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2463

RADIAL INFLOW TURBINE UPDATE

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This study was started in association with EPRI back in 1977, initially to create radial inflow turbine designs based on experience and applicable to a broad range of hot water geothermal brines. The brine heat is used to boil a hydrocarbon mixture of isobutane and isopentane; the gas is then expanded through the turbines.

Having a very broad application, the original concept had two back-to-back turbines and a single wheel turbine. This permitted a very wide range of operation and could be simplified to suit a particular application.

What I am about to give you is an update on the progress in the radial inflow turbine field. The Heber application has varied in concept, but the latest has been to make use of the varying condensation temperature possible with varying dewpoint temperature. As Thom Page of San Diego Gas and Electric pointed out, this saves 16% on brine usage and some capital saving.

This philosophy has changed the design point appreciably so we are able to look at a very simple construction, aligning very well with machinery already manufactured and tested.

Figure 1 shows the layout of such a turbine. The gas, entering via the connection at the top into an annulus, travels or passes through variable nozzles which generate an angular swirl and thence enters the turbine where the angular swirl is removed and some further expansion takes place. With varying condensing temperature, an ability is required to operate with varying back pressure and with varying energy drop across the machine.

A multi-stage machine soon gets badly mismatched between inlet and discharge stages. Working with fixed speed and variable speed gas turbines for many years has given the author understanding in this area. This is why we see multiple spool gas turbines in existence today with each spool rotating at its own speed. A multi-stage turbine would work quite well over a large enthalpy range; that is energy drop across the machine if it had variable nozzles for each stage. We have and do adapt this solution at Rotoflow. In this case, because of the large enthalpy capacity of the radial turbine, only a single radial stage is needed. The next question to be asked is what happens in the machine with varying discharge pressure.

1. The energy drop changes.

2. The volume changes.

How does the radial inflow turbine operate under these conditions?

First, let's look at flow. All Rotoflow turbines are equipped with variable inlet nozzles which completely removes the necessity for an upstream throttling valve; no energy is wasted as it would with an upstream throttling valve, and in order to maintain control, there is no necessity for any pressure drop across any upstream throttling valve. The variable inlet nozzles do all the controlling, and all the kinetic energy goes into power conversion.

To illustrate this, Figure 2 shows how a radial inflow turbine handles flow versus what occurs with an axial multi-stage unit with upstream throttling.

The latter data is taken from the EPRI report, ER 513. The dotted line shows the excellent efficiency/flow characteristic obtained from data recently received from N.A.S.A. on one of our 26-inch turbines. This is probably the most complete set of data run on one of these machines.

The reason for this excellent flow/efficiency characteristic of the radial turbine is shown in Figure 3. Put very simply, at partial flow conditions, the radial inflow turbine develops a dead zone towards the center with the gas being concentrated to the outside and develops close to its correct discharge conditions. The N.A.S.A. data confirms this well.

The next question is what happens with the varying energy drop associated with varying condensation temperature.

For the Heber application, we are using a mixture of isobutane and isopentane as the Rankine cycle gas. The design back pressure is 56 lbs. per square inch absolute, and at this condition the gas from the nozzle has a velocity of 965 ft/sec, and the tip speed of the turbine is 896 ft/sec.

The relative velocity between the gas and the turbine wheel tip is small, permitting radial entry at low velocity which is partly the reason why it can handle condensing streams and commonly does (0-52% liquid at the discharge).

When the back pressure reduces, the pressure falls and volume increases. This results in some increase in pressure drop across the wheel, but let us ignore this compensating factor for a minute and consider what happens with all the changes in energy taking place across the nozzles.

In the Heber application, 10% change in overall enthalpy is equivalent to a change in wet bulb from 80°F to 55°F and a change in back pressure ratio from 7.6 to 10.6 to 1.

With the radial inflow turbine, these changes are equivalent to a velocity change across the nozzles of approximately 90 ft/sec relative to the turbine and corresponding to less than 1/2% loss. This loss would be far larger in an axial turbine, a maximum of 5%, due to the higher relative velocity between gas and blading.

These theoretical studies have recently been confirmed in the very extensive work on the 26-inch Rotoflow turbine carried out at the National Aeronautics and Space Administration facility at the Lewis Laboratories. This turbine demonstrated 87% efficiency at 11,100 HP and a pressure ratio of 6:1.

