare created by a typical underground mine lighting system exceeds the tolerance level of the average miner. Other studies by the Bureau [3] have shown that the cost of maintaining machine-mounted lighting systems has been relatively high. The high maintenance costs can be primarily attributed to the cost of the luminaires, which are frequently damaged. Frequent lamp failures coupled with time consuming change-out procedures also contributes to the problem.

Most of the mine lighting systems on the market today were designed several years ago, either just prior to or shortly after the promulgation of the Federal lighting regulations. At that time, most of the design emphasis was placed on developing high light-output luminaires that would provide the light levels required by the regulations, with little or no emphasis was placed on the problem of glare. The high light-output fixtures were desirable because fewer luminaires (lower cost) would be needed on each machine to bring them into compliance. As the number of lighting installations increased, more and more complaints were made by the miners about the lighting systems causing vision impedance problems. In addition, complaints were made about the equipment being unreliable and costly to maintain. Over the years, some improvements have been made on the reliability of the equipment, but maintenance costs are still relatively high owing to the frequent damaging of the luminaires, which out of necessity are placed in vulnerable locations on the machines. Few attempts have been made to resolve the glare problem. Approaches to the problem, to date, have involved changes in the regulations (increasing the assumed value of coal reflectance), which in effect lowered the required lighting levels. The net effect on resolving the glare problem has been minimal.

STATUS OF PRESENT TECHNOLOGY

Currently, six manufacturers (Crouse Hinds, McJunkin, Mine Safety Appliance, National Mine Service, Ocenco, and Service Machine) offer MSHA-approved lighting systems for underground coal mine applications [4]. A variety of light sources are available, including fluorescent, high-pressure sodium, mercury vapor, and incandescent. Popularity of particular types of light sources and systems varies with the application and individual preferences.

All of the lighting systems can be categorized into two basic types, intrinsically safe and explosion proof. Fluorescent systems are most popular and more frequently used because of their relatively lower glare characteristics, although incandescent systems are gaining popularity because of their less sophisticated powering requirements, lower cost, and availability of the lamps. High-intensity discharge (HID) lamp systems (e.g., high-pressure sodium and mercury vapor) are more widely used in high coal applications, where these relatively high light-output fixtures are desirable. Presently, very few HID systems are installed in low coal because of their higher profile design and higher glare characteristics.

COMPARISON OF FIBER OPTICS CONCEPT AND PRESENT MINE LIGHTING TECHNOLOGY

Present studies of the Bureau have shown that the application of fiber optics to the design of mine lighting systems offers a potential solution to most of the identified problems. The fiber optics system, although simple conceptually, offers an opportunity to significantly advance the state-of-the-art. To fully elucidate the concept and its potential advantages over conventional mine lighting systems, a comparative analysis is given below.

A typical mine lighting system consists basically of five luminaires distributed around the periphery of the main frame of a mining machine as shown in figure 1. The luminaires are relatively expensive owing to their explosion-proof construction and are frequently broken and relatively time consuming and costly to replace. Since the light sources are contained in the luminaires, the luminaires are heavy and large, and have a high profile, which further contributes to their vulnerability. Power to the light sources is supplied through electrical cables and packing glands from a main power supply or ballast box. The electrical cables are routed around the machine and are subject to damage, which can present a potential shock hazard. A summary component analysis shows that a typical system consists of 23 components (6XP enclosures, 6 electrical cables, 11 packing glands) that relate directly to the safety, cost and maintainability of the system.

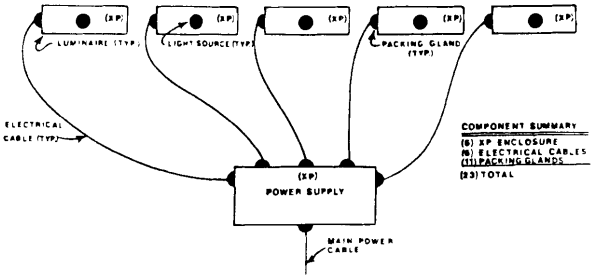

FIGURE 1. - Typical mine lighting system

In comparison, the fiber optics lighting system (figure 2) consists of a single explosion proof enclosure which houses the power supply and individual light sources.

