BUREAU OF MINES COAL-FIRED GAS TURBINE RESEARCH PROJECT:

Redesign and Assembly of Turbine[1]

by

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SUMMARY

The Bureau of Mines is doing research and development work on a coal-fired gas turbine plant initially developed by the Locomotive Development Committee (LDC) of Bituminous Coal Research, Inc. The Bureau is redesigning the turbine blading and some of the auxiliary equipment, and is reerecting the plant at the Morgantown (W. Va.) Coal Research Center. The present goal is a 1,500-hour run at virtually the same operating conditions used by the LDC in their final 1,100-hour test with the turbine. This will allow the Bureau to properly evaluate the new blade design.

Erosion of the turbine blades (particularly the roots) by ash in the hot gases from the combustion of coal was the most serious problem in extended operation in earlier experimental work. New blades made of Stellite[6] are being fabricated for the stator and rotor, and armored wear strips of titanium carbide will be inserted in the blades at the areas of probable maximum ash velocity and concentration. The trailing edges of the rotor and stator blades are being thickened and thinned, respectively, to induce the ash to travel to the casing and prevent it from returning to the base of the rotor blades. The first stage rotor and second stage stator blades are being removed to provide an annular space for maximum quantities of coal ash to centrifuge to the casing. Additional blades will be added to most of the rows in the stator to stop secondary flow of dust-laden gas toward the rotor. A contract has been awarded for fabrication of the new blades. The 1,500-hour run will be started as soon as the new blades are installed.

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[6]Reference to specific brands is made to facilitate understanding and does not imply endorsement of such items by the Bureau of Mines.

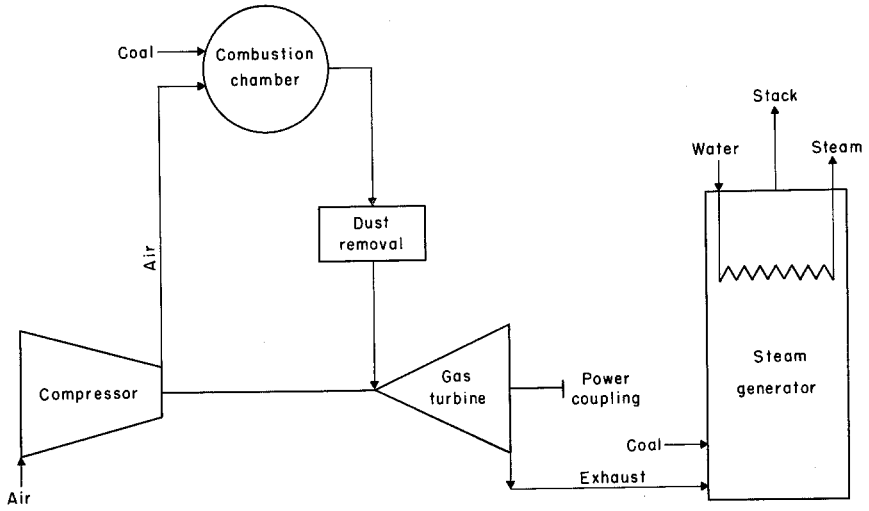

FIGURE 1. - Gas Turbine With Exhaust-Heat Recovery.

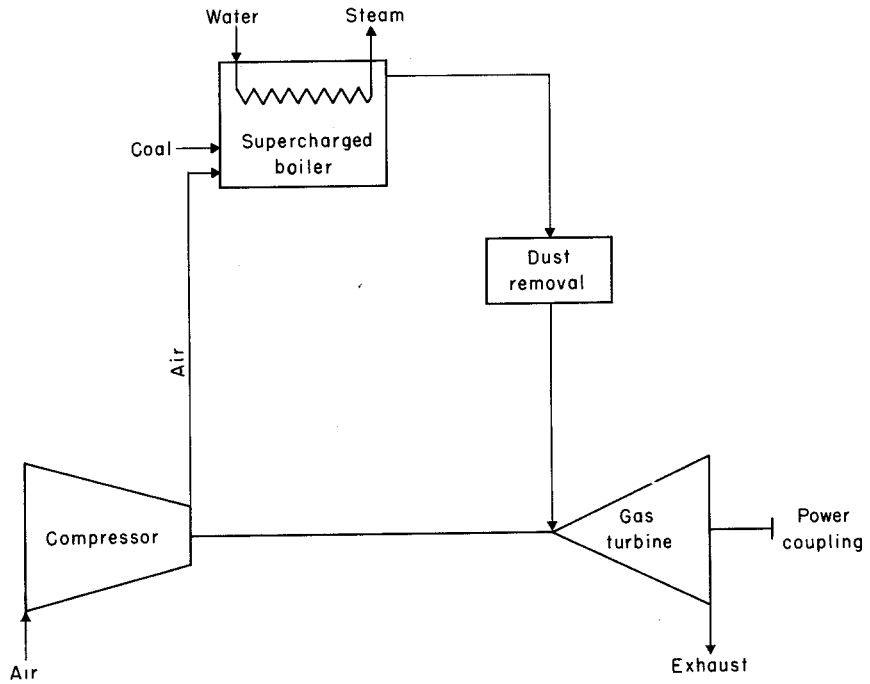

FIGURE 2. - Gas Turbine With Supercharged Boiler.

Two systems are being readied to feed coal to the turbine. One system includes components developed by LDC to store the 3/16-inch by 0 coal and to transfer it to a pump that pressurizes and feeds it to an attrition-type pulverizer. The 90-percent through 200-mesh coal from the pulverizer is fed to the combustors on the turbine. This system will be used during the 1,500-hour run.

An alternate system is being installed. This system includes a Bureau adaptation of a feeder developed to feed coal to a boiler. Coal is metered by a rotating, multipocket feeder into a stream of air. The coal-air mixture is fed to the combustors on the turbine.

