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HELICAL ROTARY SCREW EXPANDER POWER SYSTEM

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A technical survey made by the Jet Propulsion Laboratory (JPL) led to the conclusion that an energy converter well suited to wet steam geothermal fields could be a major stimulant to the development of these energy resources. The helical rotary screw expander, developed by the Hydrothermal Power Co., Ltd. (HPC), is a very promising candidate to fill this need. JPL has proposed to evaluate and characterize the screw expander in conjunction with HPC. The work will use commercial-size equipment operating on low saline and then hypersaline brine with members of the geothermal industry participating. The helical screw expander is a positive displacement machine of the Lysholm type which can accept the untreated corrosive mineralized hot water of any quality from a geothermal well. The subjects of corrosion, mineral deposition, the expansion process, the experience to date with a prototype and the proposed evaluation project are discussed.

I. INTRODUCTION

In all the world, there are only 12 locations where electrical power is presently generated from geothermal energy, providing a total installed capacity of about 1100 MW (Refs. 1-4).* In these locations energy is available from the ground as geothermal fluid, either in the form of steam (vapor-dominated fields) or in the form of hot brine (liquid-dominated fields). In all cases, energy is converted to electrical power by means of a vapor turbine as the prime mover. In the vapor-dominated fields (four locations), the procedure is essentially simple. Dry steam from the producing wells is

*For comparison: As of 1970, the world's largest high-pressure steam-driven turbogenerator was the 1150-MW unit at the TVA power plant at Paradise, Ky. Two nuclear plant additions now under construction at San Onofre, California will be 1140 MW each.

cleaned of entrained solids, and then passed directly to turbines which drive electrical generators. In the case of the liquid-dominated fields, the brine is either flashed to liberate steam, which is then separated from the residual brine and sent to the turbogenerators (seven locations), or it is used to boil a secondary fluid (one location) which in turn is sent to turbogenerators.

At present, the four vapor-dominated fields noted above have a combined, installed electrical capacity of 806 MW or 73% of the worldwide geothermal total. The largest of these is at The Geysers in California, where Pacific Gas and Electric Co. (PG&E) is systematically adding 100 MW capacity per year on a schedule that extends through 1980. These additions represent 10% of the annual increases planned by PG&E from all sources (Ref. 3). There are no reported technical problems sufficient to hamper this schedule. The schedule is planned to allow the orderly development and exploitation of the geothermal reserve, and is possible because the steam turbine is an ideal match for vapor-dominated fields. Technological problems which are encountered there, such as turbine blade erosion and corrosion, are handled in the normal course of doing business.

Unfortunately, vapor-dominated geothermal fields are scarce. This helps to explain why The Geysers is the only such geothermal power plant location in the Western Hemisphere. Far more prevalent, by an estimated ratio of 20 to 1, are the liquid-dominated fields which produce hot water or brine. It thus follows that, all other things being equal, if there are four steam fields producing electricity, there should be 80 wet fields similarly in production instead of the mere 8 mentioned above. But all other things are not equal. The ideal match of a prime mover compatible with a liquid well effluent has been historically absent, and so the exploitation of the wet fields has been seriously hampered. It has been necessary to produce a vapor to drive a turbine, either by flashing part of the brine to steam, or by boiling a secondary fluid in a heat exchanger. In the steam-flashing process, much energy is lost in the waste hot brine which flows from the steam separators, and the throttling step itself is inherently inefficient. Similarly, in the process involving a secondary fluid, substantial energy losses are associated with the temperature difference necessary to drive the heat exchanger and with the power demands for pumping the secondary fluid. (It may be noted that the world's pioneer geothermal power plant at the vapor-dominated field in Larderello, Italy, switched from the use of heat exchangers to the direct expansion of the geothermal fluid because of these inefficiencies (Ref. 1).)

In addition, supplementary process equipment, especially heat exchangers, is expensive. Moreover, and perhaps most serious, scale formation from the brine can be severe. It must be recognized that the hot brine has been in contact with minerals for a long time and will be in near equilibrium at reservoir temperatures. Therefore, as the brine is cooled, part of the dissolved solids will precipitate, especially on cool surfaces. This explains some of the failures that have been experienced in attempts to harness the energy available in the geothermal fields in the Imperial Valley of California, where much of the U.S. field effort in geothermal development is centered. Fortunately, despite the presence of dissolved salts, the fluids are usually chemically reducing, and severe corrosion rates can be avoided by the exclusion of air and by proper selection of materials of construction.