In a 56-inch turbine, this is equivalent to 56,000 HP in blade loading, and it demonstrated the very flat flow efficiency curve shown in Figure 2. We believe the only turbine capable of fully utilizing the variable back pressure concept to be the radial inflow turbine.

We have been questioned on our choice of materials, but this is certainly flexible. The significant advantage of radial inflow turbines is the very large temperature drop across the nozzles, 98°F, which means average turbine temperatures of 175°F. This is cool enough for us to use already proven materials in the size range for a 90,000 HP machine.

Figure 4 shows a machine built for the Air Force test facility at Tullahoma, Tennessee; it contains a 53-inch wheel using A355 alloy and has been tested to 5,000 rpm. In comparison, the Heber unit will run at 3,600 rpm.

This is not just one unit. Figure 5 shows an early picture of 5 machines on site. This is part of a huge facility for testing gas turbines and we expect considerable feedback from these machines such as we have obtained from N.A.S.A.

In terms of power loading, we have 12 turbines operating in Algeria with an inlet pressure of about 1400 psi and a power density per unit blade area equivalent to 100,000 HP in a 53-inch machine.

Sealing systems have been demonstrated. Figure 6 shows the turbine used in a closed loop system which demonstrates self-sustained ocean thermal energy conversion, a world's first!

All these machines and a thousand others like them operating in every major country in the world are built on similar principles utilizing the many patents originated by Dr. Swearingen.

All these machines utilize a system in which the shaft, bearings, wheels, and seals are assembled in one unit that can be rapidly changed as a cartridge unit. A 10,000 HP machine loses $300,000/day in lost product for every day it is shut down. So, we do understand the need for minimum down time and much attention has been given to this. Our average in unscheduled down time is one day in 5 years.

Figure 7 shows such a cartridge unit. It has a 53-inch wheel, high speed electro-hydraulic nozzle controls, which will handle load rejection with ease. The alternative to variable inlet nozzles is a very large inlet valve closing in a small fraction of a second. This type of valve is unproven at this time and may require considerable development for repeated operation.

For a geothermal application, we have considered thrust balance, turbine stresses and low cycle fatigue. The bearings will take 40,000 lbs. of thrust load, which is excellent for two reasons. First, the axial load that occurs with an earthquake having one-half the force of gravity in the axial direction is 20,000 lbs. which is equal to one-half the weight of the generator rotor and turbine (the generator having no thrust bearings). Second, pressure variations have been calculated to produce 5,000 lbs. of axial thrust with a single turbine and balanced in a back-to-back configuration.

Copies of a final report containing more detailed information have been made available by EPRI to interested parties.

