Turbine Blades

The original blades in both the rotor and stator were seriously eroded and had to be replaced. Before this was done, however, a leading manufacturer of turbines was contracted by the Bureau to review the data from the previous tests in an effort to determine the reason for this erosion and to redesign the gas path through the turbine (6). This study failed to reveal any major defects in design. Nevertheless, the study revealed many features of the erosion problem and recommended several design changes for the blades and gas path expected to decrease erosion.

These basic design changes were recommended: (1) design the blading so that most of the ash will move toward the casing instead of the roots of the rotor blades; (2) remove blades in rotor row 1 and stator row 2 to provide an annular space for ash to centrifuge to the casing; and (3) insert titanium carbide wear strips in the base of certain rotor blades and in the outer sidewall. The wear strips at the base of the blades were recommended as a safeguard in case efforts to direct the ash toward the casing were unsuccessful. If the new gas path successfully controls erosion, ash extraction slots can be put in the casing. These slots may not be necessary if the wear strips in the casing are satisfactory.

The report also stated that even if the new design is successful probably there would still be some overall wear of the pressure (concave) surface of the rotor and stator blades. This general erosion of the blade profiles can be determined only by accurate measurements before and after a test.

The turbine blading was redesigned in accordance with specifications based on the above recommendations. The rotor, casing, and inlet hood remain unchanged. Figure 15 shows the original six-stage turbine. Figure 16 shows the new design, which changes the turbine to a five-stage unit. The pressure-drop across all the five stages will be the same as it was across the six-stage turbine. The pressure drop per stage, however, and the velocity through the turbine will be greater in the five-stage design.

Filler pieces will be inserted in the casing and rotor in the spaces formerly occupied by the blades that were removed (figs. 15 and 16). The trailing edges of the rotor blades will be made thicker and the trailing edges of the stator blades will be made thinner. This should induce the ash to travel to the outer casing and help prevent ash from returning to the base of the rotor blades. Additional blades will be installed in most of the rows in the stator in an attempt to stop secondary flow of the ash toward the rotor.

New blades will be constructed of Stellite, a cobalt-base cast alloy containing about 10 percent nickel, 25 percent chromium, 7 percent tungsten, and small amounts of manganese, iron, carbon, and silica. Addition of small quantities of boron, together with controlled casting temperatures, will help control the grain size of the metal, producing an alloy with a maximum of hard platelike carbides having a maximum resistance to erosion.

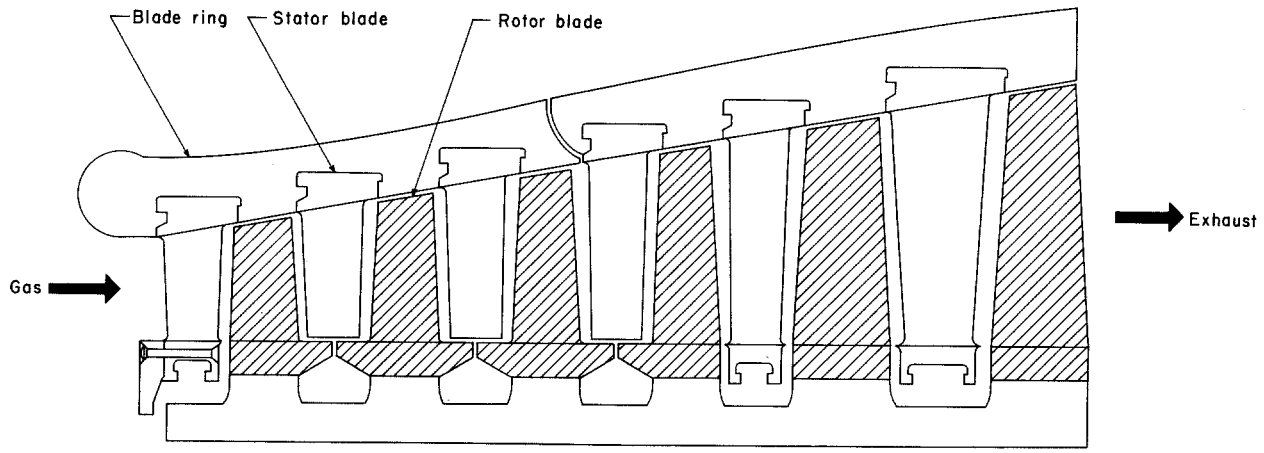

FIGURE 15. - Original Arrangement of Blades.

