Using Existing Steam Turbines in Off-Design Applications

Shawn C. Whitecar

Encotech, Inc.

Using Existing Steam Turbines in Off-Design Applications

Abstract

Recently Encotech Engineering P.C. has had several requests to evaluate the use of steam turbines in applications different from that for which they were originally designed. As a result of these requests, Encotech has designed a unique set of software tools and developed engineering skills for addressing these situations. These software tools and skills allow Encotech to quickly and effectively evaluate the use of steam turbines applied to off-design conditions.

This paper will describe software tools used by Encotech Engineering P.C., its engineering capabilities, and the methods used for conducting off-design turbine evaluations. In addition, it will provide case histories and examples of recommendations made by Encotech.

Introduction

During the last few years, Encotech Engineering P.C. has received a variety of inquires regarding the use of existing steam turbines for off-design applications. As a result of these inquiries, Encotech has developed a unique set of skills and tools. Encotech is in an excellent position to help turbine owners evaluate the use of their turbines in off-design applications.

The key to Encotech Engineering P.C.'s ability to evaluate the application of existing turbines in off-design applications is its unique set of software tools and engineering experience. These software tools include Encotech, Inc.'s Steam Turbine Performance Evaluation (STPE[1]) line of software, the Steam Turbine Redesign Program (STRE[1]), the Steam Cycle Diagnostic Program (SCDP[1]), and the Cogeneration and Energy Planning Program (CEPP[1]). These software tools are complimented by Encotech's extensive experience in analyzing steam turbines. Encotech maintains a core staff of licensed professional engineers supported by consultants and design personnel. Encotech personnel are experienced in providing performance consulting, finite-element analysis, rotor dynamic analysis, piping stress analysis, bearing design, turbine mechanical life assessment, and computer aided drafting. Recent events have allowed Encotech to gain experience in applying each of these skills to the use of evaluating steam turbines in off-design situations.

Application of A Marine Turbine in Geothermal Power Generation

A particular client of Encotech's has requested our assistance, on several occasions, in evaluating the use of surplus 1945 vintage marine turbines in various power generating scenarios. An example of one application of the use of these turbines in off-design conditions is in the geothermal area.

Figure 1 provides a general flow schematic of a geothermal plant that uses LP sections of surplus marine turbines. High pressure hot water is removed from the geothermal field and introduced into a flash tank. The water flashes to steam and is provided to two turbines. Drains from the high pressure flash tank are introduced into a second lower pressure flash tank. The steam from the

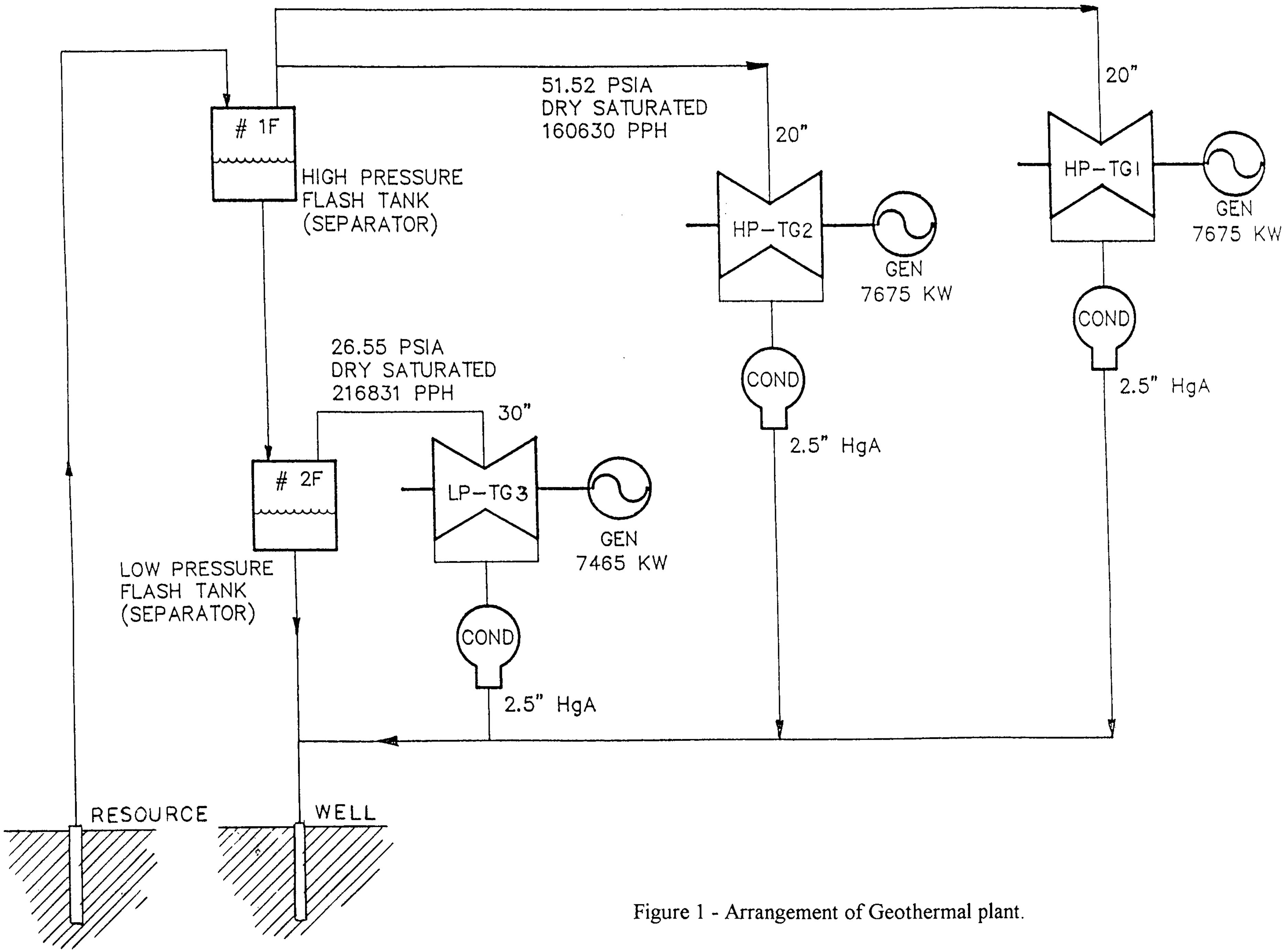

Figure 1 - Arrangement of Geothermal plant.

second flash tank is provided to a third turbine operating at a lower pressure. Remaining water in the second flash tank and water from the condensers is returned to a well.

