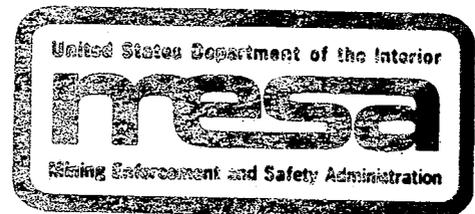


1056

MESA Informational Report/1977

Noise Control
of an Underground
Continuous Miner,
Auger-Type



Informational Report 1056

Noise Control of an Underground Continuous Miner, Auger-Type

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UNITED STATES DEPARTMENT OF THE INTERIOR
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NOISE CONTROL OF AN UNDERGROUND CONTINUOUS MINER, AUGER-TYPE

by

Dennis A. Giardino,¹ Thomas G. Bobick,² and Leonard C. Marraccini³

ABSTRACT

This report describes the noise control modifications made on a Wilcox Mark 20⁴ underground auger miner and related bridge conveyor. Sufficient detail is given so that interested parties can use the report as a manual for conducting similar modifications. The reported reduction in operator noise level is 10 dBA as measured unloaded at the MESA test facility. Underground noise surveys conducted over a 1-year interval showed the noise level at the operator's position to be 97 dBA, a reduction of 5 dBA from the before modification noise level of 102 dBA. An extensive diagnosis of the machine noise sources is also given along with comprehensive acoustical data including 1/3 octave band spectra of noise, vibration and sound power.

INTRODUCTION

Recent findings have shown that next to the underground stoping drill,⁵ the equipment which has the second greatest number of violations is the underground auger miner. Numerous surveys which have been conducted on this equipment have verified that the total noise exposure of the operator and helpers can be quite excessive. A typical survey was the one conducted at the No. 19 Mine of Buchanan & Sons Coal Company, Wise, Va., during October 1974. Data obtained from a Wilcox Mark 20 auger miner showed an average noise level of 102 dBA for the operator and 103-104 dBA for the jacksetters. The average operating time was approximately 3-1/4 hours (ranging from 2-1/2 to 4 hours). Using this data, an average noise exposure index of 2.15 (ranging from 1.65 to 2.64) is computed for the operator and 2.64 (ranging from 2.03 to 3.25) for the jacksetters.

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⁴ Reference to specific brands, equipment or trade names in this report is made to facilitate understanding and does not imply endorsement by the Mining Enforcement and Safety Administration.

⁵ "The Noise Environment of the Underground Coal Mine" by T. G. Bobick and D. A. Giardino, MESA Informational Report No. 1034.

Besides verifying that the noise exposure of the workers exceeded the Federal noise regulations, the field survey identified several noise sources on the miner and accompanying bridge conveyor which contributed to the high noise levels. The major source was the chain conveyor which transported the mined coal from the face. Another source was the noise generated by the auger heads as they cut coal. Even though the major noise sources were identified, very little noise control work could be done underground because of inconvenient working conditions.

After months of planning and negotiating, a cooperative agreement was entered into with Buchanan & Sons Coal Company, mine owner; Fairchild, Inc., machine manufacturer; and MESA, to noise control the machine. The terms of the agreement were that the owner supplied the auger miner. The manufacturer transported the equipment and provided a mechanic to the Pittsburgh Technical Support Center. After the arrival of the equipment, it was the responsibility of the Noise Branch to provide modifications for quieting the system.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Buchanan & Sons Coal Company, Fairchild, Inc., and Mr. Gilmur Hughes, mechanic, Fairchild, Inc., whose cooperation and suggestions contributed to the success of the project.

The authors also wish to acknowledge members of the Noise Branch for their participation in this project which involved countless hours of work beyond the normal duties. As a result of their work on this project, the following individuals received a Special Achievement Award from MESA for performance above and beyond their normal duties. They are:

Jerry W. Antel
 Felix J. Della Valle
 Cornelis A. Dirkmaat
 George Durkt
 John H. Perry
 John P. Seiler
 Anthony J. Strazisar
 James A. Voelker
 Roland Tyler

MACHINE DESCRIPTION

The Mark 20 auger miner and related bridge conveyor, shown in figure 1, are manufactured by the Wilcox Division of Fairchild, Inc., Beckley, W. Va. The Mark 20 is a controlled arc miner designed for mining coal from seam heights of 26 to 50 inches. The overall length of the Mark 20 is 24 feet; the width is approximately 8 feet. The overall height with the augers lowered is 24 inches and the maximum height is 48 inches when the augers are fully elevated. The weight of the machine is approximately 12 tons.

Dual rotating augers, which can be individually raised or lowered according to seam thickness, are used to extract the coal. Each of the augers is

powered by a 100-hp, 440-volt, dc motor. The coal is extracted as the miner advances in a sweeping pattern across the face. This sweeping movement is achieved by the use of two anchor jacks, one located on the right and the other on the left side of the miner. The machine sweeps to the right as it is pulled in that direction by the right front winch that winds cable attached to the right anchor jack. The opposite jack system is then used in moving the miner to the left. The 100-hp drive motors, besides operating the gear chain drives which turn the cutting auger heads, also power the hydraulic pumps. These pumps supply the hydraulic power for the control system of the machine.

Once the coal is cut, it is gathered by means of rotating screws onto the conveyor pan of the miner. The coal is moved the length of the machine via a chain conveyor and dumped onto a bridge conveyor system which removes it from the face area. Both the machine and bridge conveyors are powered by individual 15-hp, 440-volt, 3-phase, ac motors. The conveyor motors are mechanically linked to a sprocket assembly which operates the chain conveyors on the miner and bridge conveyor.

The bridge conveyor unit is a continuous haulage system for removing the coal from the working area quickly and efficiently. The bridge attaches directly to the rear dumping point of the Mark 20, thus enabling it to follow each move of the miner uninterrupted. The coal is moved by the bridge to a second dumping point approximately 34 feet away where it begins the journey to the surface. The bridge conveyor receives its ac power through a direct electrical hookup with the miner control panel.

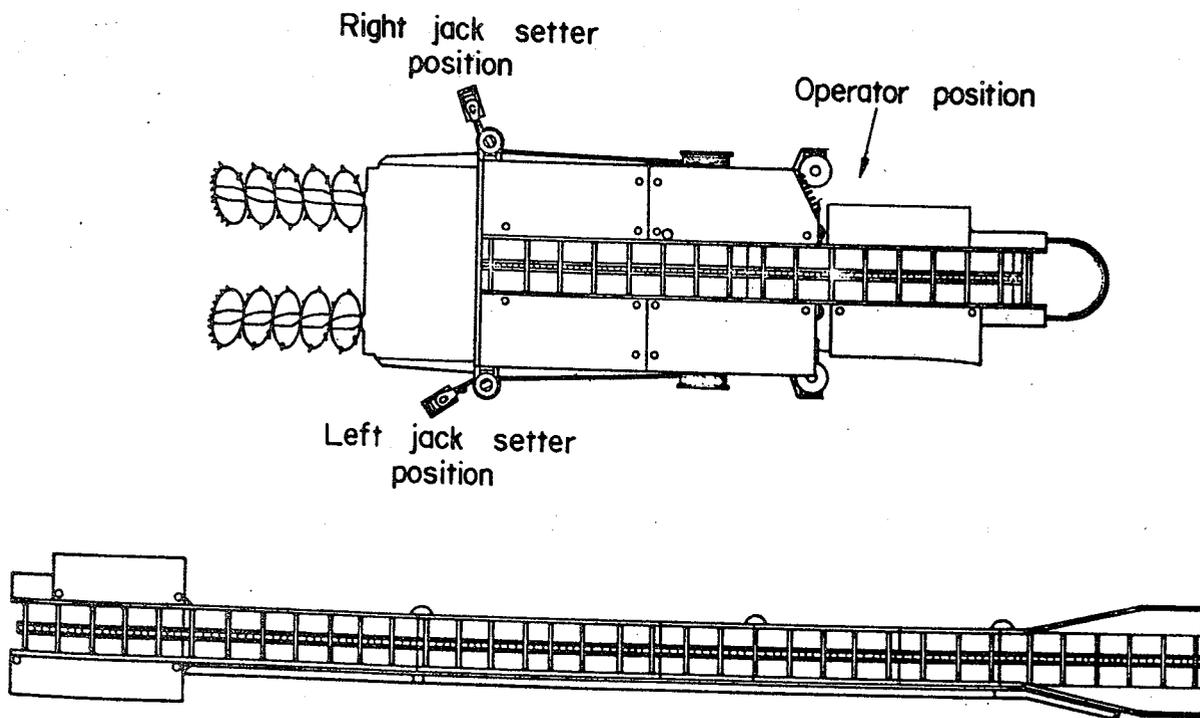
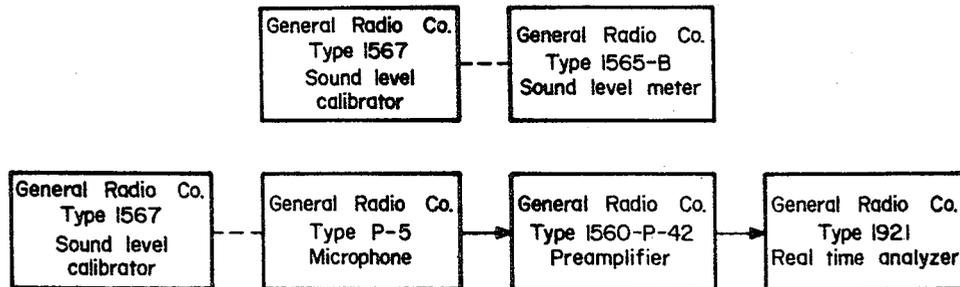
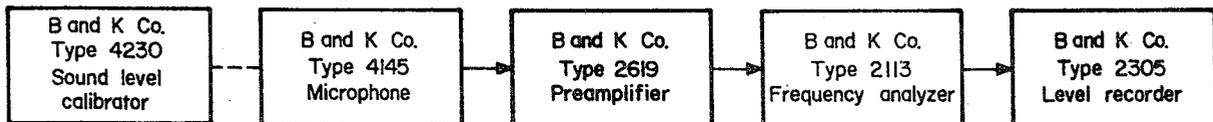


FIGURE 1. - Mark 20 auger miner and bridge conveyor.

A



B



C

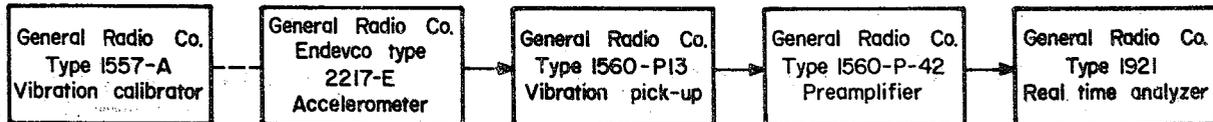


FIGURE 2. - Instrumentation systems used to measure sound, vibration and reverberation times.

INSTRUMENTATION

Various types of instrumentation systems were utilized to measure the noise, vibration and reverberation during this noise control project. Figure 2 gives a block diagram of the systems used. The instruments met all the various ANSI Standards for Type I or II systems. The manufacturers names are shown for compatibility of the components, not as an endorsement of the products by MESA. Other instruments could have been used in place of those mentioned.

PROCEDURE

The Wilcox auger miner was placed on two 4" x 4" wooden beams on the concrete floor of a large, garage-type building at the Pittsburgh Technical Support facilities. In an attempt to characterize the acoustical environment in which sound measurements were to be taken, reverberation times were measured inside the building where the Wilcox auger miner was located. This was done, prior to any noise measurements, in order to relate the surface experimental data to actual underground noise levels.⁶ Using an impulse noise

⁶"Predicting Noise Levels From Sound Power Data" by L. C. Marraccini and D.A. Giardino, published in Sound and Vibration Magazine, November 1974, pp. 28-30.

source, decay curves were obtained using the system described in figure 2B. These decay curves were then used to calculate reverberation times in octave band center frequencies of 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 Hz, as well as the total A- and C-weightings.

After the reverberation measurements were completed, a comprehensive survey of noise, vibration and sound power levels were conducted to obtain baseline data. Sound and vibration measurements were taken both with and without the associated bridge conveyor attached to the miner. In order to accurately compare the before and after modification data, sound measurements were taken at fixed locations around the miner and bridge conveyor. The microphone was oriented in a vertical, upward direction approximately 30" above the floor and 2' from the test item. Vibration measurements were also taken at standardized locations on both the miner and bridge conveyor.

Sound measurements were taken utilizing the instrumentation system shown in figure 2A. The system was acoustically calibrated using a General Radio Type 1567 sound level calibrator. The microphone was tripod-mounted and positioned so it would be 30" above the floor at each monitoring location. Sound pressure levels were monitored sequentially at each fixed location by the real time analyzer. The sound pressure levels were printed out in 1/3 and full octave frequency bands by means of a teletypewriter which was attached to the output of the real time analyzer. A- and C-weighted noise levels were also measured with a General Radio Type 1565-B sound level meter at the same location.

The vibration monitoring system is shown in figure 2C. The system was calibrated using a General Radio vibration calibrator Type 1557-A. The accelerometer was mounted to the measuring location by use of a permanent magnet. Vibration was monitored at each premarked location by means of the real time analyzer. Vibration data was given in decibels (re 30 μ g) and frequency analyzed into 1/3 and full octave bands.

The total sound power output of the Wilcox miner was measured using a standard hemispherical technique.⁷ With all systems on the miner in operation, the acoustical center was first determined. This was then used as the center point about which an imaginary hemisphere was constructed around the machine. The radius of the hemisphere was selected to be 15' based on the geometry of the building housing the miner. Sound pressure level readings were taken at the center of 12 predetermined equilateral triangles defining the surface of this imaginary hemisphere. A B&K Type 4145 microphone, calibrated using a B&K Type 4230 calibrator, was positioned at the center of each equilateral triangle. This was accomplished (fig. 3) by utilizing an Atlas Model BS-37 microphone boom. The acoustical signal from the microphone was sent through a B&K Type 2619 preamplifier into a B&K Type 2113 audio frequency spectrometer. Sound pressure levels were plotted at octave band center frequencies (31.5 to

⁷Harris, C. M. (ed.). Handbook of Noise Control, McGraw-Hill Book Company, 1957, pp. 17.30-17.32.

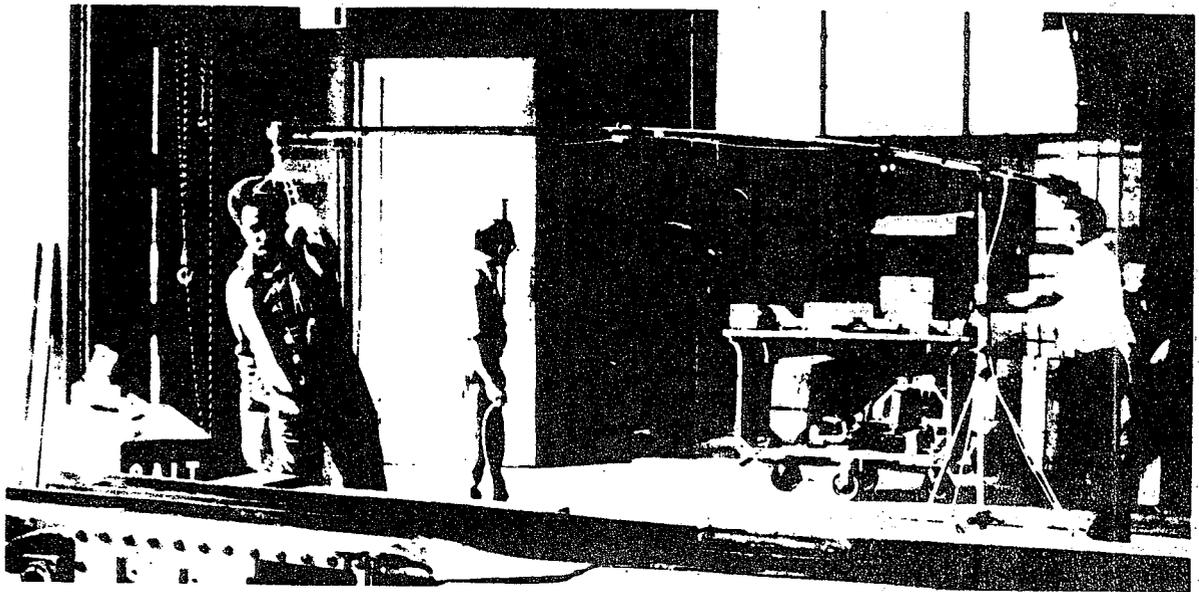


FIGURE 3. - Microphone boom system used in sound power measurements.

8 kHz) by means of a B&K Type 2305 level recorder. These results were then used to calculate sound power levels.⁸

Upon completion of all noise control modifications, a survey of noise, vibration and sound power levels was again conducted. All of these measurements were made at the same locations and using the same instrumentation as used in the premodification survey.

MATERIALS AND COSTS

In noise controlling the Wilcox Mark 20 mining system, several different types of materials were needed. These included vibrational damping materials, acoustically absorptive materials, adhesives, steel wear strips and assorted nuts and bolts. A complete breakdown in terms of use, quantities, manufacturers and costs is given in table 1. The total cost for materials was about \$2,400. It should be noted that since this was a prototype project, larger quantities of materials were ordered than actually used. Other workers attempting this project, with the directions supplied in this report, would probably use significantly less material than specified in table 1. This would result in less cost than the quoted \$2,400.

Labor costs, for the noise control procedure, were estimated to be about \$3,000 corresponding to 30 mandays at \$100* per manday. Again, more mechanically skilled workers (attempting the procedure with beforehand information) could probably finish the noise control project in less than 30 mandays. This would result in a further savings in cost.

⁸Beranek, L. L. (ed.). Noise and Vibration Control, McGraw-Hill Book Company, 1971, pp. 149-155.

*These were the prevailing rates as of July-August 1975.

TABLE 1. - Noise control materials used during the modification program

Material type	Use	Quantity	Brand name and manufacturer*	Approx. cost
Dense, vibration absorbing rubber	Vibration damping and/or isolation	3 sheets--each 4' x 4' x 3/16"	E-A-R C-2003, E-A-R Corp. 376 University Ave., Westwood, MA 02090	\$420
Dense, vibration absorbing rubber, good transmission loss	Vibration damping and/or acoustical barrier	3 sheets--each 4' x 4' x 1/4"	E-A-R- C-1002, E-A-R Corp. 376 University Ave., Westwood, MA 02090	675
Light-weight, sound absorbing fiberglass	Absorption of airborne noise	4' x 35' x 1"	Insul-Quilt AGC, Insul-Coustic/Birma Corp., Jernee Mill Road, Sayreville, NJ 08872	200
Combination sound barrier material and sound absorbing foam	Acoustical barrier and sound absorption	4' x 20' x 1/2"	Durasonic No. 5155, Duracote Corp., 350 N. Diamond St., Ravenna, OH 44266	100
Viscous liquid which dries into a vibration absorbing rubber	Vibration damping of hollow or hard to reach structure	20 lb	Flexane 80, Liquid Urethane, Devcon Corporation, Danvers, MA 01923	100
Epoxy adhesive	To firmly glue acoustical material to metal parts	3 gal	Bostik No. 7132, Two-part vinyl laminating adhesive, USM Corp., Bostik Division, Middleton, MA 01949	70
Hardened steel wear strips	To provide long wearing surfaces on acoustical material where needed	18 pieces--each 3' x 20' x 1/4"	Jalloy Material, Jones & Laughlin Steel Corp., Etna, PA 15223	750
Metal studs	To permit installation of acoustical materials inside cover panels	150, 1/4" diam, 3" length	Barrier Corp., Tigard Industrial Park, 9908 S. W. Tigard St., Tigard, OR 97223	12
Cover buttons	To secure the materials to the metal studs	150	Barrier Corp., Tigard Industrial Park, 9908 S. W. Tigard St., Tigard, OR 97223	30
Stud welding gun	To install the metal studs on the inside of the cover panels	1	Barrier Corp. (Supplied to Noise Branch, no charge)	Rental \$100/wk. \$300/mo.
Steel plate/sheet metal	Used in conjunction with acoustical material to form barrier	3' x 3' x 1/4" 5 ft square, 18 gage	Not applicable, local source	50
Assorted nuts, bolts and screws	For attaching wear strips, barriers, etc.		Not applicable, local source	50

Material Cost = \$2,457

Labor Costs,
30 days at
\$100/day = 3,000

Total Cost = 5,457

*These materials are listed specifically for identification purposes and should not be construed as an endorsement of these products by MESA. Other materials which could be used as substitutes are available commercially. However, regulations concerning the flammability requirements of materials used underground will be promulgated in the near future. Before using any materials underground, they must pass the requirements for flame retardation.

From the above discussion, it can be seen that the total cost for this prototype noise control project was \$5,400 (approximately 4 percent of the cost of a new miner-bridge conveyor system). It is estimated that if the same noise control program was conducted on another Wilcox miner, the job could be completed for substantially less, probably in the neighborhood of \$3,500.

IDENTIFICATION AND TREATMENT OF MARK 20 NOISE SOURCES

In order to noise control the Wilcox auger miner, it is first necessary to determine specific sources of noise and their relative contribution to the noise levels as experienced by the workers (that is, operator, right and left jacksitters). An investigation of possible noise sources was undertaken by analyzing the miner on a systems basis. The noise contribution of each component in the system was determined by careful acoustic measurements. The four systems considered in this analysis, listed in order of their noise emission levels, are as follows: (1) cutting heads (augers), (2) conveyor system, (3) cutting head drive assembly, and (4) winch system. Figure 4 illustrates the relative position of these systems for the Wilcox auger miner and bridge conveyor.

The following section gives a description of the noise sources and generating mechanisms for each system, along with the acoustical modifications which can be made for noise control purposes.

1. Cutting Heads

The coal cutting heads for the Wilcox Mark 20 are shown in figure 5A. Each of the two cutting heads, when mounted on the miner, are powered by a 100-hp, 440-volt, dc motor and drive train. In operation, they rotate in

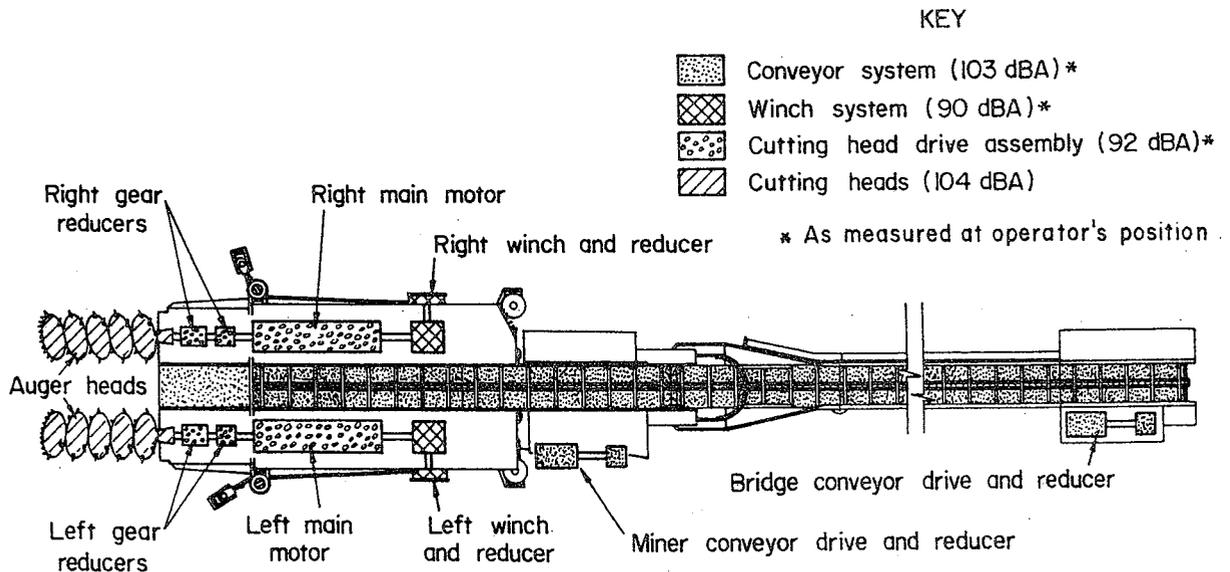


FIGURE 4. - The four basic noise producing systems for the Wilcox miner.

opposite directions to each other. Incorporated in the core of the cutting heads are nozzles, from which water is sprayed onto the face to reduce dust.

