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REMOTE VISUAL INSPECTION SYSTEM

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16. ABSTRACT

The purpose of this project was to develop a visual inspection system and techniques for inspecting areas not accessible for direct viewing, such as the inside of valves and lines installed on a flight vehicle. The phases of research included mirror systems, rigid borescopes, flexible fiberscopes, closed circuit television, and light supplies. The project produced an operational television-fiberscope inspection system which is available with an operator for "on-call" service. The system is mounted in modular sections on a standard laboratory cart, weighs only 220 pounds, operates on 110 volts, and can be moved in a car or light truck by one or two people.

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REMOTE VISUAL INSPECTION SYSTEM

SUMMARY

The purpose of this project was to develop a visual inspection system and techniques for inspecting areas not accessible for direct viewing, such as the inside of valves and lines installed on a flight vehicle. The parameters within which this system was developed included:

- Portability
- High image resolution
- Permanent image retention
- Operator ease of operation

The phases of research included mirror systems, rigid borescopes, flexible fiberscopes, closed circuit television, and light supplies.

The project produced an operational television-fiberscope inspection system which is available with an operator for "on-call" service. The system is mounted in modular sections on a standard laboratory cart, weighs only 220 pounds, operates on 110 volts, and can be moved in a car or light truck by one or two people.

SECTION I. INTRODUCTION

The purpose of this project was to develop a visual inspection system and techniques for inspecting areas not accessible for direct viewing, such as the inside of valves and lines installed on a flight vehicle. The parameters within which this system was developed included:

- Portability -- System was to be compact and flexible enough to permit easy transportation by one or two people in a common vehicle such as a pickup truck or large car.

- High image resolution -- System resolution was to be equal to the present inspection devices or about 40 paired lines per millimeter.

- Permanent image retention -- Permanent image retention was to be either photographic film or video tape.

- Operator ease of operation -- System was to be capable of entering close places on space vehicles and still be efficiently operated for long periods of time without undue physical strain on the operator.

SECTION II. DISCUSSION

The different phases of the investigation included mirror systems, rigid borescopes, the newer flexible fiberscopes, closed circuit television, and light supplies.

Mirror systems range from a simple, hand-held mirror (used in almost all areas of inspection) to a 3-foot long, 1/2-inch diameter tube made with a series of mirrors or prisms which can transmit the image through a limited curve.

Borescopes have been used in inspection for many years. They can be obtained as "off-the-shelf" models (see figure 1) or as very sophisticated special purpose models made to perform a specific task. Borescopes are precision optical instruments used for a wide variety of internal surface inspection problems. They can be used to inspect surfaces through holes as small as .020 inch or to inspect larger surfaces such as heat exchanger tubes, 4 inches in diameter and 60 feet long. Their optical systems provide for oblique, right angle, or retrospective visual fields. (See figure 2.) Their lens systems are usually nonreflective coated to provide maximum light transmission and brilliant, distortion-free images. The brightest images are obtained with borescopes of large diameter and short length. As the length is increased, the image brilliance decreases due to light loss. In most borescopes, the observed visual area is approximately 1 inch in diameter at a 1-inch distance from the objective lens. The size of the visual field usually varies directly with the borescope diameter for a given magnification.

The borescope has three basic lens systems, the objective, middle, and ocular. The objective lens system consists of a group of prisms and lenses mounted close together. (See figure 3.) Design determines the angle of view, size of visual field, and the amount of light gathered by the system. The middle lenses conserve the light entering the system and conduct it through the tube to the eye with a minimum of light loss. The design of the middle lenses has such an important influence on the quality of the image obtained, that one company uses achromatic middle lenses, i.e., each lens is composed of two elements having the proper curvature and indices of refraction. This system helps to preserve the sharpness and true color of the image. Depending on the design of the borescope, the image requires reversal and/or inversion at the ocular. This is accomplished with a prism in small diameter borescopes and erecting lenses in larger systems.