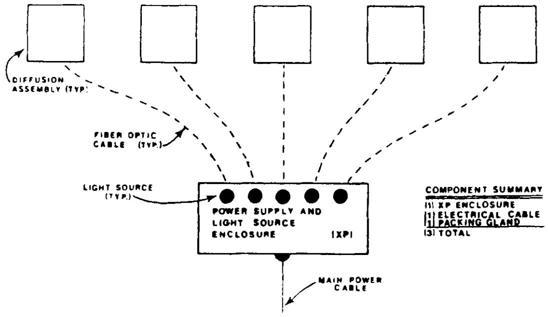

FIGURE 2. - Fiber optics lighting system

The light from the sources is piped out of the enclosure through fiber optics cables. These fiber optics cables are terminated with light-diffusing assemblies which in effect replace the explosion proof luminaires containing light sources. Since the diffusing assemblies contain no light sources or electrical power sources, they need not be explosion proof and can be constructed inexpensively. Furthermore, they can be cast or molded of plastic and made in a variety of shapes and sizes with a very low profile. Because of their low profile and solid construction, they will be less vulnerable to damage. In event damage did occur, they could be replaced easily and inexpensively. Also, the diffusing assemblies can be designed with a larger surface area so that the light will be spread out more uniformly and with a lower surface brightness and lower glare characteristics. The fiber optics concept also eliminates most of the electrical cables and packing glands in the system. The elimination of the electrical cables reduces the potential shock hazards of conventional systems, and in event of damage, the time consuming task of replacing the cable and repacking. A summary component analysis of the fiber optics system shows a reduction in the number of components from 23 to 3 (1 explosion-proof enclosure, 1 electrical cable, 1 packing gland). This significant reduction in the number of critical components relates directly to the safety, cost, and maintainability of the system.

CONCEPTUAL MODEL DEVELOPMENT

Once the fiber optics system was conceptualized, a prototype system was designed to demonstrate the feasibility of the concept. The conceptual model (figure 3) consisted of a complete six-light, machine mountable lighting system which included a main light source and power supply enclosure, associated fiber optics cables, and diffusing assemblies.

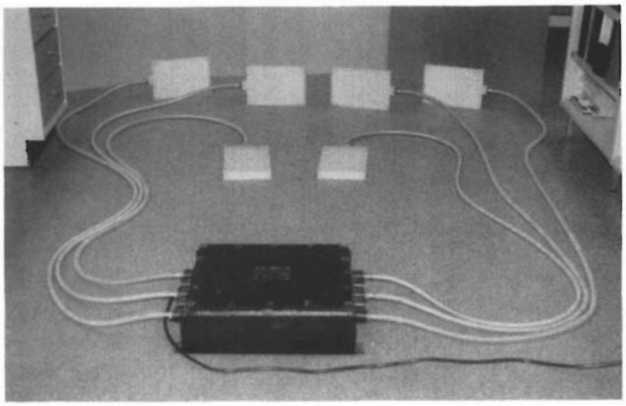

FIGURE 3. - Conceptual model fiber optic mine lighting system

Off-the-shelf, 80 watt tungsten halogen slide projector lamps (figure 4) were chosen as a light source and powered by a 24 volt, constant-voltage stepdown transformer fed from a 120 VAC line (figure 5). These lamps were chosen because of their relatively high source brightness, small source size, and good projection efficiency.