The noise generated by the cutting head system is the predominate noise when the machine is mining coal. It especially affects the jacksetters who are located toward the front of the miner. There are several mechanisms which generate noise during the cutting operation. They are:

a. Cutting Bit-Coal Interaction

This noise is the result of individual bits on each cutting head impacting into the coal. It occurs not only in the auger miner system, but in all continuous miners. Presently, minimal effort has been expended to treat this noise source.

b. Cutting Bit-Bit Holder Interaction

This noise is the result of two actions by the individual bits. First, each bit is free to rotate in its holder to insure symmetrical wear. Secondly, as each bit strikes the coal, it can recoil slightly, striking the back of the holder. The combination of these two actions produces noise.

c. Vibrating Helix

As seen in figure 5A, the bit holders are welded directly to the edge of the helix. As previously stated, an impact occurs each time a bit strikes the coal. This impact is transferred directly through the bit holder into the helix which responds to these vibrations. Because the helix is a plate with little damping, it can vibrate, radiating sound directly to the environment or transmitting the vibrations to other parts of the miner.

d. Cutting Head Central Core Vibration

The basic foundation of the cutting head is the hollow core. On this core is attached the circular helix with the cutting bits. The central core (shaft) is the prime path for vibrations from the previous three interactions to be transmitted to the frame of the miner.

In this particular project, the modifications made to the cutting heads were conducted by Fairchild, Inc. In general, the major modification centered on shifting the resonance of the helix by stiffening it through the use of metal supports welded between the helix edge and the auger core. This modification is shown in figure 5B.

2. Conveyor Systems

The conveyor system, which is used to transport the cut coal, is the second noisiest system on the Wilcox Mark 20 miner. The machine mounted conveyor is similar, in many respects, to the bridge conveyor system. Both have component parts which are much alike. Because of this, the noise sources and control treatments to be described are applicable to both. In those

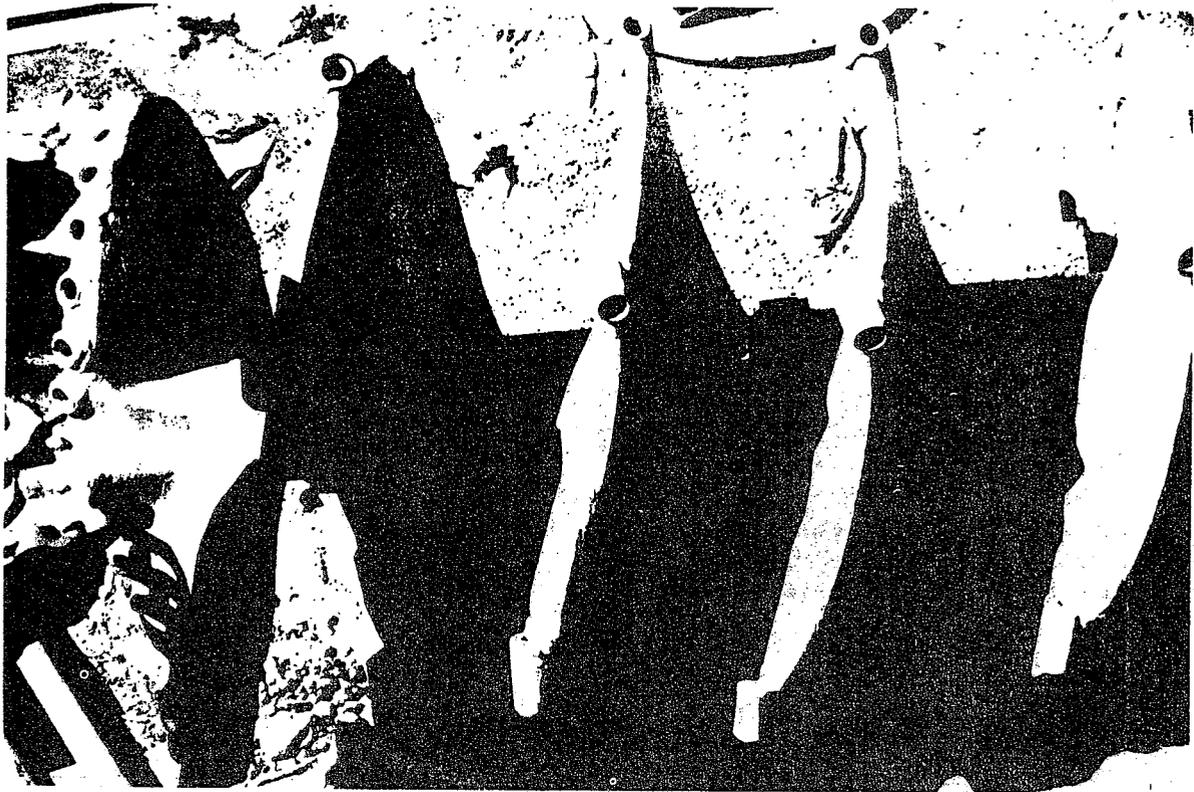


FIGURE 5A. - Unmodified cutting heads (without bits) for the Wilcox Mark 20 miner.

instances where dissimilarities exist, the noise control modifications applied to each are discussed separately.

a. Conveyor Pans

The flights and chain used to transport the coal along the conveyor scrape and impact the pan, causing a high level of noise. Damping-isolation strips, which are composed of an energy absorbing material (E-A-R Type C-1002) covered by a steel wear strip (Jalloy No. 360), are installed on the upper side of both the top and bottom conveyor pans. These damping strips effectively keep the conveyor chain and flights from impacting and scraping on the metal pans while also damping the pans themselves.

A short summary of the procedure to be used in installing the damping strips is shown in figure 6 (a through g). First, the steel wear strips are cut to the proper length and thoroughly cleaned with a sanding wheel, as shown in figure 6a. Next, matching strips of E-A-R material (1/4" in thickness) are cut and glued to the wear strips. Figure 6b shows the E-A-R strip being cut from a large panel of material. This sandwich combination is then drilled for screw clearance holes. For the miner conveyor, oversized 2" holes are burned into the top pan, as illustrated in figure 6c. Through these holes, the bottom pan is drilled and tapped to secure the bottom damping strip. Likewise,

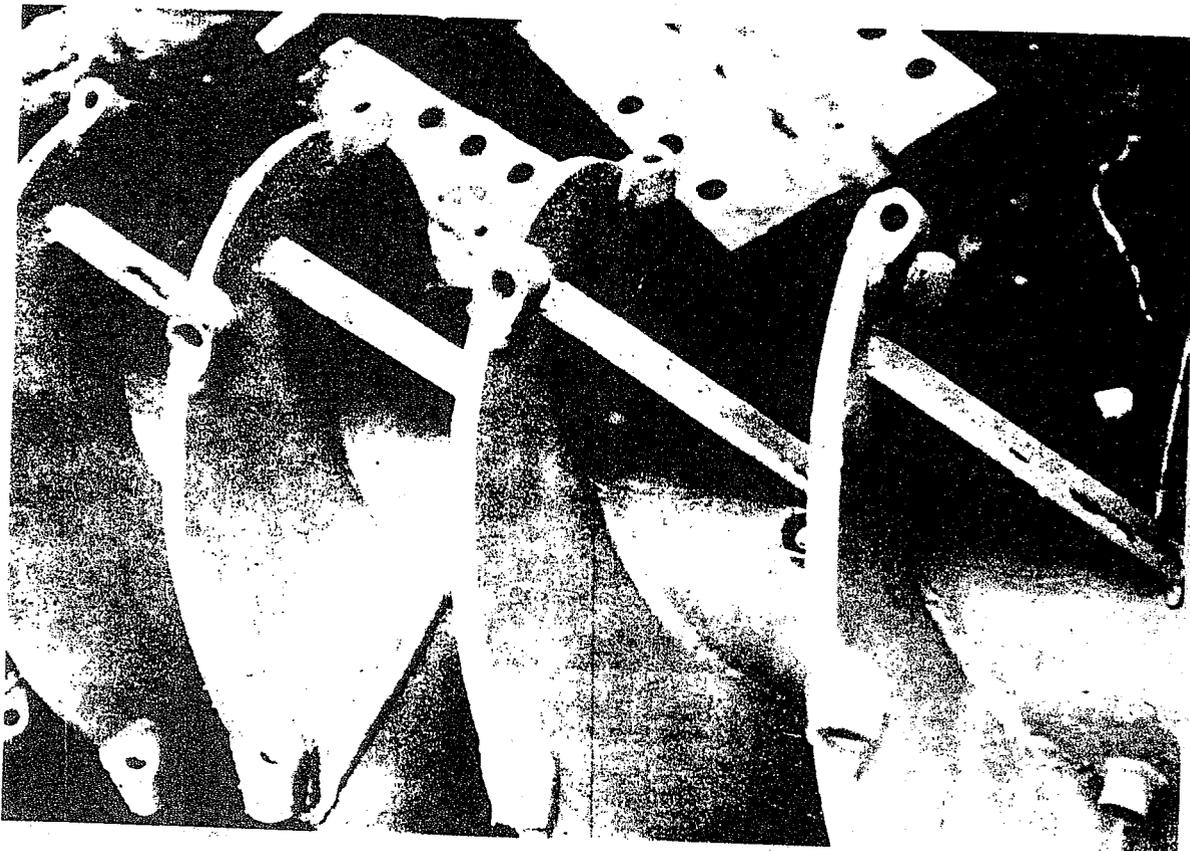


FIGURE 5B. - Cutting heads (without bits) for the Wilcox Mark 20 miner, modified with metal supports.

the top pan is drilled and tapped and the center damping strip is secured over the 2" hole (fig. 6d). As shown in figure 6e, three strips are placed on the top and one on the bottom pan. In addition to the mounting bolts, epoxy adhesive is used to insure that the strips would not lift from the pan. For the bridge conveyor, figure 6f, much the same procedure is used except that the bottom pan is drilled and tapped from underneath. Again, three strips are used on the top pan and one on the bottom, as shown in figure 6g.

A more detailed description of the conveyor system modification is as follows: The basic construction and attachment of the wear strips to the bridge conveyor is made by cutting a 1/4" x 3" steel strip to the corresponding length of the pan which is to be treated. The strip is then drilled for screw holes using a 3/8" bit. Two holes are made at each end and single holes approximately 10" apart are made along the length of the strip. Next, a strip of 1/4" E-A-R 1002 is cut to proper size and punched for screw holes. It is then glued to the wear strip.

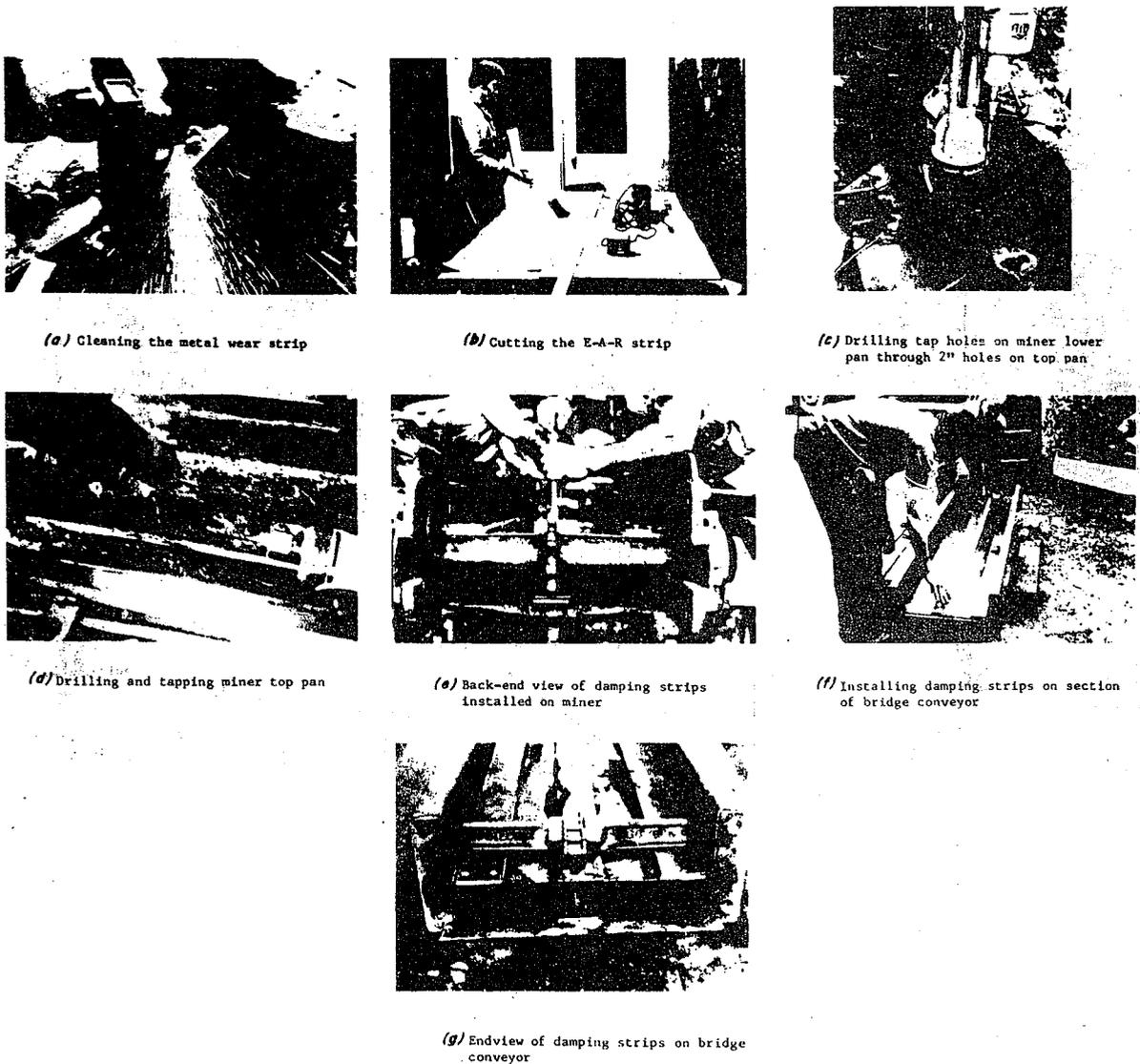


FIGURE 6. - Summary of noise control procedure used to quiet conveyor pans.

For the upper pan, the composite wear strips are positioned on it so that markings can be made through the screw holes of the strip onto the pan. The wear strip is then removed and $5/16$ " tap holes are drilled into the pan. Finally, the composite wear strip with the E-A-R face down on the pan, drill holes aligned, is glued into place. To rigidly secure the wear strips to the pan, $3/8$ " \times $3/4$ " machine screws are installed. This procedure is shown in figure 7.

For the lower pan, the procedure is slightly different. Here, clearance holes are drilled into the wear strip and tap holes are drilled into the underside of the return pan. The composite wear strip is placed inside the conveyor return, glued as before and secured with $3/8$ " machine screws. It is

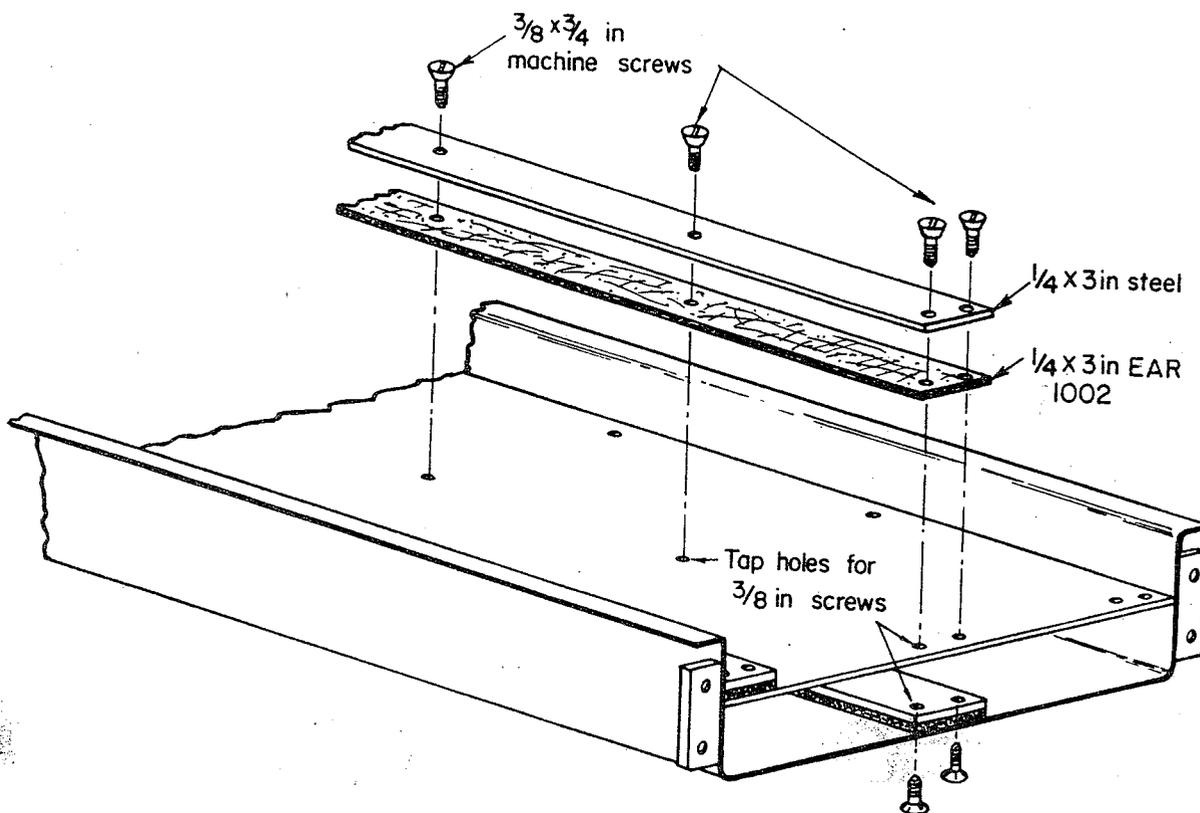
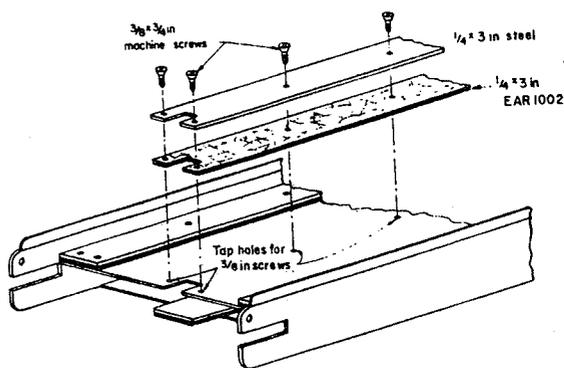


FIGURE 7. - Diagram showing the installation of damping strips to a section of the bridge conveyor.

important that the length of the screws do not protrude above the wear strip to insure that the chain does not bind.

Additional comments concerning the wear strips on the bridge conveyor are as follows:

1. With both the upper and lower pans, closer screw intervals are needed where the wear strips have to be bent (the sloped front of the conveyor). This insures that the strips will conform to the sloping pans.
2. At the front of the bridge conveyor, 1/8" E-A-R 1002 and 1/8" steel are used on the upper pan, under the flight hold-downs, instead of the 1/4" materials. This is done to prevent the flights from jamming against the hold-downs (see fig. 13).
3. On the discharge end of the bridge and miner conveyors, the center wear strips are slotted to accommodate the chain sprocket. This is shown in figures 8a and 8b.



(a) Slotted center strip at end of bridge conveyor.



(b) Slotted center strip at end of miner conveyor.

FIGURE 8. - Configuration of center damping strip at the rear end of the bridge and miner conveyors.

4. On the discharge end of the conveyor, bottom pan, the center wear strip is extended several inches to provide a gradual return of the chain and flights from the sprocket to the pan. This will be discussed in more detail in the next subsection dealing with the chain turn-around noise.

The procedure for installing the composite wear strips on the miner conveyor is somewhat different. The strip on the bottom pan is installed first. After the composite strip is fabricated, 2" diameter holes are cut down the center of the top pan. The bottom pan is drilled and tapped through these holes (fig. 6c). The composite strip is then aligned on the bottom pans and fastened to it with glue and 3/8" x 3/4" machine screws. For the upper pan, the wear strips on each side are installed first. This utilizes the same technique as the installation of the wear strips on the upper pan of the bridge conveyor. When installing the center wear strip, it has to be aligned to cover all the 2" holes. Then new tap holes are drilled (fig. 9) and the wear strip is then fastened to the upper pan with glue and machine screws. In both the miner and bridge conveyors, all wear strips are tapered at the ends to prevent the chain or flights from snagging. The adjoining wear strips also should be butted as smooth and flush as possible.

b. Chain Turn-Around

As the chain and flights travel around the sprocket at the rear end of the miner, they change direction quite drastically. The chain is traveling at 420 ft/min (84 in/sec), and as it goes around the drive sprocket at the rear, the momentum buildup in the chain causes it to impact violently against the edge of the bottom pan.

During the testing, this phenomenon was observed with high-speed photography. Both the miner and bridge bottom pan edges were badly bent from this impacting. To correct this situation, the back end of the conveyors are modified providing a smoother return for the chain.

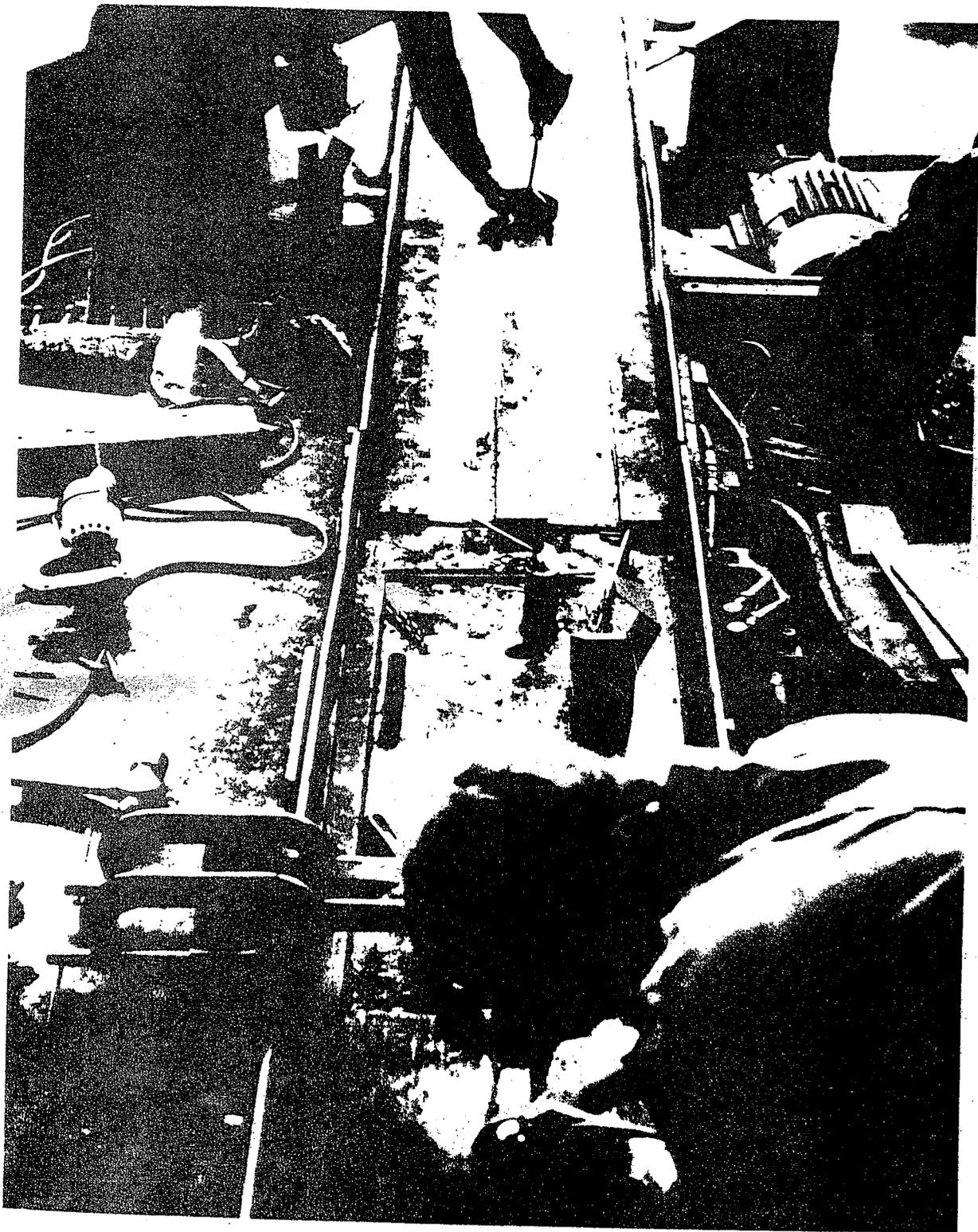


FIGURE 9. - Installing damping strips on the miner conveyor.