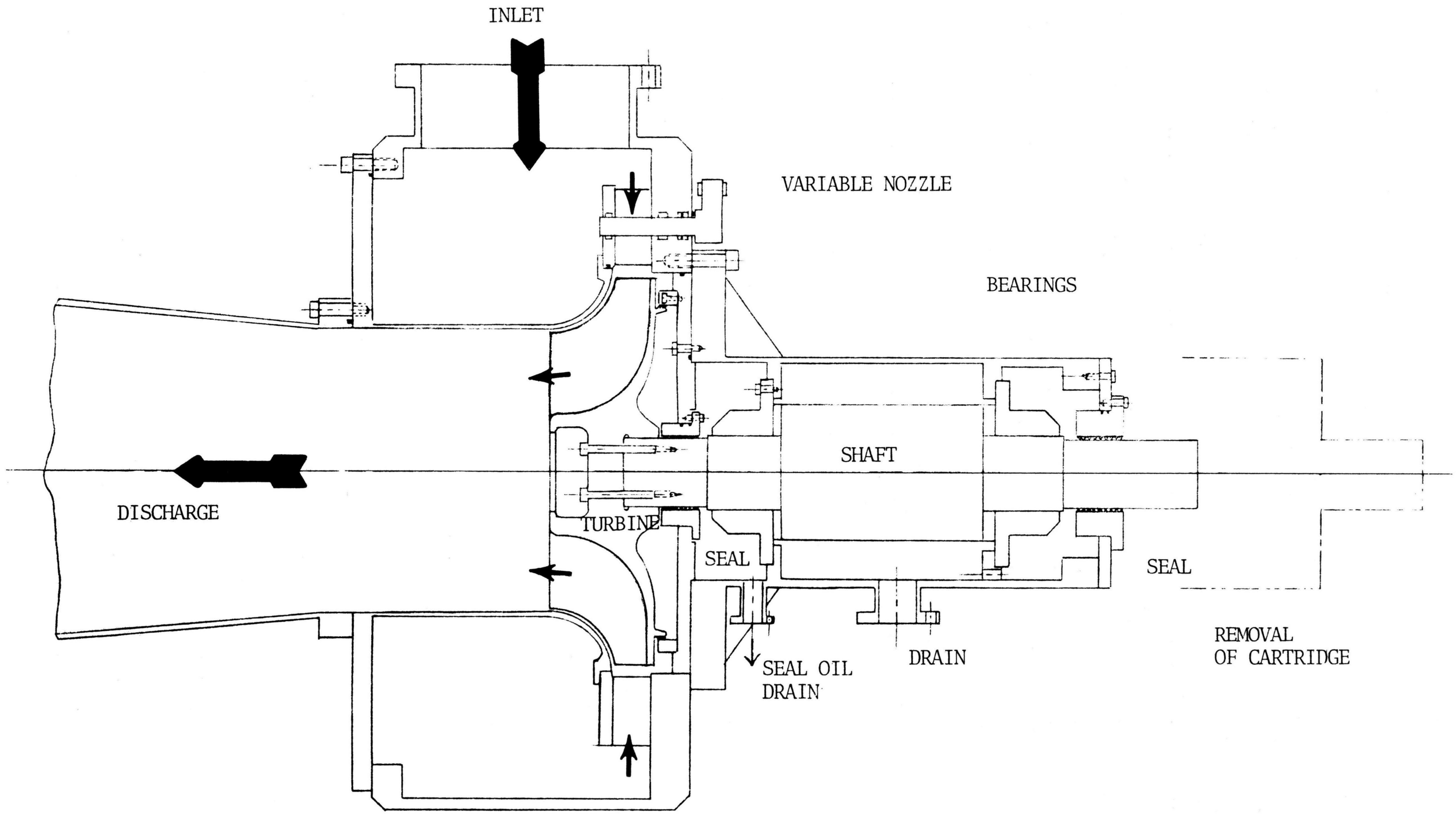

INLET
VARIABLE NOZZLE
BEARINGS
SHAFT
DISCHARGE
TURBINE
SEAL
SEAL
REMOVAL
OF CARTRIDGE
DRAIN
SEAL OIL
DRAIN

FIG. 1

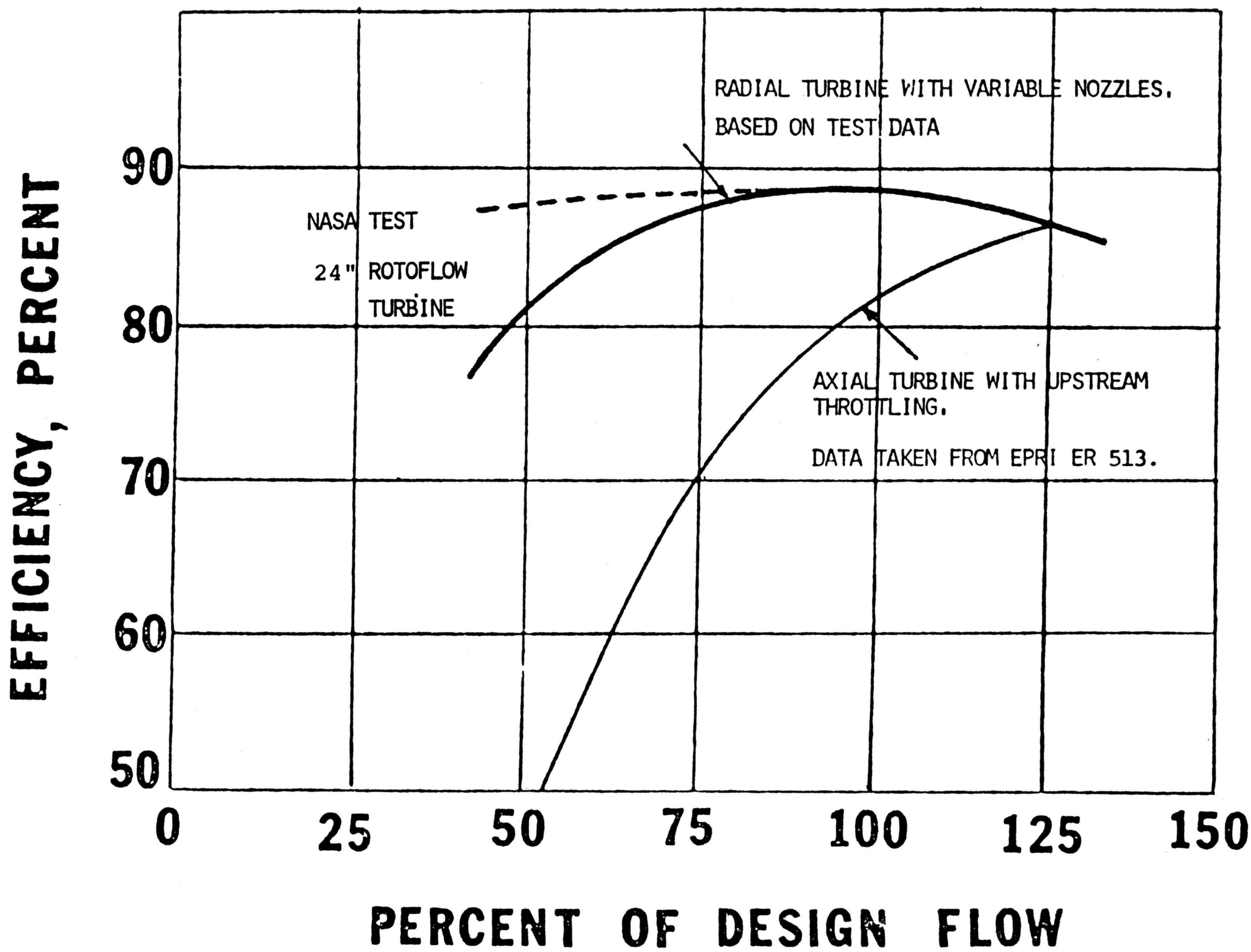

RADIAL TURBINE WITH VARIABLE NOZZLES.
BASED ON TEST DATA
NASA TEST
24" ROTOFLOW
TURBINE
AXIAL TURBINE WITH UPSTREAM THROTTLING.
DATA TAKEN FROM EPRI ER 513.
EFFICIENCY, PERCENT
90
80
70
60
50
0
25
50
75
100
125
150
PERCENT OF DESIGN FLOW

