

**Report of Investigations 8134**

# **Laser Alinement Sensor for Continuous-Mining Machines**

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**UNITED STATES DEPARTMENT OF THE INTERIOR**

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**BUREAU OF MINES**

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The work upon which this report is based was done for the Bureau of Mines, U.S. Department of the Interior, by Bendix Research Laboratories under contract number H0111194.

This publication has been cataloged as follows:

**Bowser, Merle L**

Laser alinement sensor for continuous-mining machines.  
[Washington] U.S. Bureau of Mines [1976]

10 p. illus. (U.S. Bureau of Mines. Report of investigations  
8134)

Based on work done by Bendix Research Laboratories under  
contract number H0111194.

I. Coal-mining machinery. 2. Lasers in mining. I. U.S. Bu-  
reau of Mines. II. Title. III. Title: Laser alinement sensor.  
(Series)

TN23.U7 r.o. 8134 622.06173

U.S. Dept. of the Int. Library

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# LASER ALINEMENT SENSOR FOR CONTINUOUS-MINING MACHINES

by

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## ABSTRACT

An alinement (steering) sensor for continuous mining machines has been developed under a Bureau of Mines contract.

A laser source in the entry projects a beam parallel to the centerline of the entry. The beam is optically shaped to a narrow, vertical fan and illuminates an array of optical sensors mounted on the mining machine. These sensors interpret the location of the beam into meter readings of heading (angle) error and lateral displacement errors. The system, which was tested for 5 months in an operating mine, appears to be fundamentally sound, and with some modification, should be applicable to remote or automatic guidance of continuous miners and other machines.

## INTRODUCTION

Presently used techniques for guiding a continuous-mining machine while advancing an entry are not totally satisfactory. The machine operator guides the mining machine by observing a line painted or chalked on the mine roof. Errors in entry bearing and alinement result from this method. Thus, an improved system for guiding a continuous-mining machine under manual control is desired and becomes a necessity when remote or automatic controls are being used.

The control of continuous-mining machines from a remote location provides safety and production benefits, but it presents additional guidance problems. Visibility of the machine by the operator is impaired by distance and other environmental conditions. Therefore, it is necessary to provide a remote operator with a readout at his position to show the exact location and attitude of the machine.

Automatic control of mining machines make additional demands on an alinement system; the alinement sensors must be included as part of the feedback loop in the automatic steering system.

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Bendix Research Laboratories,<sup>2</sup> under contract to the Bureau of Mines, has developed an alinement sensor system for use on continuous-mining machines. This system utilizes a low-powered laser in the entry to define a vertical reference plane for the continuous-mining machine. A meter display visible to the operator shows errors in heading (skew) and tracking (lateral displacement) that are detected by an array of photosensors and suitable optical components.

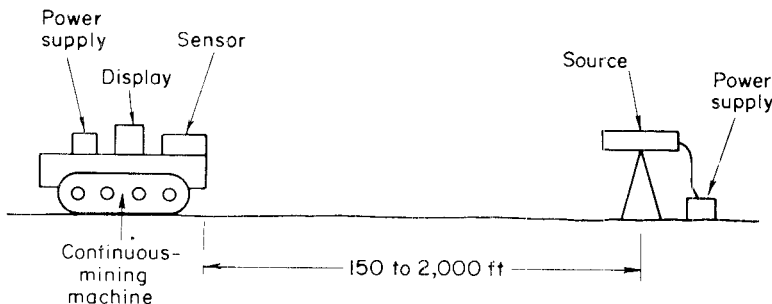
#### FUNCTIONAL DESCRIPTION OF ENTRY-ALINEMENT SENSOR

The continuous-mining machine entry-alinement sensor provides guidance signals, via meter display, to the operator of a mining machine. These signals indicate the lateral position of the machine and angular heading relative to a defined or reference direction.

