DOE/ET/27252--T9

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO

1868

SANTA BARBARA • SANTA CRUZ

COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING

BERKELEY, CALIFORNIA 94720

May 7, 1984

Mr. John Crawford
Geothermal Energy Division
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612

DOE/ET/27252--T9

DE84 013599

RE: DOE Contract No. DE-AT03 80 ET 27252
"Hybrid Staging of Geothermal Energy Conversion Process"

Dear Mr. Crawford:

This letter report is submitted, in lieu of a final technical report, for the contract period June 1, 1980 through May 31, 1982.

The original and accepted proposal was for thirty months for $151,769, but only $78,000 was awarded; $55,000 for the first year, from June 1, 1980 through May 31, 1980, and $23,000 for the second year June 1, 1981, through May 31, 1982.

You have on file the progress reports for the contract period, except for the last two months, April and May, 1982. At that time, the project had been out of funds for a number of months, and no progress had been made. Copies of the progress reports are appended.

Eight Master's degree projects were completed during the contract period, and two ASME papers were prepared, which are also appended. Because of the withdrawal of funds, hybrid staging was not accomplished, except in a most rudimentary form.

THE PROJECT OBJECTIVE

The primary purpose of this research was to demonstrate the feasibilty or infeasibility of hybrid staging in geothermal energy conversion, particularly processes involving the Lysholm engine. The Lysholm engine had already demonstrated a capability of utilizing two-phase flow, but with some performance limitations regarding inlet and exhaust pressures, speed, etc. A secondary purpose was to determine and understand the performance limitations of the Lysholm engine.

DISCLAIMER

Staging increases the system performance of the thermodynamic processes of energy conversion. In the conversion of geothermal energy, staging can be particularly critical, since many geothermal resources exist as a mixture of liquid and vapor, with the vapor fraction considerably less than 40%. This means that much available energy is lost in the process of flashing and separating usable steam from hot water. The hybrid staging of energy conversion machines is one means of obtaining the advantages of staging while minimizing the disadvantages of flashing. Our demonstration project was to show the power generating capabilities of a two-stage, single flash hybrid system, with a Lysholm engine as the first stage, and a separator and conventional turbine as the second stage, and using two-phase water and steam as a source.

With hybrid staging consisting of the Lysholm engine and a conventional turbine, the specific power, which is the power produced per unit of mass flow, kW.hr/lb, should be nearly 10% higher than a comparable two-stage, double flash system, and with fewer pieces of equipment.

TEST PROGRAM

In order to test the concept of hybrid staging experimentally the University of California, Berkeley, borrowed the Lysholm engine which had been tested at the Lawrence Livermore National Laboratory. This particular engine is a modified 5.12 inch diameter rotor Gardner-Denver SC-71 air engine, itself an experimental adaptation of their commercial line of Lysholm air compressors. The geometric volume expansion ratio was 1:5.3, determined by the inlet port contour. The nominal rating of the engine is 25 kW. This engine had been tested at Livermore several hundred times, and operation was routine. We tested it at nearly seven hundred more points.

Two Westinghouse type E impulse turbines were in place as the second or lower stage of the system. These turbines originally had four, or six nozzles, a partial admission Curtis wheel design, and operate with a nominal blade velocity of 320 feet per second. Eight additional nozzles were added to one of the turbines, and five more have since been added to a second, to provide the necessary flow area for condensing mode operation. These turbines are not optimal for this application, but they do provide the representative characteristics needed for system evaluation. The relatively low blade velocity lessen the anxieties in a system where large quantities of water may accidentally introduced, but do not yield maximum efficiencies.

The thermal resource for the system is the campus heating system, steam at a pressure of 875 kPa (125 psia). The steam is also used in a seven pass shell and tube heat exchanger to heat the water phase supply to the saturation temperature of 174°C (345°F). Mixing of the saturated steam and water is regulated by closed loop PI flow control systems, one in each phase. This system provides closely controlled inlet conditions ranging from 450 Btu/lb. to 1180 Btu/lb, or vapor qualities from 20% to 100%.