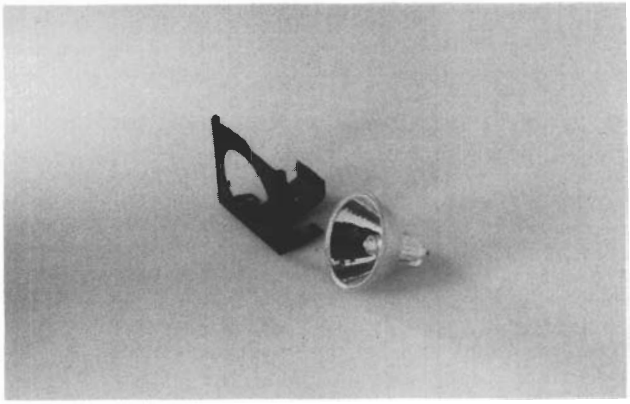

FIGURE 4. - 80 watt tungsten halogen projection lamp

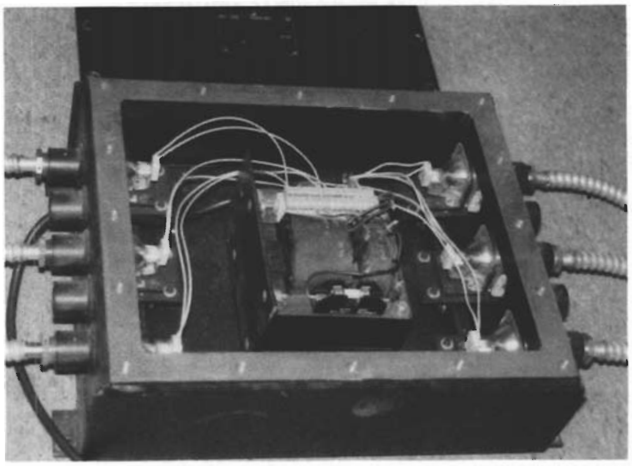

FIGURE 5. - 24 volt lamp power supply

The enclosure design (figure 6) was of conventional explosion-proof box construction with a flange and bolted lid. The beam of light from the projection lamps exits the enclosure through explosion-proof optical windows and is focused on the ends of the fiber optics cables, which are butted up against the windows. The fiber optics cables are 1/2 inch diameter and are the standard variety used in the photoelectric controls industry. They are covered with a flexible steel sheath for protection (figure 7), much the same as armored electric cables. The other end of the cable is terminated with a diffusing assembly which is used to spread the intense narrow beam of light which exits the cable and act as a low glare, relatively diffuse secondary source for area lighting (figure 8). The diffusing assemblies are solid cast using clear urethane resin. They were designed to have a low profile so as to minimize their projection height when mounted on a mining machine and reduce potential damage. The bottom surface is curved and painted white to act as a reflector (figure 9). The top surface was sanded with fine grain emery paper to improve its diffusing properties. The final 8 by 10 inch diffusing assembly provides relatively low glare characteristics when compared to conventional mine luminaires.