On the miner, the lower wear strips are extended 3" beyond the end of the pan. This can be seen toward the bottom center of the photo in figure 6e. The extended strip is welded to a 3" x 18" composite wear plate. This plate, consisting of 1/4" E-A-R sandwiched between 1/4" and 1/16" steel, is shown in figure 10. It is welded perpendicular to the sides of the miner boom and situated at a 5° angle to the bottom pan. The plate is added to provide a gradual return from the sprocket to the pan which will eliminate the impact of the chain and flights against the bottom pan.

As seen in figure 11, toward the bottom center of the picture, a similar wear strip extension is used on the return of the bridge conveyor. The center wear strip on the bottom pan is extended by several inches. This strip is slightly bent at an angle to provide a gradual return of the chain and flights from the sprocket to the pan. There is no additional perpendicular plate used here as with the miner.

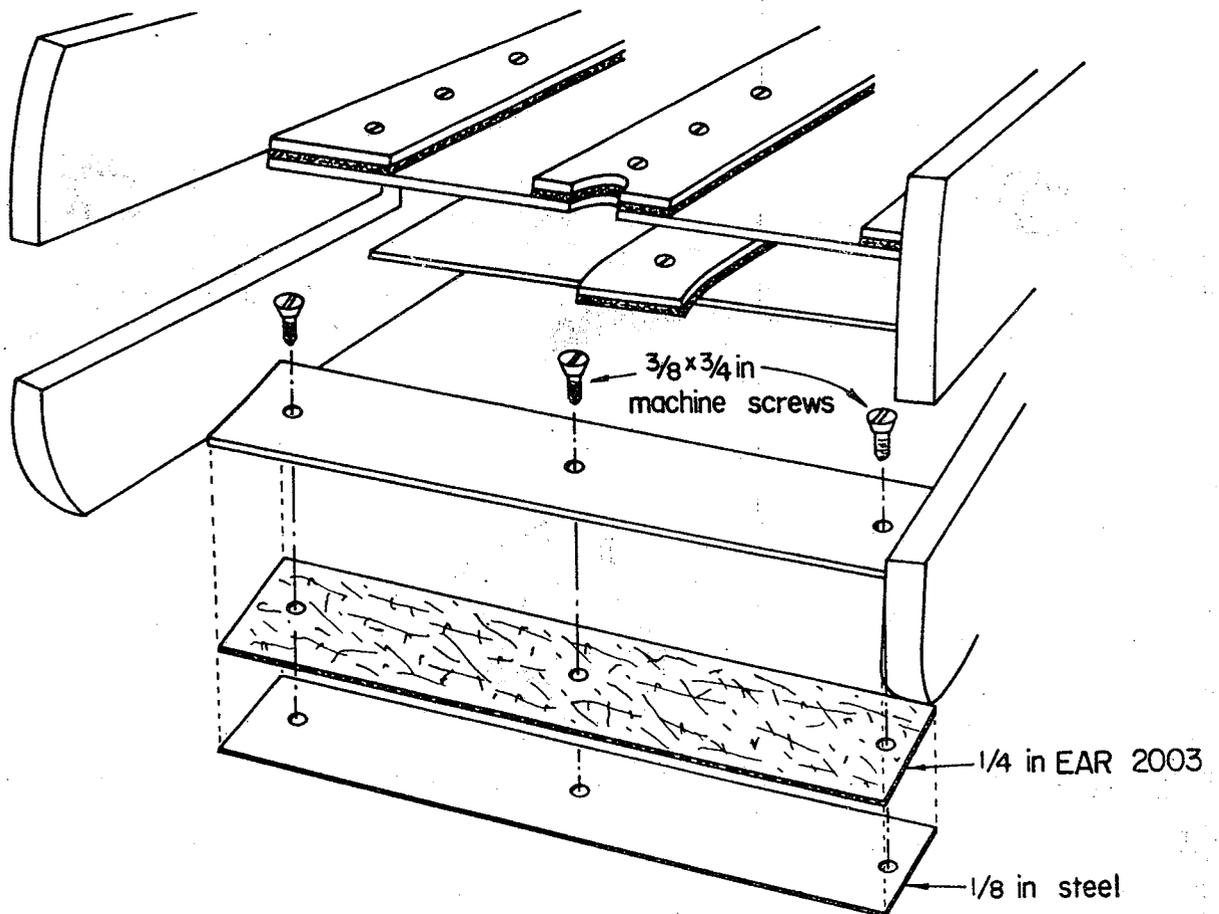


FIGURE 10. - Diagram showing construction details of extended lower wear strips on the miner.

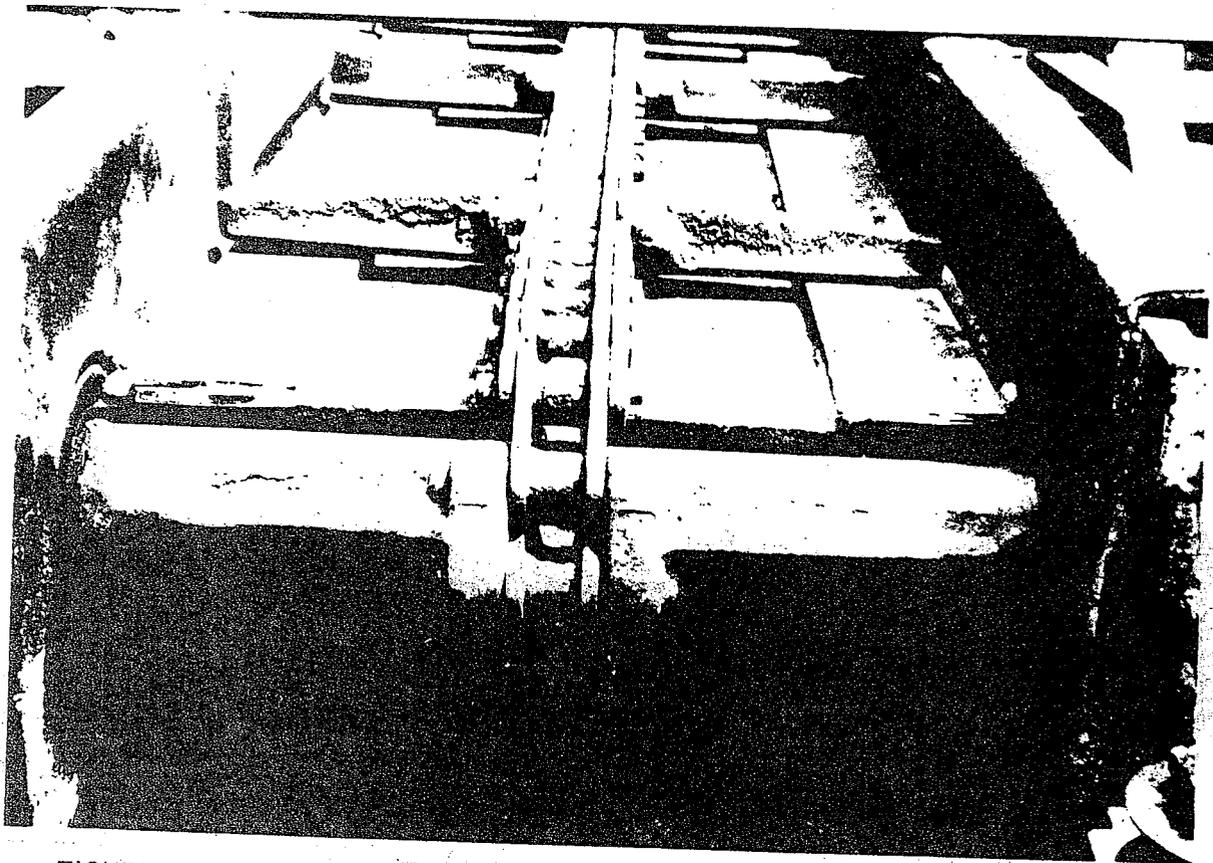


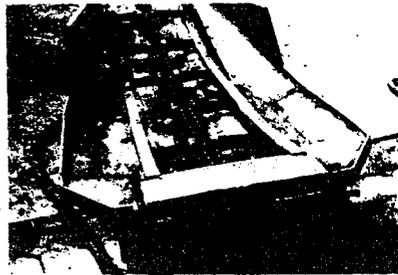
FIGURE 11. - Back-end view of bridge conveyor showing the lower extended wear strip.

c. Chain Hold-Downs

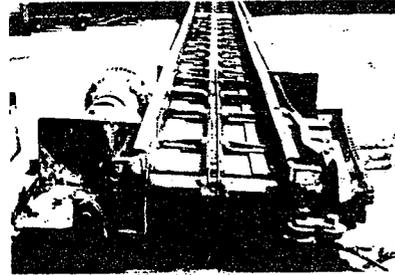
The front portion of the conveyor pans, for both the miner and bridge, slope downward with respect to the center portion of the conveyor. The flights, when traveling up this slope, are held down to the surface of the top pan by means of metal strips welded to the conveyor sides. The moving flights, as they are being held in place by the hold-downs, scrape and impact against the hold-down surface producing high levels of airborne noise. Also, this vibrational energy is transmitted through other parts of the machine producing additional airborne noise.

Several modifications can be made to the front of the conveyors to reduce the noise level. The modifications to the bridge conveyor include the following:

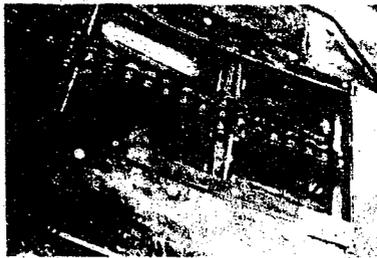
1. A 1/4" x 1" E-A-R 1002 and 1/8" x 1" steel plate damping strip is mounted on top of each hold-down (see fig. 12a).
2. Three 1/8" x 3" E-A-R 1002 and 1/8" x 3" combination wear-damping strips are installed on the top pan (see figs. 12b and 12c).



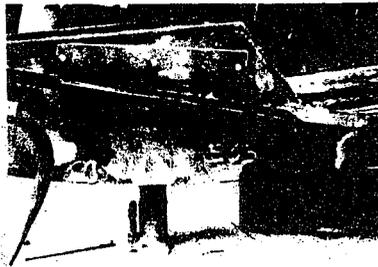
(a) Front view showing chain hold down modifications



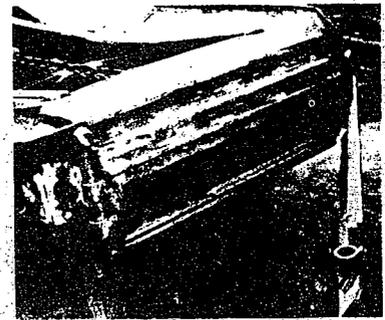
(b) Top view of damping - isolation strips



(c) Close-up view of damping strips near conveyor front



(d) View of spill plate, side and bottom damping strips



(e) View showing damping strip on top of door frame and treatment to inside of door

FIGURE 12. - Noise control modifications made to the front of the bridge conveyor.

3. Two damping strips are mounted on the outside of each spill plate, sides and bottom (see fig. 12d).

4. Damping strip (1/8" steel, 1/4" E-A-R) is installed on top of the door frame and a 1/4" E-A-R strip plus 1/4" Duracote strip is installed on the inside of the front door (see fig. 12e).

In addition, each hollow area on both sides of the bridge conveyor front is filled with approximately 3 pounds of Flexane 80 through three 1/2" holes which are drilled into the cavity. The holes are then sealed with metal plugs as shown in figures 12a and 12c. All of the above modifications can be seen in figure 13.

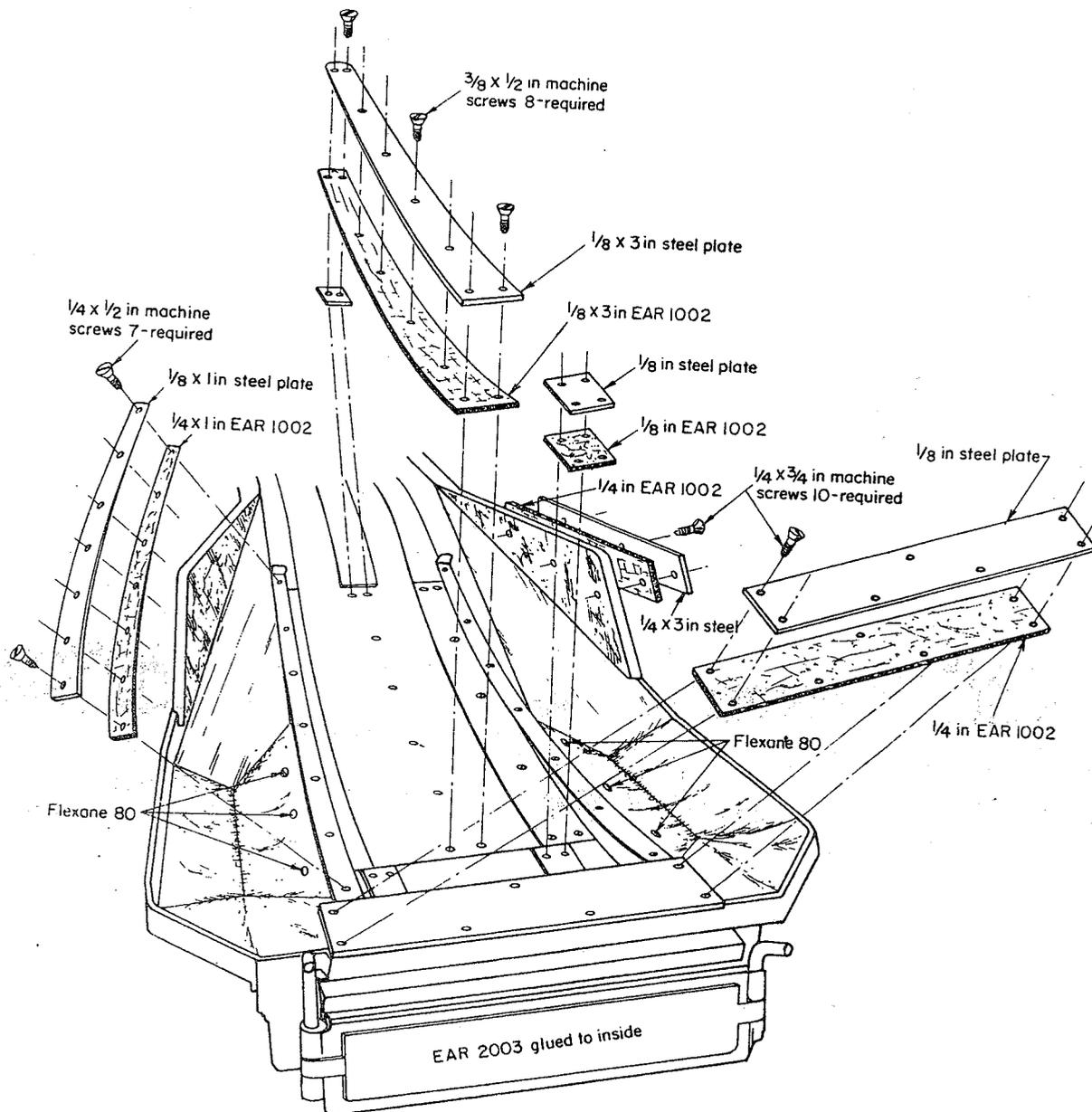


FIGURE 13. - Diagram showing the noise control modifications made to the front of the bridge conveyor.

The hold-downs on the front of the miner are also damped to reduce any vibrations caused by the impacting flights. To do this, two $1/4$ " holes are drilled into the top of each hold-down and approximately 3 pounds of Flexane is forced into each cavity (fig. 14). Figure 15 shows the damped hold-downs on the front of the miner as well as the three tapered wear strips mounted near the sprocket. These strips are tapered so that a gradual return is provided for the flights as they leave the sprocket. This prevents them from banging against the pan.

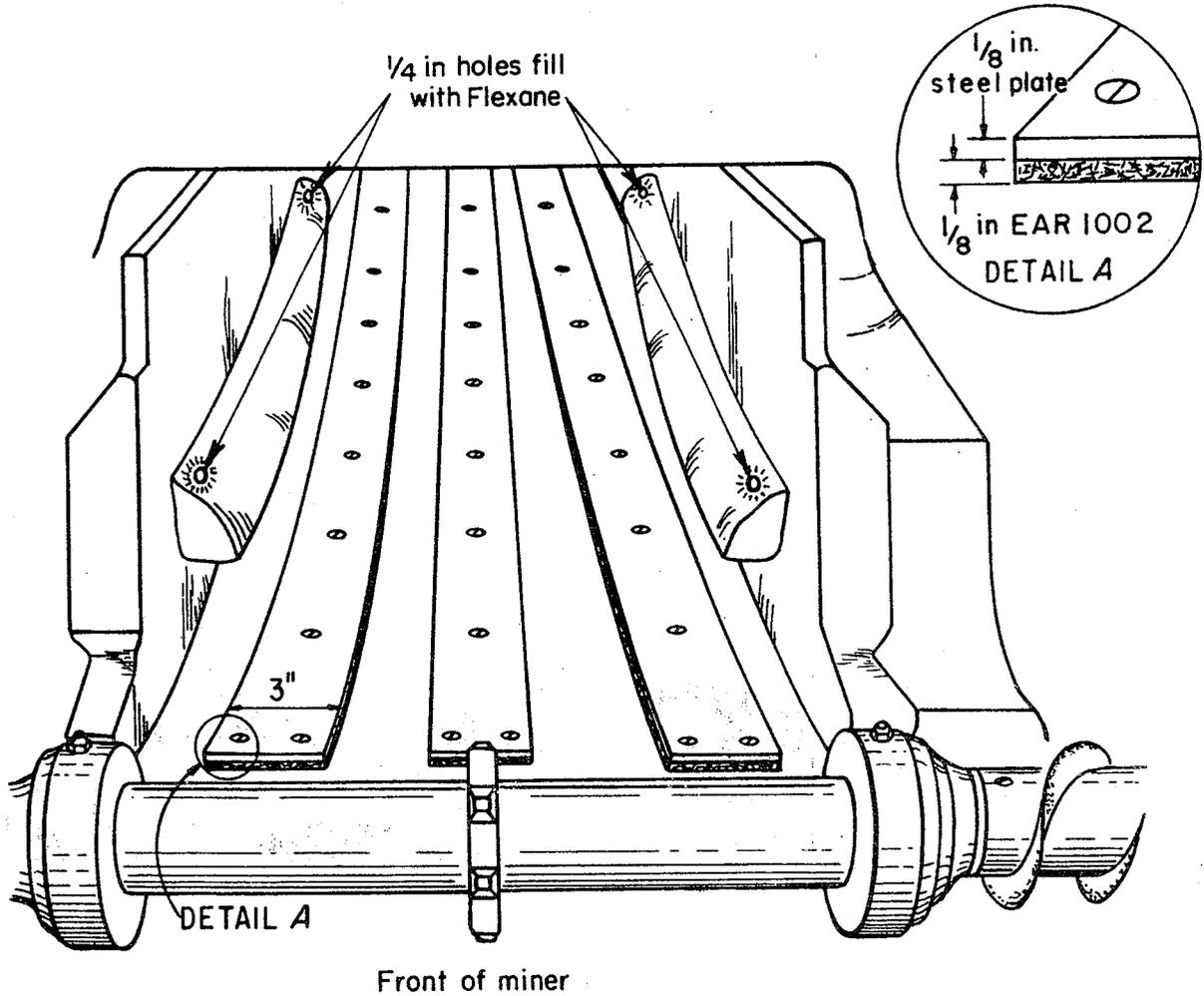


FIGURE 14. - Diagram showing noise control modifications made to the front of the miner.

d. Chain-Sprocket

After the completion of all the previous modifications, it was determined that the primary noise source is the chain link-sprocket teeth interaction. This occurs at both ends of the miner. To verify this, half of the conveyor chain was coated with Flexane 80 material. Subsequent measurements showed that when the treated half of the conveyor chain arrived at the sprockets, the noise level was significantly reduced compared to the measured noise level of the untreated portion. However, this material is not durable enough for underground use; it began to wear after 12 hours of running time. Regardless of the short wear life, the application of the Flexane material indicates that the interaction of the sprocket teeth and chain links is a source of noise. However, the front sprocket of the miner ceases to be a major noise source in an underground mine because it is usually covered with coal which tends to reduce the sprocket noise.

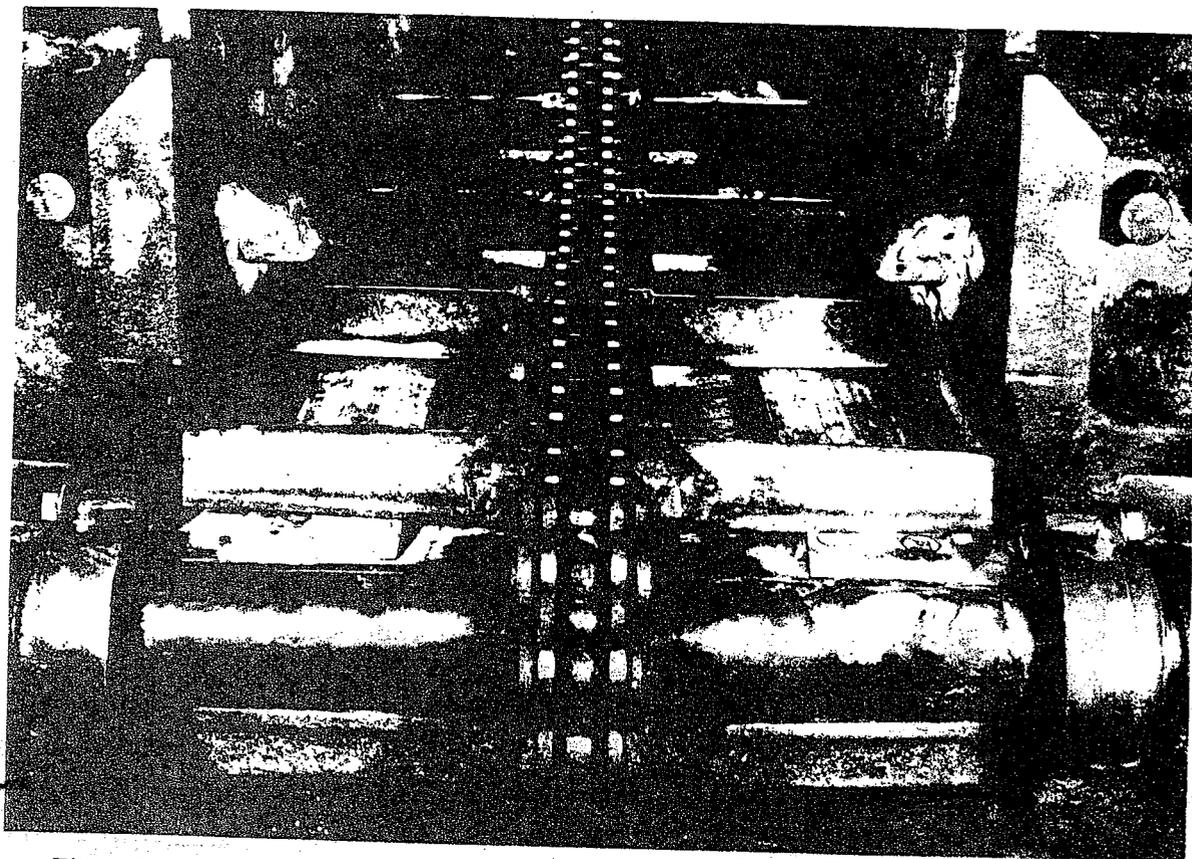


FIGURE 15. - Close-up view showing noise control modifications made to the front of the miner.

e. Conveyor Drive Assemblies

The conveyor drive assemblies for the miner and bridge conveyor are similar. The predominate noise sources in both assemblies are gear noise from the gear reducer, drive motor noise caused by the interaction between the bearings and rotating shaft, and noise radiated by the machine frame because of induced vibrations. Each of these adds to the overall noise level.