The exploration for geothermal energy is moving forward, with numerous examples of success. For example, the well known reserve in Imperial Valley has been estimated as sufficient to support the generation of 100,000 MW for 50 years of electricity (Ref. 5). The significance of this can be inferred from the rate of consumption of electricity in California, which was about 35,000 MW in 1973 (Ref. 6) (U.S. total: 300,000 MW (Ref. 7)). Other known U.S. reserves lie explored but dormant in the Mono-Long Valley area of California, in Beowawe, Nevada, and in Sandoval County, New Mexico, among others. These reserves are all liquid-dominated fields.

The NSF report Geothermal Energy (Grant GI-34313) anticipated the production of 395,000 MW from U.S. geothermal resources by the year 2000. However, this goal is attainable only with developments not yet achieved (Ref. 8). If the resources were largely vapor-dominated, the orderly development of the geothermal power industry would be assured. But it is the liquid-dominated fields which is prevalent, and the outlook for the geothermal industry is not clear. There is an acute need for a prime mover which can operate directly on the hot brine. Such a prime mover would almost certainly be the key to unlocking much of the treasure of geothermal energy in the U.S. and in other liquid-dominated fields all over the world.

II. HELICAL ROTARY SCREW EXPANDER

A 62.5-kVA prototype geothermal power plant utilizing a new helical rotary screw expander has been developed by Hydrothermal Power Co., Ltd. (HPC). The prototype plant has been tested and demonstrated by HPC for extended periods of time as a total flow wellhead system operating on hot untreated brine or brine and steam mixtures.

The helical rotary screw expander is a machine based upon development work conducted by Alf Lysholm in Sweden in the 1930's. By the 1950's Lysholm's machinery began to see extensive commercial application as a gas compressor. This application has had continued growth to the present date with installations involving 100 MW currently in operation. Early in 1971, HPC began development work in applying the Lysholm machine as a prime mover operating on geothermal hot water and brine. This development work has continued to the present.

The screw expander is a unique positive displacement machine, which bridges the gap between centrifugal or axial flow type aerodynamic machines and reciprocating positive displacement machines. It runs in a slower speed range without the high radial loads and balance problems characteristic of turbines.

As a geothermal prime mover, the helical screw expander is a total flow machine, which can expand directly the vapor that is continuously being produced from the hot saturated liquid as it decreases in pressure during its passage through the expander. The effect is that of an infinite series of stages of steam flashers, all within the prime mover. Thus, the mass flow of vapor increases continuously as the pressure drops throughout the expansion process, and the total fluid is carried all the way to the lowest expansion pressure. The process approximates an isentropic expansion from the saturated liquid line for the total flow. The expansion within the machine can be illustrated with drawings such as Fig. 1. The geothermal fluid flows through the internal nozzle control valve and at high velocity enters the high-pressure pocket formed by the meshed rotors, the rotor case bore surfaces, and the case end face, designated by A in the two figures. As the rotors turn, the pocket elongates, splits into a V, and moves away from the inlet port to form the region designated by B. With continued rotation, the V lengthens, expanding successively to C, D, and E as the point of meshing of the screws appears to retreat axially from the expanding fluid. The expanded fluid at low pressure is then discharged into the exhaust port.

III. SCALE FORMATION, CORROSION, AND EROSION

Conditions for mineral precipitation from saturated brines within the expander occur for several interrelated reasons, including temperature decrease, pressure decrease, solvent removal, turbulence, and the presence of nucleation sites. The internal surfaces of the expander serve as mineral deposition sites. Mineral deposition on these surfaces provides several beneficial results. The thickness of the mineral layer increases until the rotor-to-rotor and rotor-to-case leakage clearances disappear and the mineralized surfaces are continually lapped; steady state is reached. The loss of leakage clearances results in substantial increase in the efficiency of the expander. This clearance removal mechanism will make possible the use of less expensive fabrication and machining procedures during manufacture, and also makes the expander self-healing in the event that scarring of the case or rotors should occur. Moreover, the mineral layer has been demonstrated to provide excellent protection of the case and rotors against corrosion. This protection will provide greater flexibility in the selection of relatively low-cost materials of construction. Similarly, there has been no evidence of erosion, either because the scale layer forms a protective coating or because the fluid velocities within the machine are not high, or both. The effects of much higher velocities by nozzling at the inlet are still to be determined for the high-pressure fields.