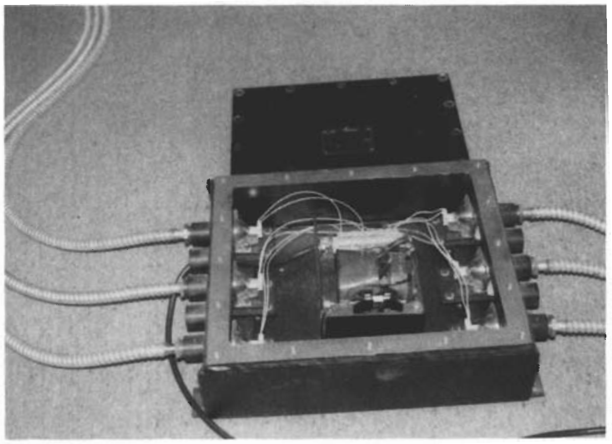

FIGURE 6. - Explosion-proof lamp and power supply enclosure

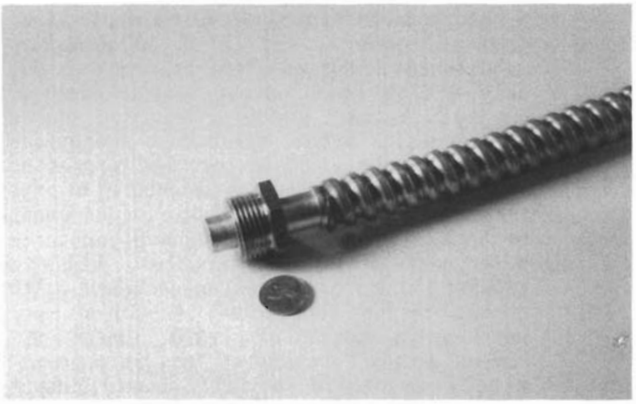

FIGURE 7. - Fiber optics cable with armored sheath

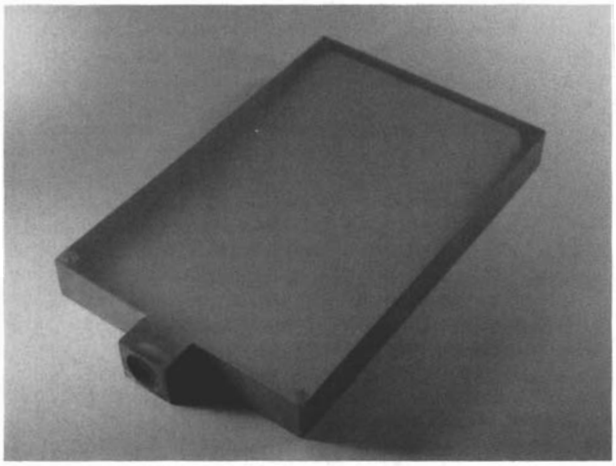

FIGURE 8. - Light diffusing assembly

FIGURE 9. - Diffusing assembly design

Tests performed on the model have demonstrated that the concept is feasible, although several major technical problems must be overcome before the system can become a practical and commercial reality.

MAJOR TECHNICAL PROBLEMS

In order for the concept to become a practical reality, two major problem areas must be addressed:

(a) **Inadequate light output from the system** - Present lighting regulations for underground coal mines require that the surfaces of a defined workplace be illuminated to a value of .06 foot lambert. Assuming a nominal reflectivity of 4% for coal surfaces and a safety factor of .77 for lamp maintenance, the .06 foot lambert of reflected light from a surface equates to approximately 1.95 foot candles of light incident on the surface as shown below:

$$E = \frac{L}{\rho(.77)} = \frac{.06}{(.04)(.77)} = 1.95 \qquad \textbf{(eq. 1)}$$

where E = illuminance in foot candles
L = luminance in foot lamberts
ρ = reflectance

The conceptual model equipped with an 80 watt tungsten halogen lamp and a 15-foot glass fiber optics cable and diffusing assembly is capable of illuminating a surface 6 feet away to approximately .32 foot candle. This is approximately one-sixth of the amount of incident light required to meet the regulations.

(b) **Overheating of the light source and power supply enclosure** - As mentioned previously, the present conceptual model consists of six 80 watt tungsten halogen lamps, which are contained in a single XP enclosure. This amounts to a total of approximately 480 watts of power (not including the power consumption of the transformer) and its resultant heat that must be dissipated. As a consequence of that amount of power and the enclosure design, the enclosure overheats. The overheating problem is not just a problem of the enclosure exceeding the overall surface temperature requirements of MSHA's schedule 2G (less than 150 C), but is also a problem of exceeding the maximum operating temperature of the components contained in the enclosure, such as lamp sockets, leads, capacitors, transformer windings, etc.

SOLVING THE PROBLEMS

A major key to the solution of both problems (low light output and overheating) lies in the development of a new light source that will produce a higher light output and at the same time generate less heat. To address the problem of the light source, a contract was awarded to a major lamp manufacturer to review existing lamp technology and make recommendations for the development of a lamp with sufficient light output and optical coupling efficiency for this application. On the basis of the technology review, it was determined that there were no off-the-shelf light sources available for this application, but that the technology did exist to develop such a lamp.

Based on the application requirements of high brightness, low heat generation, long life, and compact and rugged design, short-arc metal halide technology was recommended. Tungsten halogen technology was ruled out because of its high heat production and short operating life; this is particularly true for a mining environment, where it would be subjected to high shock and vibration.

A calculation of the lamp output required using measurements of the efficiencies of the light loading assembly (optical window, 15 foot length of fiber optic cable, and diffuser) and assuming a collection or delivery efficiency of 35% for the lamp reflector indicates that an illumination of 2 foot candles at 6 feet away from the diffuser would require a 6,600-lumen source.

$$\phi = \frac{\pi E D^2}{(\eta \text{col.})(\eta \text{win.})(\eta \text{cable})(\eta \text{dif.})} \quad \textbf{(eq. 2)}$$

where ϕ = luminous flux of the source
E = illuminance at a distance of 6 feet from the diffuser
D = distance from the diffuser
ηcol. = collection efficiency of the lamp reflector
ηwin. = transmission efficiency of the 1/2-inch-thick optical window
ηcable = transmission efficiency of a 15-foot fiber optic cable
ηdif. = transmission efficiency of the diffuser

Assuming a collection efficiency of .35 for the lamp reflector and measured values of η window = .95, η cable = .23, ηdiffuser = .45, then

$$\phi = \frac{(3.14)(2)(6)^2}{(0.35)(0.95)(0.23)(0.45)} = 6{,}569 \text{ lumens}$$