The noise control modifications which can be performed on the conveyor drive assemblies are illustrated in figures 16a through 16e. As seen in figure 16a, the drive motor, gear reducer and base plate are removed from their enclosure. At this time, the inside of the enclosure, sides and bottom, are thoroughly cleaned with a sand blaster. After this preparation, pieces of steel plate are welded into any openings that exist inside the enclosure. This is to insure that with the cover panel in place, the leakage of noise is minimized. For the miner, 1/4" steel plates are welded into the inner side of the enclosure between the machine frame and conveyor. For the bridge conveyor, a 1/4" steel plate is welded on the forward end of the cover panel. Next, as shown in figure 16b, a sheet of 1/4" E-A-R 1002 is cut to size and glued into

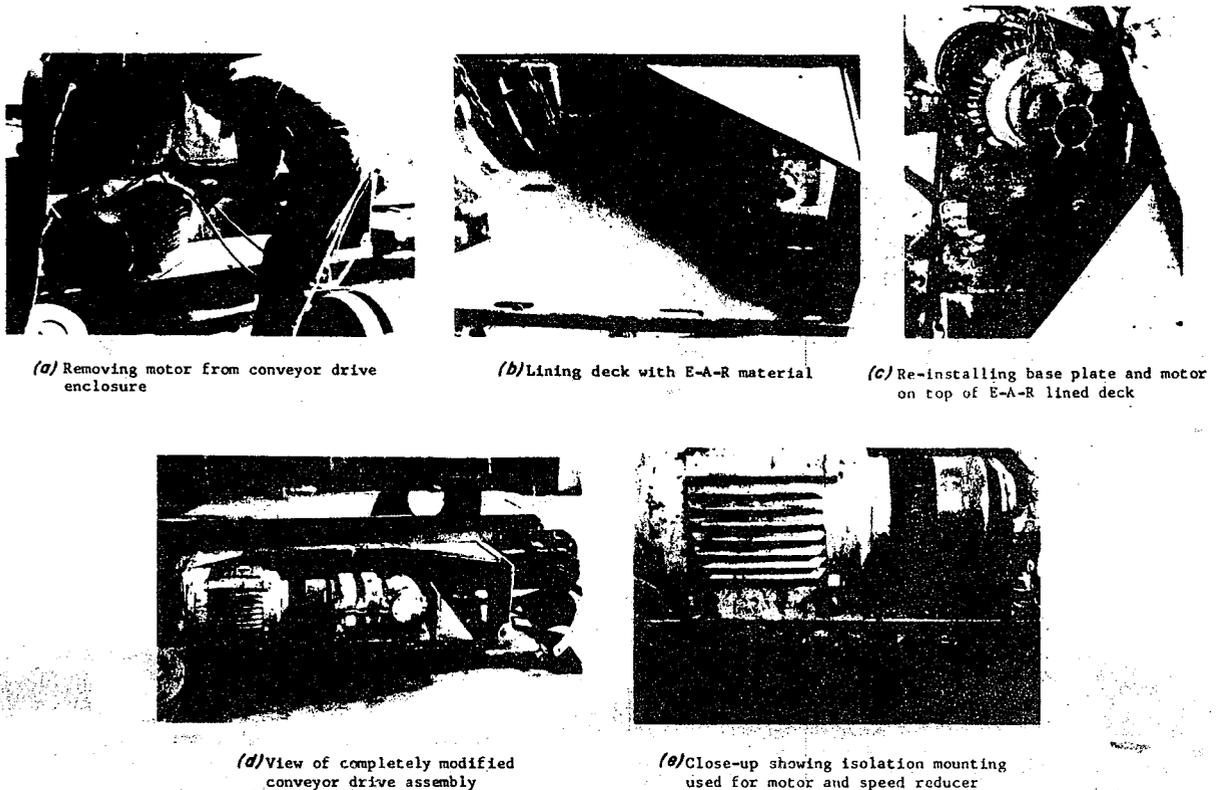


FIGURE 16. - Summary of the noise control procedure used on the conveyor drive assemblies.

the bottom of the enclosure. The base plate is then reinstalled on top of the E-A-R material (fig. 16c). Around the sides of the enclosure, Durasonic material is glued. This material, which can be seen in figure 16d, provides vibration damping, as well as sound absorption. The drive motor and gear reducer are then replaced. As depicted in figure 16e, small E-A-R washers are used under the head and nut of each mounting bolt to further isolate the transfer of vibration into the frame.* Referring back to figure 16d, it can be seen that 1/4" E-A-R isolation pads are also glued around the cover panel bolt holes. This helps isolate the cover panel from the machine frame. To further reduce the noise, the inside of the cover panel is first lined with 1/4" E-A-R to reduce vibrations. On top of this, sound absorbing fiberglass is then installed. Lining of cover panels will be discussed in the next section.

*When an electrical component is isolated from the machine frame, a ground strap must be connected from that component to the frame. The strap is usually made of braided copper. When isolating the conveyor motor, as described above, a 1/0 braided copper strap is connected between the motor case and the machine frame. To insure good electrical connections, the places where the strap is to be connected should be thoroughly cleaned using a metal file or a grinding tool.

Figure 17 illustrates in detail all of the noise control modifications discussed above.

3. Cutting Head Drive Assemblies

Two cutting head drive assemblies, one mounted on each side of the miner, provide power for the right and left auger cutting heads. Each cutting head is chain driven by a separate, 100-hp, 440-volt, dual shaft, electric motor through a gear reducing unit. Besides powering a cutting head, the motor drives a cooling fan, as well as a hydraulic pump system. This pump system powers the various hydraulic cylinders used to orient the machine cutting heads, boom and carriage.

In this assembly there are several mechanisms responsible for the generation of noise. They are the motor cooling system, the main motor drive assembly and the cover panels.

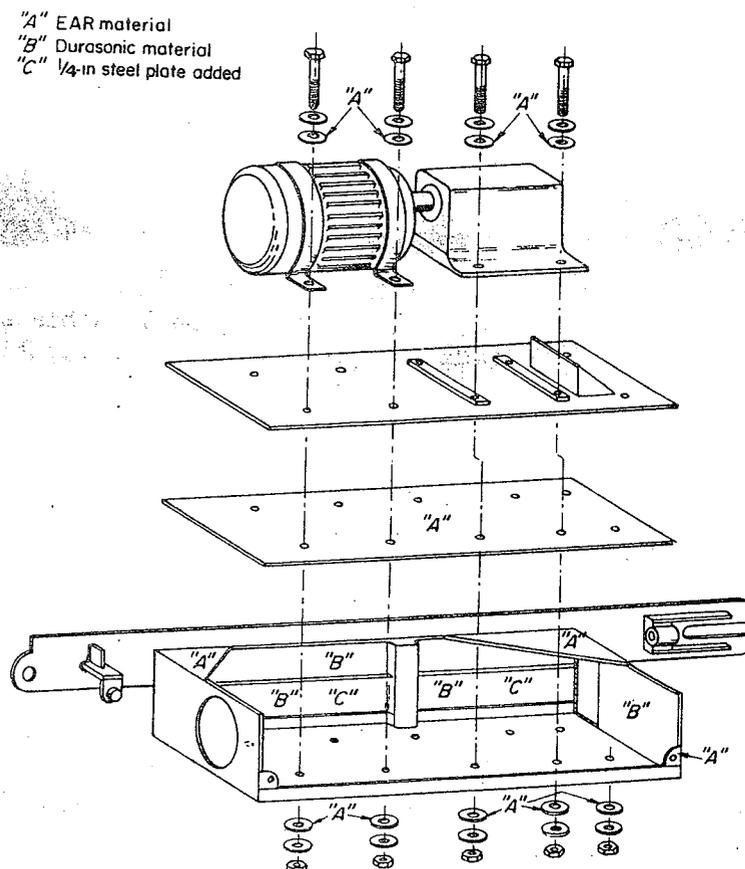


FIGURE 17. - Diagram illustrating the noise control modifications made to the conveyor drive assemblies.

a. Motor Cooling System

This system produces primarily fan noise and airflow noise. The fan is an integral part of the motor. Air is drawn in by the fan blades through the vents on the sides of the miner. It is circulated around the motors for cooling and is exhausted out through the exit vents. Cooling system noise affects the machine operator and jacksetters in different ways. The paths followed by the noise are illustrated in the upper half of figure 18. Here it can be seen that, for the operator, the noise source is the motor and fan on the right side. This noise takes a dual path reaching the operator through the control panel and rear exit vent. For the jacksetter, however, only one noise path is followed. That path, as shown, is from the motors and cooling fans

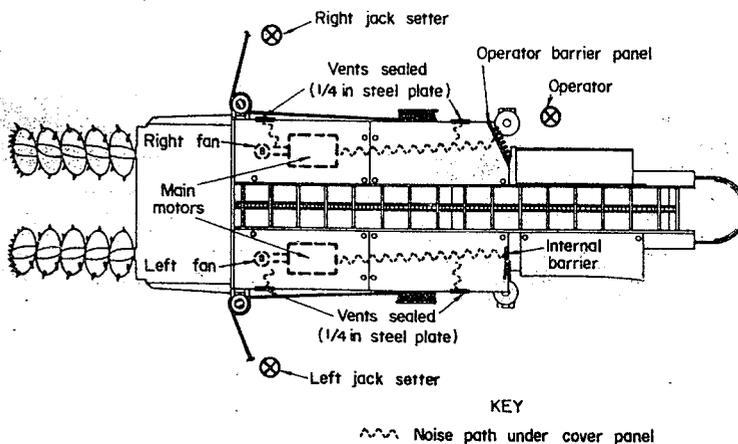
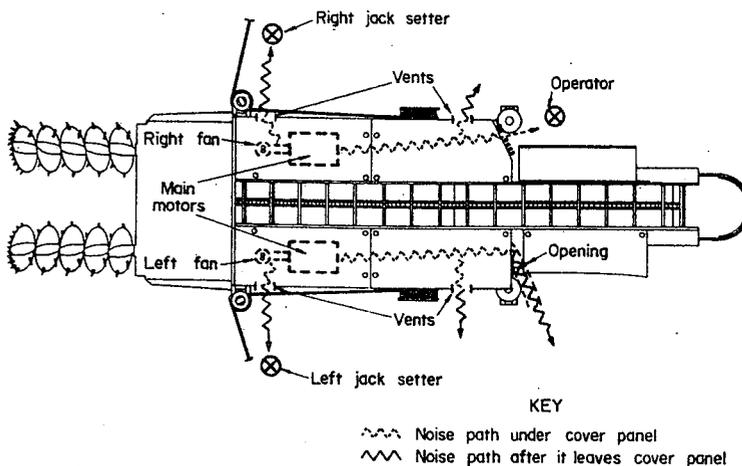


FIGURE 18. - Diagram illustrating sources and paths of cooling system noise and subsequent noise control treatment.

the vents is not critical. Tests which were conducted showed that after several hours of continuous operation, the temperature inside the panels rose to only 60° C. The maximum temperature ratings for the motors, according to the manufacturer, is 150° C. Therefore, this test and the subsequent use of the miner in a working section of an underground mine show that temperature rise is not a problem.

(2) Construction of Operator Barrier Panel--In designing the operator barrier panel, consideration should be given to obstacles which could provide difficulty in constructing an effective cover. Protruding from the control box are a total of 11 levers, 6 on top, 5 on the bottom, that are to be manipulated either up and down or in and out when operating the miner. Located on the left, angled toward the control box, is the hydraulic cylinder

directly through the front exhaust vents. Additionally, the vibrating cover panels produce airborne noise which causes an increase in the overall noise level of the jacksetters.

Motor cooling system noise is reduced by the incorporation of three separate modifications on the miner. These modifications, illustrated in the lower half of figure 18, are:

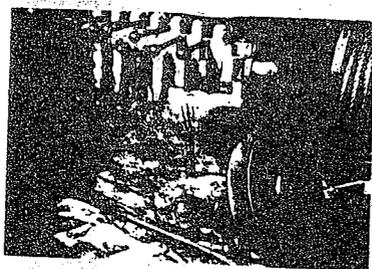
- (1) Sealing the four vents.
- (2) Construction of an operator barrier panel.
- (3) Construction of an internal barrier on the left back end of the miner.

The following is a detailed description of each of these modifications:

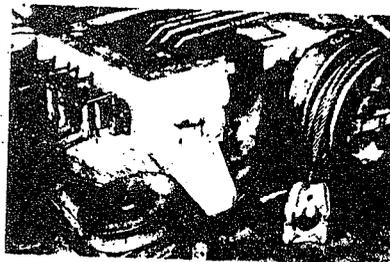
(1) Sealing the Vents--The vents on the sides of the cover panels are sealed by removing the existing gratings and welding in their place 1/4" thick steel plates. The temperature rise due to the sealing of

of the right jackleg. Above this cylinder, heavy-duty power cables make their way forward. A pivoted winch sheave is folded in the down position when not in use and occupied the right hand corner directly under the control box. The best solution would be to make the cover out of two pieces. The top half overlaps and is fastened to the bottom half with sheet metal screws. Both pieces are fabricated from 16 gage galvanized sheet steel. The bottom piece, as shown in figure 19a, is fabricated first. A piece of 1/2" angle iron is tack welded underneath the control box to provide a place to fasten the top of the bottom shield. Fastening is accomplished by tapping holes in the angle iron and by using 10/32" screws. The shield is pushed inward, bottom first, until the left side achieves the same slope as the hydraulic cylinder. The slope on the right side will be more pronounced since this side has to miss the winch sheave. A 1" wide area on top of the shield is bent parallel to the angle iron. Next, the shield is bent at approximately 90° so it will fit behind the main cover panel. An overlap is left to provide a bolting surface for sheet metal screws coming from the outside of the main panel through clearance holes. Prior to installation, a sandwich liner of E-A-R 1002 and Durasonic Type 5155 is glued to the back of the shield with an overlap of 1" on the bottom to provide a good acoustic seal. Similarly, on the left, approximately 12" of material is left in place protruding past the shield. To prevent the liner from peeling, a 1" wide aluminum strip is fastened around the edge of the shield.

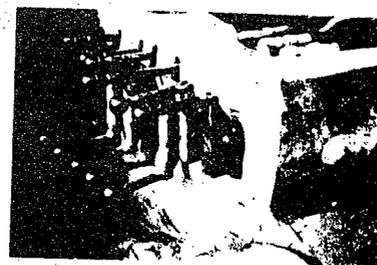
The top part of the barrier, which is fabricated next from 16 gage sheet metal, is shown in figures 19b and 19c. Slots are provided for the operating



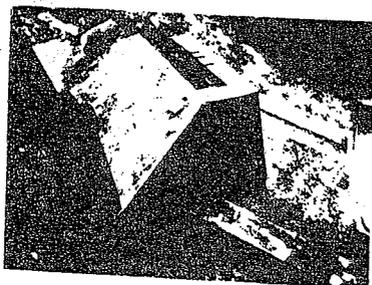
(a) Bottom section of operator barrier panel



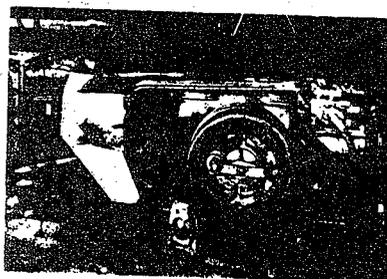
(b) Front view of both sections installed (cover panel removed)



(c) Close-up of bottom and top sections



(d) View of completed barrier panel (removed from miner)



(e) Side view of completed barrier panel (cover panel removed)



(f) Completed barrier panel with cover panel in place

FIGURE 19. - Summary of the construction of the operator's barrier panel.

levers to facilitate the removal of the top cover for servicing. This side of the shield is bent to effectively seal any openings. However, a bulky hydraulic fitting mounted on the side of the control box makes it necessary to provide a hole in the shield so that a proper fit underneath the main cover plate is assured. Sheet metal screws are used to fasten the top shield to the bottom shield. Figure 19d shows the complete barrier removed from the machine. Here it can be seen that E-A-R C-1002 material, cut from a single piece, is fitted and glued to the inside of the barrier. To increase the effectiveness of the barrier, Insul-Quilt material is then glued to the E-A-R material. Similarly, a large piece of Durasonic material, also fitted with Insul-Quilt material on the inside and at the same height as the barrier, is carefully inserted around the side and in between the winch box, as shown in figure 19e. In addition, pieces are inserted underneath the top shield and around the power cables, increasing the effectiveness of the barrier. Figure 19f shows the completed operator control barrier with the cover panel in place. A detailed drawing showing the construction of this operator barrier panel is illustrated in figure 20.

(3) Internal Barrier Construction--The construction of the internal barrier for the inside of the left side cover panel is shown in figure 21. The addition of this barrier reduces noise escaping from the open end of the left side cover panel. This barrier is made from 16 gage sheet metal, 1/4" E-A-R 2003, and 1" Durasonic No. 5155 cut in 18" x 28" sheets. These materials are glued together and screwed to two angle irons welded to the bed of

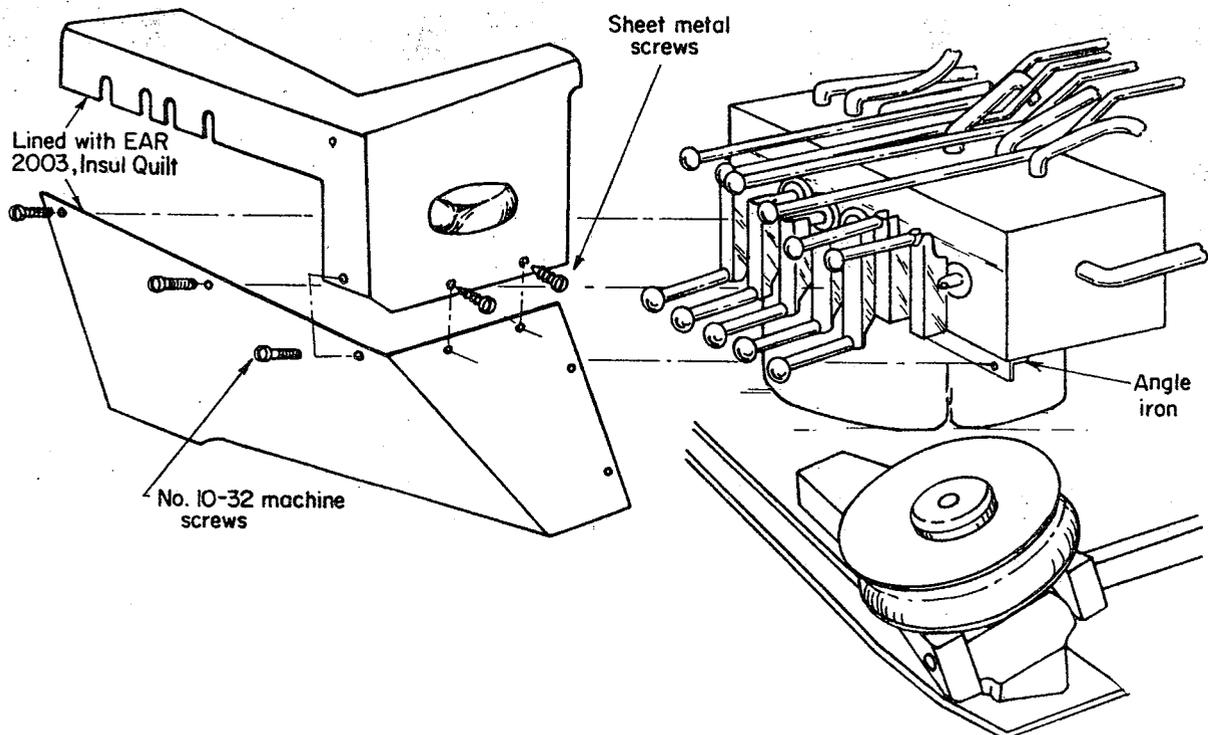


FIGURE 20. - Diagram showing details of operator barrier panel.

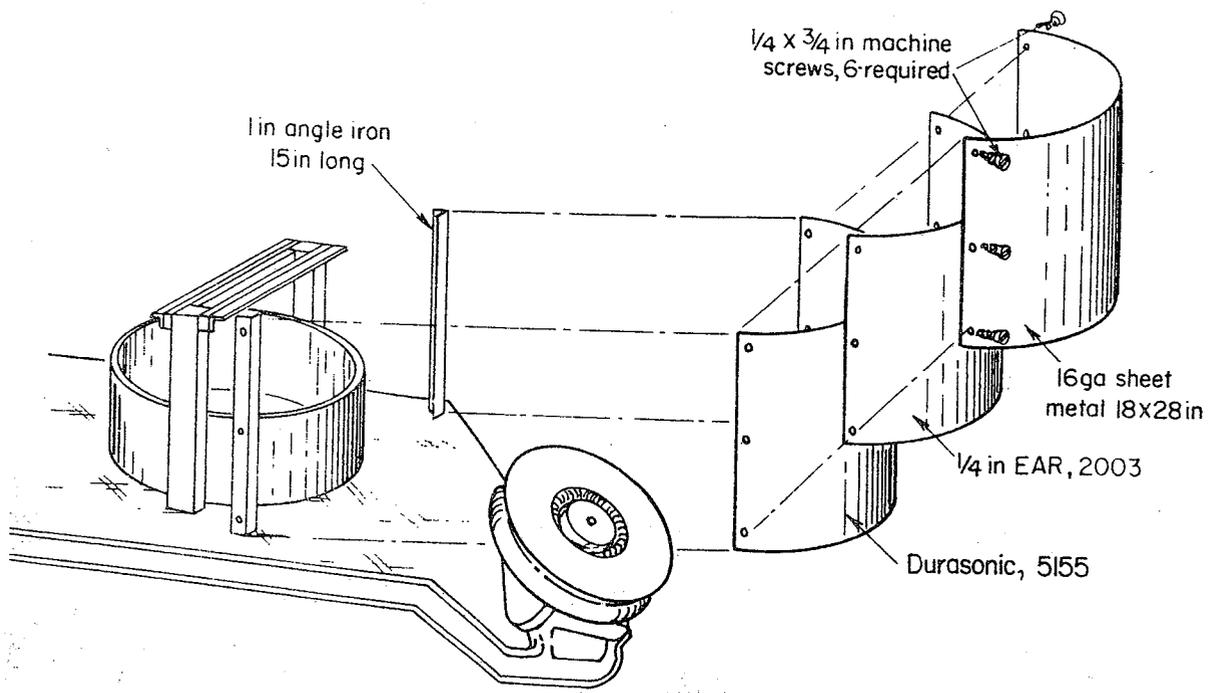


FIGURE 21. - Diagram showing construction details of the internal barrier.