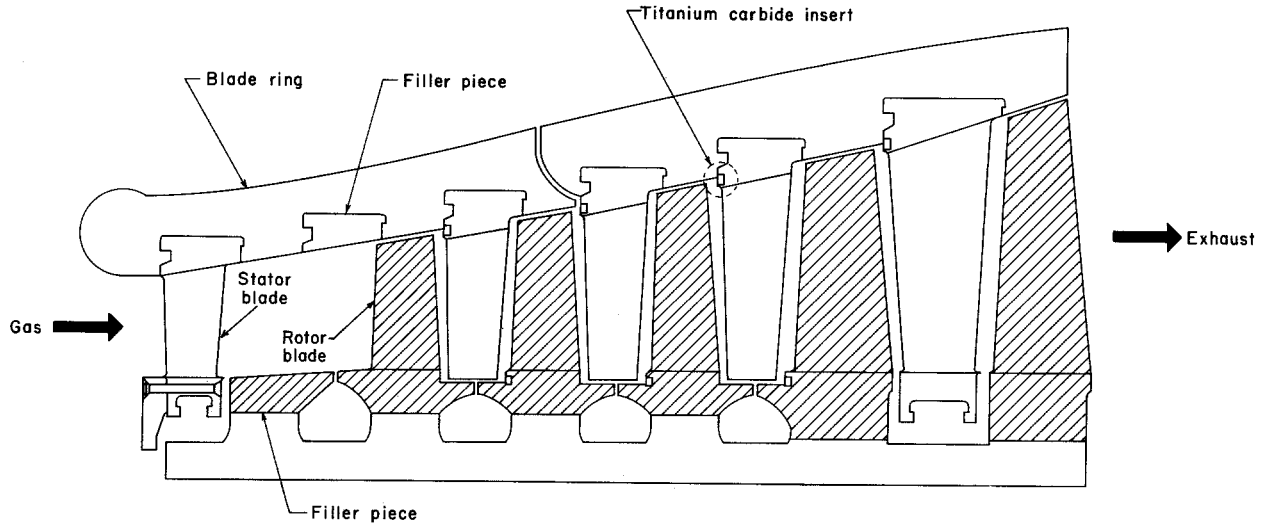

FIGURE 16. - New Arrangement of Blades.

Air Compressor

Blades in the rotor of the air compressor were in satisfactory condition. Nine cracked blades in stator rows 18 and 20 were replaced.

Several small cracks were observed in various parts of the casing. Some of these are shown in figure 17. The cracks were repaired by a method prescribed by the manufacturer of the turbine.

Coal-Handling Equipment

Two systems are being readied to prepare and feed coal to the turbine. One of these systems is essentially the same one that LDC used in their development work. The second system will be used as an alternate to the LDC system.