The lapping process associated with the minerals which are deposited on the machine surfaces within the expander is a source of suspended nuclei for additional mineral deposition and crystallization within the brine. These nuclei supplement those which form spontaneously throughout the brine in the flashing turbulent conditions within the expander. In an experimental investigation of mineral deposition carried out in October 1971, while operating a helical screw expander on Well M-10 at Cerro Prieto, HPC observed that mineral deposition occurred either almost exclusively within the expander or on the seed particles traveling with the exhaust brine. After 307 hours of operation, the deposits ranged from 5/32 in. at the expander exhaust port to 1/64 in. 50 feet downstream. In the absence of the expander, the same well and feedline plugged shut a 12-in. diameter exhaust pipe in 72 to 96 hours. An expander with an insufficient expansion ratio was used in this investigation, and some flashing occurred in the exhaust port. The present prototype expander features a larger expansion ratio so that very little flashing has occurred in its exhaust port; no scale deposit problem has been detected during over 1000 hours of testing. This characteristic of mineral precipitation occurring preferentially within the expander, either on the expander surfaces which are self-cleaning or harmlessly in suspension, is highly beneficial. The tendency to deposit scale downstream appears to be negligible, at least along an isothermal path. This is important for inter-staging as well as in waste lines.

IV. EXPANDER ENGINE EFFICIENCY

Performance tests of the 62.5-kVA prototype HPC geothermal power plant were performed August 21, 1974, on brine from Well 6-1 at the U.S. Bureau of Reclamation geothermal test facility on the East Mesa KGRA. The two tests gave results of 65 and 74% for the expander efficiency compared with an ideal machine. The test results should be considered preliminary since no attempt was made to optimize the operating conditions or the test set-up. (A report of the details of the tests is in preparation.)

Industrially, the helical rotary positive displacement machine is widely used to compress air, nitrogen, hydrocarbons, and a variety of refrigerants. As expanders, these machines are used as prime movers, accessory power drives, and for temperature reduction in gas cycle refrigeration systems. They have been demonstrated to have overall adiabatic efficiencies typically well in excess of 70% over a wide operating range and as high as 85%.

An essential to high engine efficiency is small leakage past the rotors. This requires small clearances, both rotor-to-rotor and rotor-to-case. The minute clearances brought about the wet lapping of the mineral deposits in the geothermal expander may lead to the maximum efficiencies in this new unique application.

V. SYSTEM EFFICIENCY

Three energy conversion concepts -- the Flashed Steam System, the Binary Cycle System, and the Total Flow System -- are present contenders for producing electricity from hot-water geothermal resources. In the Total Flow System, as represented by the Helical Rotary Screw Expander Power System, the hot wellhead product follows on isentropic expansion directly from the wellhead through a two-phase expander to the exhaust pressure and temperature. This system is thermodynamically the simplest and is theoretically optimum. In several excellent papers (Refs. 9-11), it has been estimated that the Total Flow System offers a 60% efficiency gain over the other two, assuming that all systems have a 70% engine efficiency. The engine efficiencies of greater than 70%, which seem assured for the helical rotary screw expander, will give the Screw Expander System an added advantage. Moreover, the estimated 60% efficiency gain is conservative, resulting from optimistic assumptions including, for example, achieving 70% of the Carnot efficiency for the secondary loop of the Binary Cycle System, and perfect steam separation in the Flashed Steam System. Actual field experience to date indicates an efficiency advantage of considerably greater than 60% for the Helical Rotary Screw Expander Power System operating on high enthalpy brines.

VI. PROPOSED EVALUATION PROJECT

A project plan has been prepared by the Jet Propulsion Laboratory for the evaluation of the Helical Rotary Screw Expander Geothermal Power System jointly by JPL and HPC. This plan has been submitted to the Division of Advanced Energy Research and Technology of the National Science Foundation for consideration in the NSF/RANN FY 1975 geothermal program.

Initially, a modular 1250-kVA geothermal power plant incorporating an HPC Lysholm-type helical rotary screw expander as the prime mover will be constructed and then operated on total flow brine to evaluate its mechanical and thermodynamic performance. In the initial work the prime mover will be single stage, expanding to atmospheric pressure or above. Studies of its interactions with the well and an electrical grid system are planned as well as an assessment of brine scale formation, corrosion, erosion, vibration, endurance, and other mechanical problems. The work will lead to design and cost studies of a broad range of applications followed by the testing and evaluation of a completely automated versatile pilot mini-plant of 5 to 7 MW for wellhead siting in liquid-dominated fields.