INTRODUCTION

Sixty percent of all power generated from fossil fuels in the United States is made from coal. Coal is burned in a boiler to make steam, and the steam drives a turbine that is coupled to an electric generator. The overall efficiency of these plants can be increased, however, if a turbine driven directly by the hot gases from burning coal is combined with the steam powerplant.

Several methods have been proposed for utilizing coal firing in a gas turbine cycle (7). Two of these methods (figs. 1 and 2) are of special interest

[7] Underlined numbers in parentheses refer to items in the bibliography at the end of the report.

because they promise more efficient power generation. In one method, hot gases from burning coal drive a gas turbine coupled to a generator; exhaust gas from the turbine which contains about 17 percent oxygen, is a source of pressurized, preheated combustion air for a conventional coal-fired steam turbine powerplant. In the other method, steam from a coal-fired pressurized boiler drives a turbogenerator; the exhaust gases from this coal-fired boiler drive a gas turbine coupled to an electric generator. These systems, both of which incorporate a coal-fired gas turbine, offer a 4- to 8-percent increase in efficiency over the conventional steam-turbine system.

The Locomotive Development Committee (LDC) of Bituminous Coal Research, Inc., carried out the first development work on a coal-fired gas turbine in the United States between 1945 and 1959 (see bibliography). This research was sponsored by several major eastern railroads and coal companies and was directed toward the development of a unit for use in locomotives. The LDC terminated this program in 1959, stating that it had demonstrated the feasibility of developing a coal-fired gas turbine for locomotive service.

In 1959, the LDC offered the turbine and auxiliary components to the Bureau of Mines for continued research and development. Having been interested in developing a coal-fired gas turbine for use in powerplants, the Bureau accepted this offer and transferred the turbine to the Bureau of Mines Coal Research Center at Morgantown, W. Va. In all, the LDC operated the turbine for almost 4,000 hours, of which 1,100 were logged just before the plant was transported to Morgantown.

The basic objective of the work at Morgantwon is to develop a gas turbine that can operate continuously for much longer periods, such as from 50,000 to 100,000 hours, as would be required for stationary powerplant operation. For a coal-burning gas turbine to give this kind of service, however, a method must be found to eliminate or control the erosion of turbine blades by coal ash in the hot gases. Bureau researchers are taking two approaches to solve this problem: (1) design and arrange the blades so as to minimize erosion; (2) develop methods of removing the ash before it enters the turbine. This report describes how the turbine blading is being redesigned in an effort to solve the problem of blade erosion, and the progress made in assembling the plant for additional operating tests.

The first test planned for the turbine is a 1,500-hour run with virtually the same equipment and operating conditions used by the LDC in their final 1,100-hour operation. This will allow the Bureau to properly evaluate the new blade design for the turbine. The run will start when the new blades are installed and the gas turbine plant is assembled.

The Bureau is also working on improved methods of preparing and feeding coal to the turbine, and on improvements in the coal combustion and ash-removal system. Additional publications by the Bureau will describe the operating performance of the turbine and progress in the other investigations.

ACKNOWLEDGMENTS

The Bureau of Mines is conducting this investigation under a cooperative agreement with Bituminous Coal Research, Inc. The Bureau gratefully acknowledges Bituminous Coal Research, Inc., for furnishing the turbine and auxiliary equipment.

DESCRIPTION OF COAL-FIRED GAS TURBINE

Figure 3 shows a cross section of the coal-fired gas turbine plant. Figure 4 shows a schematic diagram of the plant. Coal crushed to 3/16-inch by 0 is transferred to a pulverizer that grinds it to 90-percent through 200-mesh. The pulverized coal is mixed with air and burned in the combustors (fig. 5). Hot high-speed gas from the ash separators (figs. 3 and 6) rotates the turbine, which drives an air compressor and electric generators. Exhaust

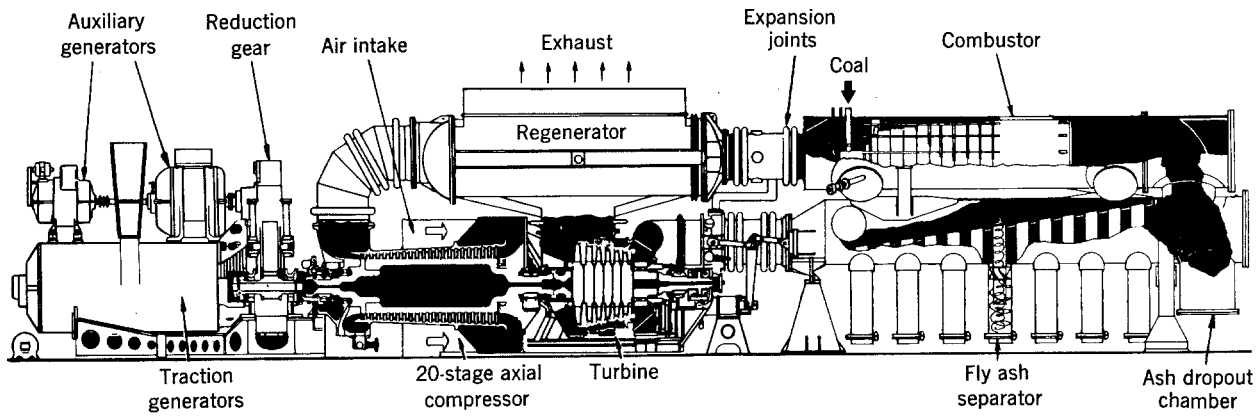

FIGURE 3. - Cross-Section of Coal-Fired Gas Turbine Plant.