FIG 2

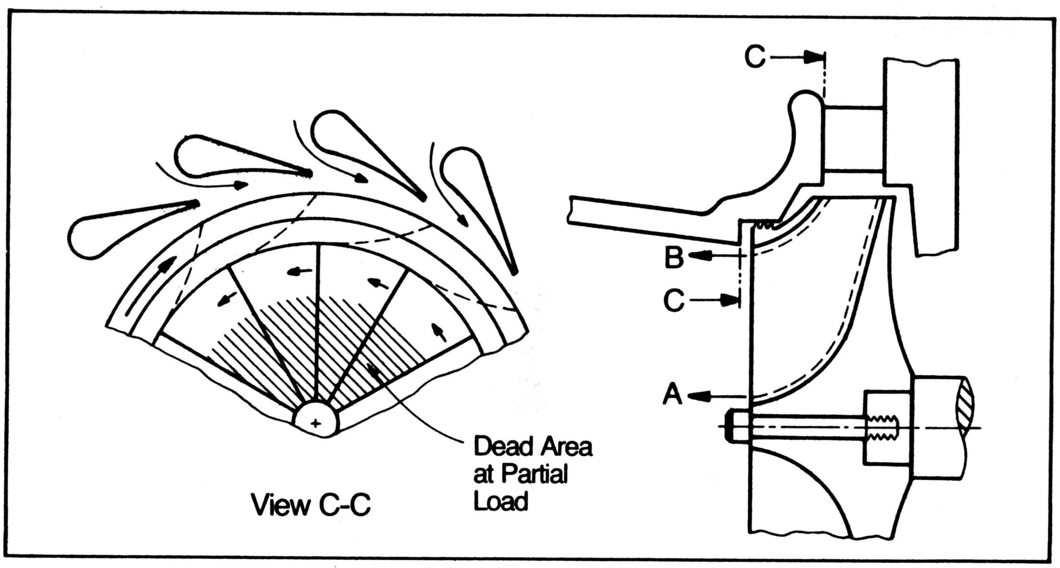
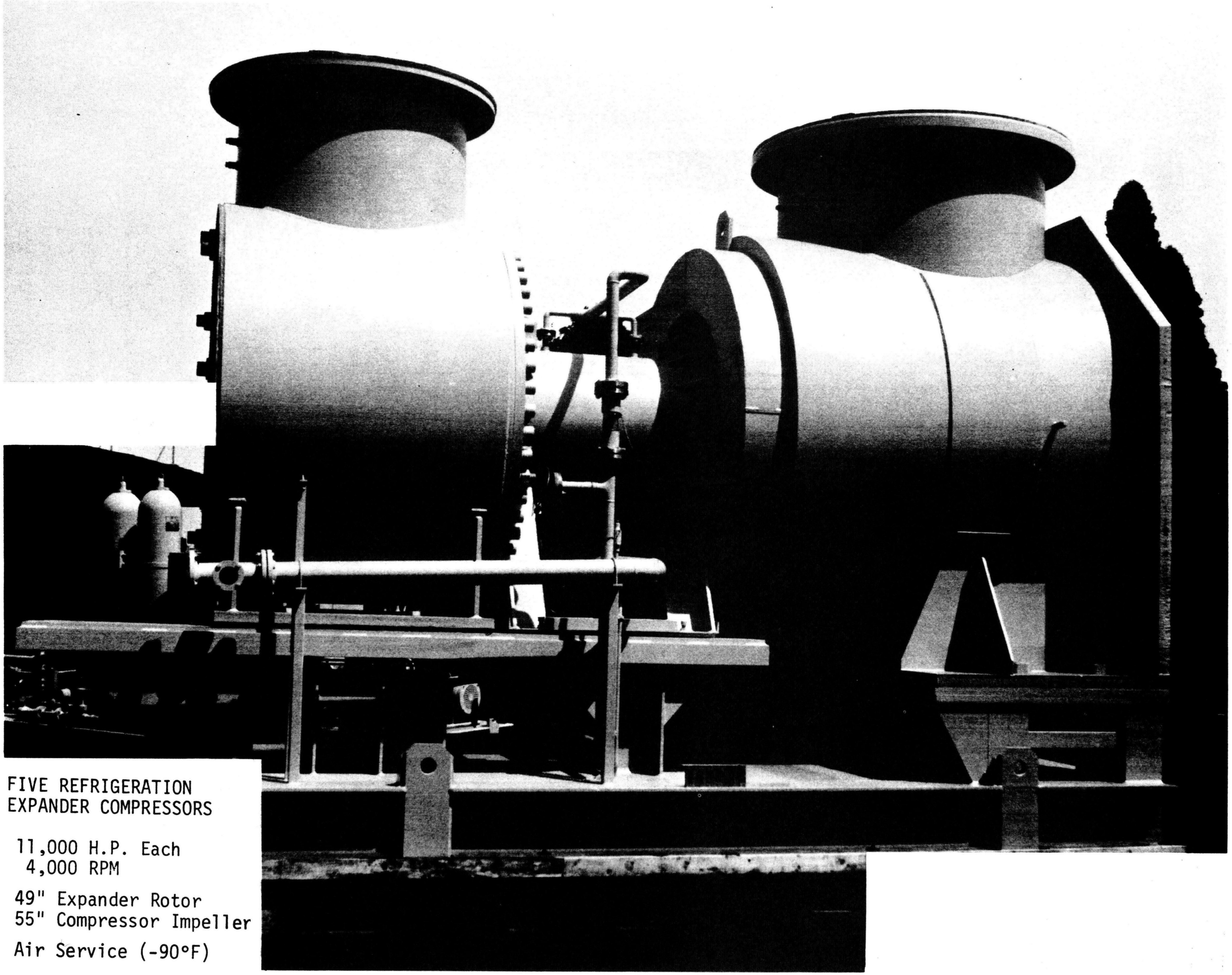