A cross section of the marine low pressure turbine is shown in Figure 2. The turbine is a double flow turbine with six stages per flow. The original design features a velocity compounded astern element on either flow. In marine service, the LP section of the turbine is designed to operate with inlet steam pressures up to 59.8 psia and inlet steam temperatures ranging from 180 to 421 degrees Fahrenheit. In marine service the turbine is expected to operate at speeds up to 4714 RPM.

For use in the geothermal application, the reversing elements and the steam deflector were not required. In addition, piping and valving needed to operate the turbine with full arc admission was necessary. Figure 3 shows the final external arrangement of the turbine.

Determining The Flow Passing Capability and Performance of The Turbine

Encotech's initial involvement in the project, consisted of determining the performance and flow passing capability of the turbines and conducting a study to evaluate the turbine's mechanical condition. By determining the performance and flow passing capability of the turbines, Encotech assisted its client in best utilizing the turbine given the available steam supply from the geothermal field.

To determine the flow passing capability and performance of the turbines, Encotech Engineering, P.C. modeled the turbine using Encotech, Inc.'s STRE software. The STRE software calculates the flow passing capability and efficiency given the turbine stage areas, turbine geometric dimensions, and thermodynamic boundary conditions. Once a "base" model of a unit has been created with STRE, the impact of changing stage areas, boundary conditions, or removing stages can be determined. In addition, STRE allows the turbine speed to be varied so that the optimum rotational speed of the turbine for the given application can be selected.

An example of the type of information that can be determined using STRE is shown in Figures 4 and 5. Figure 4 provides the flow passing capability of the turbine given the inlet pressure and a 2.5 in.-HgA" exhaust pressure. Figure 5 provides the expected valves-wide-open efficiency of the turbine, for a given rotational speed, at various inlet pressures.