The search for a suitable lamp configuration and technology began with a 40-watt, short arc metal halide lamp. The 40 watt configuration was chosen because of our particular application, which is basically a projection system requirement rather than a general or area illumination requirement. Our application requires not only a high lumen output (6,600 lumens), but also a small source size (high source brightness), so that the output energy can be conveniently collected and projected into the small 1/2-inch aperture of the fiber optic cable. This dual requirement of both high lumen output and high source brightness presents a problem, since a 40-watt, short-arc tube can generate (with normal design boundaries) 58 lumens per watt or a total of 2,320 lumens (58 lumens/watt x 40 watts). This is approximately one-third of the lumen output required. One might ask, "Why not move up to a higher wattage arc tube configuration?" This solution is not satisfactory, since using the higher wattage arc tube means an increase in the size of the arc tube and in effect lowers the source brightness of the lamp and the collection efficiency.

There are two basic areas of potential significant improvement by which the output of the system can be increased: The standard 40-watt arc tube design can be modified to improve the output, and the efficiency of the light-loading assembly (fiber optics cables and diffusers) can be improved. Considering the amount of improvement needed, both areas will have to be addressed.

(a) Lamp Modifications: As previously discussed, a 40-watt short-arc metal halide lamp of standard design is capable of generating approximately 2,300 lumens, which is far short of the lumen output required for our application. Normally, arc discharge lamps such as the metal halide have rather long operating lives, usually in excess of 10,000 hours. To improve the lumen output of the lamp, one has the option of overdriving the lamp, but the lamp operating life will be sacrificed. The possibility of overdriving the lamp at 60 watts, thus increasing the output to approximately 3,500 lumens, was considered, but the operating life would be far below the originally targeted 3,000 hours. In other applications with a similar dilemma, a double-walled arc tube construction is used to improve the life when overdriving the lamp; this would be difficult to do conventionally in a small projection lamp such as ours. The idea then occurred that a lens or window fused to the front of the integral reflector could be used to form the basis of the second wall in a double-wall design. The double-wall construction prevents water vapor, and consequently hydrogen, from migrating through the hot inner wall of the arc tube and contaminating the fill gases, which reduces the lamp life. The technique was successful in maintaining the necessary operating life.

Expected performance parameters for the metal halide lamp and a comparison to the present tungsten halogen source used in the conceptual model follow:

Tungsten Halogen Technology

Lead-Wire Conduction	2%	
Gas Conduction & Correction	10%	heat (93%)
Infrared	81%	
Ultraviolet	0.5%	
Visible	6.5%	
Total................	100%	

Metal Halide Technology

Electrode Losses	12%	
Gas Conduction & Wall Absorption	25%	heat (54%)
Infrared	17%	
Ultraviolet	19%	
Visible	27%	
Total................	100%	

From the above information, it can be deduced that the present 80 watt tungsten halogen lamp used in the conceptual model will generate approximately 74 watts of heat and 5 watts of light. In comparison, the 60-watt standard fill metal halide will generate 32 watts of heat and 16 watts of light.

The resultant design improvements are -

Heat reduction - 57%

Light production - 320%

As can be seen in the preceding analysis, significant improvements have been made in the areas of heat reduction and light production. **Unfortunately, this is not enough in terms of light production.**

The present 60 watt prototype metal halide lamp is capable of producing approximately 3,480 lumens (60 watts times 58 lumens/watt). Using equation **2** and rearranging the terms to solve for E yields

$$E = \frac{\phi(\eta\,\mathrm{col.})(\eta\,\mathrm{win.})(\eta\,\mathrm{cable})(\eta\,\mathrm{dif.})}{\substack{2\\ \pi D}} \qquad \text{(eq 3)}$$

where ϕ = 3500 lumens
D = distance from diffuser = 6 feet
Let η_{tp} = present total system efficiency
where $\eta_{tp} = (\eta\,\mathrm{col.})(\eta\,\mathrm{win.})\ (\eta\,\mathrm{cable})\eta\,\mathrm{dif.})$

Assume 35% collector efficiency and a 15-foot fiber optics cable

Then $\eta_{tp} = (.35)(.95)(.23)(.45) = .0344$

$$E = \frac{\eta_{tp}}{\substack{2\\ \pi D}} = \frac{3500(.0344)}{\substack{2\\ 3.14(6)}} = \frac{119}{113} = 1.06\ \mathrm{F.C.}$$

As shown in the above analysis, the 60-watt metal halide lamp with the present light-loading assembly is capable of producing 1.06 foot candles at a distance of 6 feet from the diffuser. This is a little more than one-half of the 2 foot candles required by the regulations.