The operator can maintain the continuous miner on the proper track by observing the signals displayed on the tracking-error and heading-error meters. When on zero, the pointers of these meters indicate that the miner is on track with respect to lateral displacement from the desired entry centerline, and that the miner heading is in agreement with the described heading of the entry. Each meter scale has a "window" within which the operator should endeavor to keep the meter pointers. The width of the window on the tracking error meter is tentatively set at  $\pm 4$  inches; the width of the window on the heading error meter is tentatively set at  $\pm 2.0^\circ$ . The principal meter that the operator will use will be the tracking error meter, which indicates machine location with respect to the desired entry centerline. The heading error meter will be used as a reference and guide for the operator so that he will not introduce large erroneous headings, which result in rapid and large lateral displacement errors.

The total system has four major components: The laser light source, the sensor, the display, and a power-supply package for the sensor and display units.

The laser source would be set up in the entry with the beam parallel to the centerline of the entry, but off-set when the mining machine is in its proper position.



The sensor, display, and power supply are mounted on the vehicle to be guided (fig. 1). The position of the source laser

FIGURE 1. - Sketch of continuous-mining machine alinement system.

<sup>2</sup> Bendix Research Laboratories. Feasibility of Remote Control and Development of Remote Control Devices and Sensors. Bureau of Mines Contract HO111194, June 1971.

beam on the sensor is interpreted by the sensor electronics; this information is presented to the machine operator on the display console.

In practice, the operator will make a rough alinement of the mining machine by referring to the visible laser beam while tramping up to the face. He will approach the face and position the cutting head so that pointers of both the tracking error meter and the heading error meter read close to zero. He will then advance, making heading changes as required to maintain the position of the pointer of the tracking error meter within the window. While mining, the operator will check for alinement before the start of each sump and adjust the heading to minimize tracking error. Thus, in the course of a 20-foot advance, the operator may check the alinement instruments six or seven times.

#### Laser Source Unit

The light source (fig. 2) projects a low-power laser beam along the path that the continuous miner has to follow. The source beam is pointed in the required direction during the setup procedure. A tripod was provided for support of the source unit, but other methods of support may be more desirable.

The source unit has adjustments used to establish the correct direction, shape, and focus of the light beam. Once adjusted, the light will continue to point in the required direction until physically moved or disturbed.

The laser beam has a narrow elliptical cross section; after adjustment; the beam is about 6 feet high and about 1/4 inch wide at the sensor. The