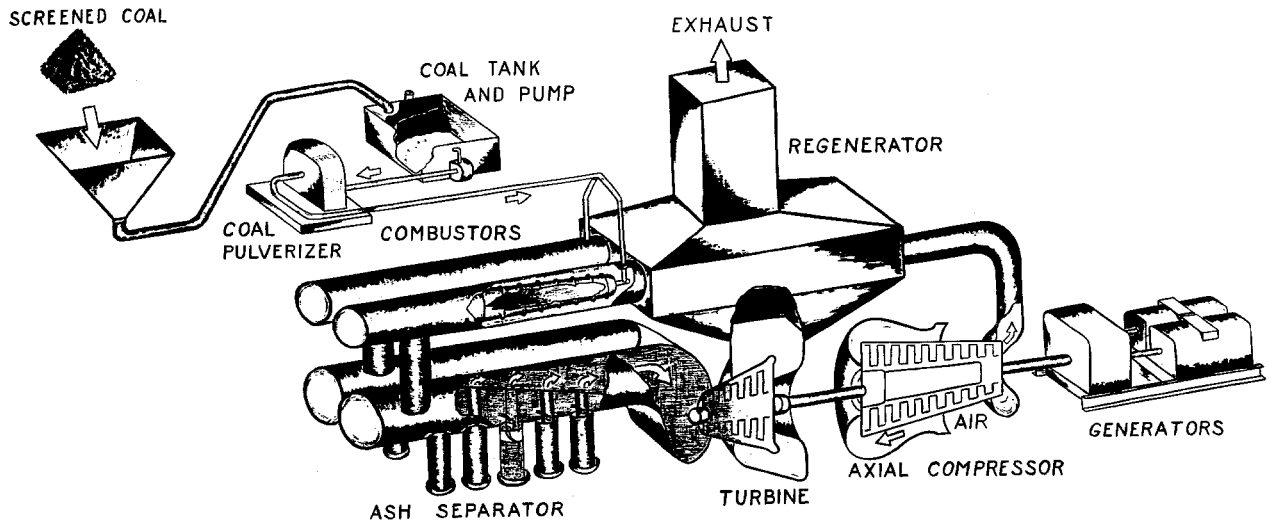

FIGURE 4. - Schematic Diagram of Coal-Fired Gas Turbine Plant.

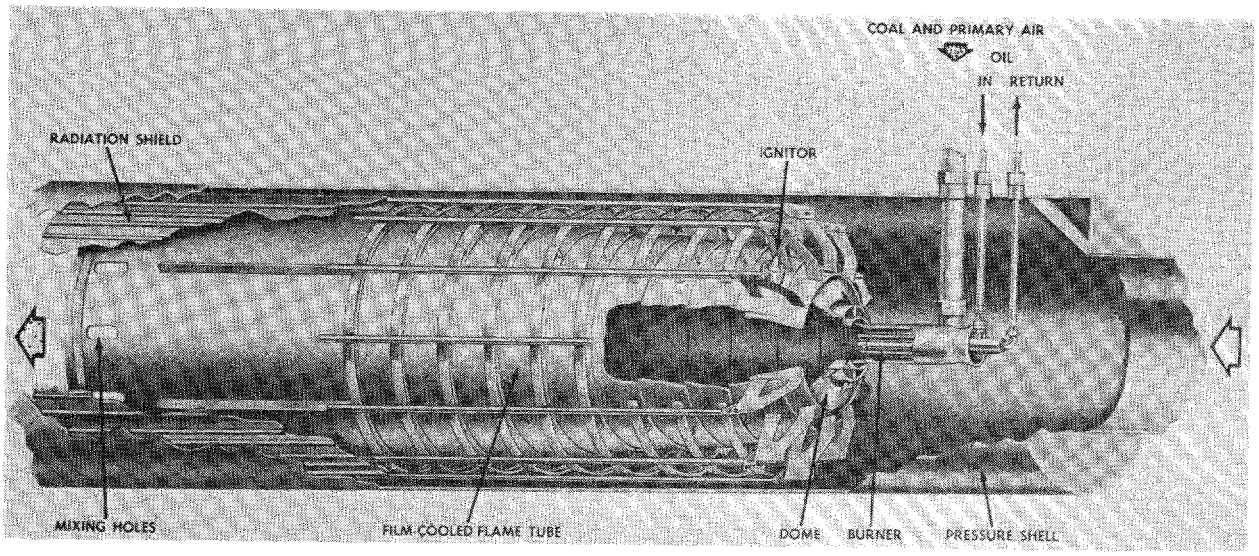

FIGURE 5. - Cut-Away View of Combustor.

gas from the turbine passes through a regenerator that preheats the compressed air to the combustors. Illustrations of other components are included later in this report.

Gas enters the turbine at about 1,300° F. and 60 p.s.i.g. Operating at 5,000 to 5,400 r.p.m., the turbine generates 3,000 to 3,500 usable horsepower from approximately 3,500 pounds of coal per hour. The compressor delivers about 60,000 std. c.f.m. of air at 65 p.s.i.g.

INSTALLATION OF TURBINE AND ACCESSORY EQUIPMENT

Except for changes in the design of the turbine blades and alterations to the coal pulverizer, the plant is being assembled in virtually the same way it was assembled originally. Modifications to the plant are discussed later in this report.

Many of the components of the plant have been installed. Other components, such as the regenerators and air inlet and exhaust ducts, cannot be permanently fixed until the new blades have been fabricated and installed. Photographs in this report show some of the major parts and equipment. Because some of the components are installed temporarily, these photographs do not necessarily illustrate final installation and cannot be used as a guide to degree of completion.

Figure 7 shows the turbine from the generator end. The combustors are the open chambers in the background. The turbine and air compressor are located between the combustors and the generators. The regenerator, exhaust stack, and inlet to the air compressor are not shown.