In addition to overdriving the lamp, another option is available for increasing the lumen output. This option involves changing the metallic salt mixture that is added to the arc tube. It is known that the addition of thallium iodide to the fill mixture can increase the lumen output of the standard metal halide lamp from 58 lumens/watt to 75 or 80 lumens/watt. This is accomplished by altering the spectral distribution of the lamp and, in effect, providing more emission in the yellow-green portion of the spectrum and less emission in the blue end. This technique does alter the color rendering properties of the lamp, however, and for this reason, it is normally not used because most applications require lighting with good color-rendering properties. It is believed by the author that in mining applications, color rendition is not an essential consideration, particularly when you have the use of a caplamp for detailed task work. In this case, the altered color rendition produced by the thalium iodide doping is not very severe and is a far cry from that of the monochromatic low pressure sodium lamp. Visually, the lamp appears a greenish-white because of the enhanced yellow-green emission and decreased blue.

Another important aspect or benefit of this effect is that the resultant spectrum shift will allow more light to be transmitted through the fiber optics cables because the new spectral distribution is more compatible with the spectral transmission of the cables. In effect, we are impedance matching to obtain maximum power transfer. The net magnitude of this effect is not known at this time.

If the thallium iodide studies prove successful, the following light levels could be achieved:

$$E = \frac{\phi \eta_{tp}}{\pi D^2}$$

where ϕ = 4500 lumens (60 watts x 75 lumens/watt)
η_{tp} = .0344
D = 6 ft

Then: $$E = \frac{4550(.0344)}{3.14(6)^2} = \frac{154.8}{113.04} = 1.37 \text{ F.C.}$$

Note: The above levels do not take into account the impedance-matching effect previously mentioned.

(b) Efficiency of the Light Loading Assembly

The preceding analysis is based on projected or expected lumen output levels, and it would be unrealistic to assume that all of our expectations would come to fruition. In addition, if the levels were achieved, they would only be sufficient for thin seam mining applications. Ideally, one would like the new lighting system to be applicable to all mining environments, so that its inherent benefits could have widespread use.

In view of the fact that we are operating at the state-of-the-art of source technology, if additional light output from the system is required, it can only be obtained by improving the efficiency of the light loading assembly.

As can be seen from equation **3**, there are three parameters that can affect the light output of the system: , tp, and D.

$$E = \frac{\phi \eta_{tp}}{\pi D^2}$$

is the luminous flux from the source; efforts to maximize this parameter have been discussed in the previous section. D is the distance from the diffuser to the mine surface and is determined by the seam width or height, and the machine dimensions, which are beyond our control. η_{tp} is the present total efficiency of the light loading assembly and can be expressed as the product of four component efficiencies:

$$\eta_{tp} = (\eta_{col.})(\eta_{win.})(\eta_{cable})(\eta_{dif.}) \quad \textbf{(eq. 4)}$$

$\eta_{collector}$ is the collection or delivery efficiency of the reflector assembly of the lamp and is determined by the design limits of the lamp designer; it is estimated at .35.

Note: Some control of the delivery efficiency can be obtained by increasing the numerical aperture (N.A.) of the fiber optics cable and by increasing the diameter of the cable. This will be discussed in a later section.

η_{window} is the transmission efficiency of the 1/2-inch-thick optical window used in the XP enclosure and has been measured at 0.95.

η_{cable} is the transmission efficiency of a 15-foot glass fiber optics cable and has been measured at approximately .23.

$\eta_{diffuser}$ is the transmission efficiency of the diffusion assembly and has an average measured value of .45.