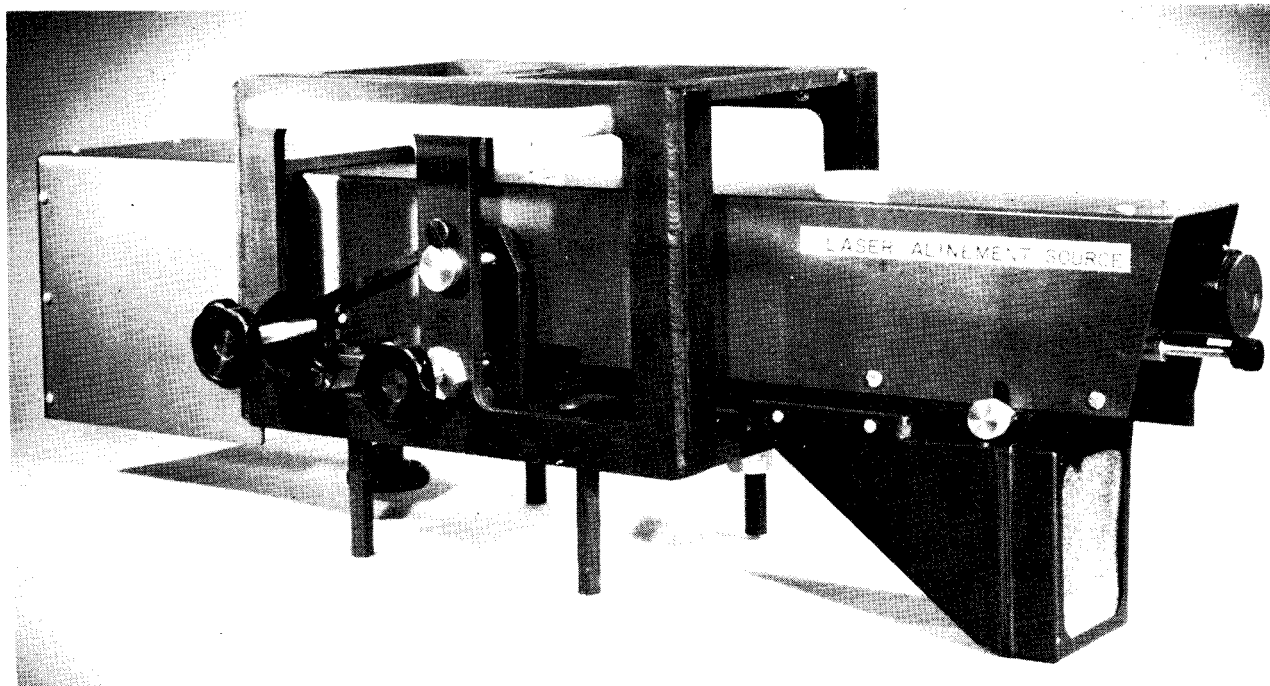


FIGURE 2. Laser source.

height of the beam allows the continuous miner and sensor array to move vertically and to pitch and roll without altering the display indication (provided the heading remains the same). Thus, the system can operate in spite of undulations in the seam. The light beam is interrupted at 1,000 Hz, and the sensor electronics respond only to signals of this frequency. Other lights such as vehicle headlamps and caplamps that may illuminate the sensor do not affect the display indication.

The optical elements are kept clean by blowing filtered air over them from a blower-filter located within the unit.

The source is powered by a standard 96-amp-hr automobile battery that can be recharged using a standard battery charger. When fully charged, a good battery will operate the source continuously for 24 hours. The prototype laser source is not approved for use in an explosive atmosphere and could only be used in intake air.

The light beam from the 3-Mw laser will not harm human eyes even when viewed directly since the energy density is extremely low.

#### Sensor Unit

The permissible sensor package detects the light beam and interprets the direction and position of the light beam to provide signals to the display unit. Figure 3 presents a general view of the sensor unit, and figure 4 shows how the sensor and display units fit onto the mining machine.

Sensor operation can be explained by referring to figure 5. The sensor box contains seven cylindrical Fresnel lenses that focus the light beam from the source onto one (or at most, two) split light detectors. (The light beam in figure 5 is imaged onto two detectors.) If the mining is proceeding in the correct direction (parallel to the light beam), the light is focused onto the center of the detectors (as shown in figure 5) and the signals are balanced. If the mining machine is not proceeding parallel to the light beam, the two halves of the split detector are unequally illuminated and unbalanced signals result. The electronics inside the sensor package provides a signal voltage to the display unit corresponding to the angle error of the mining machine; this is called the heading indication.

To determine the tracking error, or how far the mining machine is laterally displaced from the desired path, the electronics in the sensor unit determines which detector is receiving the highest signal. If it is the center detector, a "zero tracking error" is sent to the display unit. If one of the other detectors receives the highest signal, the electronics provide a "tracking error" signal to the display.

The sensor unit uses highly reliable, conservatively rated, solid-state devices and components. As such, it should provide long, maintenance-free service. In normal usage, internal circuit adjustments will not be necessary.