C
B
C
A
Dead Area at Partial Load
View C-C

FIG 3

FIG 4



FIVE REFRIGERATION
EXPANDER COMPRESSORS

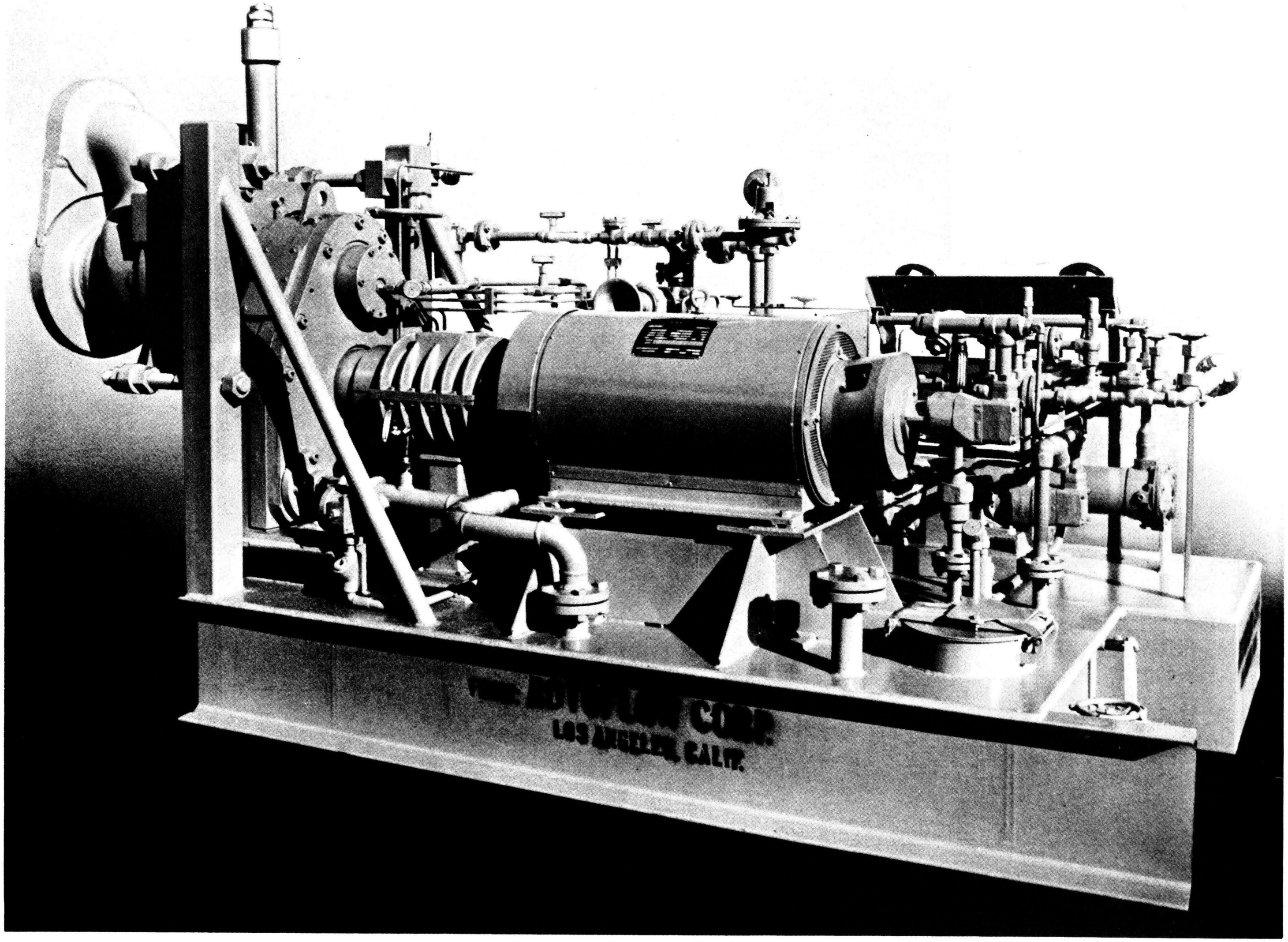
11,000 H.P. Each
4,000 RPM

49" Expander Rotor
55" Compressor Impeller

Air Service (-90°F)