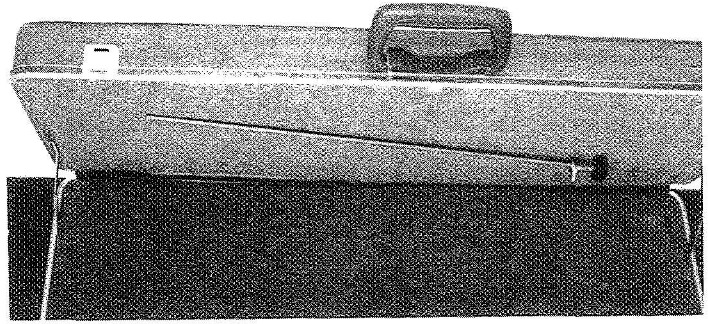


Figure 1. Borescope

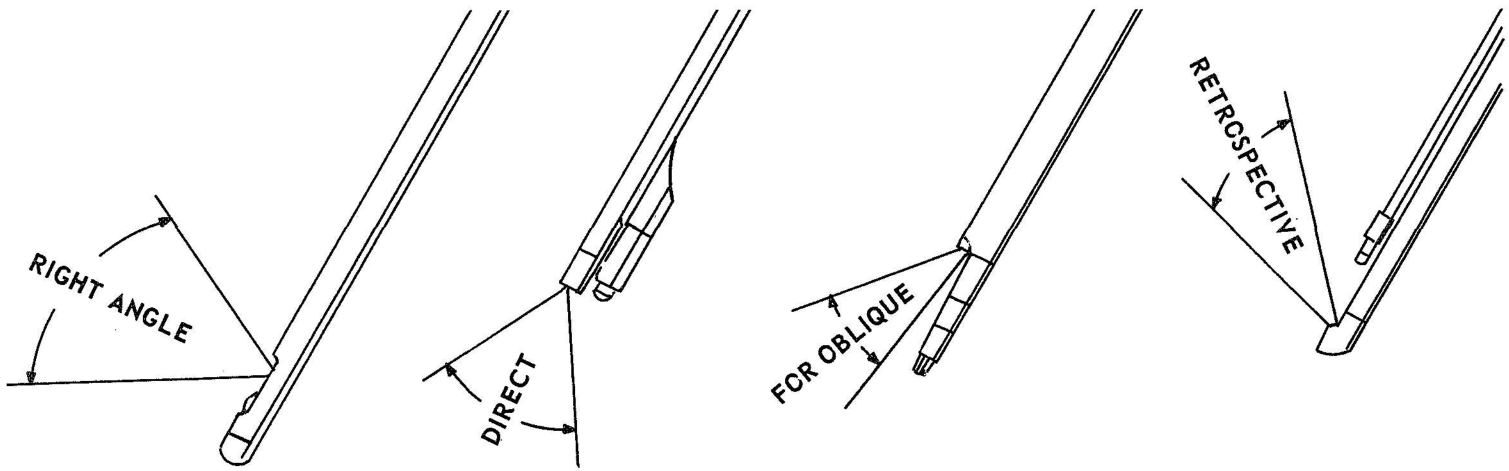


Figure 2. Inspection Uses of Borescopes

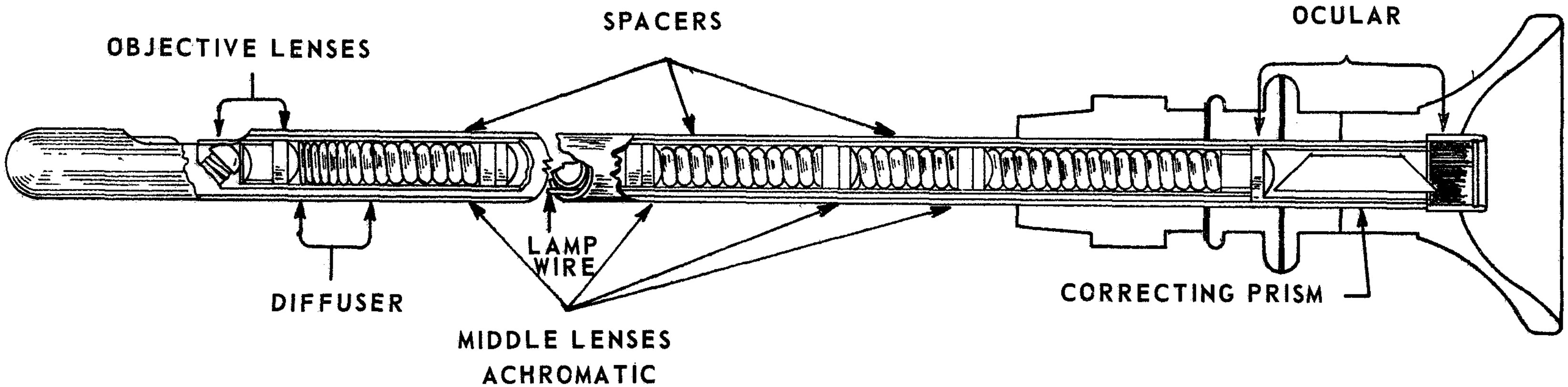


Figure 3. Cutaway View of a Borescope

As a result of the large number of different designs and configurations produced over the years by the various borescope manufacturers, common practice is to present the inspection problem to one or more borescope companies to design and build the precise borescope required.

Although borescopes are a valuable inspection tool, they are limited. While they can be used to inspect around a corner, their rigid structure limits their ability to go around a bend. The configuration of their objective end with its required light source also limits the size of hole the unit can pass through.

The bending limitations of borescopes are largely overcome by recent developments in image transmitting coherent fiberoptic bundles. These fiberoptic bundles, commonly called fiberscopes (see figure 4), have basically the same ocular and objective lens systems as rigid borescopes. Thus, with the same lens systems, the same design criteria and optical operating parameters apply to both fiberscopes and rigid borescopes. However, the fiberscope suffers a slightly greater loss of light and resolution in the fiber bundle which is used in place of the middle lense system of the rigid borescope. The better quality fiber bundles are made of high quality optical glass with a high refractive index, each fiber being coated with a low index optical glass. The light entering one end of an individual fiber is first refracted by the end surface and then reflected at a series of points along the wall of the fiber, the reflected angle being greater than the critical angle of the glass. Finally, the light emerges at the other end at an angle of the same order as the entrance angle. (See figure 5.) Since the fiber is coated with a low index of refraction optical glass, the loss of light is due mainly to absorption and most of the light entering one end emerges at the other. To produce an image, each fiber (over 250,000 fibers in a 1/4-inch square bundle) must be in the exact corresponding position at each end of the bundle. Thus, they form an optical plane and an image will be transmitted from one end to the other.

Some fiberscopes have had a breakage problem. In a standard fiberscope, each fiber transmits a portion of the image and if a fiber is broken, it appears as a dark spot. One design forms the individual fibers into small square bundles which are then grouped to form a larger bundle. This technique results in a mosiac pattern of the image carrying fibers. This type of bundle, if formed in a curve and then rotated from one end, will result in a large percentage of broken fibers after a very short use period. (See figure 6.) Another design leaves the individual fibers loose in a flexible metal or plastic shield. This design permits small radius bends of the bundles and the sheath permits the rotation of