Hydrothermal Power Co., Ltd. will build the 1250-kVA power system model. The ensuing research will be carried out by the Jet Propulsion Laboratory and the Hydrothermal Power Co., Ltd., first using low-saline high-enthalpy brine from an area to be selected as part of the project, and subsequently utilizing hypersaline brine in the Imperial Valley, California. It is anticipated that the brine-producing agencies or site operators will participate in the research at no cost to the project. The possibility of additional mutually beneficial research activities to be carried out jointly with other organizations as part of the project on a similar basis will be explored early in the project.

The overall project is planned in five phases to be managed by JPL in approximately the following sequence as shown in Fig. 2: (1) project presentation, power system module construction, test site selections, and research planning and preparation; (2) power system characterization and evaluation; (3) longevity testing and interaction studies with the producing well and an electrical grid system; (4) applications systems studies; and (5) design, construction, testing, and evaluation of the pilot mini-plant.

The research is expected to provide the performance maps for this new equipment application for the wide range of conditions which might be found in liquid-dominated geothermal fields. It will deal with the questions of performance optimization, expander staging, effects of brine quality and non-condensables, sink pressure and temperature, brine management, waste disposal, noise, equipment size, and costs. It will aim at optimum exploitation of the resource. The concept of the wellhead power plant will be examined in detail.

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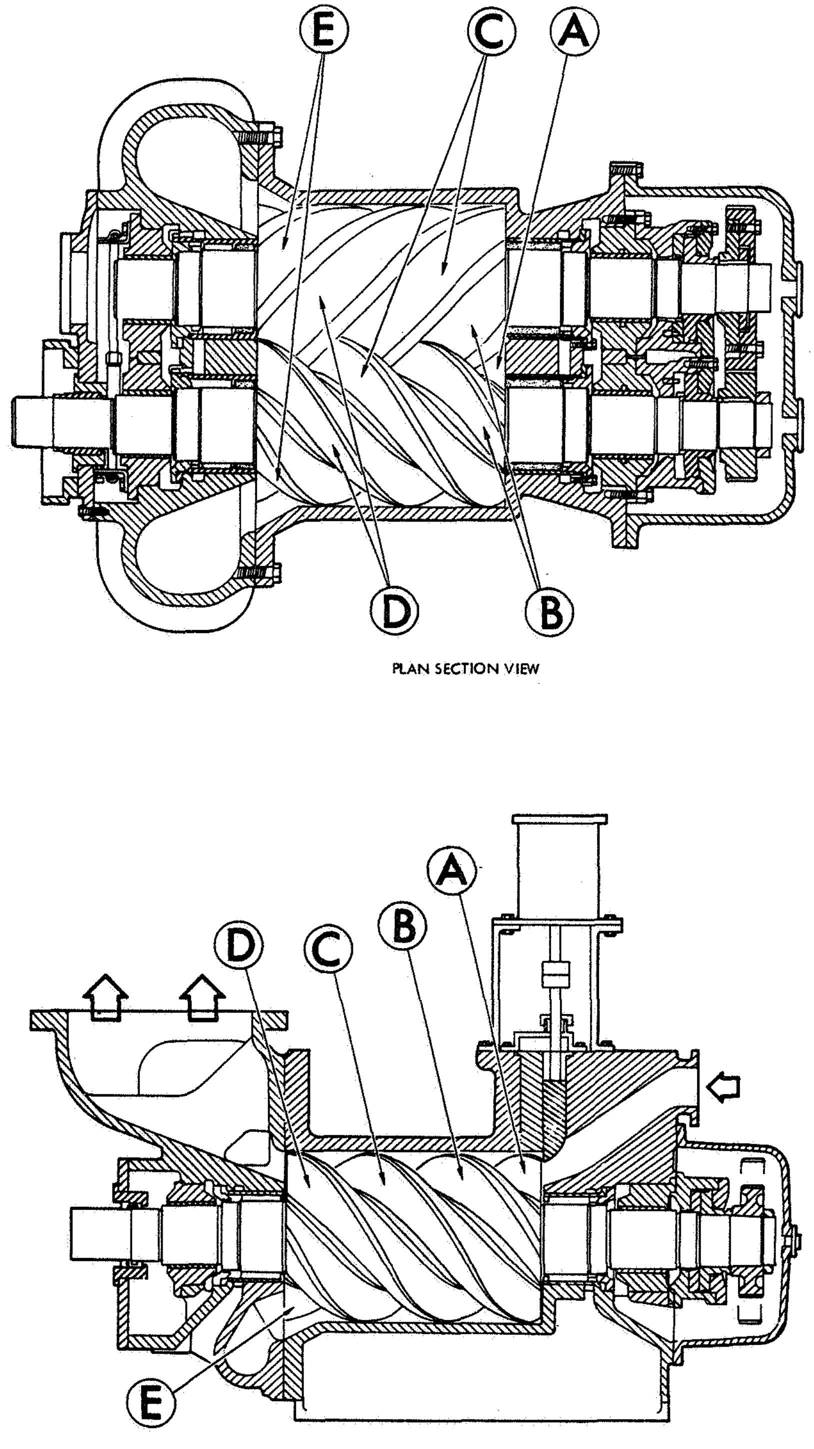