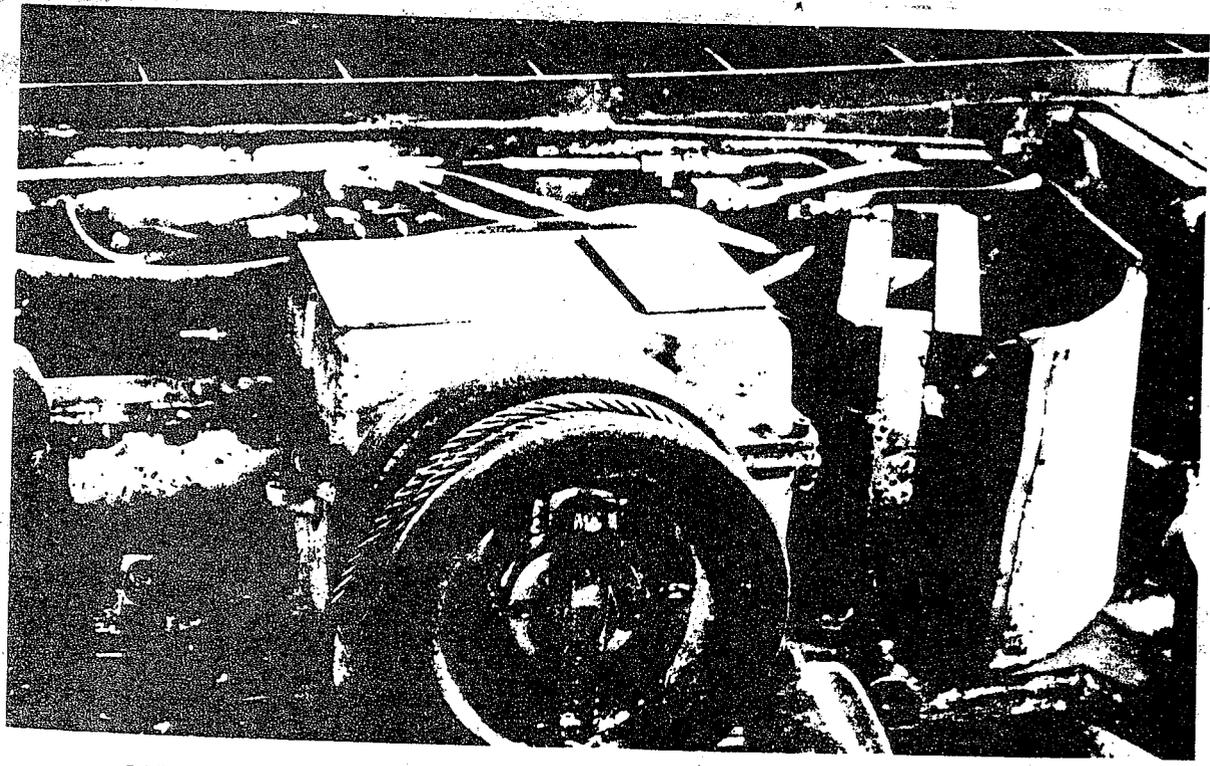


FIGURE 22. - Placement of the internal barrier for the left side of the miner.

the miner. The barrier is bowed to form a quarter cylinder and made to fit flush to the inside of the cover panel. Figure 22 shows the placement of the internal barrier on the machine.

b. Main Motor Drive Assembly

At the request of the equipment manufacturer, this assembly was not treated.

c. Cover Panels

The cover panels are provided as standard equipment on the miner and bridge to protect the motors and other operating gear. They are composed of

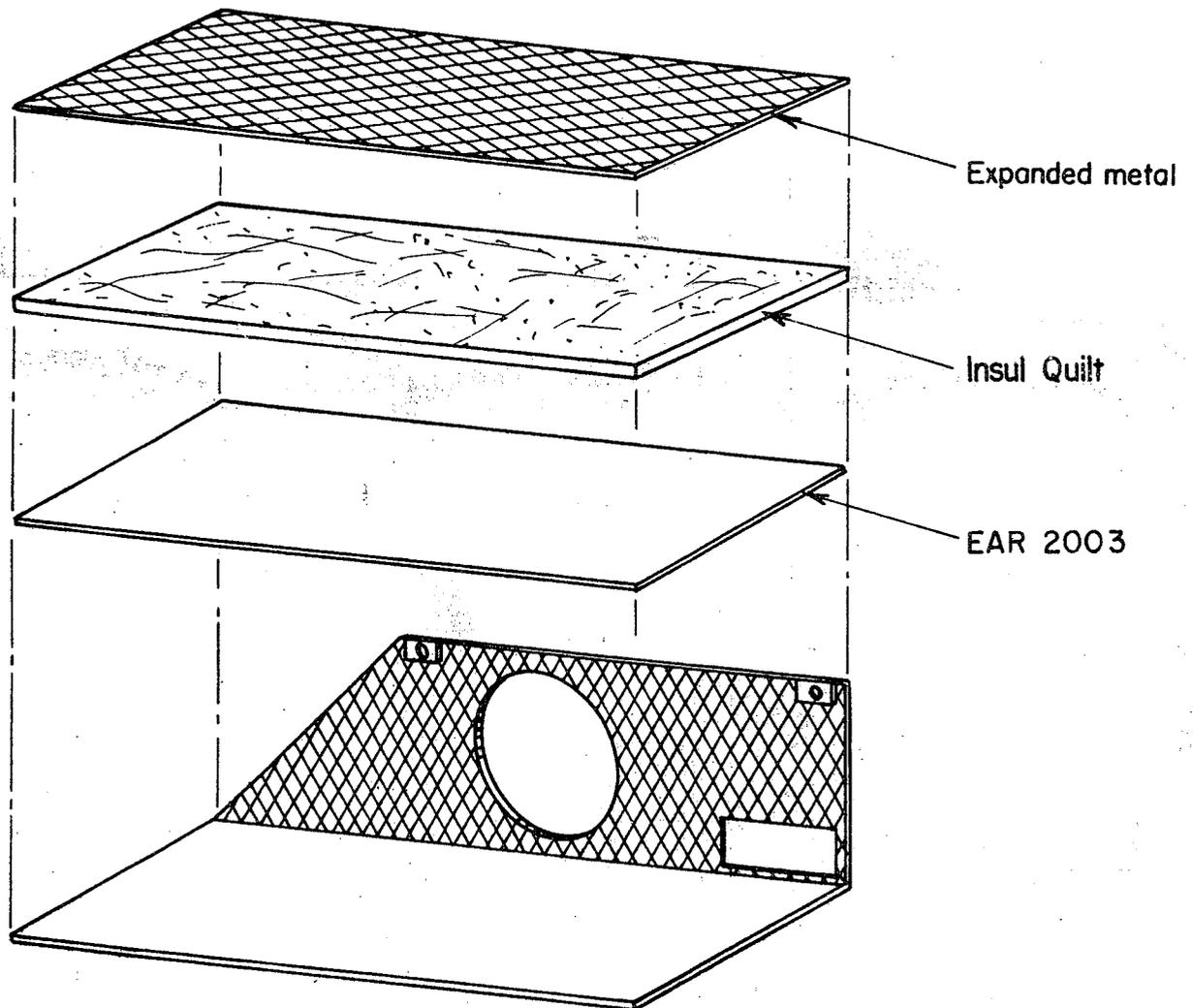
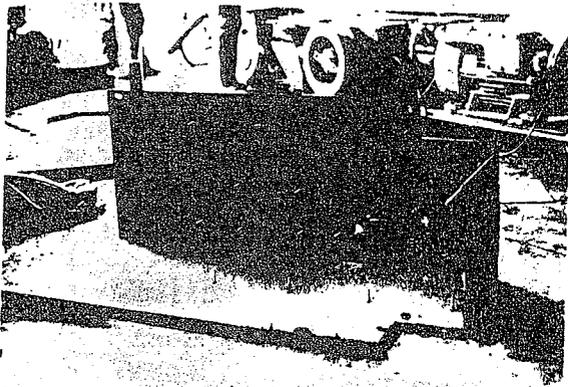


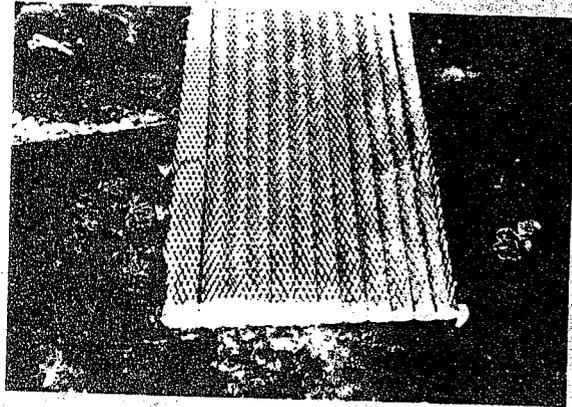
FIGURE 23. - Diagram illustrating one treatment technique used on cover panels of miner.

1/4" steel and made to be bolted directly to the frame of the machine. Vibrations from the operating components can cause these panels to vibrate and radiate noise.

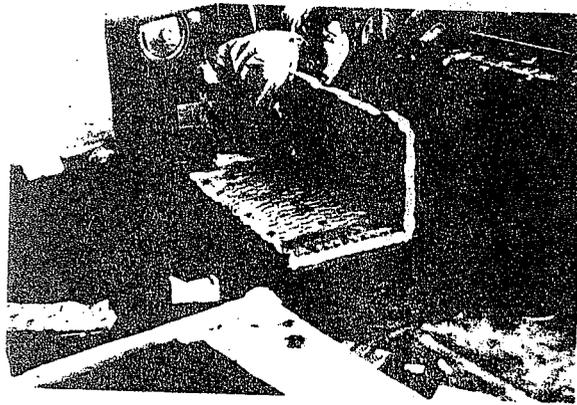
The acoustical treatment for the cover panels was designed with two thoughts in mind: first, the vibration of the covers must be damped, and second, the cover panel can act as a good acoustical enclosure with the installation of sound absorbing material. Treatment begins by closing all panel openings that are not needed for maintenance or lighting. The inside of every panel is thoroughly cleaned by sand blasting. A piece of E-A-R 1002, cut to fit, is then glued to the inside surface using an epoxy adhesive (fig. 23). Next, a properly sized piece of fiberglass material (having an impervious front layer) is glued to the E-A-R material. An expanded metal screen is then placed on top of the fiberglass and tack welded to the cover panels around the



(a) Partially completed cover panel showing welded studs and E-A-R material



(b) Fiberglass material used in cover panel treatment

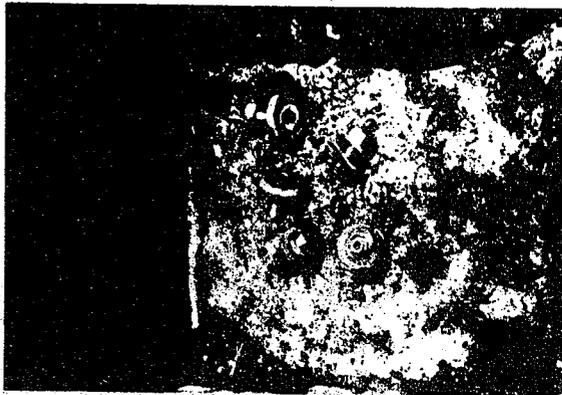


(c) view of completed cover panel

FIGURE 24. - Summary of alternate treatment used on cover panels of miner and bridge conveyor.

edges. The expanded metal screen is installed to protect the fiberglass when the panels are removed for maintenance.

An alternate method that can be used for installing the fiberglass material is shown in figures 24 (a through c). After cleaning the panels, a series of metal studs are welded to the inside surface. The E-A-R material is glued to the panel as before except that small clearance holes are cut into the material for the studs, as shown in figure 24a. Fiberglass material with protective screen, shown in figure 24b, is then pushed onto the studs. Rubber retaining caps are used on the studs to keep the fiberglass and screen in place (fig. 24c). For some of the panels, small areas of the screen and fiberglass are removed to give clearance for the motor and gear assemblies.



(a) Isolation washers for cover panel mounting bolts



(b) Isolation washers installed



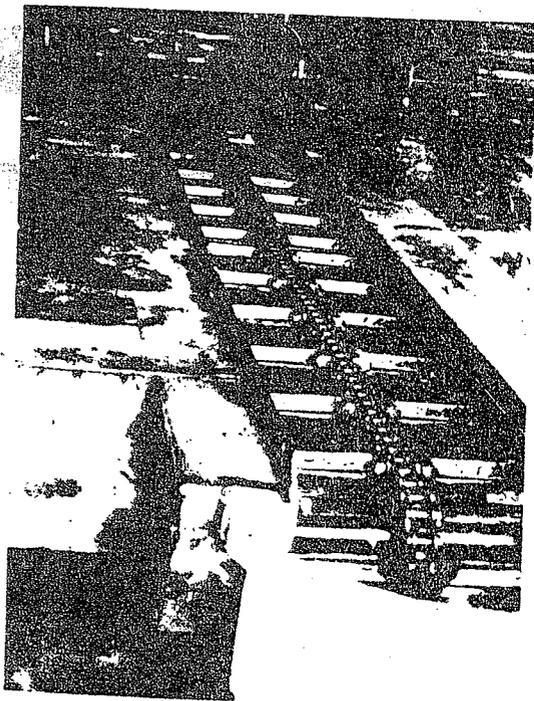
(c) Side view showing isolation washer and pad

FIGURE 25. - Summary of techniques used in mounting cover panels on miner and bridge conveyor.

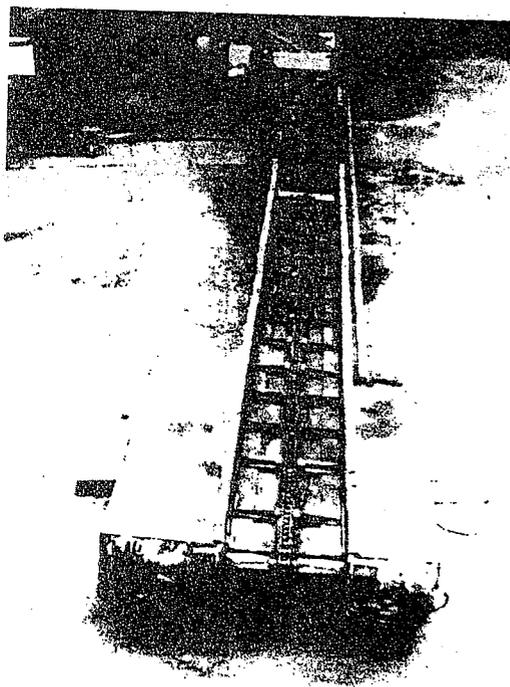
In replacing the modified cover panels on the miner and bridge conveyor, precautions are taken to vibrationally isolate them from the machine frame as much as possible. Every mounting bolt used has a specially fabricated isolating washer as shown in figure 25a. When installing the bolts, regular metal washers are used on top of the isolating washers (fig. 25b). To further isolate the covers, E-A-R pads are constructed and glued to every cover panel mounting bracket (fig. 25c). Thus, the final configuration of the cover panels shows them to be damped, isolated from frame vibration and acting as noise absorbing, high transmission loss acoustical enclosures.

4. Winch System

The winch system on the Wilcox auger miner is used in conjunction with metal jacks to position and advance the miner across the coal face. This system is composed of two 40' lengths of 5/8" wire rope wrapped around drums on each side of the miner. The drums are gear driven by the main drive-train motors. Noise measurements were taken both without the winch system in operation and with the winches energized (tension on the cables). Results showed that the contribution of noise generated by the winch system to the overall noise level is negligible. Because of these results, acoustical modifications are felt to be unnecessary.



(a) Miner



(b) Bridge conveyor

FIGURE 26. - A, Noise controlled Wilcox Mark 20 auger miner; B, noise controlled Wilcox bridge conveyor.

5. The Completed Mark 20 Miner System

The completed Wilcox Mark 20 miner and bridge conveyor employing all the noise control modifications described in this report are shown in figures 26a and 26b. From the photographs, it can be seen that none of the noise control techniques used have drastically altered the physical dimensions of the miner and bridge. Except for the conveyor damping strips, a casual observer would experience difficulty in recognizing the difference between a noise controlled and an unmodified machine. The difference, however, would become readily apparent once the machines were operated. This difference, the noise reduction, will be discussed for both the surface and underground environments in the following sections.

RESULTS--SURFACE

All of the acoustic data presented in this section were measured in accordance with the procedures and instrumentation specified in the sections titled "Instrumentation" and "Procedure." The miner and associated bridge conveyor were operated in an unloaded state; that is, the system was neither cutting nor transporting coal.

1. Reverberation Measurements

In order to utilize the above ground noise data in predicting underground machine noise levels, an acoustical characterization of the above and below ground environments was performed. This was done using an impulsive noise source (bursting balloons) and measuring the reverberation or decay times of the sound field, in 1/3 octave bands, with the miner in place. The resulting A-weighted reverberation time for the surface work area was 1.3 seconds. The underground A-weighted reverberation time, as measured in a low coal entry, was significantly less, averaging 0.8 second. This indicates that the surface environment was acoustically less absorptive than the underground environment. Thus, the machine noise levels as measured in the surface work area would be higher than those measured, under the same machine operating conditions, in an underground coal mine. This difference in the above and below ground noise levels will, of course, vary with different locations around the machine, being a function of the relative strengths of the direct and reflected sound fields.

2. Noise Level Reductions--Miner

Figure 27 illustrates the A-weighted sound level reductions measured at nine positions around the miner. These measurements were made with all miner systems in operation and no bridge conveyor attached. In the figure, the following notation is used: bracketed numbers < > indicate before modification sound levels, while unbracketed numbers () indicate after modification sound levels, while unbracketed numbers are the resulting dBA noise reductions. As can be seen, the noise reductions vary in magnitude around the miner, reaching a maximum at the operator's position of 10.1 dBA (103.0 dBA before, 92.9 dBA after). The reductions measured for the right and left jacksitters' positions are 6.4 dBA (98.5 dBA before, 92.1 dBA after) and 7.3 dBA (99.5 dBA before, 92.2 dBA after), respectively.

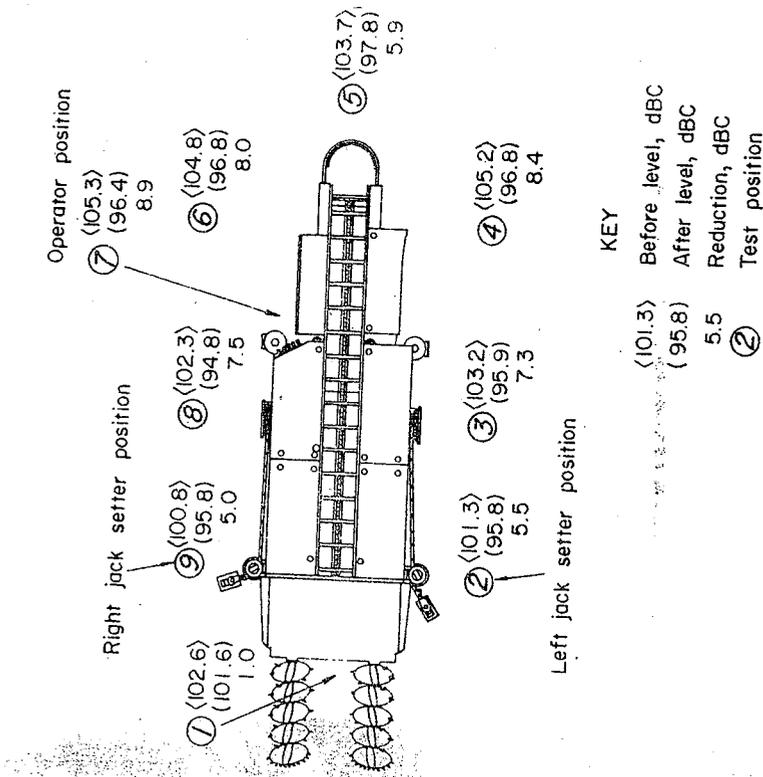


FIGURE 27. - A-weighted noise levels around miner, before and after modifications.

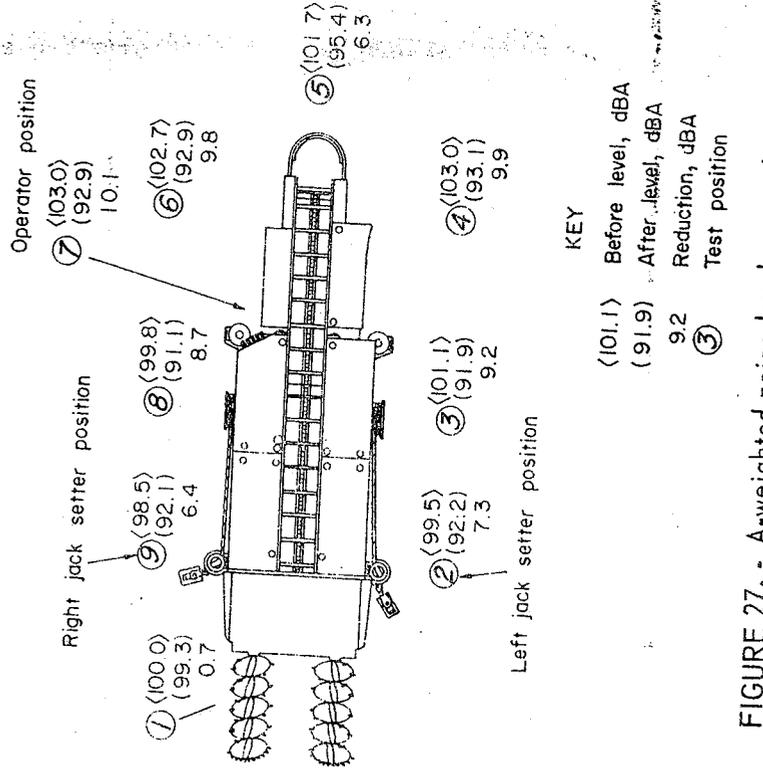


FIGURE 28. - C-weighted noise levels around miner, before and after modifications.

To further characterize the noise emitted from the miner, C-weighted noise data is given in figure 28. Here the same before and after notation is used as in figure 27. The dBC noise reductions are, for the most part, less than the dBA reductions, being 8.9 dBC for the operator, 5.0 and 5.5 dBC for the right and left jacksetters' positions. Table 2 summarizes the A- and C-weighted noise level measurements obtained around the miner.

TABLE 2. - Noise levels (RTA output) around miner before and after modifications--everything on miner in operation; no bridge conveyor

Position	Average dBA before modifi- cation	Average dBA after modifi- cation	Reduction in dBA	Average dBC before modifi- cation	Average dBC after modifi- cation	Reduction in dBC
1	100.0	99.3	0.7	102.6	101.6	1.0
2 Jack- setter	99.5	92.2	7.3	101.3	95.8	5.5
3	101.1	91.9	9.2	103.2	95.9	7.3
4	103.0	93.1	9.9	105.2	96.8	8.4
5	101.7	95.4	6.3	103.7	97.8	5.9
6	102.7	92.9	9.8	104.8	96.8	8.0
7 Operator	103.0	92.9	10.1	105.3	96.4	8.9
8	99.8	91.1	8.7	102.3	94.8	7.5
9 Jack- setter	98.5	92.1	6.4	100.8	95.8	5.0

The octave band spectrum for each of the workers' positions is given in figure 29. Referring to the before curves in each graph, it is apparent that most of the sound energy, before modification, is evenly distributed with the 125 to 2,000 Hz frequency bands, falling off at about a 10 dB/octave rate below 125 Hz and 7 dB/octave above 2,000 Hz. The noise reduction obtained, which is shown in the shaded region in each graph, is maximum within the frequency bands of 125 to 4,000 Hz. Thus, the noise reduction achieved lies within the frequency range which is most critical to human hearing. Appendix A provides a complete description of the acoustical data, giving the before and after 1/3 octave band spectra as measured at all positions around the miner.

3. Vibration Level Reductions--Miner

Vibration levels (acceleration) were measured before and after noise control treatment of the miner. Figure 30 shows the results obtained on several parts of the machine surface. These measurements were made with all miner systems operating and no bridge conveyor attached. Reductions in vibrations were significant, averaging 16 dB (re 30 μ g) for the nine positions. Table 3 summarizes the A- and C-weighted vibrational level measurements obtained on the miner.