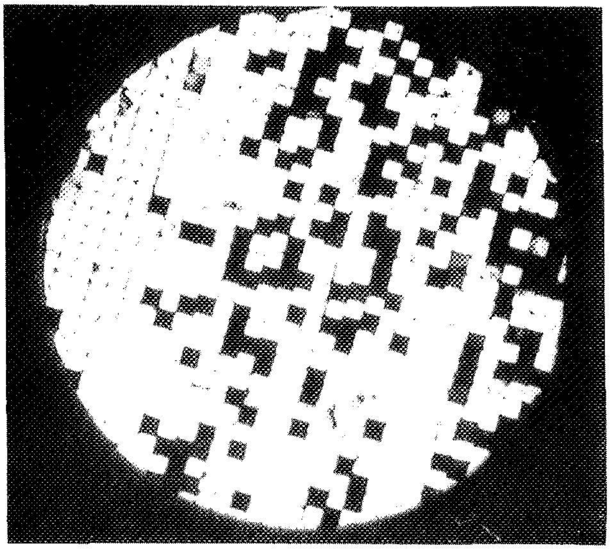


Figure 4. Fiberscope

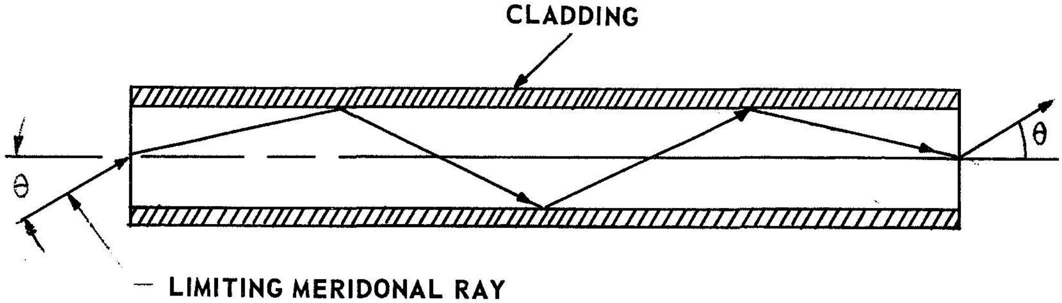


Figure 5. Light Path Through Each Fiber in Fiberscopes

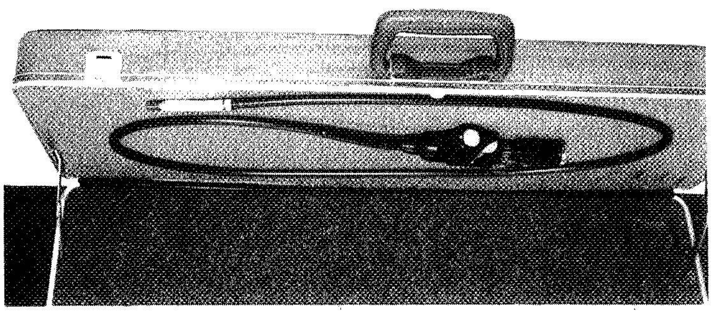


Figure 6. Fiberscope's Broken Fibers

a curved bundle without adverse effects. One company, experiencing fiber breakage, has added a prism in the objective which disperses the image so the color information from each point in the image is spread over a series of fibers. The image is then reconstructed by another prism in the ocular. Thus, if a particular fiber is broken, the effect is not a black void in the image but a slightly darkened streak, in which different wavelengths have been removed. Since this is in effect a multiplexing scheme, resolution is increased. Ten micron fiber elements have an inherent resolving capability of 50 lines per millimeter. By multiplexing bits of information through a number of fibers, this resolution can theoretically be doubled. In actual practice, the gain is about 60 percent.

The development of these fiber bundles for industrial use presents many problems. The borescopes incorporating optical image transmitting bundles must have good optical performance, good resolution, color rendition, and contrast. They must be rugged enough to stand repeated use in visually inaccessible areas and adapt themselves to the irregular contours.

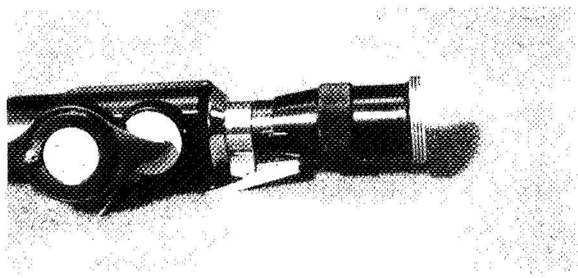
Another method of indirectly viewing areas is a closed circuit television system. The cameras can be as small as 1 1/2 inches in diameter and can be fed through hundreds of feet of pipe such as 4-inch gas mains and other larger cavities. These systems can contain video tape capabilities for a continuing picture of the objective under observation. The television system can be obtained with high resolution cameras and monitors which give results comparable to the best rigid borescope.