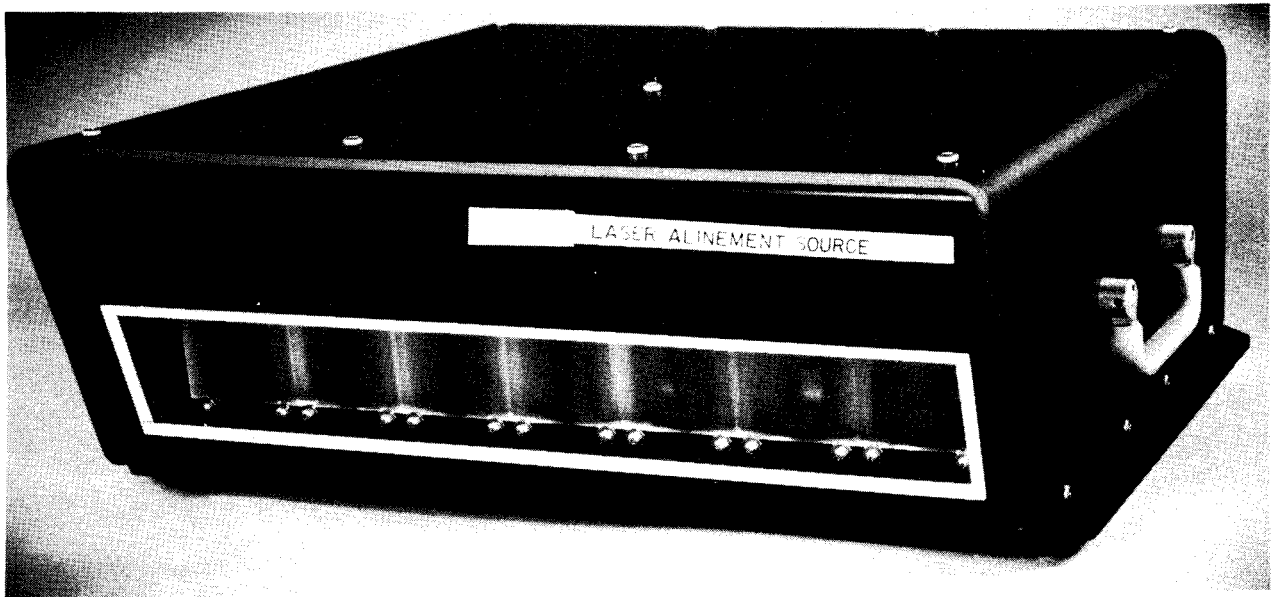


FIGURE 3. - Sensor unit.