Substituting the above values into equation **4** for η_{tp} yields the present total system efficiency:

$$\eta_{tp} = (.35)(.95)(.23)(.45) = .0344$$

It is anticipated that continuing efforts on improving the system efficiency could lead to the following increases:

$\eta_{collector}$ = .35 (no improvement)
η_{window} = .98 (increased from .95)
η_{cable} = .29 (increased from .23)
$\eta_{diffuser}$ = .65 (increased from .45)

Substituting the projected improvements into equation **4** yields

$$\eta_{tI} = (.35)(.98)(.27)(.65) = .060$$

where η_{tI} = improved total system efficiency

Substituting the new η_{tI} into equation **3** yields the following increases in the system output levels:

$$E = \frac{\phi \eta_{tI}}{\pi D^{2}}$$

where ϕ = 4500 lumens, η_{tI} = .060, D = 6 ft

$$E = 1.84\left(\frac{4500}{3480}\right) = 1.84(1.29) = 2.38 \text{ F.C.}$$

(c) Related Efforts:

(1) Source Powering: The metal halide lamp under development is essentially a mercury vapor lamp that utilizes short-arc technology and metal halide additives to alter the spectral distribution. The altered spectral distribution provides an increased lumen output when compared to the standard mercury vapor lamp. Like all arc discharge lamps, the new lamp has one major disadvantage in that it will extinguish when power is momentarily interrupted. If this occurs when the lamp is hot, conventional ballasting will not be able to restrike the lamp when power returns. Typically, it takes approximately 5 minutes for the lamp to cool sufficiently before the conventional ballast can restrike the lamp. This time delay is usually unacceptable in underground mining applications. To restrike the lamp in a hot condition requires a special ballast design that is capable of supplying starting pulses in the 6 KV range. While this is not a significant problem for the ballast designer, it does pose problems in the design of the lamp. The lamp is a short-arc single-ended lamp, which means it is physically small and that both electrode leads are exited at one end of the lamp. Because of this, it becomes a difficult design task to prevent the high-voltage starting pulses from tracking between the leads, rather than at the electrode tips. To date, a prototype ballast has been designed (figure 10). Also, a design for a lamp has been completed that can withstand the high-voltage starting pulses (figure 11). The ballast design is conventional technology (choke, transformer) and should be more reliable than a solid state configuration, particularly in a mining environment where it will be exposed to high transients.

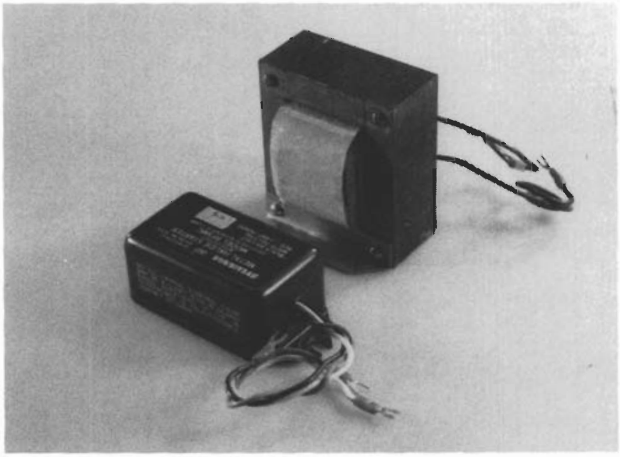

FIGURE 10. - Ballast and starter for metal halide lamp

FIGURE 11. - New metal halide projection lamp

(2) Fiber Optics Cables: Considerable efforts have been focused on improving the efficiency of the glass fiber optics cables. These efforts have resulted in a 10% increase in the transmission efficiency of the cables and involved working with the manufacturer to improve the quality control of the manufacturing process. Initially, the cables were approximately 20% to 25% low in their efficiency when compared to their advertised specifications. Studies of the problem showed that the packing fractions of the cables were low, which was the result of a reduced number of fibers in the cable. In addition to the low number of fibers, the actual control of the amount of fibers varied from cable to cable, causing large variations in the transmission of cables of the same length. This was brought to the attention of the manufacturer, and some improvements in the efficiency and consistency were obtained. In addition, the particular epoxy that the manufacturer was using did not lend itself to a good finish on the ends of the cables, resulting in higher-than-expected entrance and exit losses. The epoxy formulation has been changed, and some improvements have been achieved in this area.

In addition, the numerical aperture (N.A.) of the cables has been increased from .55 to .68. This has been accomplished by changing the core and clad materials and consequently their respective indices of refraction. The larger

N.A. gives a much larger acceptance angle and consequently allows a larger cone of light to enter the cables.