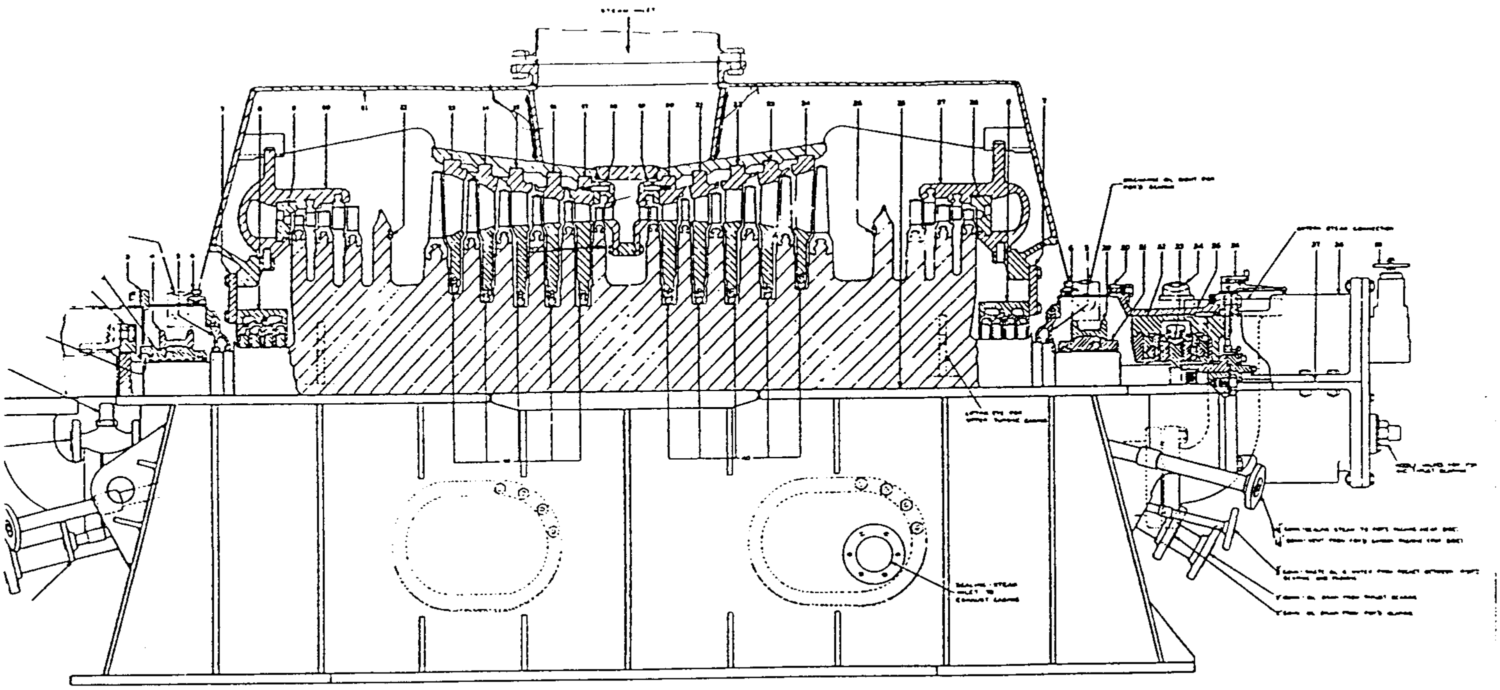

Fig. 4. Assembly of Low-pressure Turbine

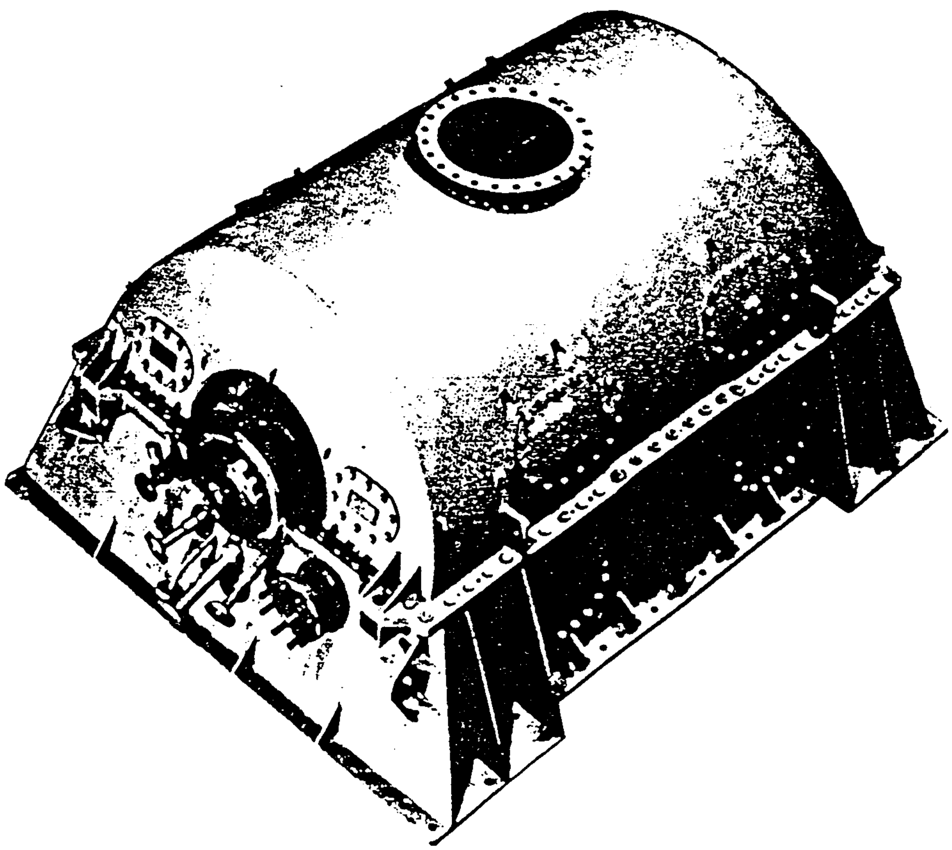

Figure 2 - Cross-section of low pressure marine turbine.

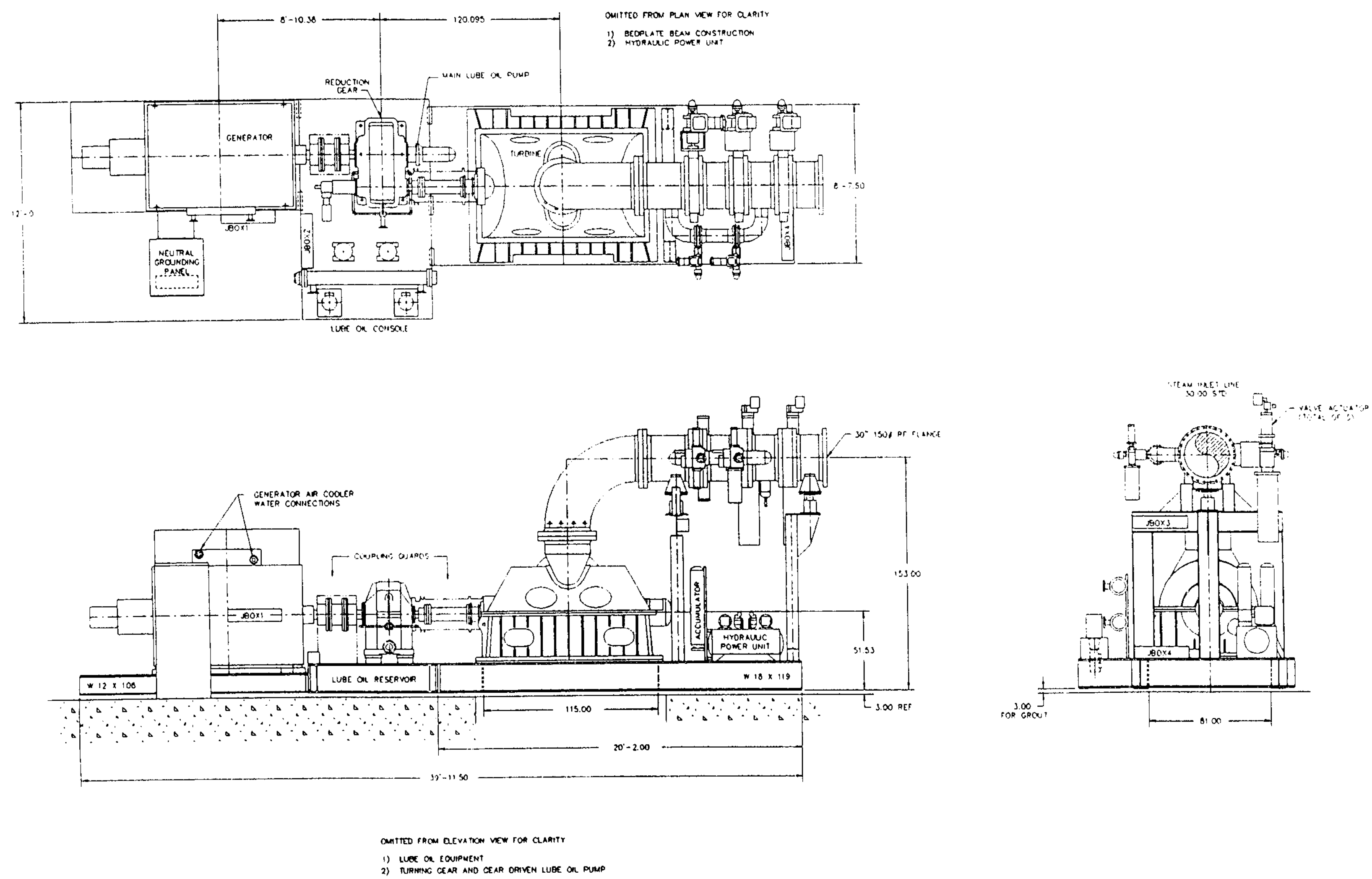

Figure 3 - External arrangement of turbine and accessories for use in geothermal application.

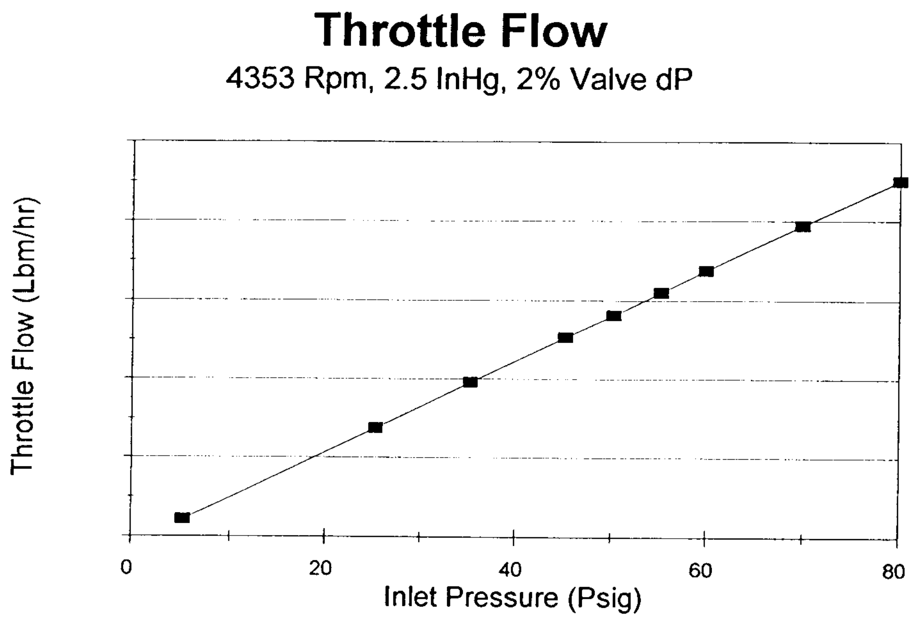

Figure 4 - Valves-wide-open flow versus throttle pressure.