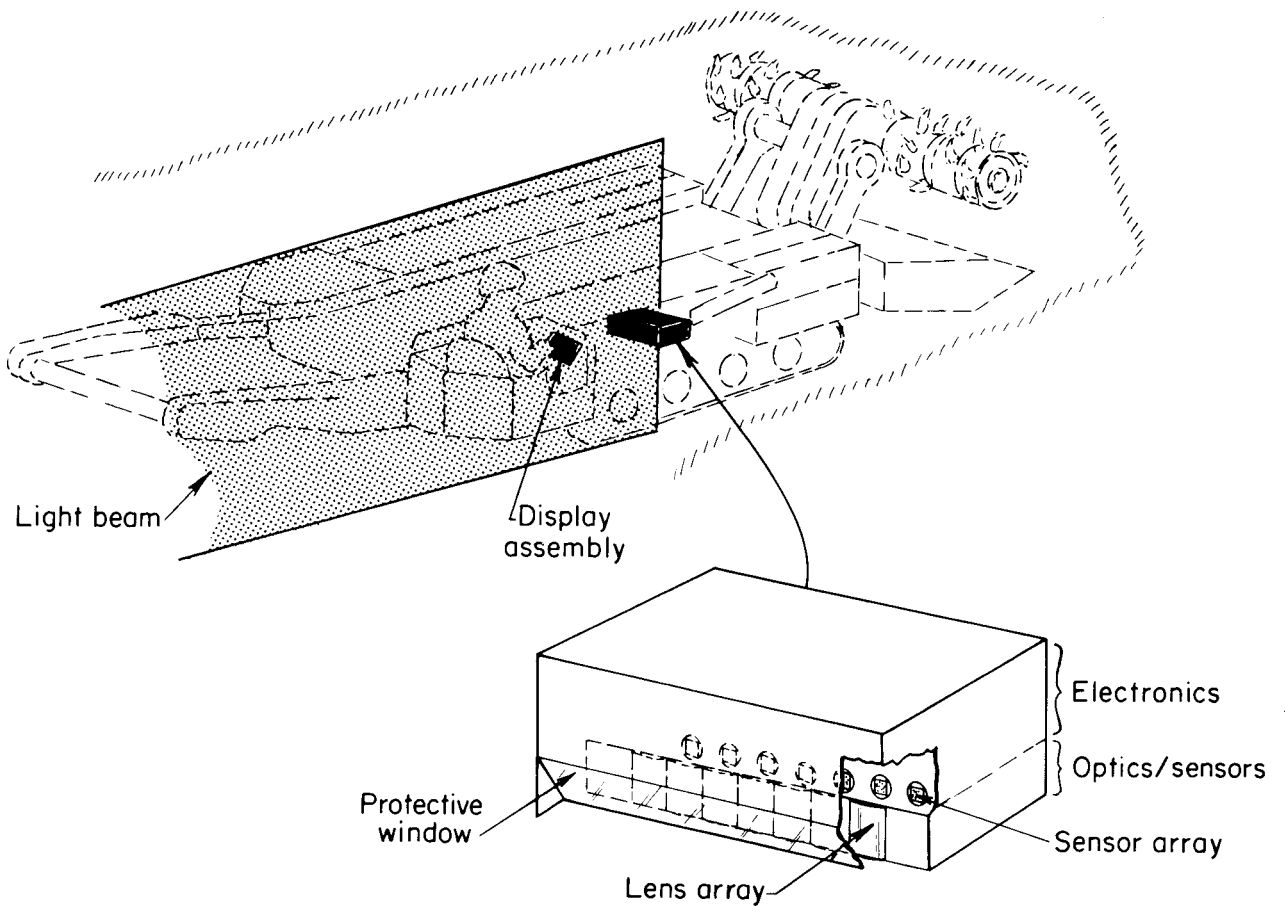


FIGURE 4. - Schematic of sensor and display units on continuous-mining machine.