When an internal inspection device such as the borescope is used, illumination is a major item. At the present time, incandescent lamps are used at the objective end of rigid borescopes and at the ocular or objective end of the flexible fiberoptic borescopes. When the incandescent lamp is used at the ocular end, it is either in a separate, remote unit and connected by an optical fiber bundle; or it is mounted directly on the ocular section of the borescope. In either case, the light is transmitted along the borescope by a fiber bundle. In one case, the light transmitting section is "halo" shaped around the image section.

While the optical fiber transmission system looses some light, it delivers "cold" light to the objective and hence, is safe in an explosive area. Light from high intensity projection bulbs can be transmitted via fiber bundles to give sufficient illumination for photographic or television recording of the ocular image. With proper lens and adaptors, a wide variety of photographic and television equipment can be used. An accurate, permanent record can be easily obtained on an entire system, and individual points may be closely scrutinized at a later date. Light intensity and polarization become a factor in highly reflective interiors such as stainless steel, aluminum, and fine surface machine work.

A review of the preceeding systems led to the development of a system mating the flexible fiberscope with the closed circuit television system. This was done by using the standard eye piece or ocular lens assembly to project the image of the item under inspection. It is a general practice to add an adapter lens between the fiberscope or borescope and the film or television cameras. The addition of this lens cuts down the available light at the film plane or on the vidicon tube of a television camera. The adapter lens also cuts down on the total system resolution. As a means of overcoming these two problems, the ocular lens of the fiberscope was modified so it projected a 5/8-inch diameter image at a distance of 4 inches from the eye piece of the fiberscope. The lens modification was accomplished by spacing the final lens assembly approximately 5/16-inch beyond its original position on the fiberscope. This can be easily done by loosening a set screw and relocating the eye piece (figure 7 a and b) or replacing the eye piece with an adaptor lens (figure 7b). Utilizing the ocular lens or eye piece of the fiberscope as a projecting lens required an adustable extension tube to keep external light from reaching the face of the television camera vidicon tube. Also, a mounting fixture was designed to hold the television camera firmly and correctly align the eye piece of the fiberscope with the vidicon tube. It was necessary to keep this unit as small as possible, so it could be carried into physically restricted areas of space vehicles. (See figure 8.) Instead of mounting the television camera on the fiberscope support, the vidicon tube and its electronic yoke control assembly were removed from the main camera body and mounted directly on the fiberscope ocular end support bracket. The assembly was electrically connected by an adapter cable to the main camera body and its controls. The camera was in turn connected to two other units. The first unit was a Model RCV 17 Conrac TV monitor with an inherent resolution of 500 lines. The second unit was a video distribution amplifier which could feed the video signal to another communications building where the image and audio could be permanently recorded or sent out over the George C. Marshall Space Flight Center (MSFC) television distribution system.

a.



b.