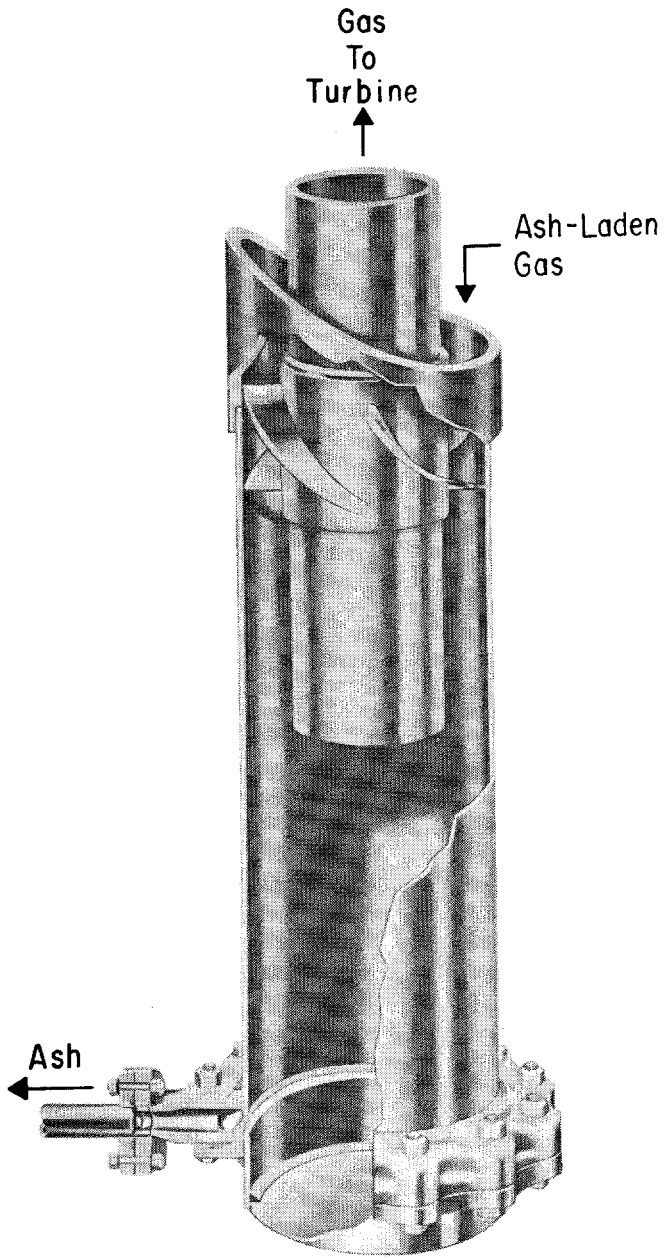

FIGURE 6. - Dunlab Ash Separator.

Figure 8 shows workmen installing the rotor of the air compressor. The lower half of the turbine housing is shown in figure 9. Figure 9 also shows the rotor installed in the partly assembled air compressor.

In figure 10 workmen are preparing to remove the regenerator from its location atop the turbine. Figure 11 shows the regenerator and exhaust duct temporarily attached to the turbine. Part of the lubricating oil cooler can be seen in the right foreground. Figure 12 shows workmen installing the lower section of the inlet to the air compressor.

REPAIRS AND MODIFICATIONS

Turbine Rotor

The coal-fired gas turbine was designed for 10,000 hours of full-power operation at 1,300° F. As stated previously, the turbine had been operated for approximately 4,000 hours during the earlier development work.

Figure 13 shows the turbine rotor before it was removed from the shipping cradle. Blasting with aluminum oxide grit revealed a number of cracks in the rotor, but the maximum depth of these cracks was only five thirty-seconds of an inch. Radiographs by the manufacturer revealed no major defects or flaws in the rotor. Figure 14 shows two cracks near the second row of the rotor. This picture also shows two of the slots ground in the shaft to determine the depth of the crack.

Most of the cracks were located in the packing gland area between the first and second stages and extended around the rotor. Cracks were less extensive and more shallow between succeeding stages, and no cracks were found between the fifth and sixth stages. All cracks were machined without changing the original axial dimensions of the packing gland area.