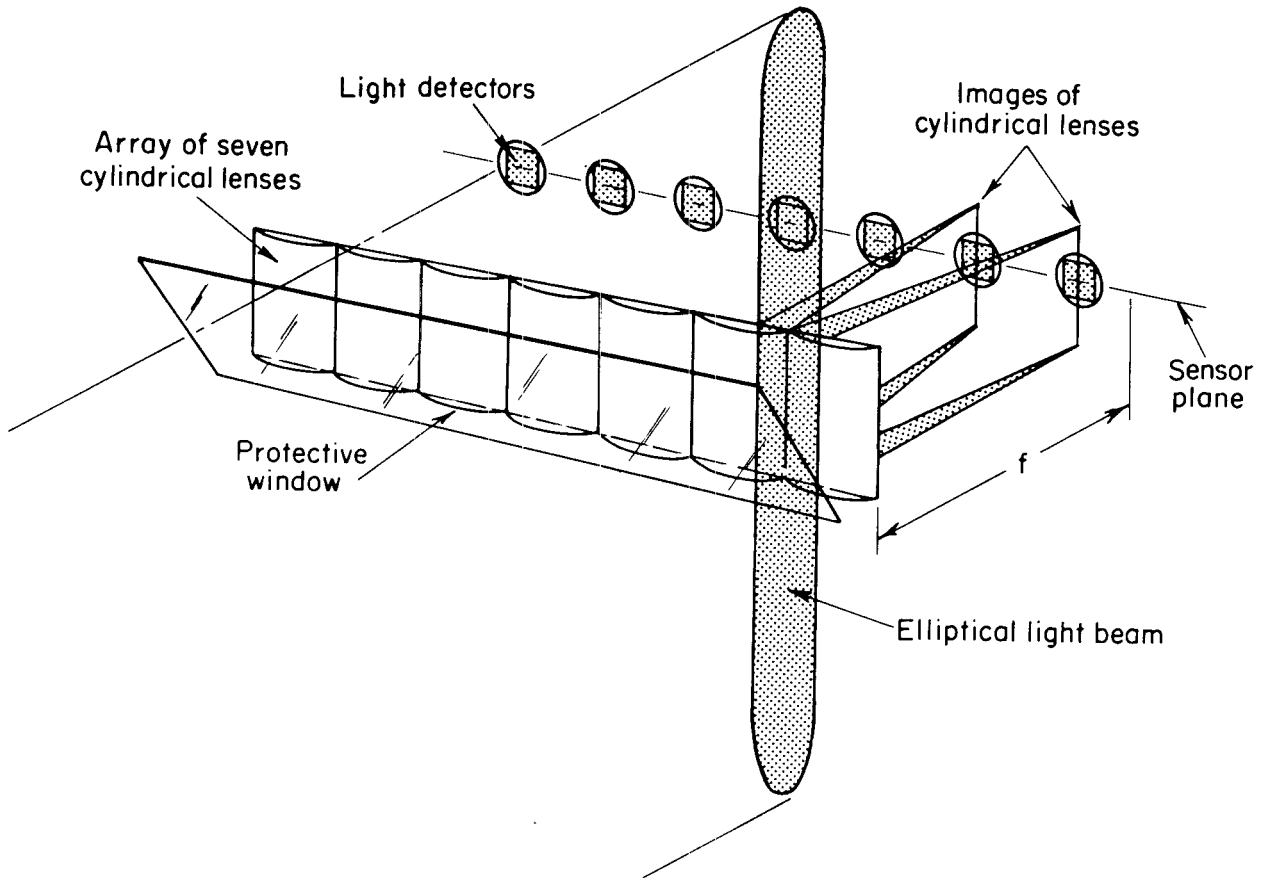


FIGURE 5. - Sensor optics.

#### Display Unit

The display unit (fig. 6) is mounted on the mining machine in a convenient position for the operator to view. The meters marked "heading" and "tracking" give the information regarding both the machine angle relative to the required direction, and the left or right position error, respectively.

A light on the display provides a "no signal" indication if there is an obstruction in the light beam, or if the sensor is not intercepting the beam. When this occurs, the display unit will "remember" the last valid heading and tracking error indications and continue to display them until the light beam is again detected.

#### Display-Sensor Power Supply and Interconnection

The power supply for the display-sensor combination, which is housed in an explosion-proof box, includes both a current limiter and a voltage regulator. The power-supply batteries are rechargeable; when fully charged, the batteries will power the sensor display package for at least 8 hours.