TABLE 3. - Acceleration measurements on miner before and after modifications--everything on miner in operation; no bridge conveyor

Position	Average dBA before modifi- cation	Average dBA after modifi- cation	Reduction in dBA	Average dBC before modifi- cation	Average dBC after modifi- cation	Reduction in dBC
1	105.1	83.0	22.1	104.7	84.0	20.4
2	100.2	82.9	17.3	99.9	86.9	13.0
3	103.2	84.1	19.1	116.3	85.8	30.5
4	108.4	80.5	27.9	108.0	88.7	19.3
5	108.7	81.8	26.9	108.7	90.8	17.9
6	110.8	97.8	13.0	109.6	98.6	11.0
7	102.2	97.7	4.5	102.1	98.2	3.9
8	100.9	83.2	17.7	100.5	85.6	14.9
9	103.2	87.1	16.1	103.0	88.4	14.6

NOTE.--All dB values are referenced to 30 μ g.

Vibrational analysis in 1/3 octave bands indicated that most of the reduction occurred in the 250 to 8,000 Hz frequency range. Many of the vibration spectra showed unusually large peaks in the 63 Hz 1/3 octave band. The phenomenon was investigated and found to be caused by electrical interference. Mathematical corrections for these electrically induced peaks were made in the vibrational spectra. Appendix B gives the complete 1/3 octave vibrational analysis done on the miner.

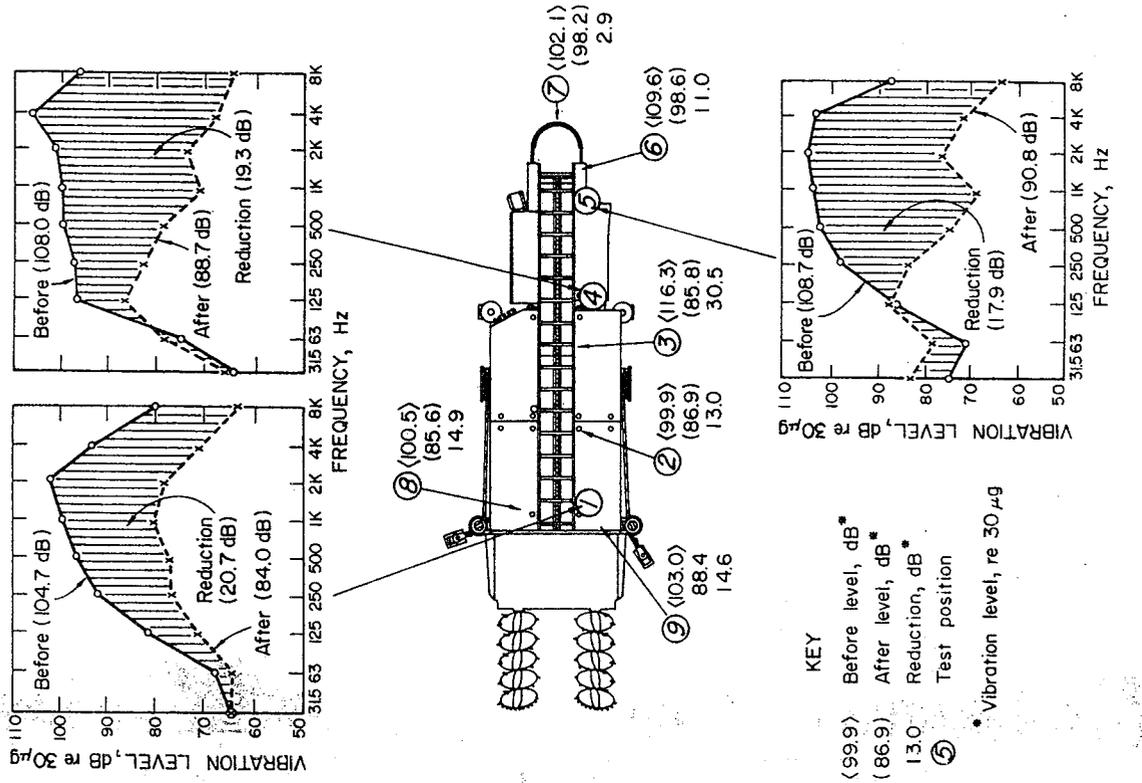


FIGURE 29. - Octave band spectra of noise at each of three worker positions, before and after modifications.

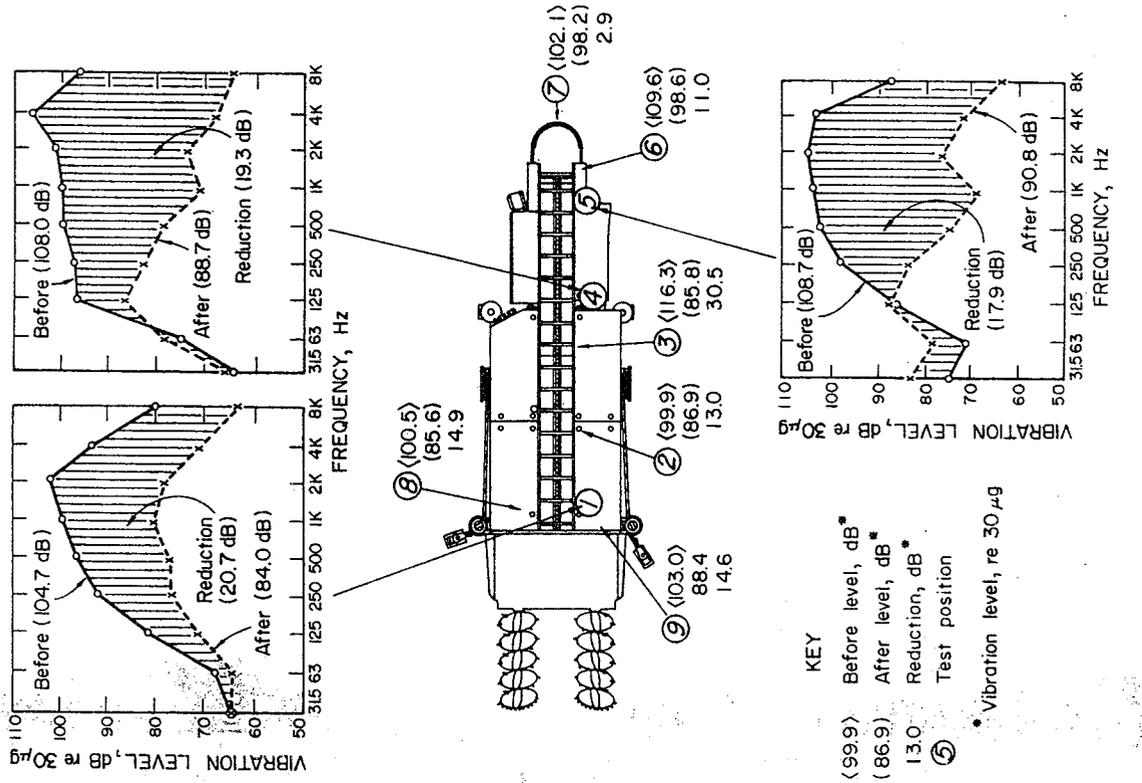


FIGURE 30. - Vibration levels (re 30 µg) at several positions on the miner, before and after modifications.

KEY
 (99.9) Before level, dB*
 (86.9) After level, dB*
 13.0 Reduction, dB*
 ⑤ Test position
 * Vibration level, re 30 µg

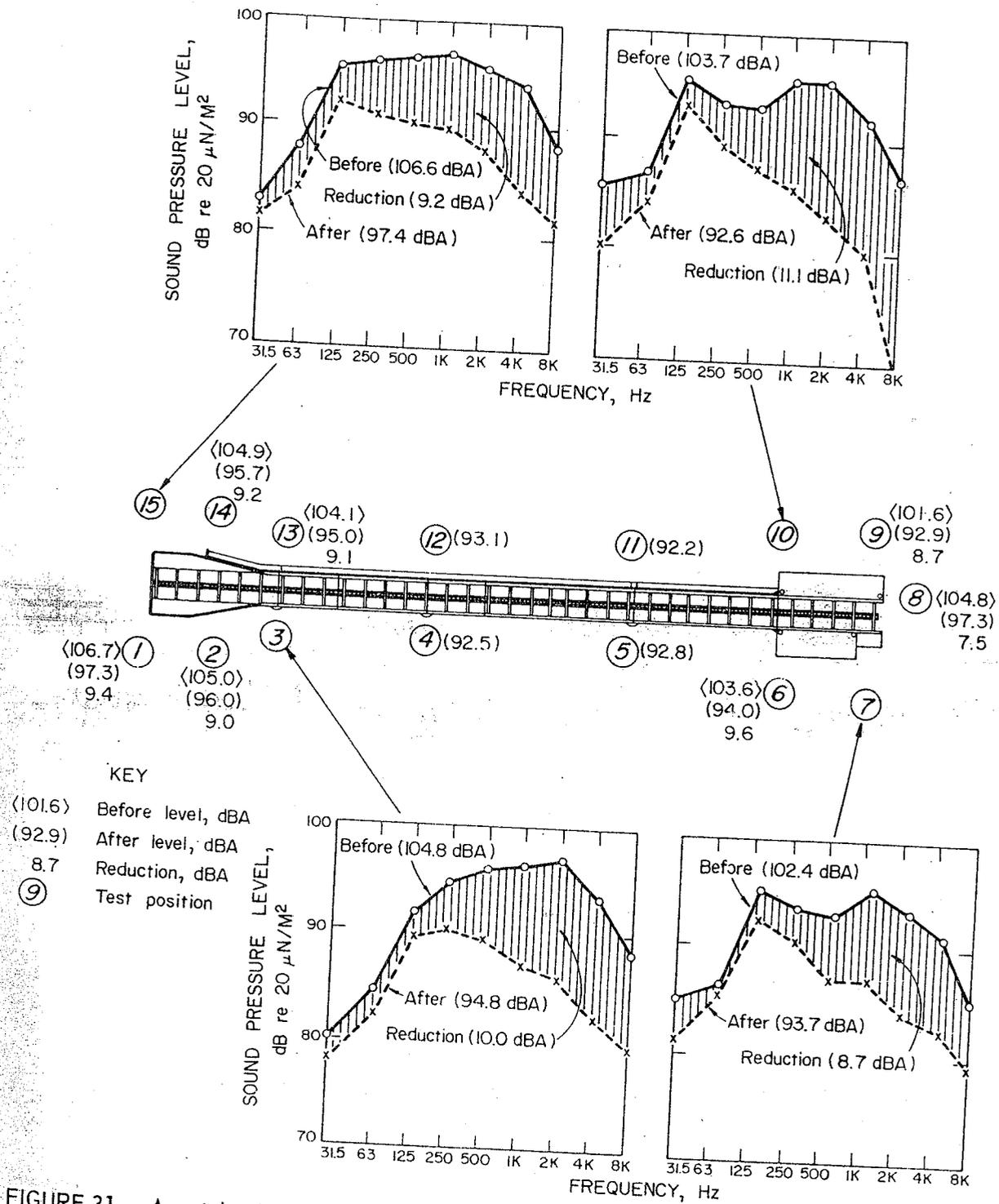


FIGURE 31. - A-weighted noise levels and octave band spectra around bridge conveyor, before and after modifications.

4. Acoustical Data--Bridge Conveyor

Noise and vibration levels were measured before and after noise control modifications at various locations around and on the bridge conveyor. Figure 31 shows the before and after sound levels. For these measurements, all miner systems and the bridge conveyor were in operation. Resulting A-weighted noise reductions at all monitored locations ranged from 7.5 to 11.1 dBA with a mean value of 9.2 dBA. Similarly, the C-weighted sound pressure levels are given in figure 32. Here again the dBC noise reductions were somewhat less than the corresponding dBA values, ranging in value from 4.8 to 7.5 dBC with a mean of 6.4 dBC. Table 4 summarizes the dBA and dBC acoustical data.

Several octave band spectra included in figure 31 describe the resulting noise level reduction as a function of frequency. Here the frequency distribution of the obtained reductions is shifted one octave, relative to that obtained for the miner, being maximum in the 250 to 4,000 Hz frequency bands. Appendix C gives a complete listing of all before and after 1/3 octave band spectra measured around the bridge conveyor.

Results of vibration levels measured before and after noise control modifications are presented in figure 33. Appreciable reductions are evidenced at all but one of the positions monitored. The mean reduction in vibration level was approximately 12 dB (re 30 μ g). Table 5 lists the A- and C-weighted vibrational level measurements and reductions obtained. The octave band vibrational data for all measured positions can be found in appendix D.

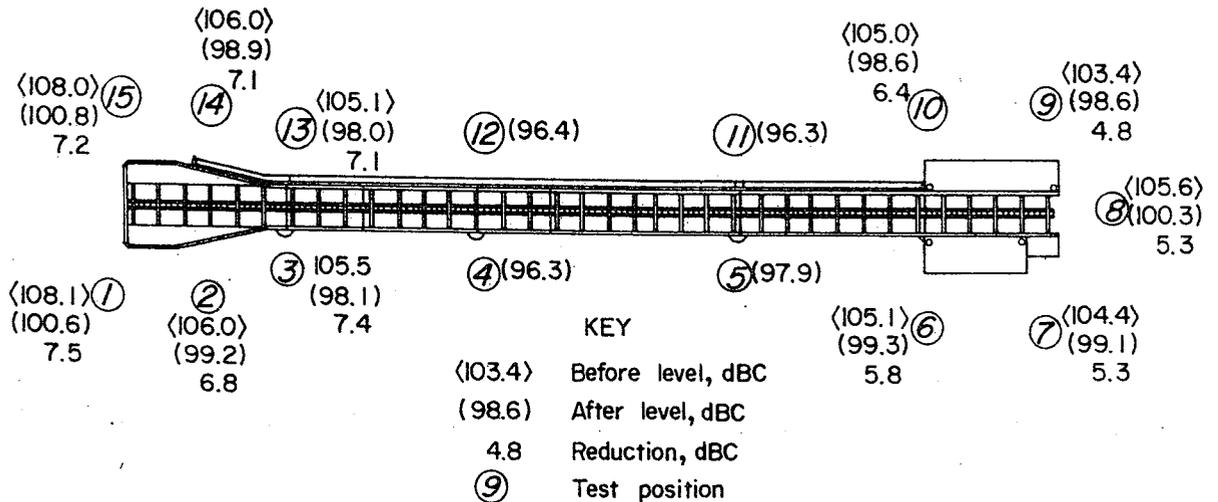


FIGURE 32. - C-weighted noise levels and octave band spectra around bridge conveyor, before and after modifications.

TABLE 4. - Noise levels (RTA output) around bridge conveyor before and after modifications--everything on both miner and bridge conveyor in operation

Position	Average dBA before modifi- cation	Average dBA after modifi- cation	Reduction in dBA	Average dBC before modifi- cation	Average dBC after modifi- cation	Reduction in dBC
1	106.7	97.3	9.4	108.1	100.6	7.5
2	105.0	96.0	9.0	106.0	99.2	6.8
3	104.8	94.8	10.0	105.5	98.1	7.4
4		92.5			96.3	
5		92.8			97.9	
6	103.6	94.0	9.6	105.1	99.3	5.8
7	102.4	93.7	8.7	104.4	99.1	5.3
8	104.8	97.3	7.5	105.6	100.3	5.3
9	101.6	92.9	8.7	103.4	98.6	4.8
10	103.7	92.6	11.1	105.0	98.6	6.4
11		92.2			96.3	
12		93.1			96.4	
13	104.1	95.0	9.1	105.1	98.0	7.1
14	104.9	95.7	9.2	106.0	98.9	7.1
15	106.6	97.4	9.2	108.0	100.8	7.2

TABLE 5. - Acceleration measurements on bridge conveyor before and after modifications--everything on both miner and bridge conveyor in operation

Position	Average dBA before modifi- cation	Average dBA after modifi- cation	Reduction in dBA	Average dBC before modifi- cation	Average dBC after modifi- cation	Reduction in dBC
1	105.9	95.7	10.2	104.3	94.6	9.7
2	112.3	105.7	6.6	111.0	104.7	6.3
3	109.5	94.6	14.9	109.7	93.9	15.8
4		88.6			89.3	
5		87.8			88.9	
6	110.8	94.4	16.4	110.0	96.2	13.8
7	111.7	100.2	11.5	111.0	101.1	9.9
8		94.4			94.8	
9	109.3	90.4	14.9	108.4	91.0	13.6
10	109.4	87.3	19.0	109.1	86.6	18.1
11		87.7			86.6	
12		93.5			92.1	
13	107.1	106.2	13.6	117.5	105.1	25.4
14	103.2	93.4	+3.0	101.9	92.7	+3.2
15	108.3	93.4	14.9	106.7	92.7	14.0

NOTE.--All dB values are referenced to 30 μ g.

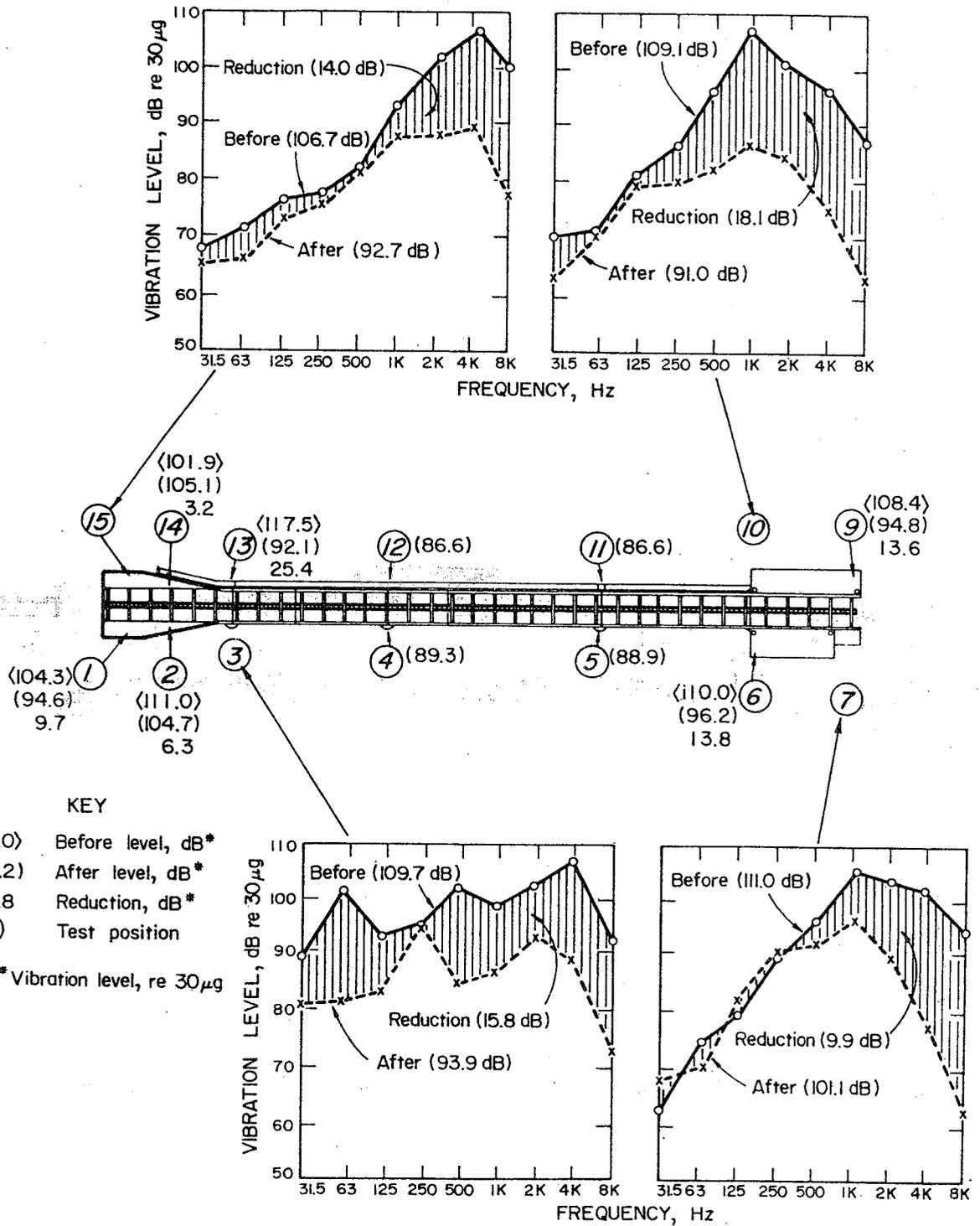


FIGURE 33. - Vibration levels (re 30 μ g) at several positions on bridge conveyor, before and after modifications.

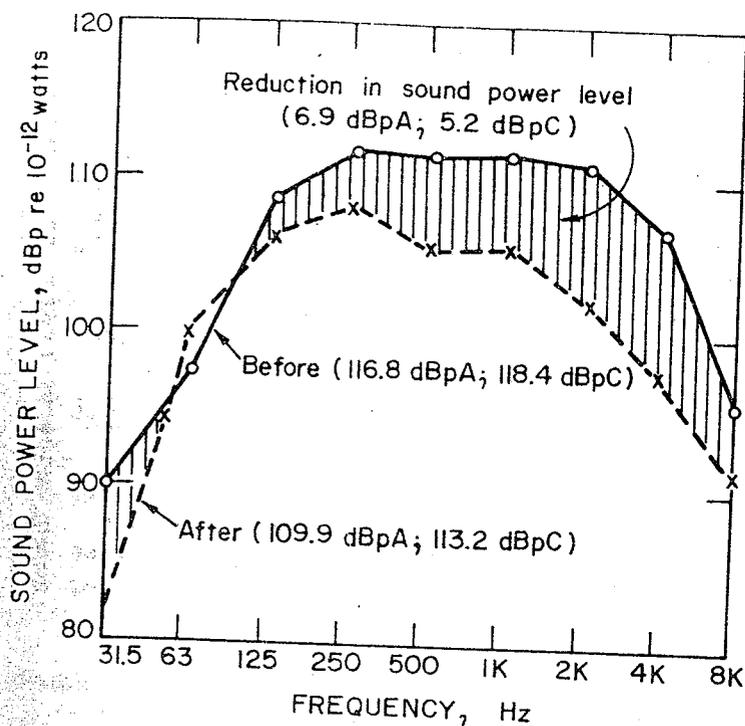


FIGURE 34. - Total sound power of miner (re 10^{-12} watts) in octave bands, before and after modifications.

watts. In this perspective, the A-weighted, premodification, acoustic power output of the miner was 0.5 watt while the post-modification power output was 0.1 watt, for a reduction of 0.4 acoustical watt. Thus, the noise control modifications were responsible for an 80 percent reduction in the total sound power emitted by the miner.

TABLE 6. - Sound power levels measured before and after acoustical modification of Wilcox miner

Frequency	dB _p before modifications	dB _p after modifications	dB _p reduction
31.5	89.7	81.7	8.0
63.0	97.9	100.0	-2.1
125	108.7	106.3	2.4
250	111.8	108.2	3.6
500	111.6	105.4	6.2
1,000	111.8	105.8	6.0
2,000	111.1	102.6	8.5
4,000	107.2	98.0	9.2
8,000	96.2	91.1	5.1
A-weight	116.8 (dB _p A)	109.9 (dB _p A)	6.9 (dB _p A)
C-weight	118.4 (dB _p C)	113.2 (dB _p C)	5.2 (dB _p C)

NOTE. --All dB_p values referenced to 10^{-12} watts.

5. Sound Power Measurements--Miner

The total sound power output of the miner was measured using the method described in the section titled "Procedure." The before and after modification results are shown graphically in figure 34 and numerically in table 6. As can be seen, the acoustic energy output of the machine was reduced the most in the 250 to 4,000 Hz frequency region. The overall A-weighted sound power output of the unmodified miner was 116.8 dB_pA (re 10^{-12} watts) while the sound power measured after modifications was 109.9 dB_pA, for a reduction of 6.9 dB_pA. Alternatively, the sound power emissions can be considered from a viewpoint of acoustic

RESULTS--UNDERGROUND

After the completion of the modification program, the miner and bridge conveyor were shipped back to the owners, Buchanan & Sons Coal Company. When the miner and bridge were put in use on an active section, arrangements were made to conduct the followup surveys. This equipment has been in continuous underground operation for more than 1 year.

During this interval of time, two separate noise surveys were conducted. To estimate the effectiveness of the modifications, the data collected on these surveys was compared to the data obtained during a premodification survey conducted on the same machine. This premodification or reference survey was performed during October 1974.