The mix of hot water and campus steam simulates a geothermal supply. A New Zealand type separator was installed between the Lysholm and the two Westinghouse turbines to remove as much of the water fraction as possible before the medium enters the impulse turbines. The New Zealand separator design was selected because of its known performance in geothermal environments. This type of separator uses centrifuging action to separate steam and water phases. The separator was operated with a minimum water level and inlet steam velocities were kept below 60 m/s (200 ft/s) to minimize water reentrainment problems. The separator is operated at a minimal superatmospheric pressure to avoid the need of a pump for the water phase, which is discharged at this point. This separator consistently provided steam to the turbines at qualities greater than 98%, over the range of operating conditions.

Turbine exhaust is piped to a shell and tube condenser. A steam driven air ejector, with closed loop PI control, provides accurate subatmospheric turbine exhaust pressures. A controlled condensate pump raises the condensate to atmospheric pressure for discharge. Real time system data was obtained with a microprocessor based multichannel datalogger. System control and data output were all via remote central console, to demonstrate unattended operation.

Exhaust pressures were limited by choking of the flow in the exhaust piping. The minimum exhaust pressure varied with mass flow rate, and thus with engine speed and inlet quality. The capacity of the conensate pump was the ultimate limit on the flow rate. Engine testing at high speeds and low vapor quality was made difficult by flooding of the condenser. The maximum flow rate was 1 kg/s (2.2 lbm/sec).

PROJECT RESULTS

A number of results and conclusions were established in the brief life of this research project.

1. The Lysholm engine was established as a rugged, reliable, easily controlled and safe energy conversion machine.

2. The performance characteristics of the engine were established. Engine efficiency does depend on exhaust pressure and pressure ratio, but is much less dependent on rotor speed.

3. The capability of the Lysholm engine within a hybrid system remains to be demonstrated.

The Lysholm engine showed great promise in these tests. As a rotary positive displacement machine, there should be no difficulty in running at any quality, and there was none. The engine showed that it could work very well under geothermal conditions, and the design is such that it should be resistant to corrosion and scaling. With its short response time, it proved to be a very flexible and controllable machine.

One of the most dramatic tests is to compare two phase and single phase performance by simply turning off the hot water, simulating single flash operation. The power drops by 50% or more. This demonstrates the power developed by the flashing of the hot water moving across the rotors.

In general, engine efficiency increased as quality decreased. This was attributed to decreasing leakage rates at lower qualities. The maximum observed efficiency was 43.3% at a quality of 0.24, an inlet pressure of 113 psia, a speed of 8400 rpm and pressure ratio of 6. The best evaluation of performance data is given in the project report of Karl Brown or the 1983 IECEC paper.

Sincerely,

R.F. Steidel, Jr.
Professor of Mechanical Engineering

RFS:pb
RFS16-16.1

PROJECT REPORTS

1. ANALYSIS AND TESTING THE PERFORMANCE OF A CENTRIFUGAL TWO PHASE FLOW SEPARATOR, Alexander Vicson Mirza-Moghadam
2. DESIGN, CONSTRUCTION AND EVALUATION OF A SIMULATED GEOTHERMAL FLOW SYSTEM, James C. Mackanic
3. PERFORMANCE CHARACTERISTICS OF THE LYSHOLM ENGINE, Ralph Edward Berger
4. OPEN LOOP PNEUMATIC CONTROL OF A LYSHOLM ENGINE OR TURBINE EXHAUST PRESSURE, Barbara A. Plonski
5. EMPIRICAL MODELING OF A LYSHOLM HELICAL SCREW EXPANDER, Karl A. Brown
6. ON THE HYBRID STAGING OF A LYSHOLM POSITIVE DISPLACEMENT ENGINE WITH TWO WESTINGHOUSE TWO STAGE IMPULSE CURTIS TURBINES, Donald Alan Parker
7. ALTERING THE VOLUMETRIC EXPANSION RATIO OF A LYSHOLM HELICAL SCREW EXPANDER, Michael K. Dunbar
8. A COMPARISON BETWEEN TWO LYSHOLM ENGINES, Bernardo A. Frau

TECHNICAL PAPERS

"Performance Characteristics of the Lysholm Engine as Tested for Geothermal Power Applications" with D. Pankow and R. Berger, *Proceedings*, 16th Intersociety Engery Conversion Engineering Conference, August 1981, pp. 1334-1340.

"The Empirical Modeling of a Lysholm Screw Expander" with D. Pankow and Karl A. Brown, *Proceedings* 16th Intersociety of Energy Conversion Engineering Conference, August 1983, pp. 286-293.