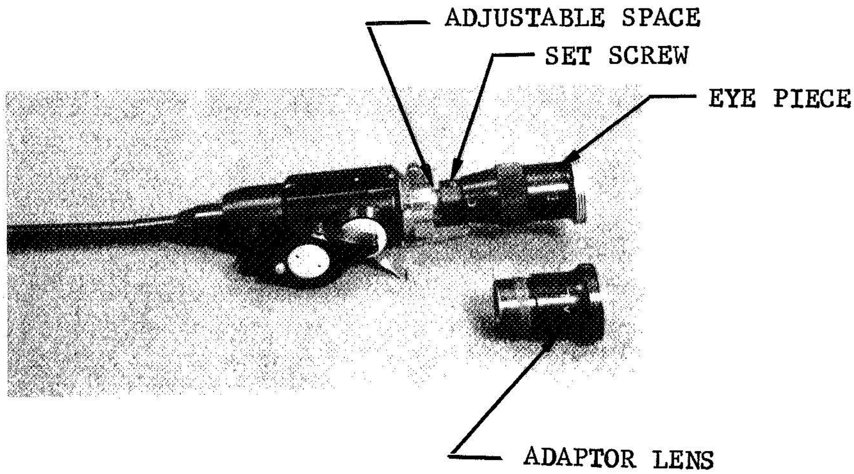


Figure 7. Lens Modification

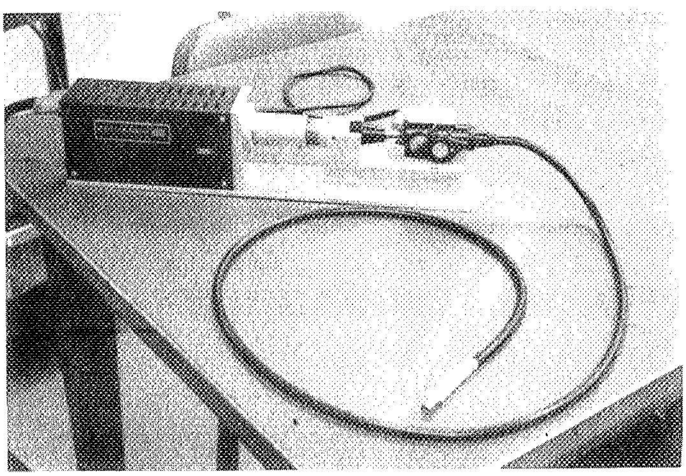


Figure 8. Camera and Fiberscope Assembly

The MSFC distribution system reaches management level offices, conference rooms, and other selected locations. If the inspection unit is not in an area where there is a hard wire connection with the communications center, then the signal can be transmitted by microwave link. There is also a capability of using the fiberscope and TV camera at a remote location such as Launch Complex 39 and having the defect shown at MSFC at the same time it is seen at the remote location.

Even though the camera was equipped with a low-light level vidicon tube, compatible with the basic 800-line resolution specification, a good light source was needed. Two commercial units were obtained. The primary light source is an American Cystoscope Makers Model FCB-1000 routine and photographic light supply (figure 9). The unit consists of two lamps. One of the lamps is an incandescent projection lamp of 150 watts, focused to provide a spot of light of maximum intensity on the face of the light carrier bundle plugged into the front of the case. The second is an arc lamp designed for photographic purposes. The intensity generated at the input fact of the fiber bundle is 300 to 500 percent greater than that of the incandescent lamp. Four thousand-foot candles are emitted at the end of a 6-foot, 5 millimeter fiber bundle. This unit is good for photographic use because of its constant 5000° K color temperature which permits better color film balance. The second light supply is an Optical Fiber Corporation Model Q1 250 (figure 10) unit which delivers up to 11,000 candle power with a color temperature of 2800°K. This light supply has an assortment of noncoherent fiberoptic "light pipes." This unit is used to "side" or "back" light the item under inspection. This gives more depth of field to the image for better identification.

The primary light supply is connected to the fiberscope bv a 5-foot long, highly flexible, noncoherent fiber bundle. Another bundle is built into the fiberscope that carries the light to the very tip of the fiberscope. In this model fiberscope, the light source illuminates an area essentially straight ahead along the axis of the fiberscope.

The fiberscope is an American Cystoscope Makers Model BFO-3864-DD. This is basically a medical device with minor adaptations for use in the mechanical inspection field. It has an adjustable eye piece and the objective end has a remote controlled focal length capability. A 6-inch section of the objective end can be remotely pivoted during use. (See figure 11.)