In general, the comparison shows that a consistent noise reduction has been achieved and that no significant loss in production has occurred because of the modifications.

1. Survey Procedure

Before any noise measurements were taken, a quick visual inspection of the miner and bridge was made each time to see if all of the modifications were intact. After the conditions of the modifications were noted, the noise survey was conducted.

At the conclusion of the noise survey, discussions were held with the machine crew and other mine officials. The purpose of these meetings was to determine their subjective reactions to the modifications and to note any significant changes in the production record of the machine.

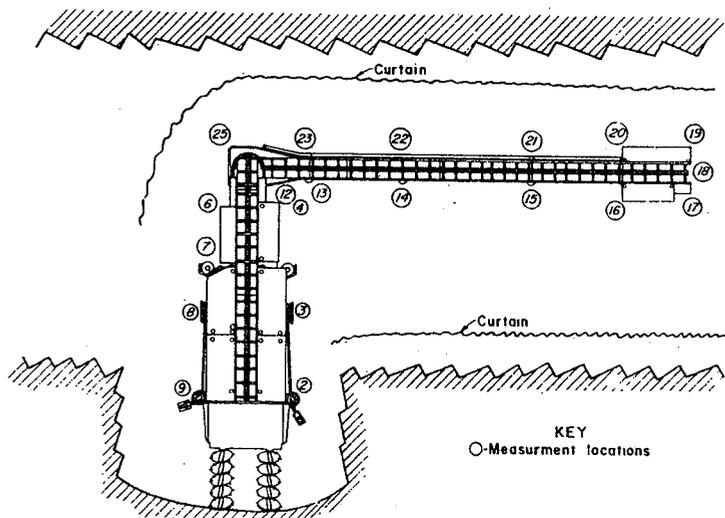


FIGURE 35. - Underground noise measurement positions around miner and bridge conveyor.

Measurements were taken at the operator's and jack-setter's positions, as well as other locations around the miner and bridge (fig. 35) to indicate the general sound field around the equipment in the underground environment. Noise levels during the different operating modes of the machine were also measured. Noise level data was obtained with a General Radio 1565-A (S/N 4481) sound level meter. Tape recordings were also made for subsequent frequency analysis at the laboratory. Before any measurements were taken, all

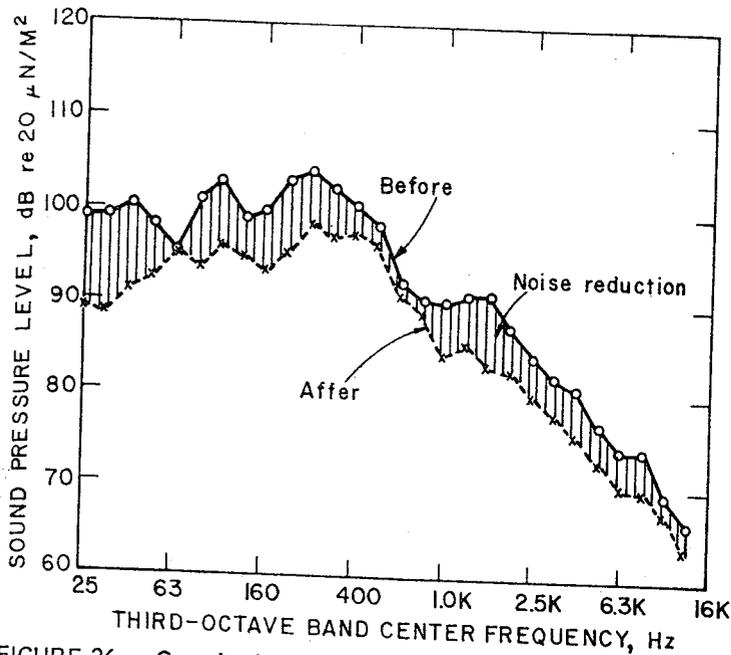


FIGURE 36. - One-third octave band analysis of noise measured at operator's position, before and after noise control modifications (cutting coal underground at Buchanan & Sons Mine, Wise, Va).

that the noise at the operator's and jacksetter's positions remained the same at 97 dBA and 102 dBA, respectively. Figure 36 shows the 1/3 octave band spectra of the noise at the operator's position, before and after the modification program. It is a well-known fact that the accuracy and repeatability of the real time analyzer system, Type I, is more precise than a sound level meter which is Type II; however, due to underground sampling procedures that were very short in duration, the real time analyzer spectrum shown in figure 36 may not be representative of the typical noise spectrum of the miner. Table 7 compares the sound level meter data obtained during the three surveys.

TABLE 7. - Noise level of unmodified and modified miner and bridge conveyor, cutting coal

Measuring location	Noise level of unmodified machine (dBA), reference survey (10/74)	Noise level of modified machine (dBA)		Average noise reduction
		First survey (9/75)	Second survey (9/76)	
Operator.....	101.9±1.5	96.7±1.2	97.0±0.7	5.0 dBA
Right jacksetter...	103.8±2.1	102.5±1.8	101.7±0.6	1.7 dBA

Referring to position 5 in table 8 and position 18 in table 9, the data indicates that the dump point of the two chain conveyors is the loudest area on the equipment when running in an unloaded condition. It should be remembered that when the equipment is cutting air, no material is being conveyed

acoustical equipment were properly calibrated using a 1,000 Hz signal at 114 dB re 20 μN/M².

2. Results

As previously stated, a reference noise survey was conducted on the miner and bridge before they were modified. Results from that survey showed the noise levels to be quite high: 102 dBA at the operator's position, and 104 dBA at the right jacksetter's position. Measurements taken during the first followup survey indicated noise levels of 97 dBA at the operator's position and 102.5 dBA at the right jacksetter's position. Data obtained during September 1976 indicated

and the noise levels will be slightly higher especially at the drive sprocket of either conveyor. Measurements taken underground at position 5 during a normal mining cycle showed a noise level of 96 dBA when running empty and 93 dBA when running full of coal.

TABLE 8. - Noise contours around miner, unloaded condition

Position*	Miner on, bridge on	Miner on, bridge off
2 (left jacksetter).....	95-97	91
3.....	97	91
4.....	99-100	92-93
5.....	99-100	96
6.....	94-95	92-93
7 (operator).....	94	90-91
8.....	93	90-91
9 (right jacksetter).....	92-93	89-90

*Refer to figure 35 for the measurement locations around the miner and bridge conveyor.

TABLE 9. - Noise contours around bridge conveyor, unloaded condition

Position*	Bridge on, miner on	Bridge on, miner off
12.....	99-100	97-98
13.....	97-98	97
14.....	96-97	96
15.....	96-97	96-97
16.....	96-97	96-97
17.....	96-97	97
18.....	102-103	102-103
19.....	96-98	97
20.....	96-97	98
21.....	95-96	96
22.....	97	95-96
23.....	97	97
25.....	98-99	96-97

*Refer to figure 35 for the measurement locations around the miner and bridge conveyor.

As mentioned previously, the noise reduction obtained at the jacksetter's position was minimal. The noise levels for these workers are primarily influenced by the augers ripping the coal from the seam. Future plans include conducting an analysis program on a set of augers to determine their vibrational response and to determine the airborne noise generated by them under a loaded condition. Modifications will then be made to the augers in an attempt to reduce this noise. After the laboratory testing is completed, these will be used with the modified miner and bridge conveyor. Underground surveys will be conducted to determine the effectiveness of the treated augers in reducing the noise levels at the jacksetter's position.

DISCUSSION OF RESULTS

The modifications to the Wilcox miner and bridge conveyor have proven their effectiveness in terms of noise reduction and durability in the underground environment. The reduction in noise at the operator's position, from 102 to 97 dBA, as measured with a sound level meter, represents a doubling of the allowable operating time from 1.5 to 3 hours. A similar retrofit program can be initiated by interested coal companies using the techniques described in this report to reduce excessive noise levels from the Mark 20 system.

A retrofit noise abatement package is available from the equipment manufacturer that can be installed on existing Wilcox machines. Additionally, this noise control package can be ordered with all new equipment purchases. The cost of these modifications (approximately \$8,400) will raise the cost of the miner-bridge conveyor system slightly, but the reduction in noise will mean an increase in the permitted operating time which will result in an increase in total coal production.

Another specific example which demonstrates the effectiveness of these modifications is a Mark 20 system retrofitted by Fairchild and in use in a central Pennsylvania coal mine. The noise levels, measured at the operator's position before any modifications, ranged from 96 to 102 dBA with a total noise exposure index (NEI) of 1.32. After installation of the noise control package, the operator's noise exposure ranged from 96 to 99 dBA with a total NEI of 0.75.

It should be realized that the noise control techniques discussed may be used successfully in modifying other mining equipment with similar noise sources.

Many types of mining equipment have component systems which are similar to those treated on the Wilcox miner and bridge. Continuous miners and loading machines use chain conveyors to transport the coal from the active face to the haulage units waiting at the end of the machine. Damping-isolation strips, similar to those installed on the Mark 20 system, could be applied to continuous miners and loading machines.

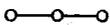
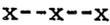
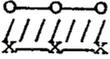
Also, various components (that is, motors, pumps, etc.) can be isolated from the machine frame to eliminate excessive vibrations causing an increase in the overall noise level. This would be best accomplished during the equipment manufacturing process when the proper isolator can be chosen and installed easily into the component system.

Finally, the use of barriers, such as the one installed at the operator's position, can be an effective means to block the transmission path of noise generated by different machine components.

As shown by this report, these modifications can be accomplished in a retrofit fashion. However, noise reduction could be achieved more effectively if these acoustical modifications were to be designed into the mining equipment.

APPENDIXES

The appendixes, A through D, have been included to allow others attempting this work to compare their results to ours. Third octave band noise spectra at various locations around the miner and bridge conveyor are given in appendixes A and C, respectively. Third octave band vibration spectra at various locations on the miner and bridge conveyor are given in appendixes B and D, respectively. In each appendix, the format for presenting the data is as follows:

- Spectra before modifications - 
- Spectra after modifications - 
- Noise reduction -  (shaded area)
- Position at which spectra was obtained - Marked with a number on accompanying diagram of machine

APPENDIX A. --ONE-THIRD OCTAVE BAND NOISE MEASUREMENTS AT VARIOUS LOCATIONS AROUND THE MINER, UNLOADED, BEFORE AND AFTER NOISE CONTROL MODIFICATIONS (9 POSITIONS)

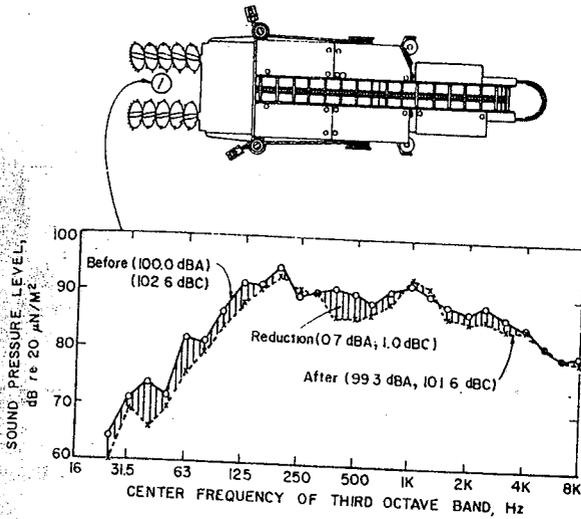


FIGURE A-1. - Noise spectrum at position 1 (front of miner).

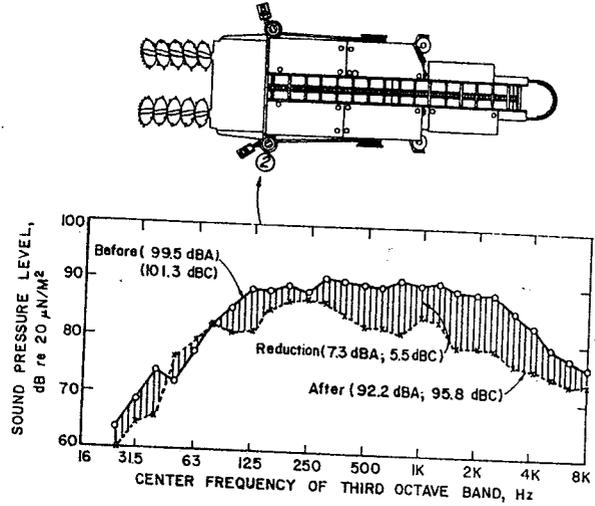


FIGURE A-2. - Noise spectrum at position 2 (left jacksetter).

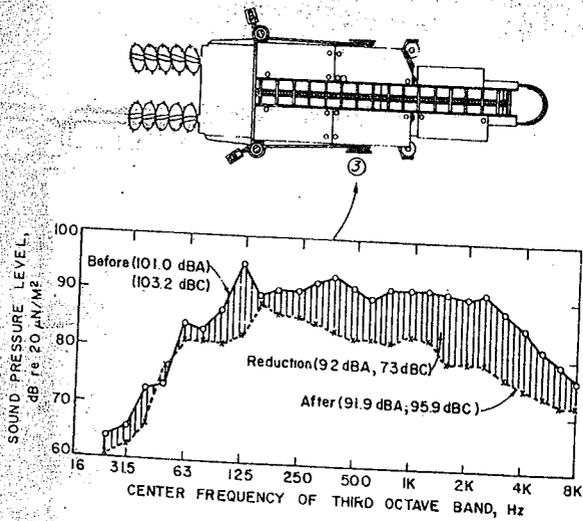


FIGURE A-3. - Noise spectrum at position 3 (left winch).

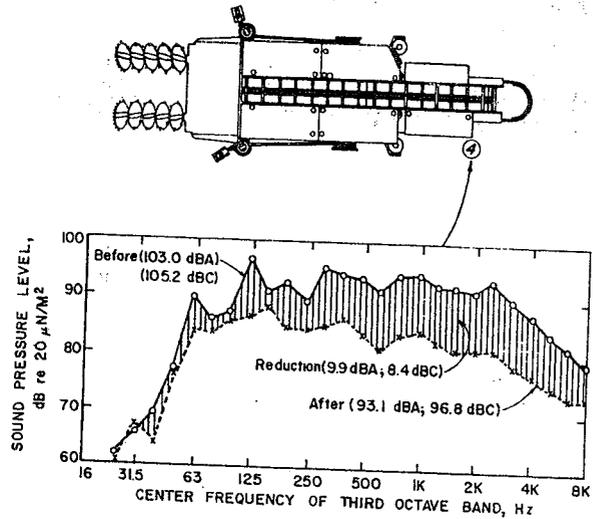


FIGURE A-4. - Noise spectrum at position 4 (left rear corner).

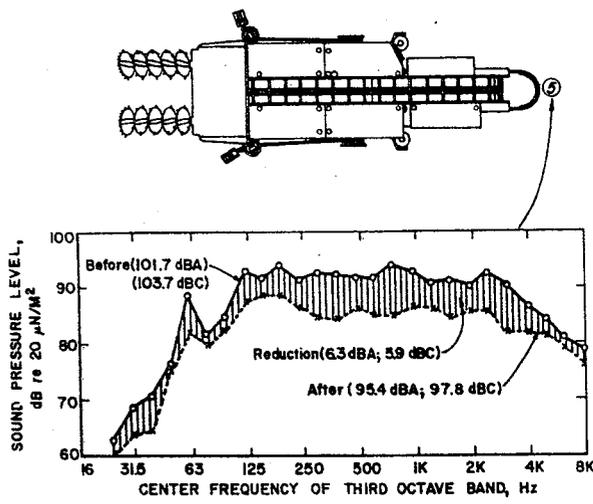


FIGURE A-5. - Noise spectrum at position 5 (discharge end).

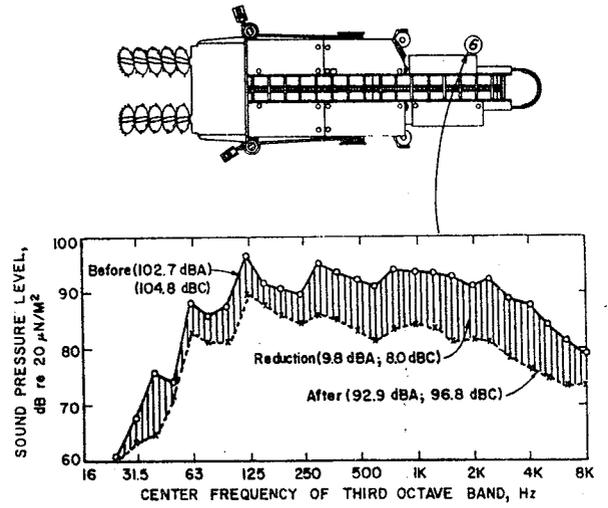


FIGURE A-6. - Noise spectrum at position 6 (right rear corner).

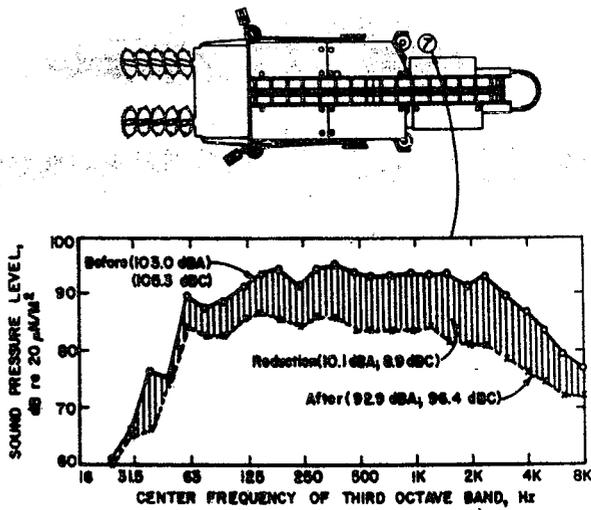


FIGURE A-7. - Noise spectrum at position 7 (operator).

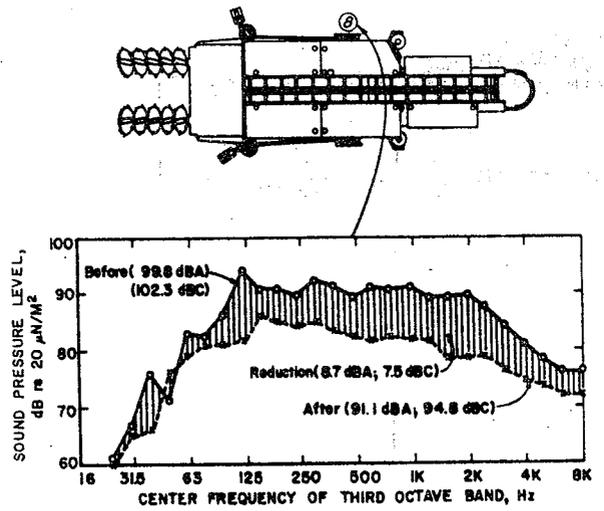


FIGURE A-8. - Noise spectrum at position 8 (right winch).

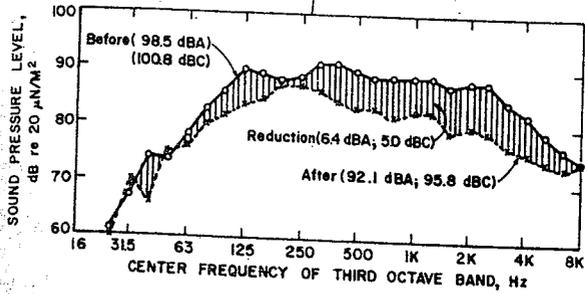
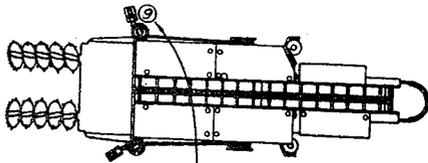


FIGURE A-9. - Noise spectrum at position 9 (right jacksetter).

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APPENDIX B.--ONE-THIRD OCTAVE BAND VIBRATION MEASUREMENTS AT VARIOUS LOCATIONS ON THE MINER, UNLOADED, BEFORE AND AFTER NOISE CONTROL MODIFICATIONS (9 POSITIONS)

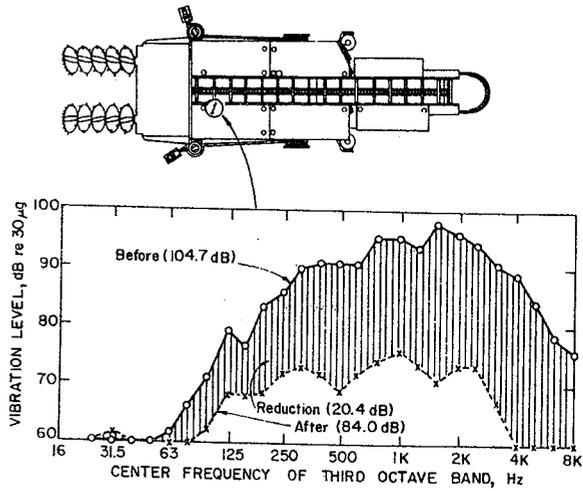


FIGURE B-1. - Vibration spectrum at position 1.

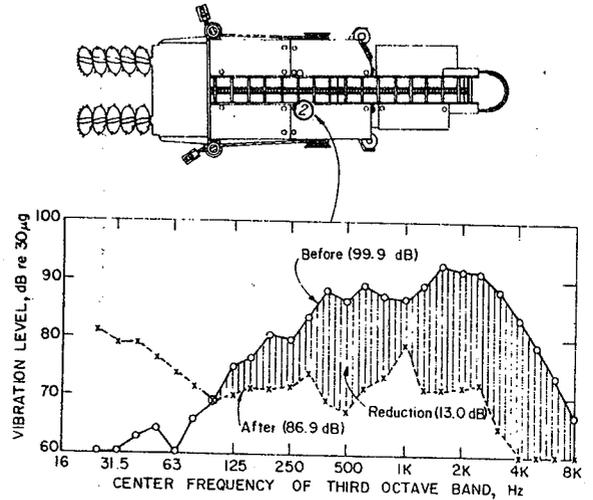


FIGURE B-2. - Vibration spectrum at position 2.

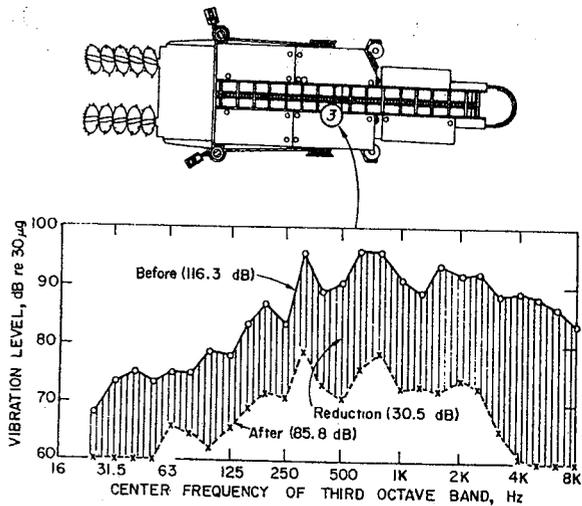


FIGURE B-3. - Vibration spectrum at position 3.

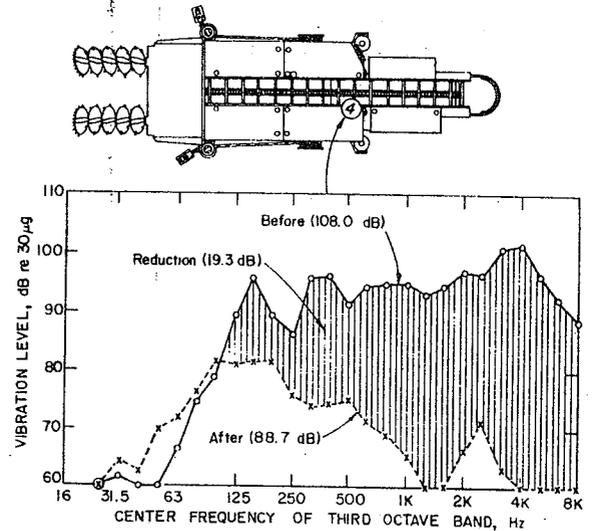


FIGURE B-4. - Vibration spectrum at position 4.