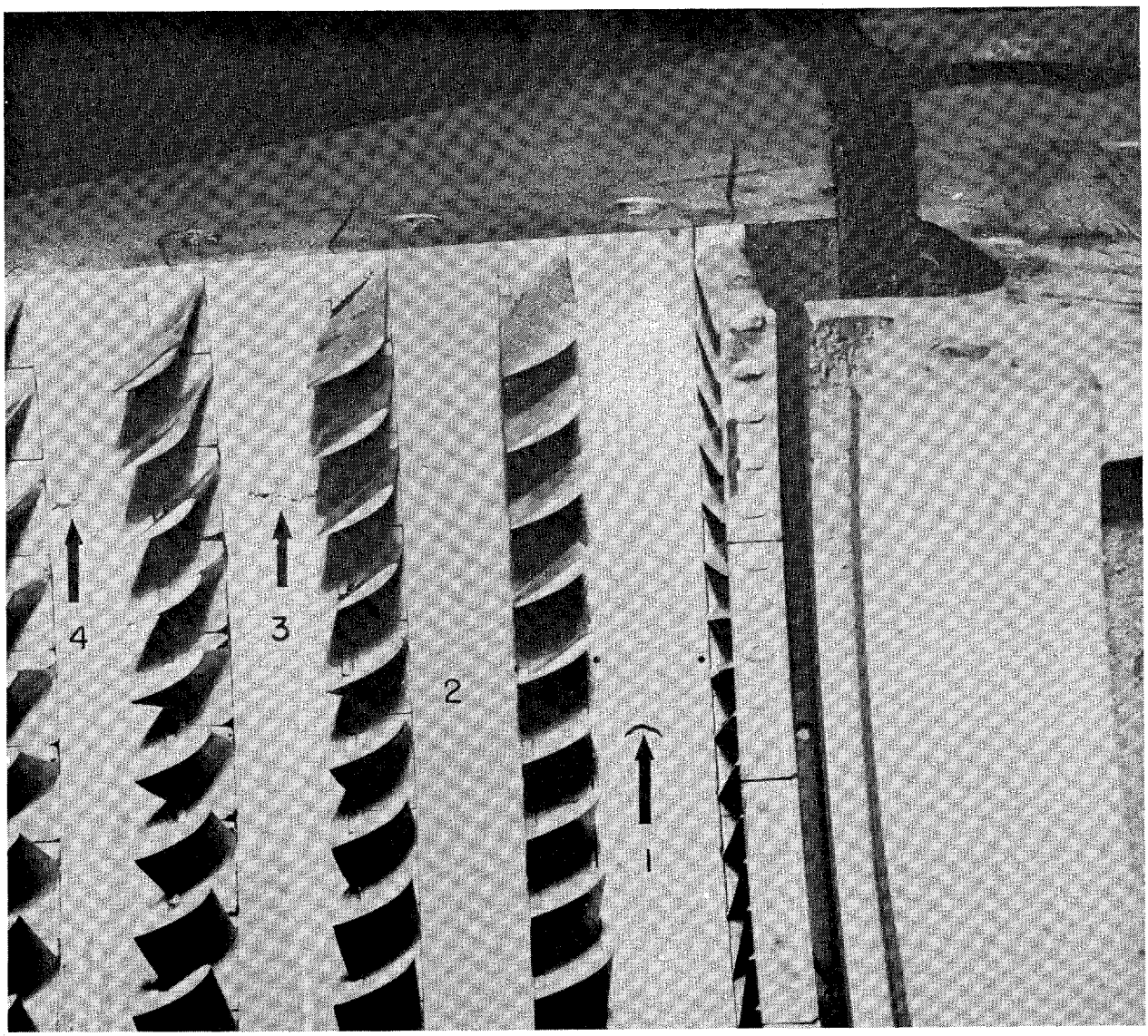

FIGURE 17. - Cracks in Compressor Casing.

The equipment used by the LDC necessarily had to be tailored to the space restriction imposed by a locomotive installation. This meant that small, nonstandard equipment had to be developed, which required extensive development work. The Bureau of Mines is investigating the coal-burning gas turbine for central-station power generation where the space limitation is not as acute as for locomotive service. This permits the use of commercial coal preparing and handling equipment. Accordingly, the Bureau plans to use an alternate system that will incorporate standard equipment items. The Bureau does not plan any further development of the LDC system for preparing and feeding coal. The LDC system will be used, however, during the planned 1,500-hour run.