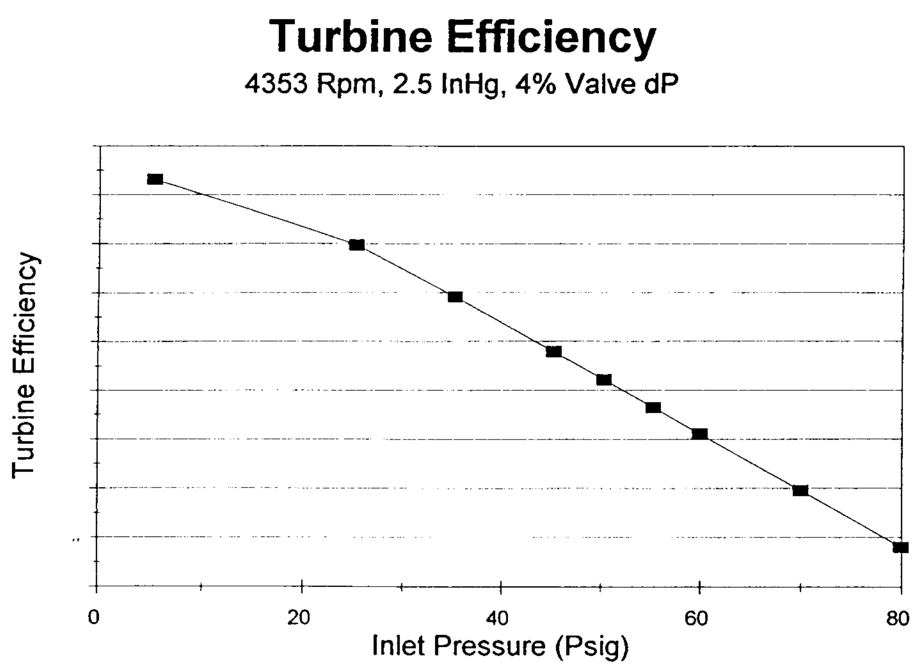

Figure 5 - Turbine efficiency versus inlet pressure.

The steam flow from the low pressure flash tank was too high for a single unmodified turbine to swallow and too low for efficient operation with two turbines. To resolve this problem, the first two stages were removed from both flows of a single turbine, thus increasing its flow passing capability.

Once the final arrangement of the turbines was determined, Encotech used STRE to calculate the expected generator output for each turbine which was used by Encotech's client in generating proposal's and guaranteeing the performance of the plant to his client.

Evaluating the Turbine Mechanical Condition

In addition to establishing the performance of a modified turbine, it is essential to determine if the turbine is mechanically suitable to operate at the new conditions. For the turbines' operating from the initial flash tank, the operating conditions were within the limits set by the original design of the turbines. However, for the single turbine operating from the low pressure flash tank, a significant change in operating conditions is expected as a result of removing the first two stages.

For the modified turbine, the average pressure drop across the remaining stages was expected to increase from 57 to 77 psia. This increased pressure drop results in several potential problems. Some of these problems include: (a) increased stress and defection of the diaphragms, (b) increased inner shell ledge loading, and (c) increased rotating blade bending and vibrating stresses.

To evaluate these problems Encotech conducted an intensive study regarding the mechanical condition of the turbine. This study included a finite element evaluation of the casing areas under increased pressure loads, the removal of the reversing stages, a redesign of the balance slot, and a static/dynamic analysis of the last stage blades. Figure 6 illustrates the model used for evaluating the last stage blading.

The finite element analysis of the last stage blading determined the static stress resulting from centrifugal loading and due to steam flowing through the blading. The dynamic analysis determined the natural frequencies of the banded groups. Encotech's analysis indicated that the application of the last stage rotating blading was near the high end of typical utility practice. Normal operation with the