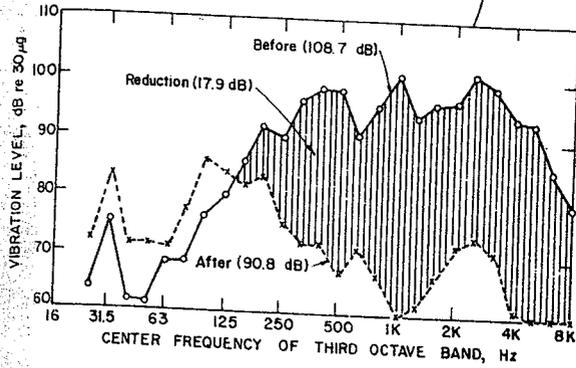
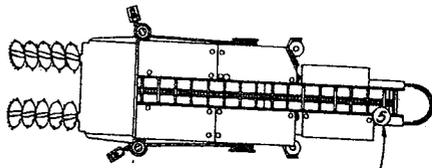


FIGURE B-5. - Vibration spectrum at position 5.

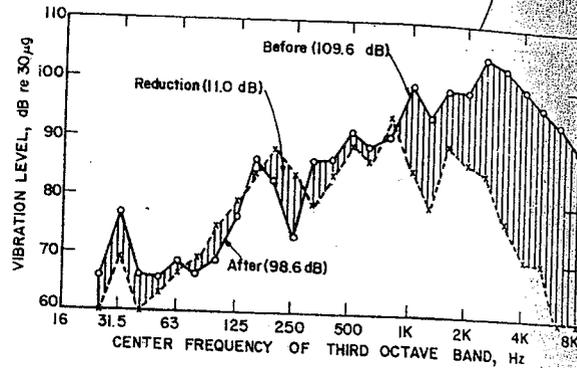
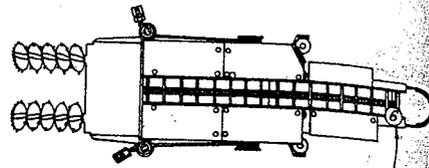


FIGURE B-6. - Vibration spectrum at position 6.

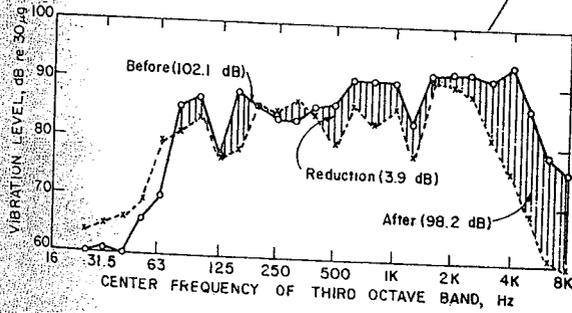
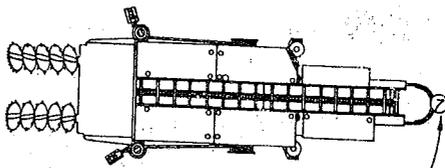


FIGURE B-7. - Vibration spectrum at position 7.

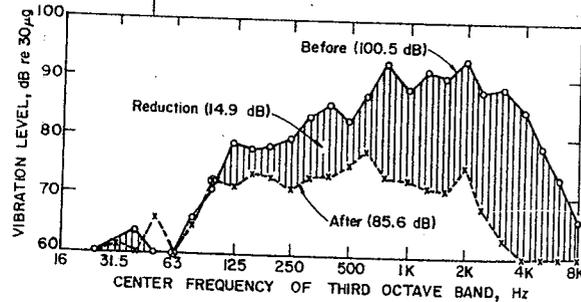
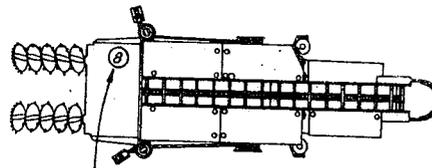


FIGURE B-8. - Vibration spectrum at position 8.

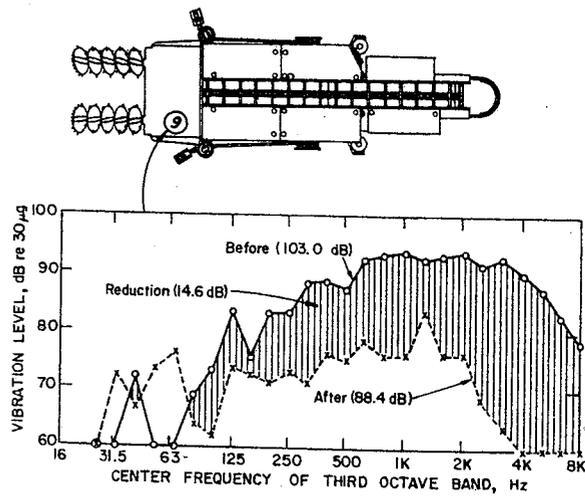


FIGURE B-9. - Vibration spectrum at position 9.

APPENDIX C. -- ONE-THIRD OCTAVE BAND NOISE MEASUREMENTS AT VARIOUS LOCATIONS AROUND THE BRIDGE CONVEYOR, UNLOADED, BEFORE AND AFTER NOISE CONTROL MODIFICATIONS (11 POSITIONS)

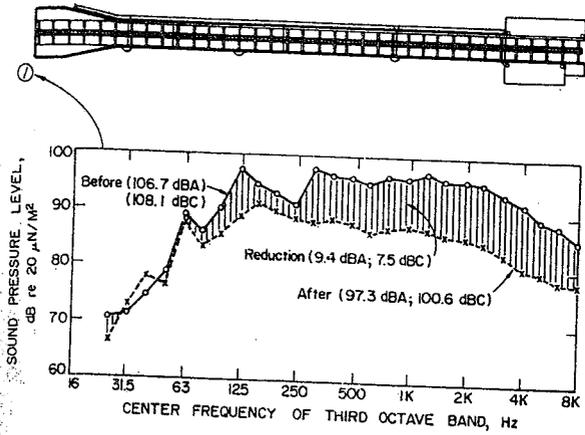


FIGURE C-1. - Noise spectrum at position 1.

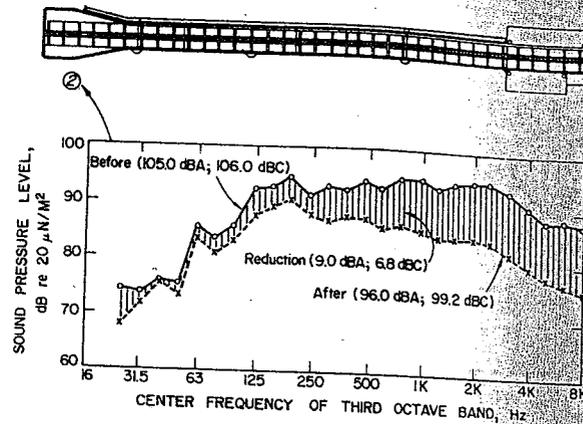


FIGURE C-2. - Noise spectrum at position 2.

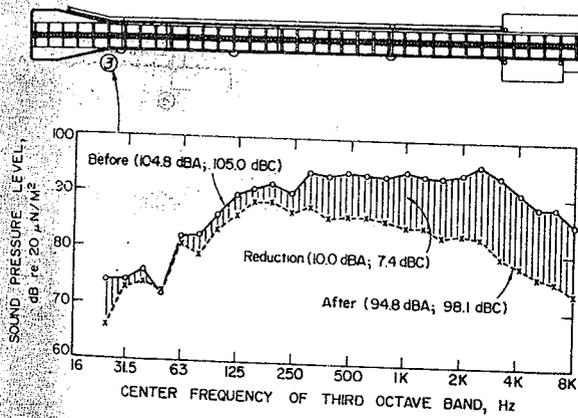


FIGURE C-3. - Noise spectrum at position 3.

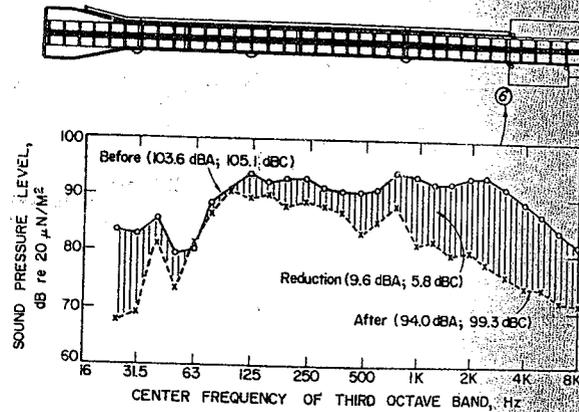


FIGURE C-4. - Noise spectrum at position 6.

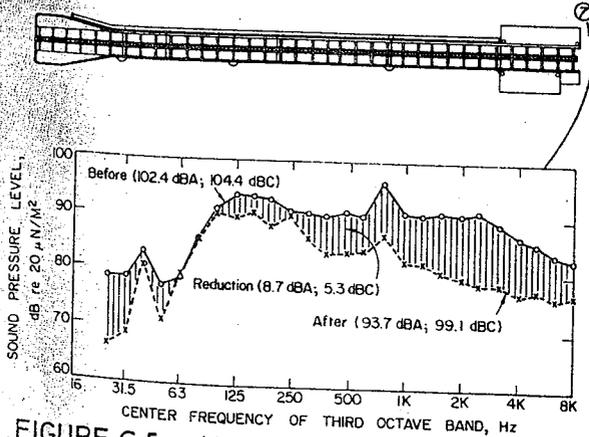


FIGURE C-5. - Noise spectrum at position 7.

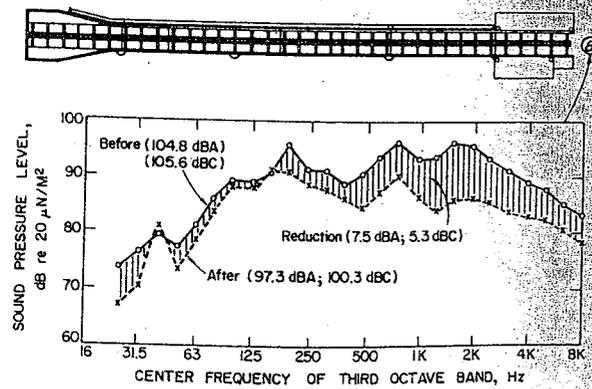


FIGURE C-6. - Noise spectrum at position 8.

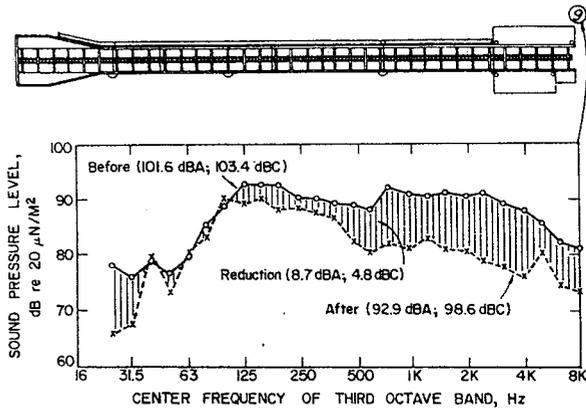


FIGURE C-7: - Noise spectrum at position 9.

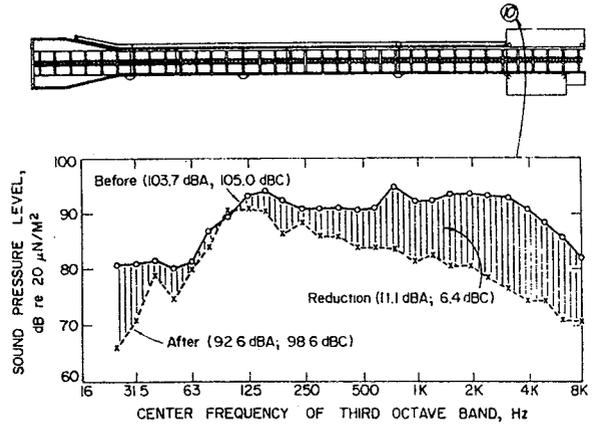


FIGURE C-8: - Noise spectrum at position 10.

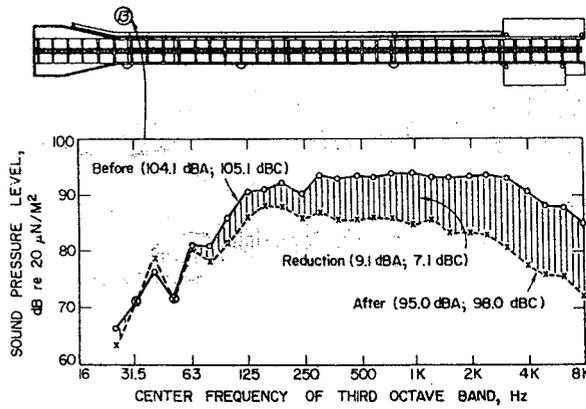


FIGURE C-9. - Noise spectrum at position 13.

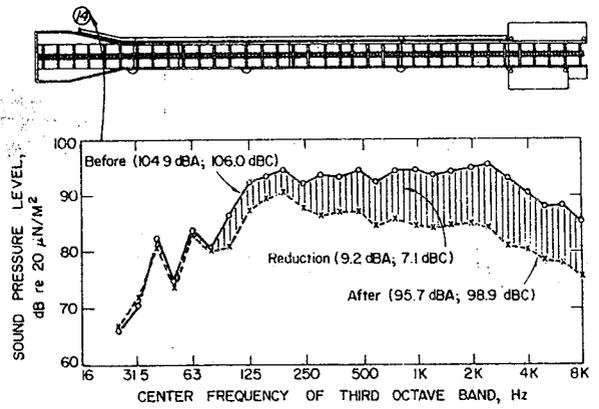


FIGURE C-10. - Noise spectrum at position 14.

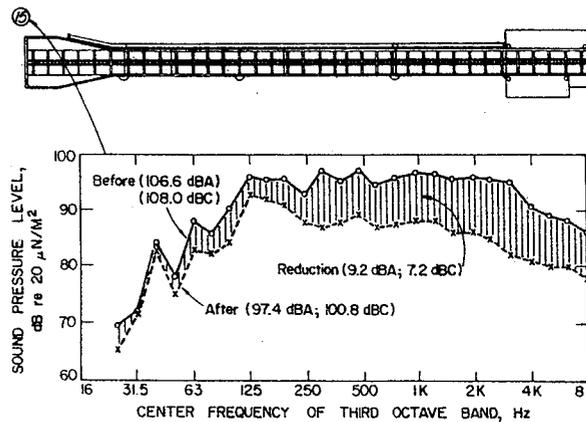


FIGURE C-11: - Noise spectrum at position 15.

APPENDIX D. --ONE-THIRD OCTAVE BAND VIBRATION MEASUREMENTS AT VARIOUS LOCATIONS ON THE BRIDGE CONVEYOR, UNLOADED, BEFORE AND AFTER NOISE CONTROL MODIFICATIONS (10 POSITIONS)

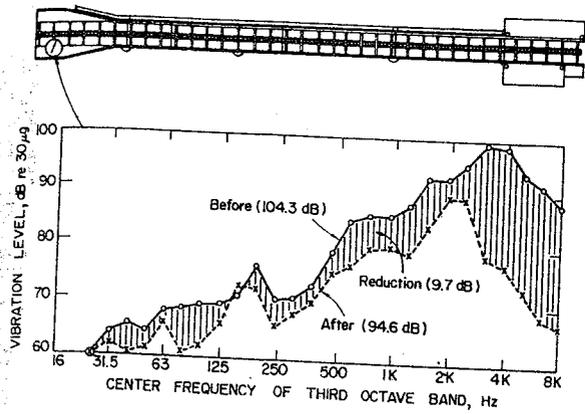


FIGURE D-1. - Vibration spectrum at position 1.

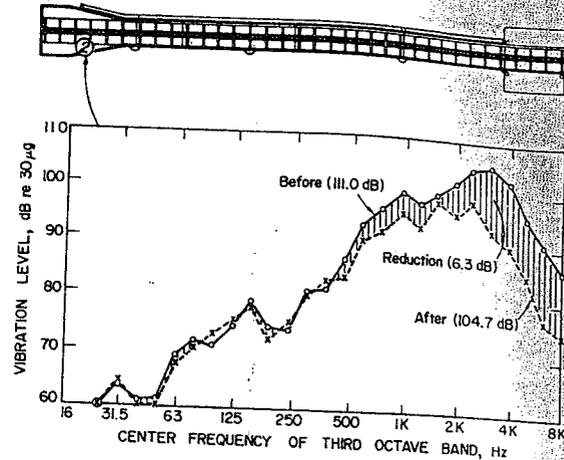


FIGURE D-2. - Vibration spectrum at position 2.

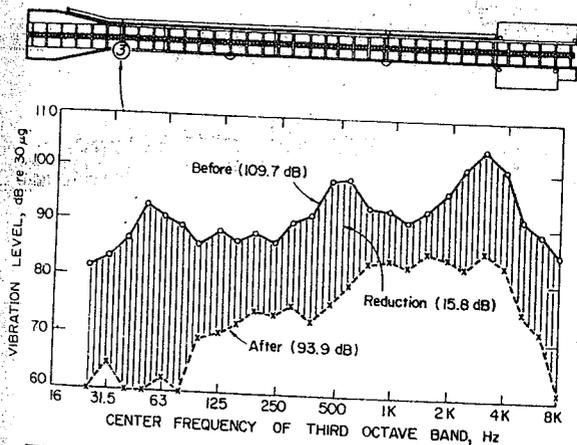


FIGURE D-3. - Vibration spectrum at position 3.

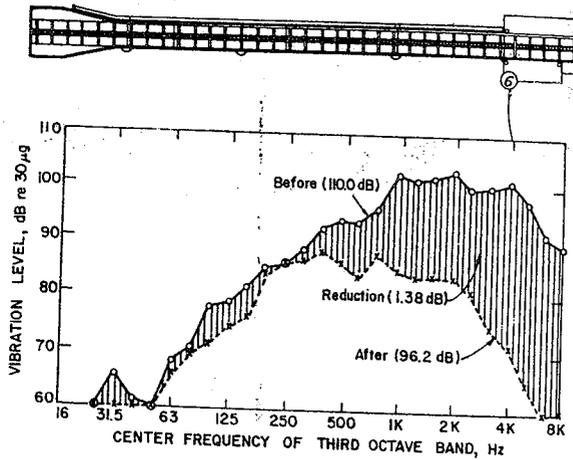


FIGURE D-4. - Vibration spectrum at position 6.

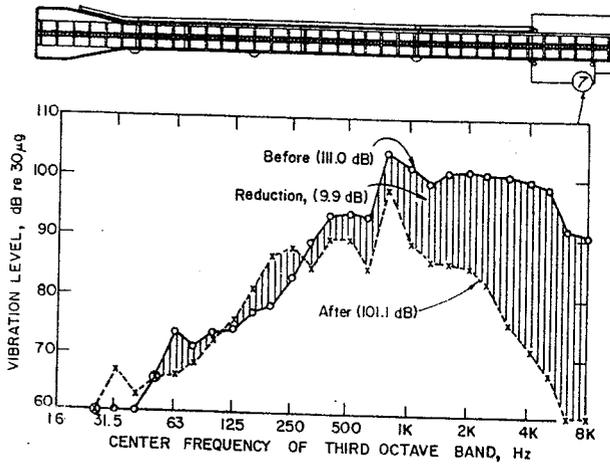


FIGURE D-5. - Vibration spectrum at position 7.

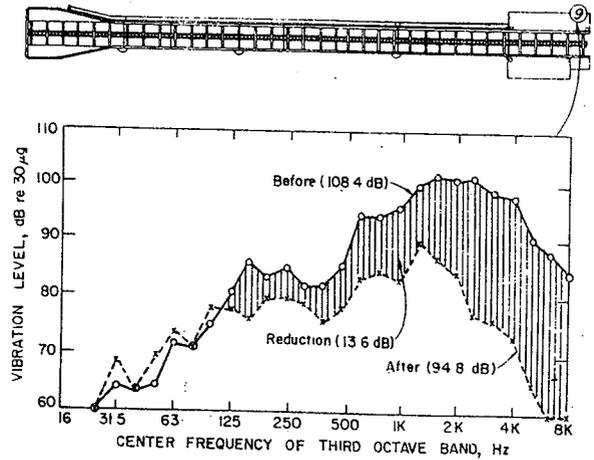


FIGURE D-6. - Vibration spectrum at position 9.

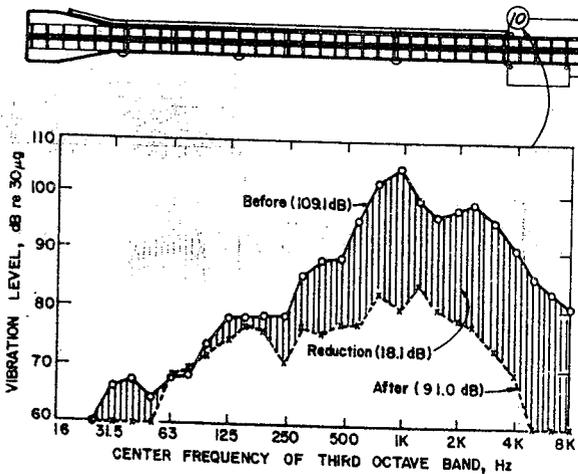


FIGURE D-7. - Vibration spectrum at position 10.

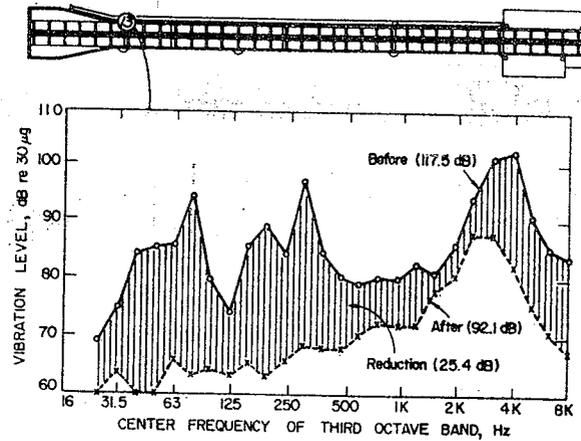


FIGURE D-8. - Vibration spectrum at position 13.

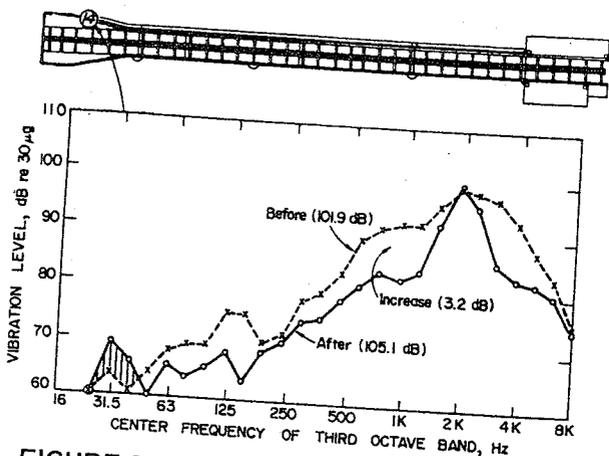


FIGURE D-9. - Vibration spectrum at position 14.

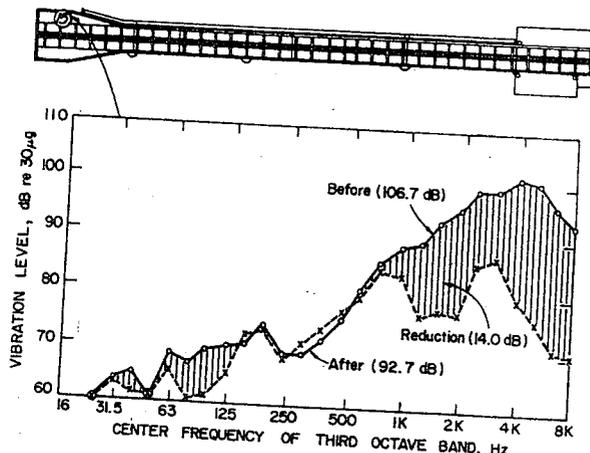


FIGURE D-10. - Vibration spectrum at position 15.