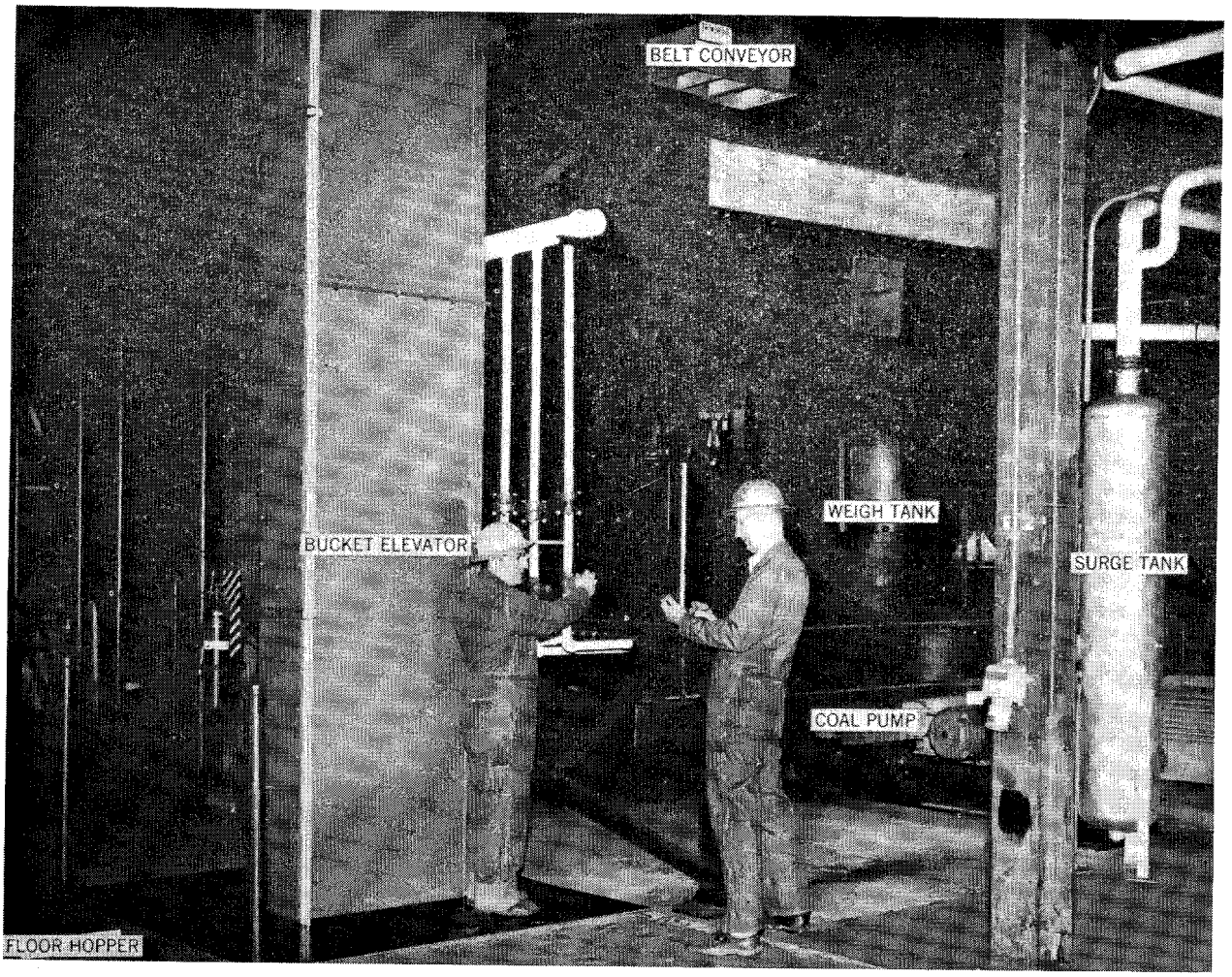

FIGURE 18. - Coal-Handling Equipment.

LDC System

In the LDC system (fig. 18) 3/16-inch by 0 coal is fed into a weigh tank via a floor hopper, screw conveyor, bucket elevator and belt conveyor. Coal flows by gravity from the weight tank into a coal pump (figs. 19 and 20). The coal pump, a moving-wall-type lock hopper, pressurizes the coal and feeds it into a high-speed attrition-type pulverizer (fig. 21). The pulverized coal, 90-percent through 200-mesh, then is transported pneumatically to the combustors.

The pulverizer has been modified to increase its efficiency and to increase its resistance to wear (fig. 21). The housing was enlarged so that segments faced with tungsten carbide could be installed in the peripheral lining (arrow 4). The pegs on the rotor (arrow 1) also were faced with tungsten carbide. Stationary pegs (arrow 2), previously attached to the housing, were attached to a doughnut-shaped stationary plate. This modification should