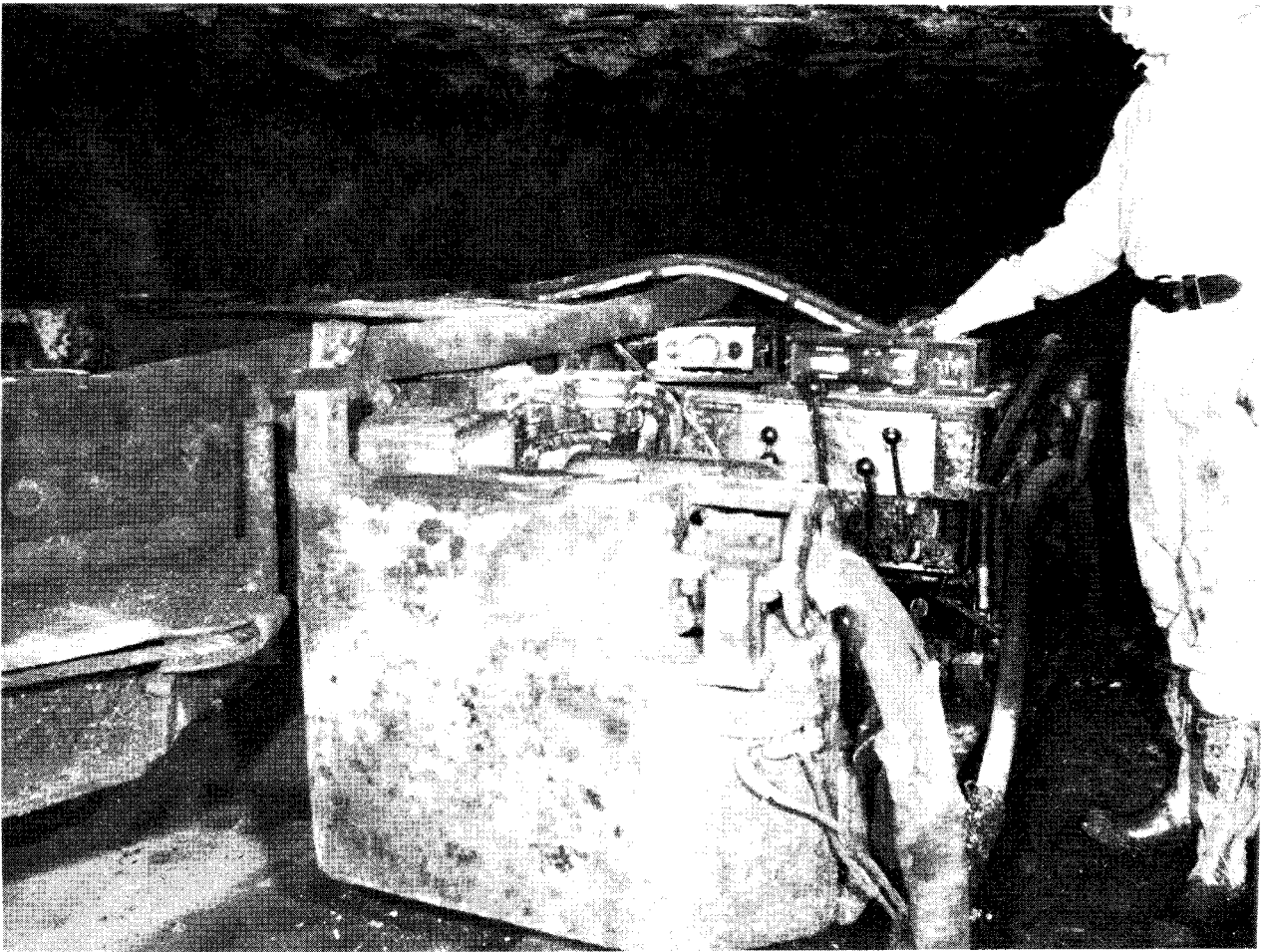


FIGURE 6. - Display unit mounted on a continuous-mining machine. The heating meter is under the operator's hand; the tracking meter immediately to the left.

The power supply box is mounted in any convenient position on the mining machine so that the interconnecting cables can be easily attached.

#### IN-MINE EVALUATION

##### Installation

The laser alinement system was installed in the Rochester and Pittsburgh Lucerne No. 6 mine. The sensor array, display unit and power supply were mounted on a Joy 9CM continuous-mining machine. The center of the sensor array was about 30 inches left of centerline of the machine and about 30 inches to the rear of the fore and aft center. (This location was selected because of accessibility, rather than by a careful analysis of machine movements.)

The display unit was mounted directly in front of the operator position. The battery power supply for the sensor and display was installed in a location convenient for easy replacement. Two interchangeable battery power

supplies were provided so that operation could continue while a battery was being recharged. Interconnecting cables were fabricated to the proper lengths for the installation.

The laser source unit was placed on a tripod in an intake air entry in a location normally having little traffic. For these tests, a check curtain was parted about 2 inches to pass the beam to the mining machine.

#### Initial Laser Alinement

The laser was set up off-center in the entry to accommodate the displacement of the sensor array as mounted on the continuous-mining machine. The laser source unit was located under one off-center spad using a plumb bob. It was then rotated so that the narrow beam was centered on a plumb-bob line hung from a second inby, off-center spad. When the laser was properly positioned, additional marks could be placed on the roof using the visible beam for spotting. This reduced the setup time required for subsequent moves of the laser source.