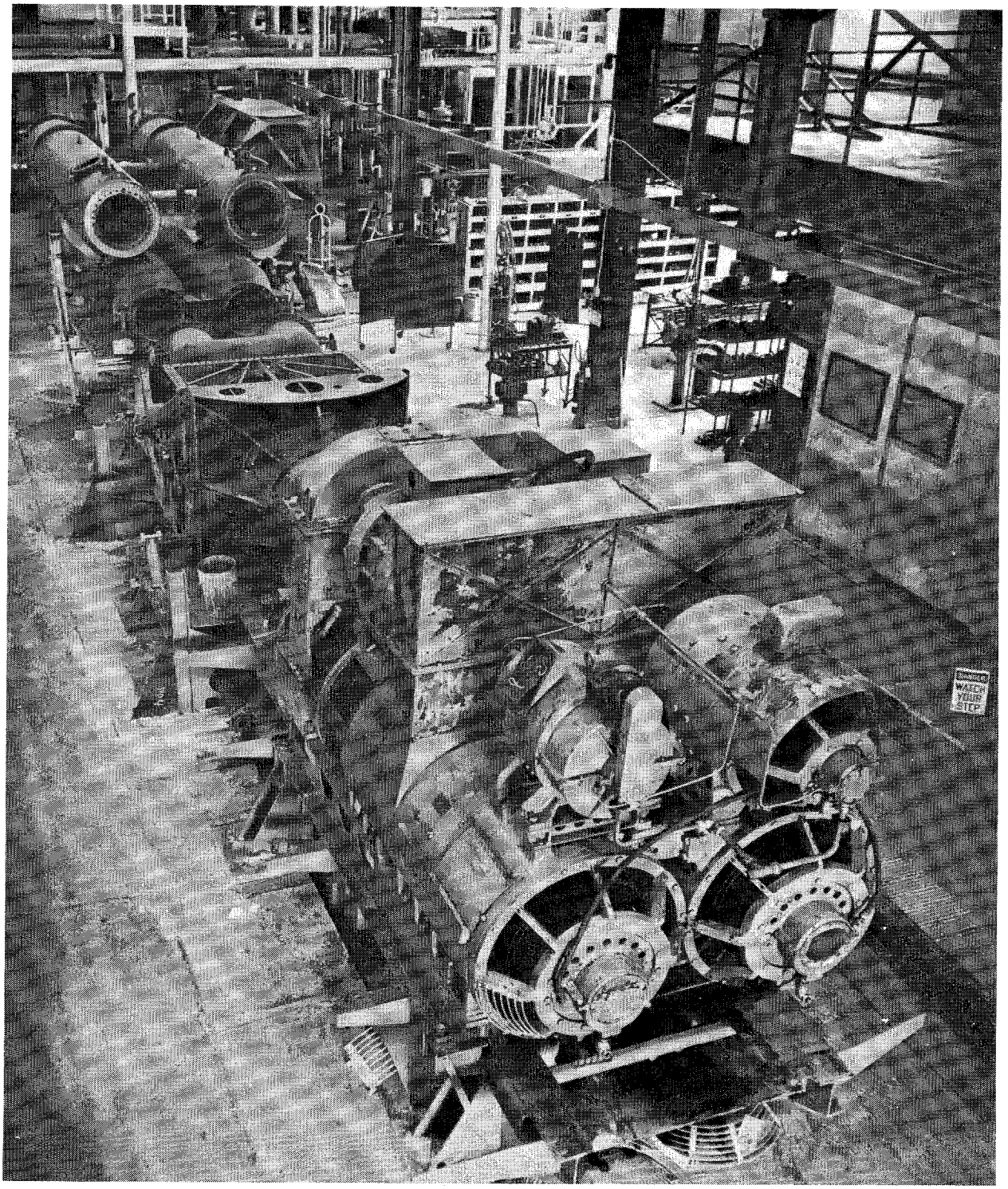

FIGURE 7. - View of Partly-Assembled Coal-Fired Gas Turbine Plant.

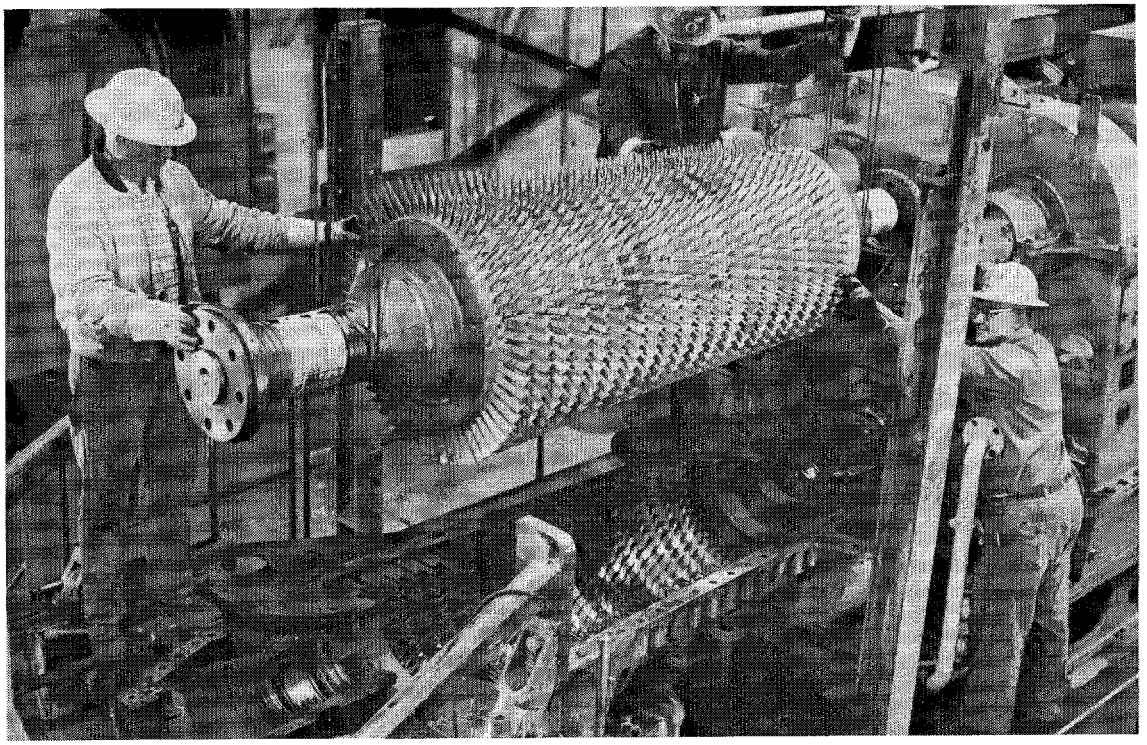

FIGURE 8. - Rotor of Air Compressor.