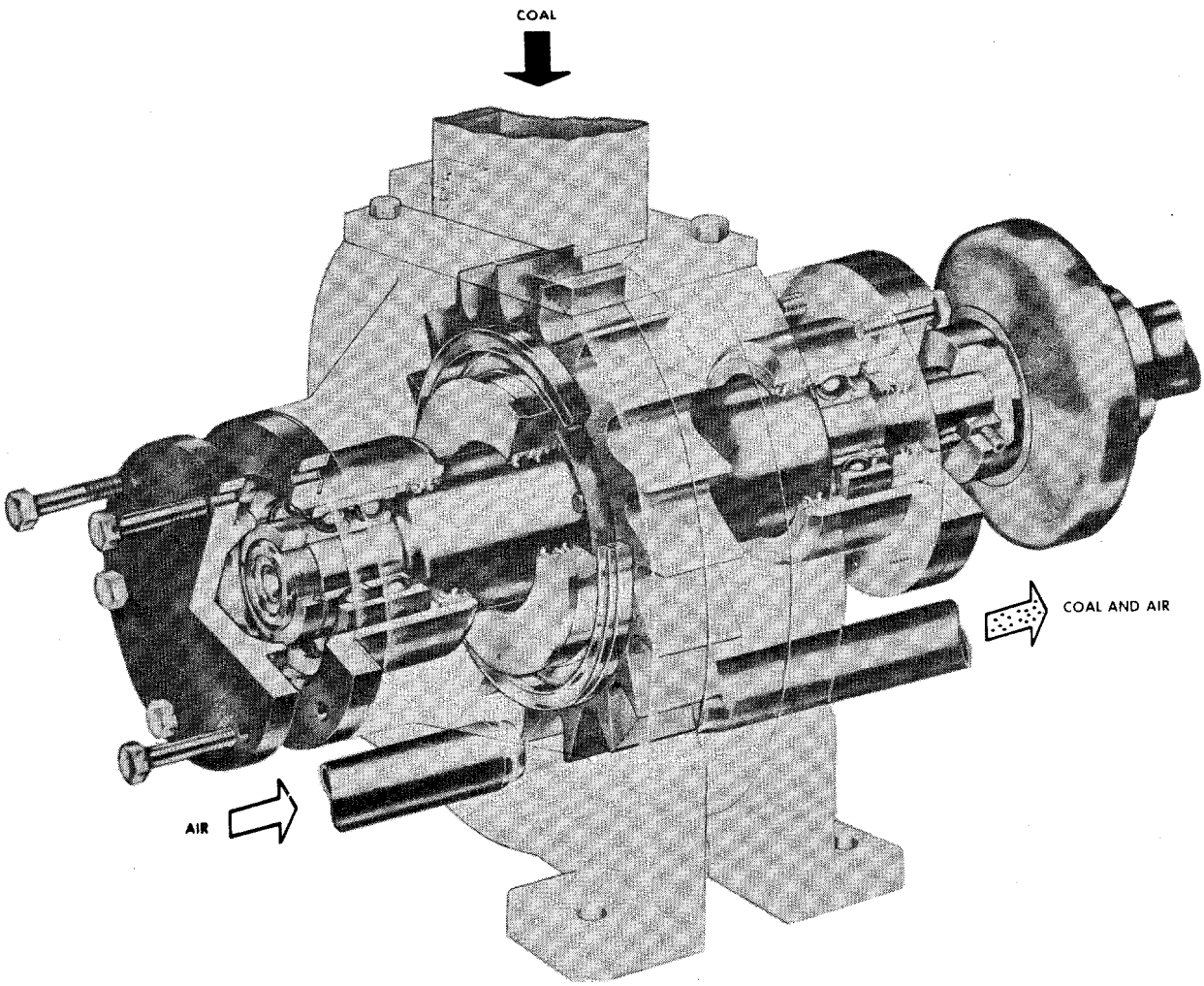

FIGURE 19. - Coal Pump.

reduce windage losses. Tungsten carbide inserts (arrow 3) were installed where erosion was severe in the previous tests.

Alternate System

The alternate system comprises conventional coal-handling equipment. It includes the floor hopper, screw conveyor, bucket elevator, and belt conveyor of the LDC system, but instead of filling the weigh tank, the belt conveyor discharges into another screw conveyor that carries the 3/16-inch by 0 coal to a roller mill and whizzer-type classifier. The 90-percent through 200-mesh coal from the classifier is separated from the air in a cyclone separator, and then fed pneumatically to a 10-ton storage silo. A screw conveyor feeds coal from the silo into a lock hopper. The lock hopper dumps into the top of a feeder hopper, which feeds into a rotating, multipocket feeder. This feeder is an adaptation by the Bureau of a feeder developed to feed pulverized coal from a bin into a boiler. Coal from this feeder is transported pneumatically to the combustors on the turbine.