Other efforts in this area have focused on obtaining a better sheathing material for the cable; in particular, a material is needed that would provide good flexibility, durability, crush resistance, and above all, good transparency so that the light that normally leaks from the individual fibers can be utilized to supplement the diffusion assemblies for area illumination. A sheathing material has been found that meets our objectives. The new sheathing is a wire-reinforced, clear polyvinylchloride hose (figure 12).

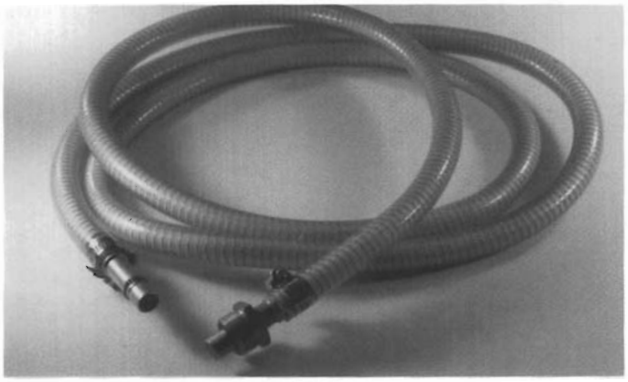

FIGURE 12. - Fiber optic cable with transparent/protective sheath

STATUS OF PRESENT RESEARCH

To date, a prototype fiber optics mine lighting system has been designed and fabricated according to the requirements of MSHA's Schedule 2G for explosion-proof enclosures (figure 13). The system uses the new standard fill metal halide lamps and ballasting system and is capable of providing 1.65 foot candles at distance of 6 feet away from the diffusing assembly. This is accomplished with a 15-foot-long fiber optics cable. The 15 foot cable is used for testing purposes because this is a worst case condition. In practice, most applications will use shorter cable lengths, and accordingly the output will be higher.

In the near future, the thalium doped lamps will be completed. It is anticipated that the new thalium lamps will bring the output close to the 2-foot-candle target.

Research to further improve the system output is continuing. Attempts will be made to improve the efficiency of the diffusing assembly, which at present is approximately 50%. It is anticipated that designs can be made that will have an efficiency in the 75% to 80% range.

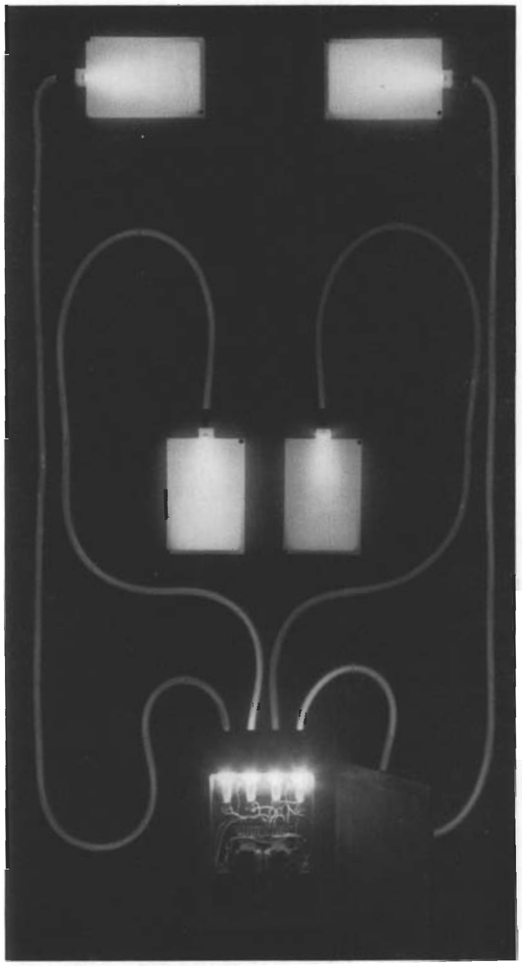

FIGURE 13. - Advanced prototype fiber optic mine lighting system

CONCLUSIONS

If ongoing research proves successful, the new lighting concept will provide the mining industry with a machine-mountable lighting system that offers significant improvements over conventional mine lighting systems in the following areas:

- glare (discomfort and disability)
- safety (electrical and explosion-proof integrity)
- reliability
- economy
- ease of maintenance and installation

Additional research is needed to improve the overall system efficiency so that its inherent benefits can be extended from low seam to high-seam coal mine applications where a greater light output would be required.

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