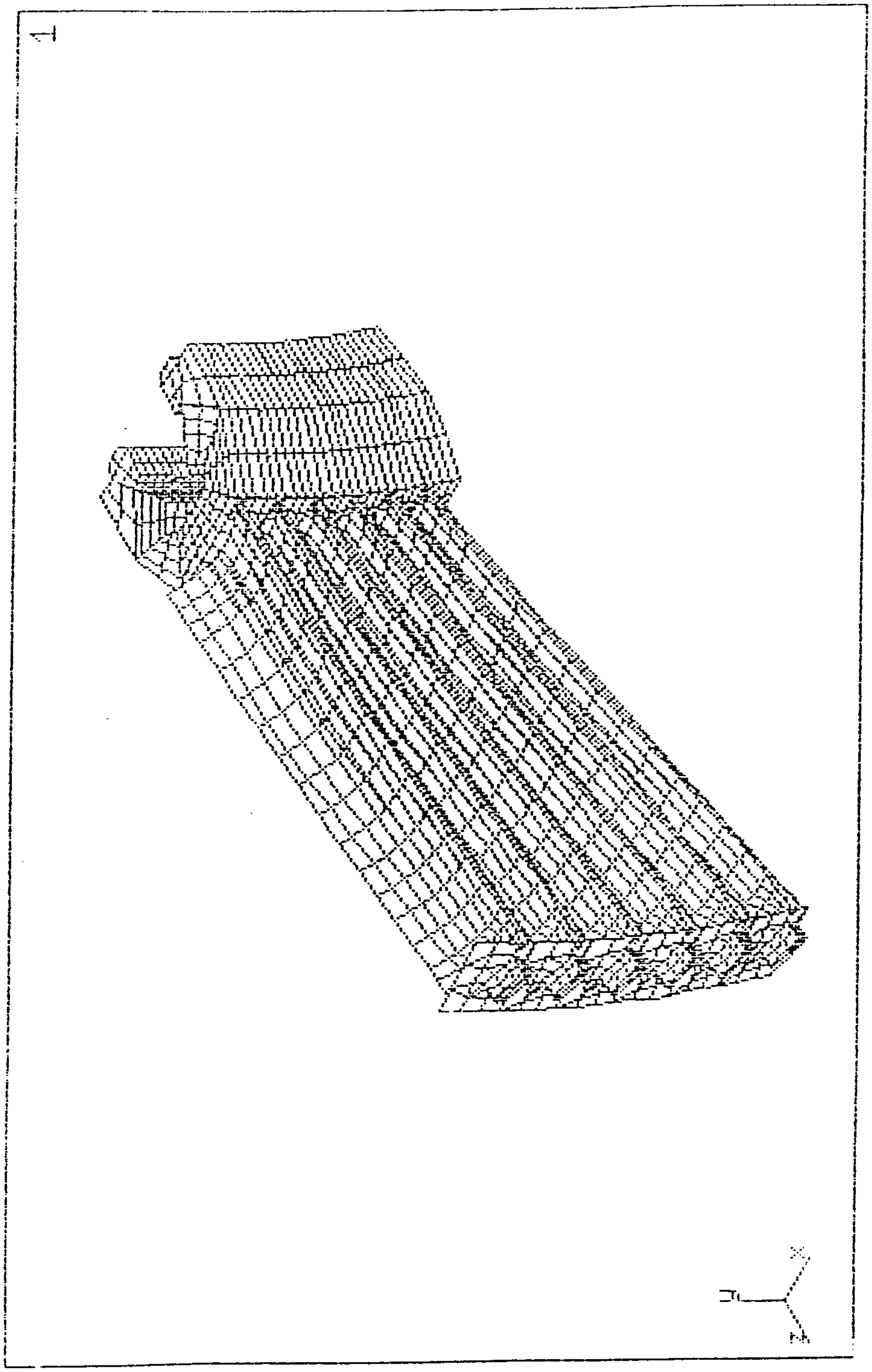

Figure 6 - Finite element analysis model of last stage blading.

existing last stage blading was possible, but could only be verified through operation of the unit.

Turbine Design Work

Once the decision was made to proceed with the construction of the geothermal plant, Encotech became involved with a variety of other additional work. This work consisted of the following:

1. Misc. Plant Layout and Computer Aided Drafting Services
2. Redesign of The Turbine Inlet nozzle
3. Design of a The Turbine-Generator Bedplate
4. Torsion and Lateral Vibration Analysis

Misc. Design And Computer Aided Drafting Services

A variety of miscellaneous design and computer aided drafting services were provided by Encotech to support the installation of the geothermal turbine. These services included creating an extensive set of drawings of the turbine installation and creating a CAD library of the various sizes of stop valves and couplings. In addition, an Encotech technician collected measurements needed to define the foot pattern and coupling locations.

Redesign of The Turbine Inlet Flange

For the modified turbine operating at a lower pressure with increased flow passing capability, the pressure drop at the turbine inlet was expected to increase. To overcome this problem, Encotech designed a 30" inlet flange to replace the original 20" inlet flange. Figure 7 provides a drawing of the inlet flange designed by Encotech. The design process for the new flange included conducting a finite element analysis to determine if stress levels were acceptable where the inlet flange attached to the turbine casing.

Design of a Turbine Bedplate

Encotech was requested to design a bedplate for the turbine-generator. Encotech's client has developed a skid-mounted concept to be used with the marine turbines. With this concept, the turbines are