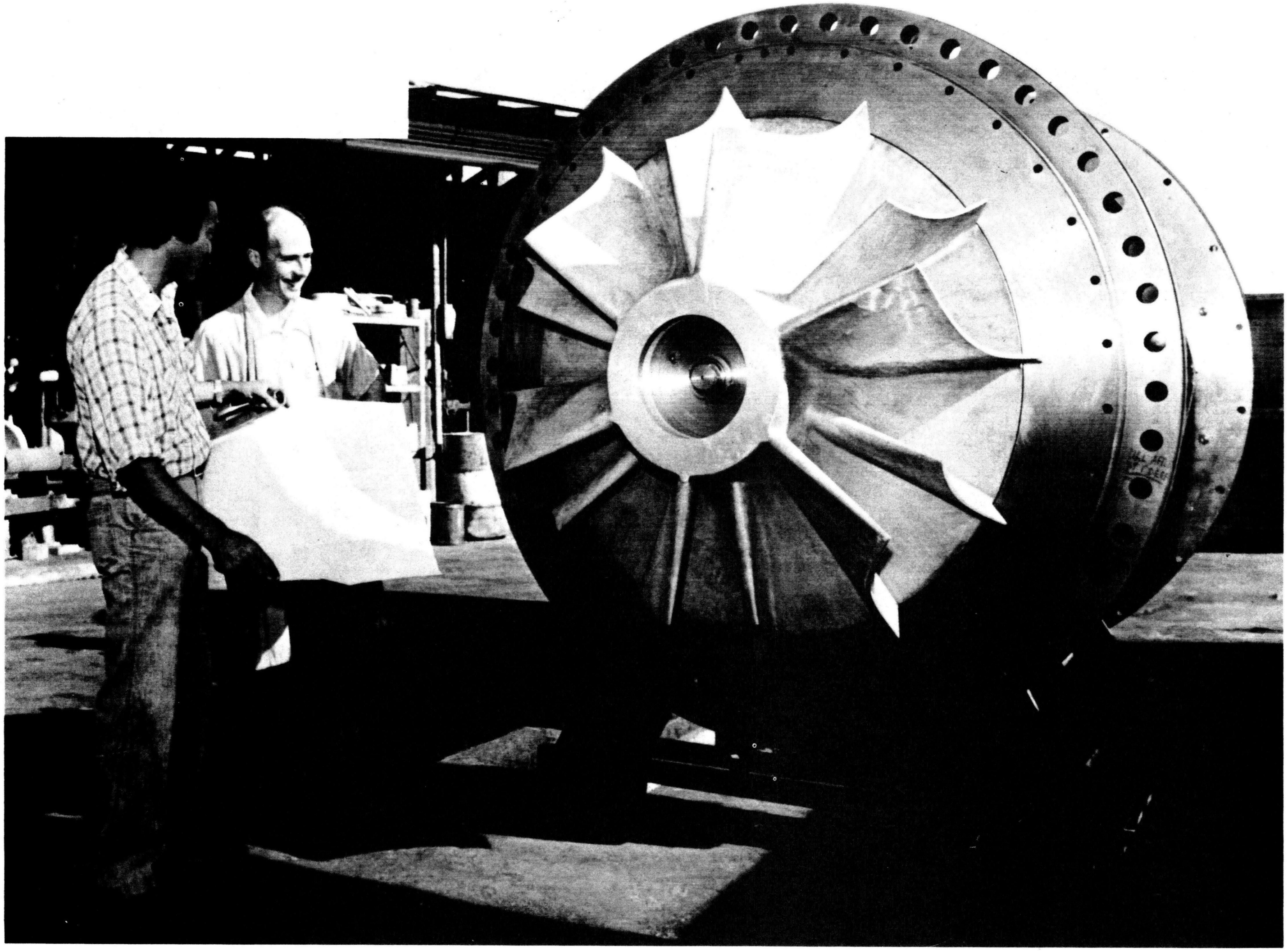
FIG 5

FIG 6



Back view of Rotoflow machine for OTEC system, showing generator.

FIG 7



Mechanical center section of Rotoflow refrigeration turbine system can be removed intact from main unit. Compressor impeller above has 55-inch diameter.