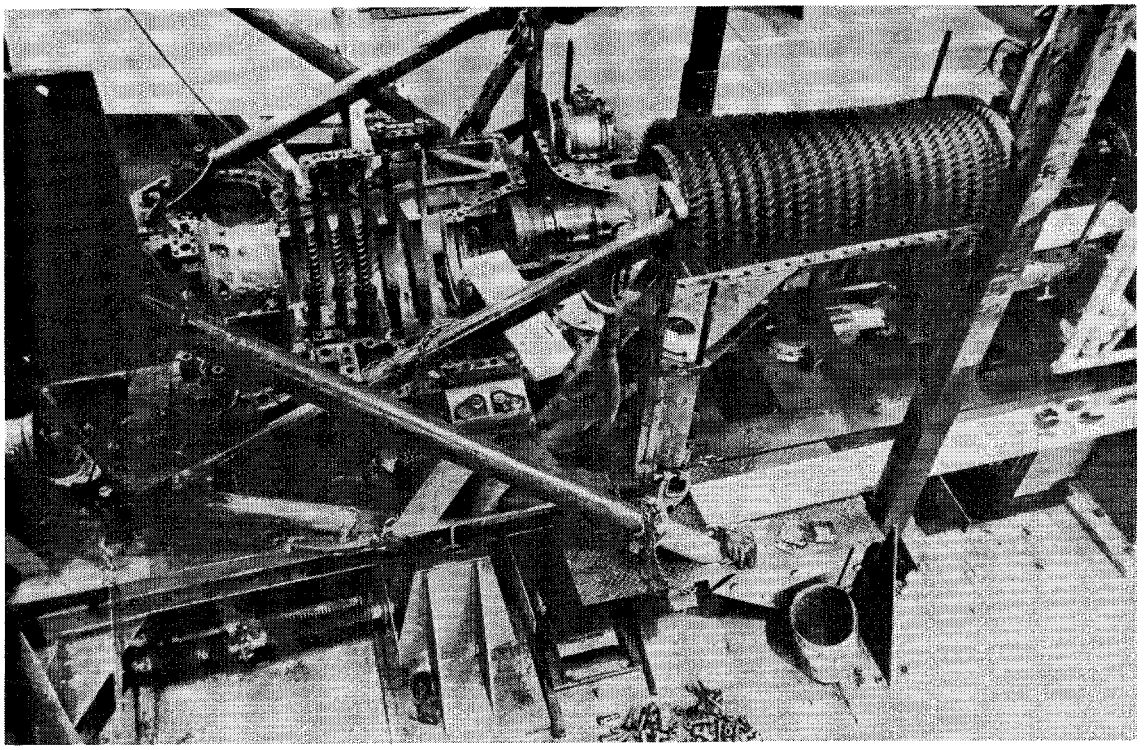

FIGURE 9. - Turbine Shell and Compressor Rotor.

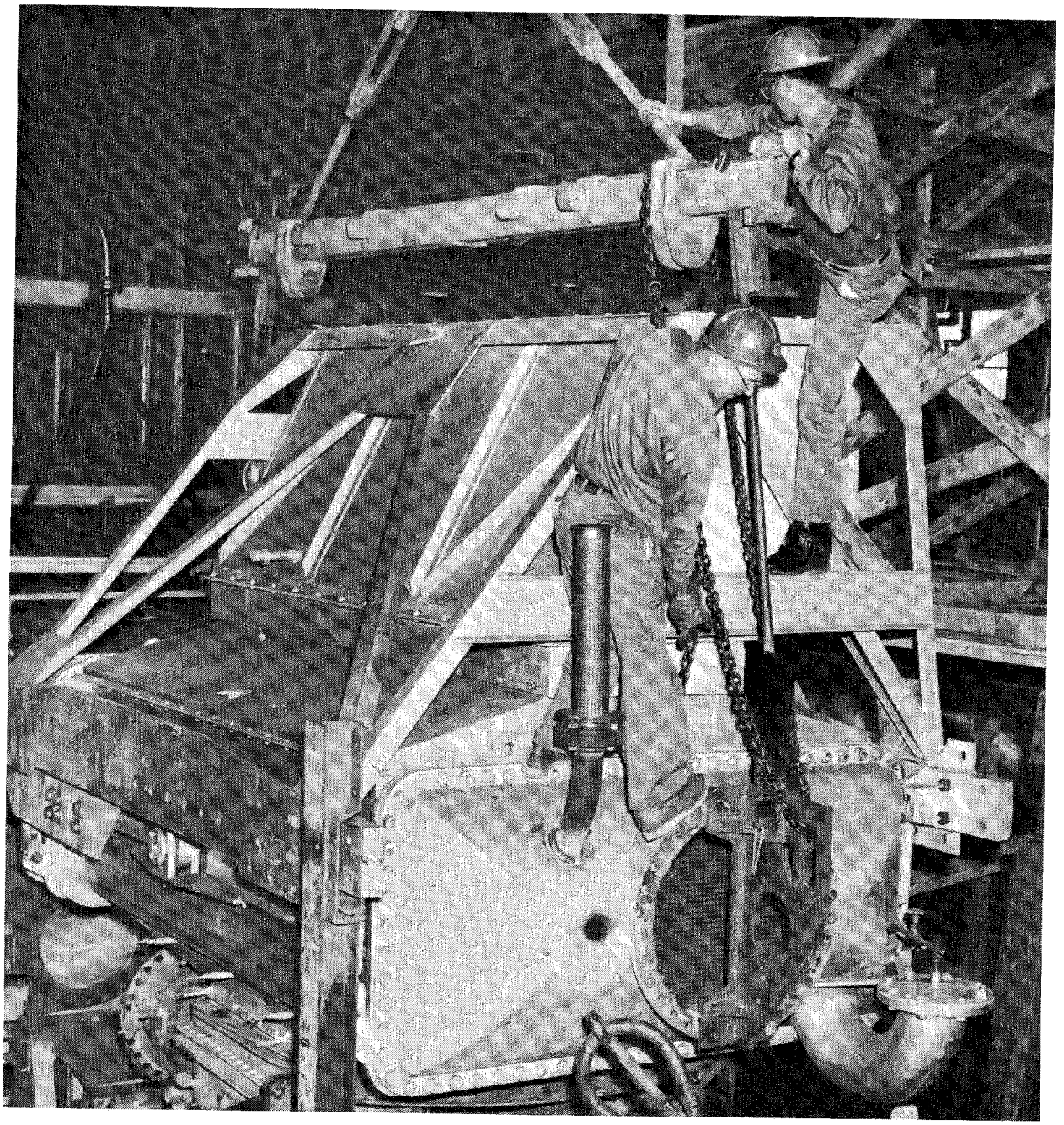

FIGURE 10. - Removing Regenerator From the Turbine.

After a complete radiograph and visual inspection, the manufacturer of the turbine judged the rotor to be sound and capable of operating for the remaining 6,000 hours. The manufacturer also stated that the turbine could be operated for 1,500 hours without disassembly for inspection.