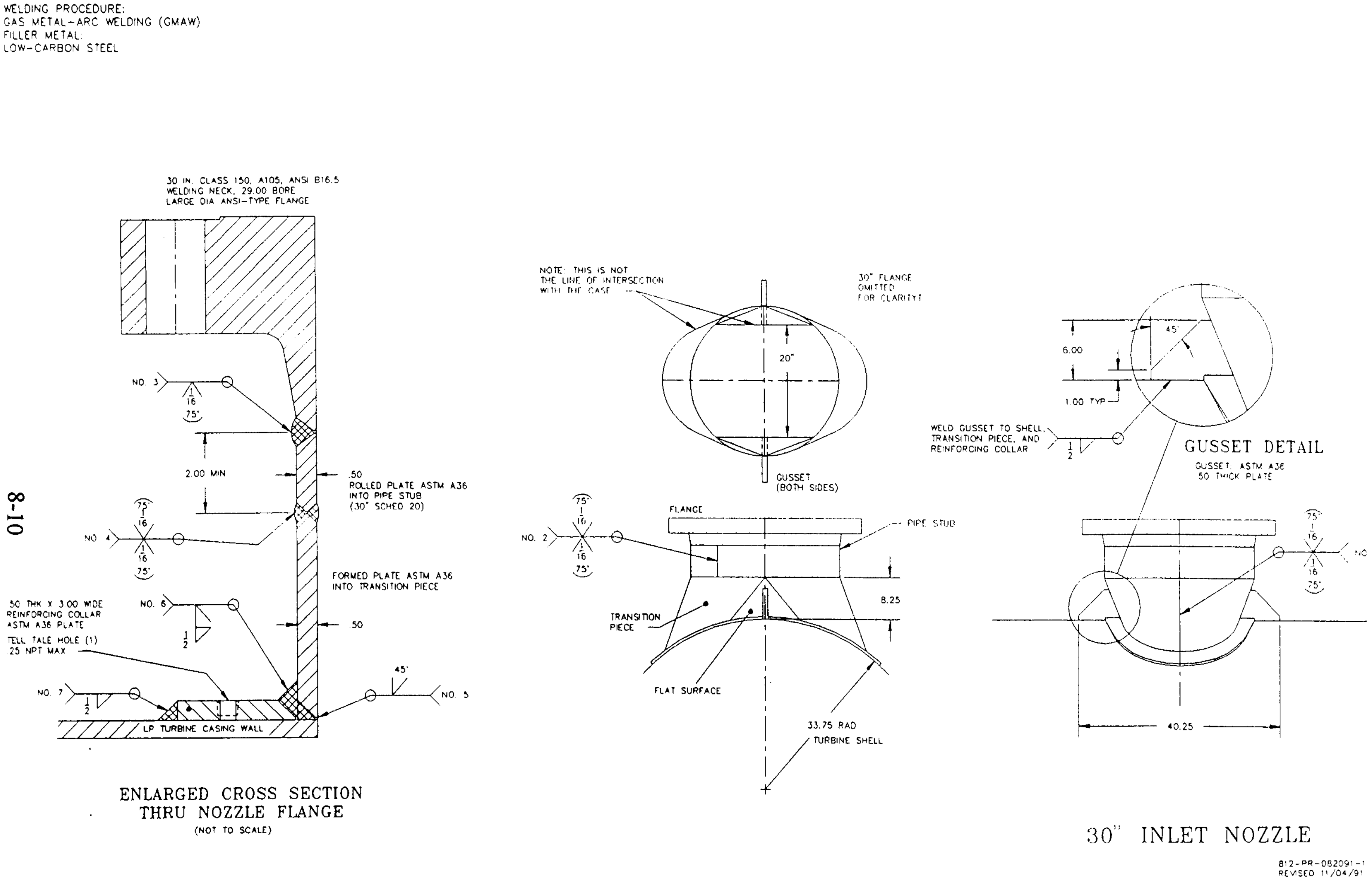

Figure 7 - Redesigned turbine inlet flange.

mounted on a standard bed-plate. This bed-plate contains the turbine, the reduction gear, the generator, the steam inlet piping, the switchgear, and controls. Figure 8 provides a drawing of the Encotech designed turbine bedplate.

After the gear box and generator had been selected, the entire train was laid out in a plan and elevation view on a personal computer using AUTOCAD. The approximately forty foot long bedplate was designed in three sections for transportability: turbine, gear, and generator. During manufacture, the bedplate sections were bolted and pinned for a strong tight fit. The mounting pads were then machined with the bedplate as one assembly for the greatest degree of accuracy. The three sections were then unbolted for easy transportation.

Torsional and Lateral Analysis

A complete torsional and lateral vibration analysis was required to confirm that the operating speed has a sufficient margin from the critical speed. Torsional and lateral vibration analysis is also useful in determining possible sources of vibration excitation.

The primary concern involved with lateral and torsional vibration analysis was whether a natural frequency occurs close to a lateral or torsional excitation frequency that may be present during operation of the turbine-gear-generator. If such a condition existed, resonance may occur, which can produce high amplitudes of vibration, often with serious consequences.

An example of the torsional and lateral analysis that Encotech conducted was on the steam turbine rotor modified for a geothermal application. The original rotor was to be modified as follows:

1. remove the reversing stages,
2. remove the reversing baffle,
3. reposition the balance slot, and
4. remove stages 1 and 2.

Physical dimensions of the original rotor were obtained by measurements and vendor drawings. The

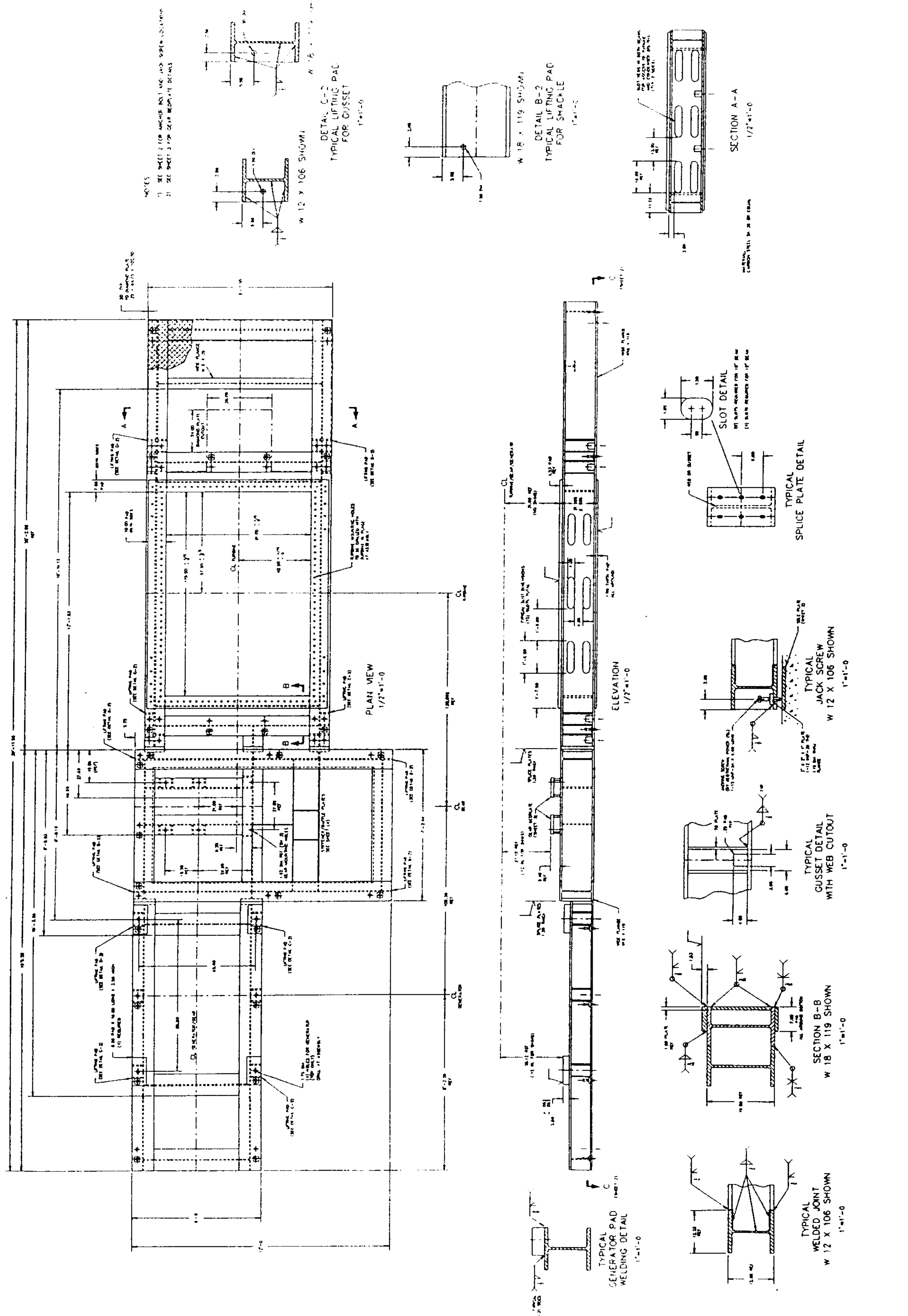

Figure 8 - Turbine/generator bedplate.

physical dimensions were then used to calculate an estimated bearing stiffness and load. A lumped-mass model was used to calculate the following:

1. lateral and torsional critical speeds (synchronous and asynchronous),
2. lateral and torsional mode shapes
3. dynamic forces on bearings at normal speeds
4. imbalance response at 90%, 100%, and 120% of normal speed

It was concluded that no natural frequencies were identified near known sources of excitation (multiples of run speed, blade passing frequency, gear-mesh frequency, synchronizing the generator out of phase, and a three-phase short) for each of the steam turbine modifications investigated.