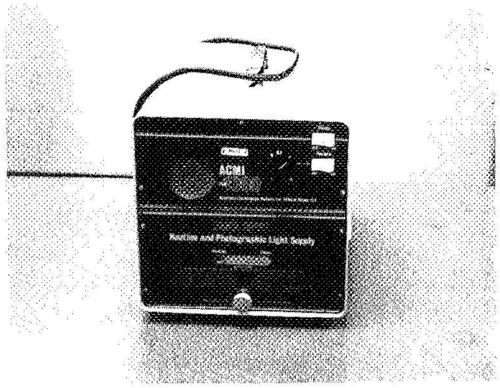


Figure 9. Primary Light Source

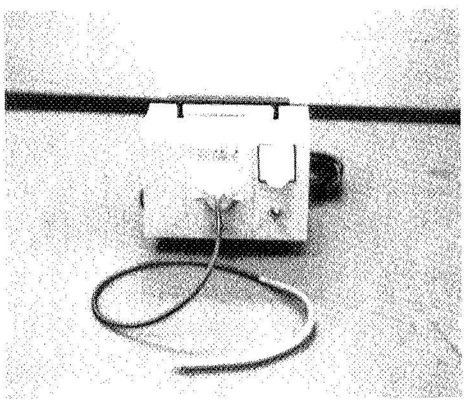


Figure 10. Secondary Light Supply

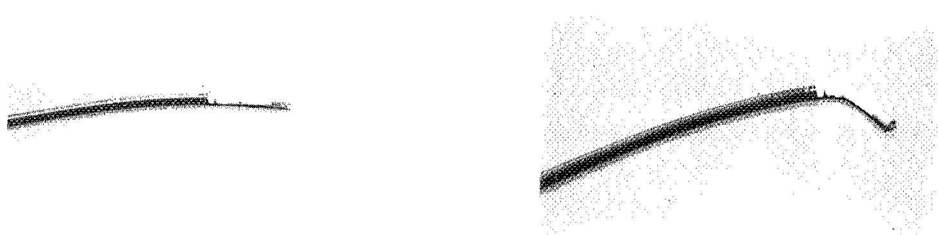


Figure 11. Pivotable Objective End of Fiberscope

The objective lens can be focused through a range of from 1/4 to 1 1/4 inches and has a field of view of from 1/8 to 1 square inch directly proportional to the viewing distance. The fiberscope can penetrate into an object up to 6 feet, which means that it can be used to inspect a 12-foot tube if both ends are open.

The camera and fiberscope can be placed into some areas that a man's head cannot reach for solid borescope use. The entire system is modularized so it can be carried into most areas that a man can get to. When the system is separated, with the camera in one area and the monitor in another, a spare monitor of small size (7 to 10 inches) must be with the operator so he can position the bundle correctly. When the light supply is moved more than 6 feet from the fiberscope - vidicon unit, excessive light loss will occur. A redesign of the fiber bundle and the focusing points would eliminate a major portion of this problem.

After these various components were integrated into a working system, it was mounted on a portable cart. (See figure 12.) This equipment can be easily transported to almost any site in the country. It requires only 20 amperes at 110 volts for operation and weighs approximately 220 pounds complete.

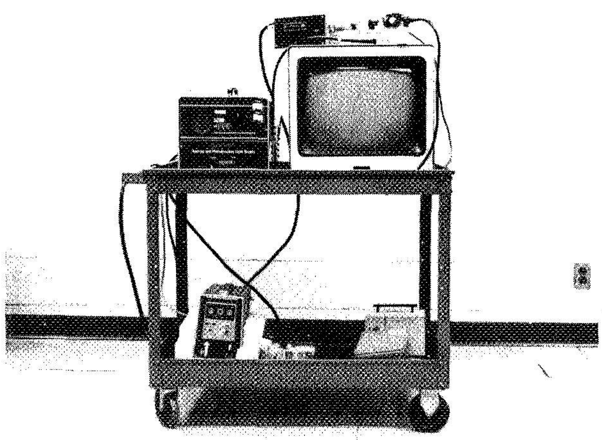


Figure 12. Remote Visual Inspection System Mounted on a Portable Cart.

SECTION III. APPLICATION

This system can be used in many areas of inspection, design, and failure analysis. The technology used to design this system could be applied to improving existing units in the medical profession for use in space medicine, i.e., measurement of organ movement during launch conditions.

In the inspection field, many systems on the space shuttle can be aided by incorporating provisions for use of this system. If small, light-weight tubes were installed during initial construction, the inspection of critical areas for possible refurbishment would be much faster. The wing attachment areas, areas of maximum heat and force, thrust areas, control surface supports, and controls will all have to be checked, some in space and all after landing. A small guide tube could direct the fiberscope to exactly the right spot to facilitate inspection of these areas. A great deal of time is lost in some areas because of the time needed to precisely place inspection devices for critical observation. Many valves, controls, and electronic "black boxes" can be quickly checked for the effects of re-entry heat. They can also be checked for damage from lift-off forces and vibrations. In the field of design analysis, the fiberscope can bring a constant, real-time image from a unit in cold tests, on vibration tables, thermal shock, and many other types of analysis to an operator or group of observers where they can view the operation directly or review it later with a taped replay.