Fig. 1. Helical rotary screw expander

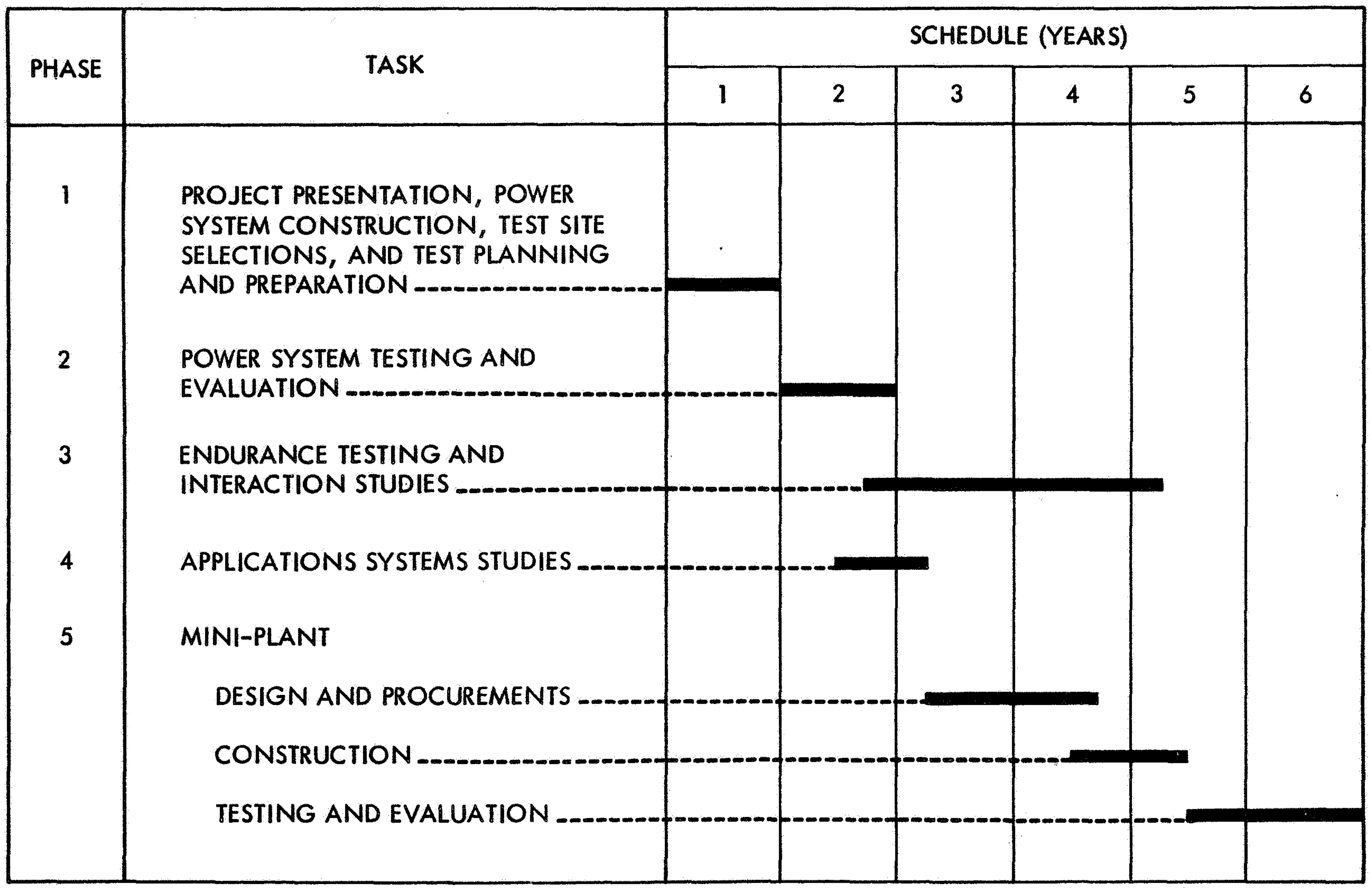

Fig. 2. Total project outline