Another example of the application of a torsional and lateral vibration analysis was in the optimization of the selection of the high and low speed couplings. Several cases were investigated to determine the appropriate coupling stiffness.

Other Encotech Redesign Projects

The evaluation of the LP marine turbine used for geothermal power generation illustrates Encotech's turbine redesign capabilities. Encotech has recently been involved in several other redesign projects. Some examples of these projects include:

1. the application of marine HP turbines for industrial/cogeneration projects,
2. the evaluation of a used reaction LP turbine in a foreign geothermal project
3. an evaluation of the impact of removing and injecting steam into an existing utility fossil cycle turbine, and
4. evaluating the addition of tip spill strips to an existing turbine.

Application of Marine HP Turbines for an Industrial/Cogeneration Project

Encotech provided assistance in evaluating the use of HP marine turbines in Industrial/Cogeneration type settings. In one case, Encotech was requested to evaluate the possible use of a marine HP turbine at a foreign sugar mill.

Evaluating the HP marine turbine was made difficult by its unique arrangement. Figure 9 provides a cross-sectional diagram. The turbine features a single Curtis control stage followed by eleven stages of

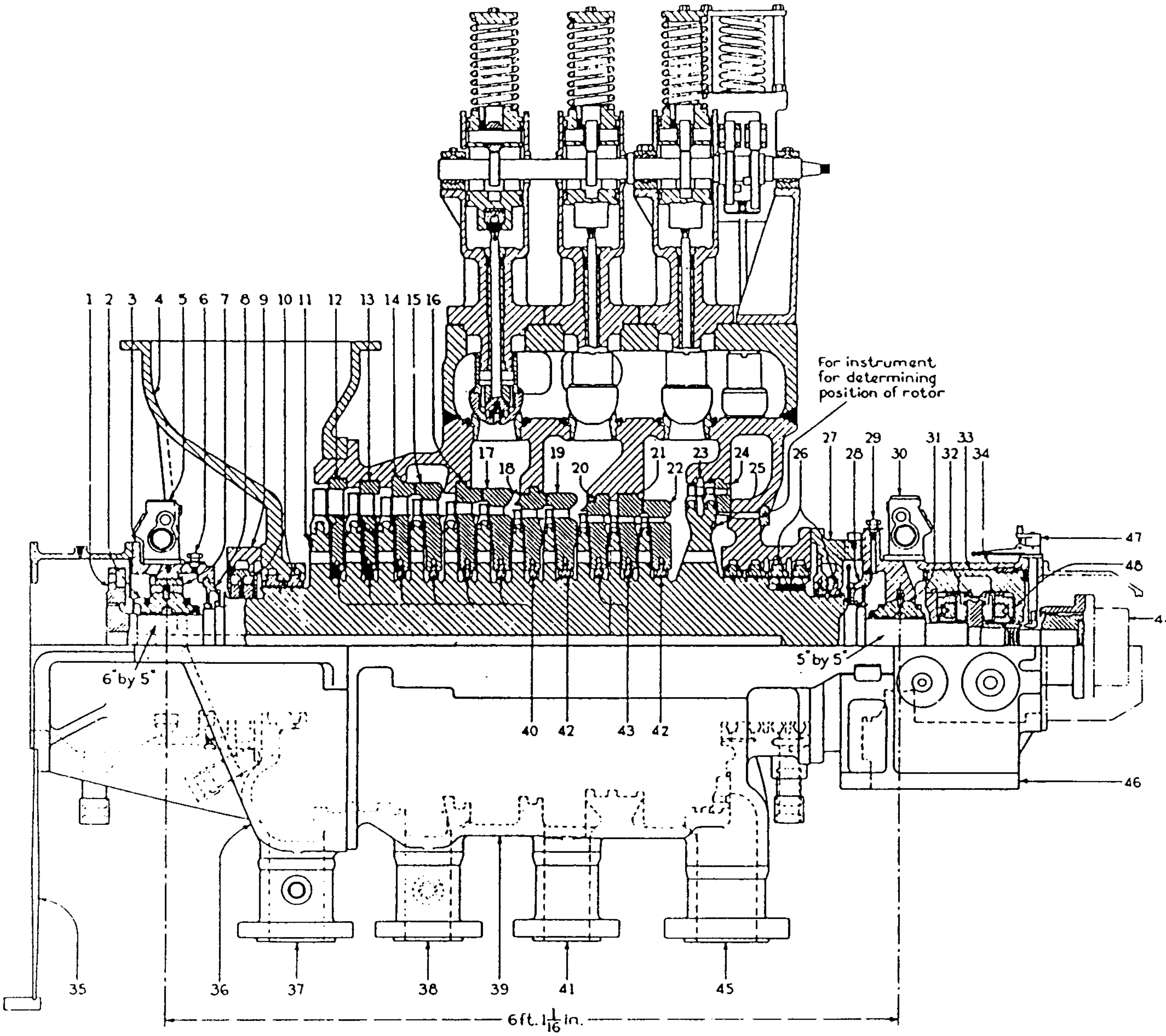

Figure 9 - Marine HP turbine cross-sectional drawing.

impulse blading. The turbine has five control valves, two at the inlet ahead of the Curtis stage and three located after the Curtis stage. The purpose of the three valves located downstream of the inlet are for emergency high speed operation of a ship during combat. By admitting steam downstream of the first stage, the flow passing capacity is increased, thus resulting in a higher power output.

For the sugar mill application, the initial inlet and exhaust conditions were different than the original marine design. STRE was used to select the best operating speed for the range of given conditions. Once an operating speed was selected, STRE was used to estimate the efficiency and output of the modified turbine. Figure 10 shows an efficiency versus throttle flow curve generated using information from STRE. Figure 11 shows the generator output versus flow curve generated using information from STRE. The curves shown in Figure 10 and 11 include only the first three valves opening.

Evaluation of A Used Reaction Turbine In A Foreign Geothermal Project

Encotech reviewed the analysis conducted by a foreign customer who had purchased a used 60 MW Parsons low pressure reaction turbine. This customer intended to use the turbine in a geothermal application. Based on studies conducted by the customer, it had been decided that the last three stages would be removed to meet the application requirements.