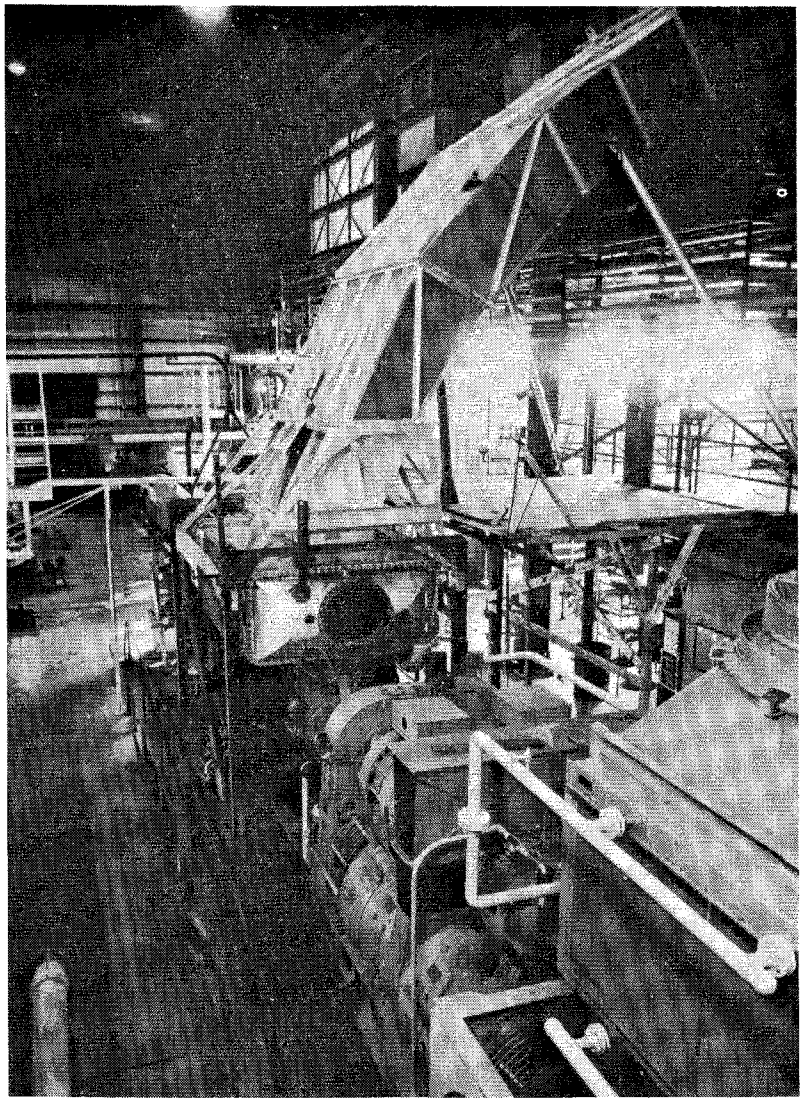

FIGURE 11. - Coal-Fired Gas Turbine Plant.

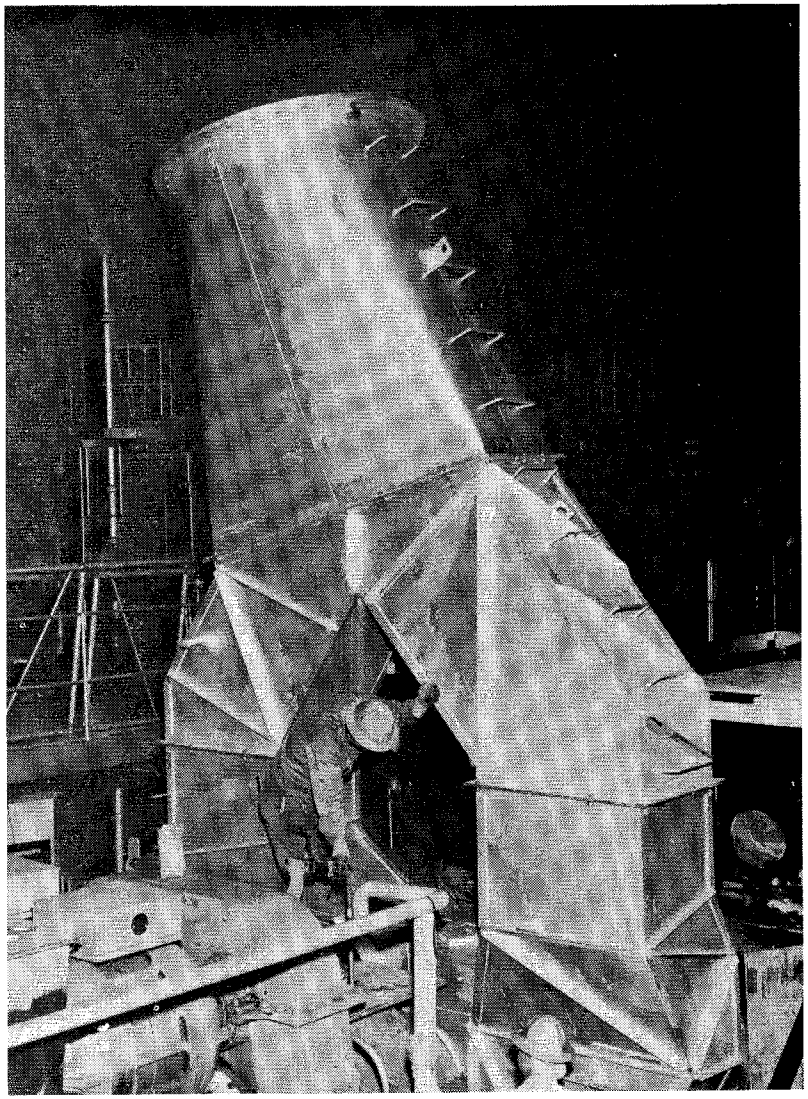

FIGURE 12. - Inlet to Air Compressor.