#### Operation

In the underground test setup, two passes of the continuous-mining machines were employed in order to mine the full width of the entry. During the first pass, which was always made behind the line brattice, the mining machine operated in a skewed attitude, therefore the alinement sensor could not be used. During the second pass, the system was used to keep the right-hand rib in the desired alinement. However, in a production installation, minor changes in the mining plan or in a full-face operation would allow the machine to work on beam during the first pass.

#### RESULTS

No attempt was made to obtain quantitative data on the "straightness" of the entry when the sensor was employed because it appeared that the time required for a machine operator to learn to use the readout meters would be excessive. Also no real point could be made in using the system as an aid to on-board manual control since the operator tended to guide the machine not by the meter indications but by reference to the visible reflection of the laser beam on the roof, face and the machine.

The system is sufficiently sturdy for use on a continuous-mining machine, and errors in tracking and heading during the mining operation were indicated as they occurred. There were no major component failures during this test (about 5 months); cable connections proved vulnerable however, and were replaced several times. Interruption of the laser beam, particularly by shuttle cars, proved more troublesome than anticipated, but the laser source unit was trouble-free.

### Recommendations for Modification

1. Power supply. A power supply should be provided for the sensor electronics and display that will operate from the mine power on the mining machine. This will require a new design that will not be damaged by transients on the powerline and will meet MESA schedules.

2. Laser source. The laser source should be housed in an approved enclosure so that it can be used in return airways. Power for the laser source should be obtained from the mine power in order to eliminate battery maintenance; this supply must also be approved.

A support system for the laser should be provided that will permit mounting close to either rib; the tripod support should be eliminated.

One laser source should be provided for each entry to be mined. This would eliminate moving the laser to each entry or trying to use a system of mirrors or prisms to provide a beam in each entry. The source could be used in a belt entry if desired; however, use in a track haulage entry would be possible only if the source unit could be kept close to a rib.

3. Sensor array and electronics. Generally, the sensor array is satisfactory. There was some objection by the machine operators to the mounting position of the array on the machine, primarily because the offset mounting required the visible laser beam to be off center.

The initial sensitivity of the system appeared too great for the direct manual control; reducing the tracking sensitivity to  $\pm 4$  inches during tests appeared to be satisfactory.

The heading meter sensitivity of  $\pm 2^\circ$  appeared to be much too great for manual control; this sensitivity should be reduced.

4. Cables. Cables and especially connectors proved troublesome. Ideally, the cables should be built into the machine so that there are no cables bridging the conveyor. Connectors on any of the equipment should have protective covers over them to reduce their vulnerability.

5. Display. The display should be redesigned to use a solid-state readout. The signal processor creates an analogue signal from a basically digital signal to display the heading error. It would be relatively simple to display the quantized information by using light-emitting diodes (LED's). The heading error should also be displayed in quantized form using LED's; this would require digitizing the signal, but it could be done with one or two integrated circuits. Ideally, these two error signals should be presented in more graphic fashion; a pictorial representation of the position and attitude of the continuous-mining machine would be superior to meter indications for remote-control applications.

### Recommendations for Additional Evaluation

The laser alinement system should be evaluated for remote-control or automatic-guidance conditions. Remote-control applications could be more readily accommodated. The only basic change needed would be to extend the cables for the display to permit its use at the remote operating position.

Remote or automatic control of a bridge conveyor behind a continuous-mining machine should also be considered.

### SUMMARY AND CONCLUSIONS

A laser guidance system for manual control of a continuous-mining machine has been developed and a prototype constructed. During evaluation of the system on a mining machine in a producing mine, some deficiencies noted were as follows:

1. The temporary tripod mounting of the laser source is unsatisfactory.
2. Interference of the laser guidance beam by shuttle cars was troublesome.
3. Power should be obtained from the mine system rather than from rechargeable batteries.
4. The laser source should be designed and constructed to meet MESA permissibility standards so that it can be used in any entry.
5. Passing the laser beam through check curtains remains a problem since window materials may cause deviation of a beam and open "window" can cause objectional air leaks in the ventilating system.

The laser alinement system appears fundamentally sound, and with suitable modification, should be applicable to remote or automatic guidance of continuous miners and other machines.