Encotech's review consisted of verifying the predicted performance of the turbine and conducting a stress analysis of the turbine blading. The stress analysis was conducted by Encotech in-house personnel assisted by an Encotech consultant. The performance analysis conducted using Encotech's STRE program.

The stress analysis conducted by Encotech indicated that it was safe to operate the turbine in its current mechanical condition at the proposed thermal conditions. However, Encotech raised concerns in regards to its performance in the presence of wet, corrosive geothermal steam. This concern resulted from the turbines' relatively slender blades and shrunk on wheel and shaft rotor construction.

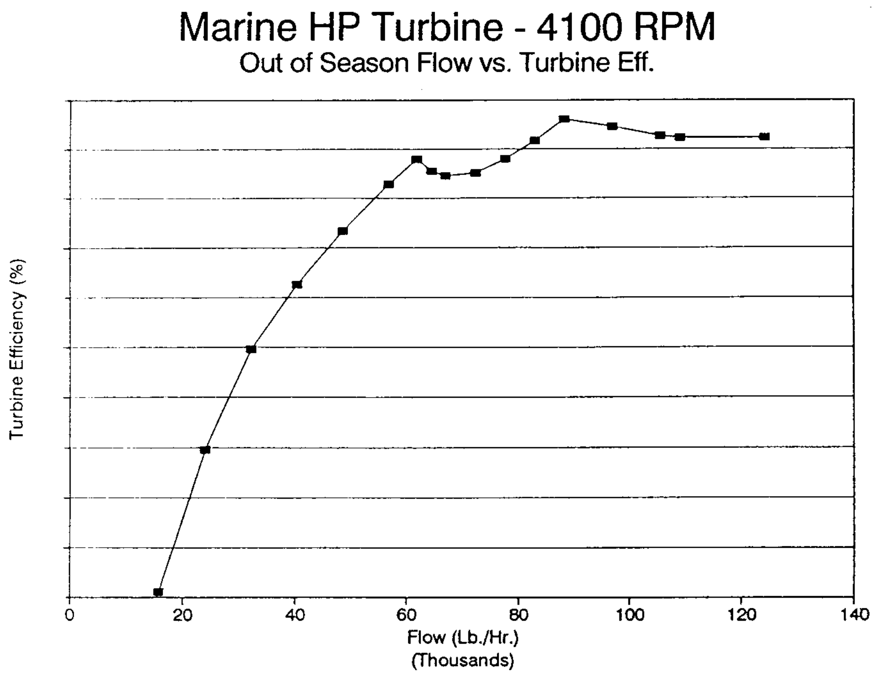

Figure 10 - Predicted efficiency versus flow for marine HP turbine.

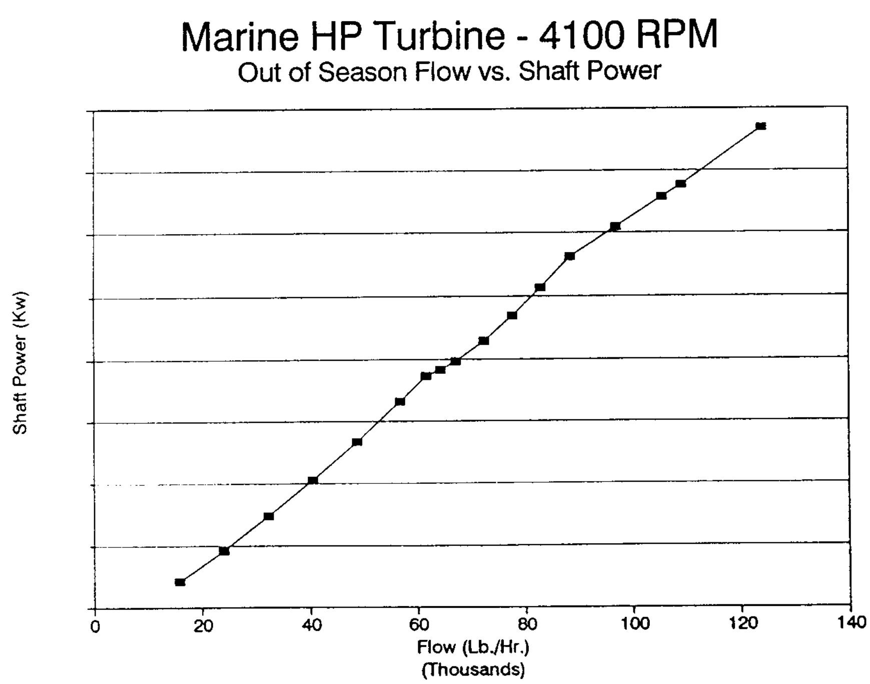

Figure 11 - Predicted shaft output versus flow for marine HP turbine.

Evaluation of Injecting Steam Into An Existing Fossil Cycle

Encotech is currently evaluating the impact of injecting additional steam into an existing fossil application. This ongoing evaluation consists of determining the best location for injecting steam and determining the overall impact on cycle performance.

To conduct this evaluation, Encotech is currently using STRE in conjunction with a heat balance program. The increase in pressure, changes in stage efficiency, and flow passing capacity are being predicted using STRE. Given the STRE predictions, the results are input into the heat balance software. The heat balance software is in turn used to predict the impact of the changes in turbine performance on the entire cycle. Future possible work on this project includes using the STRE pressure distribution in conjunction with the blading geometry to conduct a stress analysis. This work will proceed based on the results of an economic analysis to be conducted by the customer.

Evaluation of Adding Spill Strips to an Existing Turbine

Encotech is currently conducting an evaluation to determine the impact of modifying an existing turbine to determine the expected increase in turbine efficiency associated with adding tip spill strips. This evaluation is being conducted using Encotech's STPE and STRE software. Encotech's STRE software was initially used to establish the flow and stage-by-stage pressure and enthalpy distribution through the turbine. The turbine geometry and conditions determined using STRE were then input into STPE. STPE was then used to determine the expected improvement in generator output associated with adding spill strips.

Conclusion

To successfully use an existing turbine in an off-design application a detailed evaluation is required. This evaluation should include an analysis to determine how the turbine will perform under the new conditions and what potential modifications can be made. In addition, the mechanical condition of the turbine should be evaluated to determine if the turbine can be operated safely in the new application. Encotech offers an extensive line of software that can be used to evaluate the performance of the turbine. In addition, Encotech has both the in-house tools and experience to evaluate the mechanical condition of the turbines.