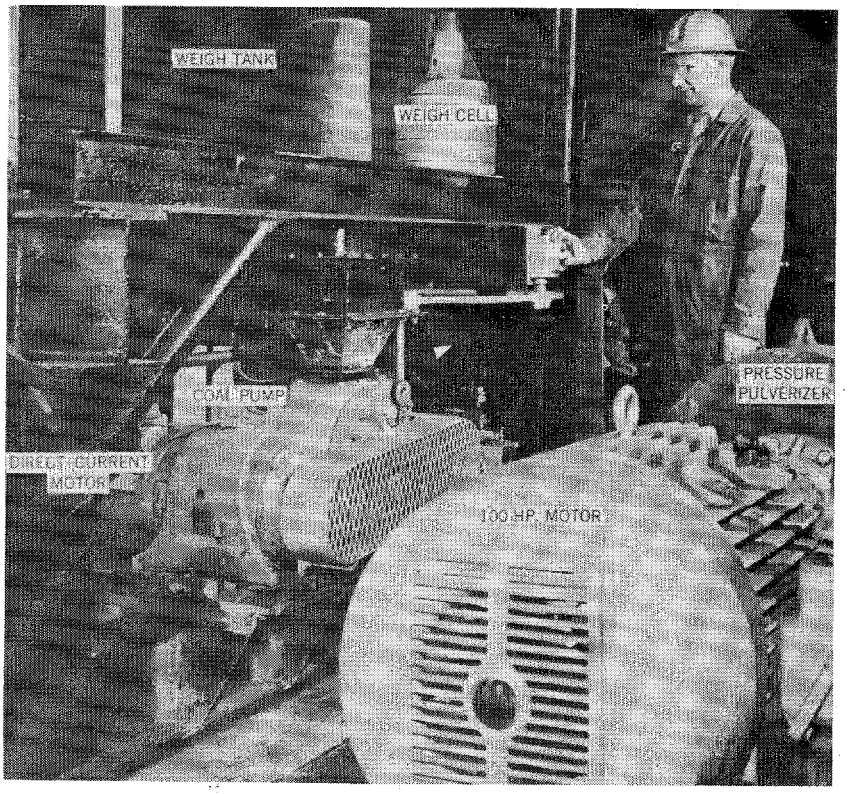

FIGURE 20. - Coal Pulverizing Equipment.

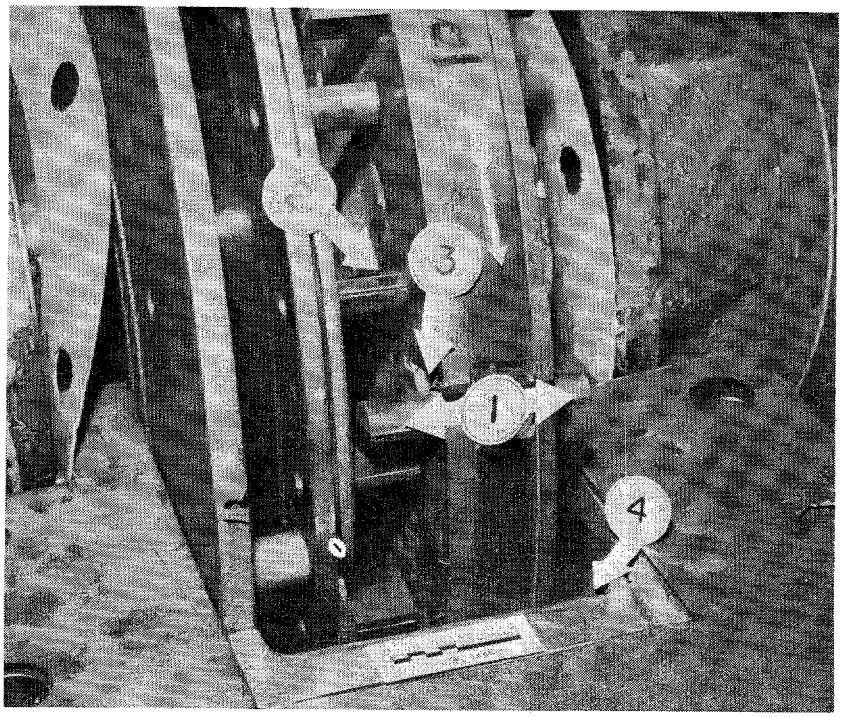

FIGURE 21. - Coal Pulverizer.

The lock hopper and feeder hopper are suspended as an integral unit on two weigh cells. These weigh cells use air pressure to balance the weight of the pulverized coal in the hoppers. The cells provide a continuous and accurate indication of the coal-feed rate.