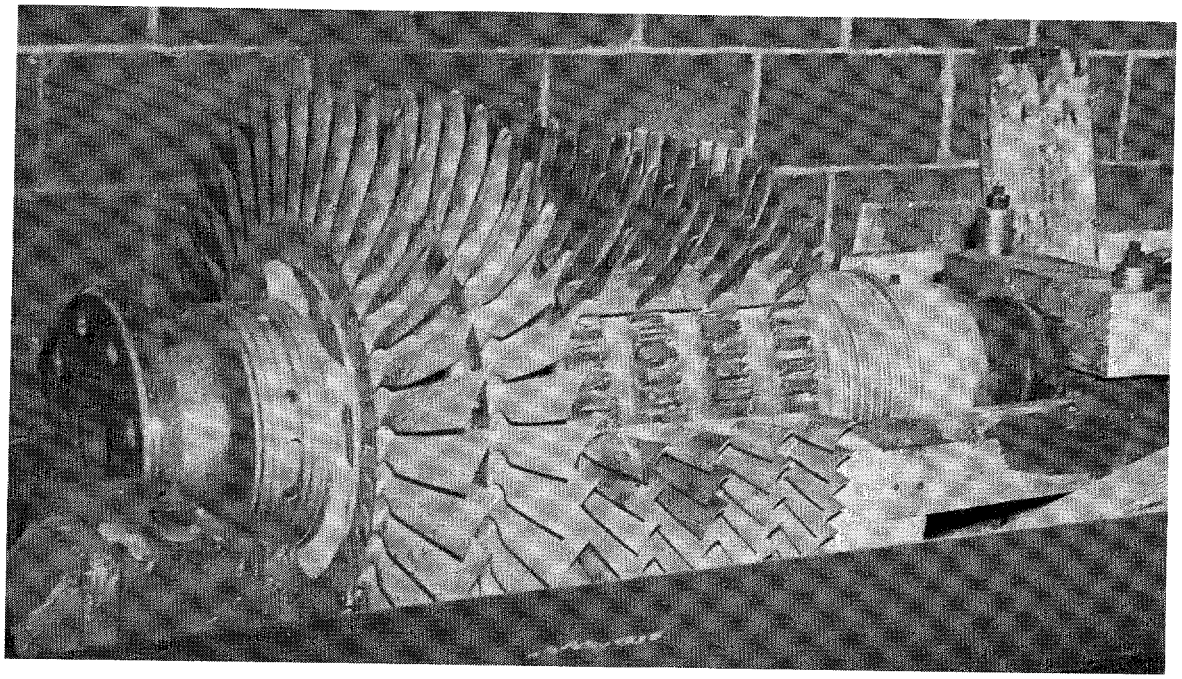

FIGURE 13. - Turbine Rotor and Blades.

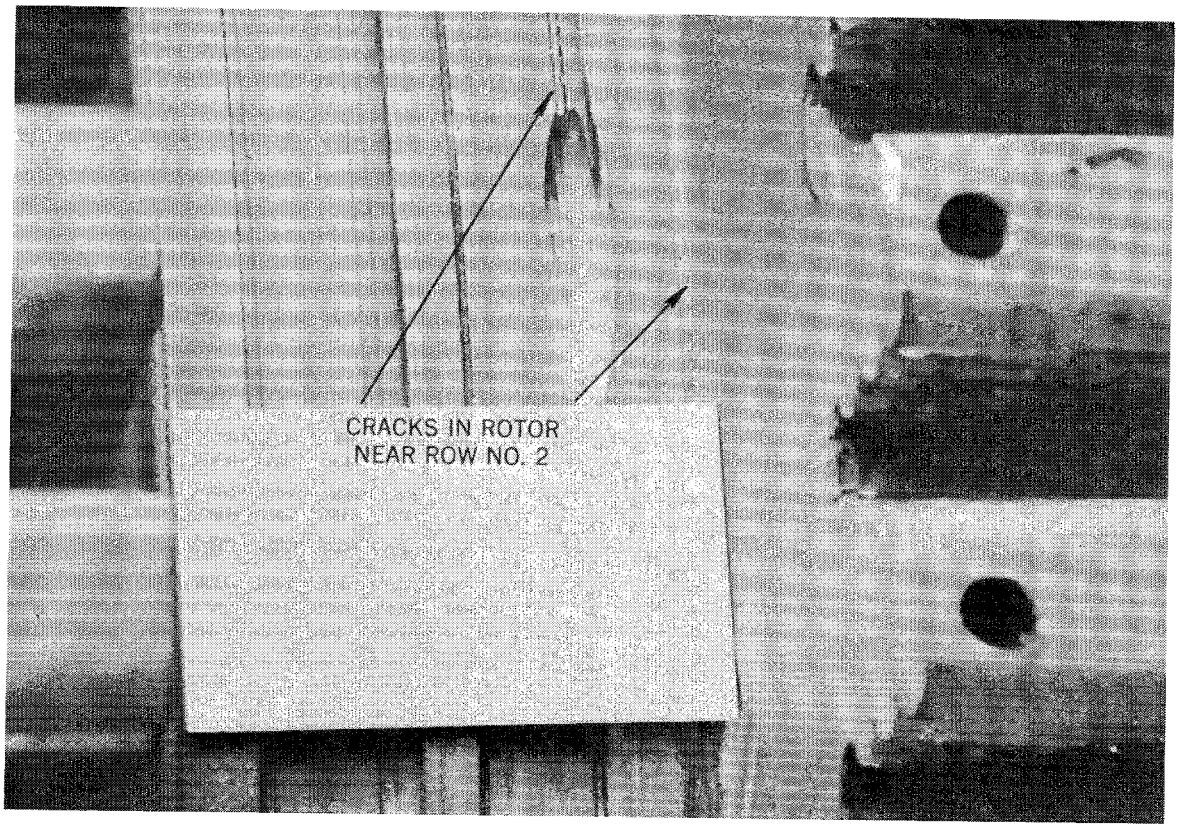

FIGURE 14. - Cracks in Rotor Row 2.