This system provides the capability for more than one man to see a defective area at the same time. For many years, a problem has existed in that when a borescope is used succeeding viewers may not see the same thing. This occurs because of the difficulty in orienting a borescope by someone who does not use one often and does not know the internal area of the item under inspection. When the borescope is passed to another person, he may not reposition it in exactly the same position and consequently will not see what the first inspector saw; hence, a faulty evaluation results. With the television system and its monitor, any number of people can see the same defect at the same time.

Now that many space boosters and subassemblies are being stored in environmentally controlled areas, another type of inspection is needed. These units need to remain sealed and yet monitored for contamination of their systems. If fiberoptic bundles were placed in selected systems at the time of storage, the systems could be surveyed during storage for contamination and corrosion. An alternate method would be to insert the fiber bundle through sealing bayonnet ports which would also permit inspection without compromising system integrity.

The techniques discussed in this report can be used in the medical field as well. While fiberscopes are in use in medicine, the need exists to develop the "real time" capability of video tape. The area of diagnostic investigation and consultation can well use the "group viewing" and long distance transmission of video data between medical centers.

SECTION IV. FUTURE DEVELOPMENT

There is much more development needed in this field. First, there are many problems with illuminating the area under investigation. The choice of vidicon tube characteristics depends on the dispersion angle of the illumination at the ocular lens, the acceptance angle of the lens, and its light gathering qualities. This means that the light that will work with one fiberscope under some circumstances will burn out and destroy the vidicon tube with another fiberscope in another situation.

Possible solutions involve polarized light, diffusion lenses developed for use with fiberscopes, and finding a limited number of vidicon tubes that will accept the different situations involving fiberscopes, light supplies and inspection situations.

Another area that needs investigation is the use of ultraviolet light with the fiberscope. When a method to produce an ultraviolet light at the end of the fiber bundle is found, a great step forward in weld and casting inspection will result. Through the use of fluorescent dye penetrants, any cracks or passages from the outside of a casting to the inside could be quickly seen. The problem lies in the fact that ultraviolet light will not pass through the glass of a fiber bundle. When a method to illuminate the area being inspected with the fiberscope is found, the dye will fluoresce and the resultant light will be visible by normal means.

Within the space field as well as the medical field there is a need for accurate color rendition and transmission through fiberoptics. This is needed for corrosion and contamination investigation. Good color rendition on a "real time" basis would greatly help the development of certain diagnostic and surgical techniques, i.e., surgery on the retina of the eye.

SECTION V. CONCLUSIONS

The project produced an operational television - fiberscope inspection system which is available with an operator for "on call" service.

The system consists of:

- o A Sylvania 800 series camera with 800 line resolution.
- o A Conrac Model 14 TV monitor with about 500 line resolution.
- o An American Cystoscope Maker's Light Supply Model 1000 containing a 150-watt lamp and a 1000-watt mercury vapor lamp.
- o A fiberoptic light supply with a 150-watt lamp.
- o Two American Cystoscope Maker's Model BFO-3864-DD fiberscopes, one has a 1/8 to 1 square inch field size and 1/4 to 1 1/2-inch focus capability and the other has a 2 square inch to over 10 square foot field with a focus capability from 1 to over 10 inches. Both fiberscopes are 72 inches long, have remote focus of the objective lens, and have remote position control of the final 6 inches of the tip.

The system is mounted in modular sections on a standard laboratory cart, weighs 220 pounds, requires 20 amperes at 110 volts, and can be loaded into a car or light truck by one or two people.

The remote visual inspection system needs further research and development in the areas of illumination, use of ultraviolet light with the fiberscope, and color rendition and transmission through fiberoptics.

TECHNICAL MEMORANDUM X-64552

APPROVAL

REMOTE VISUAL INSPECTION SYSTEM

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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