DISCUSSION

After the turbine is rebladed and assembled, it will be operated for a 1,500-hour run. The blades will be inspected at the end of the run.

Other research work related to the coal-fired gas turbine plant is being continued in an effort to improve other components of the plant. Means of improving the systems for pulverizing, feeding, and burning the coal are being investigated, and improved methods for removing the ash before it enters the turbine are being studied.

Other Bureau of Mines publications in this series will discuss progress along these lines.

BIBLIOGRAPHY

1. BITUMINOUS COAL RESEARCH. Bureau of Mines to Expand Research on LDC Turbine. Vol. 19, Spring 1959, p. 3.

2. BITUMINOUS COAL RESEARCH. Coal Burning Gas Turbine Progress in 1953. Vol. 14, April-June 1954, pp. 8-12.

3. BROADLEY, P. R., AND MEYERS, W. M. Direct Fired Coal Burning Gas Turbine Operations. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., 1956, 6 pp.

4. _____. 1957 Annual Report of the Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., 15 pp.

5. BROWNE, K. A., YELLOTT, J. I., WEINBERG, H. L., AND BROADLEY, P. R. Photographic Report No. 54-1: 300-Hour Test 4250 HP Coal-Burning Gas Turbine. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., Sept. 20, 1954, 10 pp.

6. JUNGE, R. M., AND SCHEPER, G. W., JR. Locomotive Development Committee Coal-Fired Turbine Blade Erosion Study No. DF-59-GTD-32. General Electric Co., Schenectady, N. Y., Dec. 18, 1959, 21 pp.

7. McGEE, J. P., AND COREY, R. C. Bureau of Mines Coal-Fired Gas Turbine Research Project. Combustion, vol. 31, No. 10, April 1960, pp. 67-72.

8. RAILWAY AGE. New Developments in Coal are Leading to New Developments in Coal-Fired Gas Turbine. August 5, 1957.

9. YELLOTT, J. I. AND BROADLEY, P. R. Annual Report 1950-51, Coal Burning Gas Turbine. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, New York, 1951, 43 pp.

10. _____. Fly Ash Separators for High Pressures and Temperatures. Ind. Eng. Chem., vol. 47, May 1955, p. 944.

11. _____. Progress Report...Jan.-June, 1953, to the Locomotive Development Committee of Bituminous Coal Research, Inc., Dunkirk, N. Y., June 25, 1953, 10 pp.

12. _____. Progress Report 1953, Coal Burning Gas Turbine Locomotive. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., Dec. 15, 1953, 19 pp.

13. _____. Report on 750 Hour Test of 4250 Horsepower Coal-Fired Gas Turbine Power Plant. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., 1952, 16 pp.

14. YELLOTT, J. I., BROADLEY, P. R., AND BUCKLEY, F. C. Progress Report on the Coal-Burning Gas Turbine. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, N. Y., Paper prepared for presentation on April 6, 1951, at the Midwest Power Conference, Chicago, Ill.

15. YELLOTT, J. I., BROADLEY, P. R., AND MEYER, W. M. Acceptance and Operational Tests of a 4250 HP Coal-Burning Gas Turbine. I. Preliminary Oil-Fired Operation. Paper No. 54-F-39, ASME Fall meeting, Sept. 8-10, 1954, 16 pp.

16. _____. Acceptance and Operational Tests of a 4250 HP Coal-Burning Gas Turbine: Part II - Coal-Fired Operation. Paper No. 54-F-40. ASME Fall meeting, Sept. 8-10, 1954, 19 pp.

17. _____. 1955 Annual Report, Technical Supplement. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, New York, Sept. 15, 1955, 25 pp.

18. _____. Summary of 1955 Operation. Locomotive Development Committee, Bituminous Coal Research, Inc., Dunkirk, New York, Sept. 15, 1955, 8 pp.

19. YELLOTT, J. I., BROADLEY, P. R., MEYER, W. M., AND ROTZLER, P. M. Development of Pressurizing, Combustion, and Ash Separation Equipment for a Direct-Fired, Coal-Burning, Gas Turbine Locomotive. Paper No. 54-A-201. ASME annual meeting, Nov. 28-Dec. 3, 1954, 37 pp.

INT. BU. OF MINES, PGH., PA. 3573