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PERFORMANCE TESTS OF THE RADIAL OUTFLOW REACTION TURBINE FOR GEOTHERMAL APPLICATIONS

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PERFORMANCE TESTS OF THE RADIAL OUTFLOW REACTION TURBINE
FOR GEOTHERMAL APPLICATIONS

Abstract

A unique pure reaction turbine, for geothermal applications, has been developed at the Lawrence Livermore Laboratory. This radial outflow reaction turbine (RORT) is designed specifically to produce power from the expansion of saturated or compressed liquid at temperatures of less than 180°C.

In the tests reported here the highest efficiency measured was 32.7%, clearly below the peak efficiency for this small machine. Extrapolations to larger machines indicate that an efficiency near 50% is a credible goal, an attractive performance as either a Total Flow expander for liquid or in conjunction with conventional flashed steam systems. A rough cost estimate indicates that a 7.5 MW RORT would cost somewhere between 0.5 M\$ and 1.5 M\$, and could add about 15% increase in the power output of a conventional 50 MW plant. This means that for less than a 3% increase in capital cost the bus bar energy cost can be reduced by about 10%. Another important result is that the RORT is uniquely suited for conversion of the thermal and pressure energy components in the geopressured resources. The development and proof of feasibility of efficient liquid expanders broadens the opportunities for economic power production from lower temperature geothermal resources, and possibly utilization of waste heat in industrial processes.

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Introduction

The development of unique liquid expanders for conversion of the energy contained in hot fluids has been an important part of the geothermal energy program at the Lawrence Livermore Laboratory (LLL). The basic purpose was to broaden the application of the Total Flow concept to include reliable, low cost conversion systems for lower temperature ($<150^{\circ}\text{C}$) geothermal resources, and development of expanders designed specifically for incorporation into flashed steam systems (for utilization of the higher temperature resources) to improve their overall system efficiency.

This work has led to selection and development of variations of the radial outflow reaction turbine (RORT). A unique two-stage nozzle design allows efficient energy conversion over a very wide range of pressure ratios, and allows a broad range of applications.

The development of the pure reaction turbine is of interest for three basic reasons.

1. It extends the two phase expander technology for application to the low temperature resources for direct expansion of wellhead fluids.
2. When used as part of a double flash system to expand the liquid outlet of the first stage separator, it can improve the overall conversion efficiency for a nominal added cost.
3. It is uniquely suited for conversion of the thermal and pressure energy components in the geopressured resources.

More complete descriptions of the RORT are given in previous reports^{1,2} describing the LLL program and results. This report is intended only to give the recent results of laboratory tests on a small (40 hp) prototype unit.

Expander Design

The experimental turbine incorporates a 16" diameter disk with four nozzle sets. Liquid enters the center of the rotating disk through a seal, then flows into radial passageways to the two-stage nozzles (Figure 1). Liquid nozzles reduce pressure to the saturation value and thereby recover work added to the liquid as it moves from the center to the liquid nozzles. The two-phase steam nozzles, integral with the rotating disk, convert a portion of the available thermodynamic energy into shaft power. Figure 2 shows the complete test set-up with one side of the turbine case removed to show the rotor.

Test Conditions

Test conditions are listed in Table 1. Inlet hot water temperatures ranged from 346F to 371F with exhaust pressures from 2.6 to 3.7 psia. Operating speeds ranged from 4062 to 8066 rpm.

Test Results

Efficiency, defined as measured brake power output divided by isentropic expansion power for each set of conditions, is listed in Table 1 and plotted in Figure 3. The highest measured value is 32.7% at 8066 rpm.

Discussion of Results

Engine efficiency was based on the power at the eddy-current brake. Since losses in the power transmission belts, pulleys and jackshaft bearings are not accounted for, the actual engine efficiency is slightly higher than the listed values.

It is clear from Figure 3 however, that the engine efficiency peak had not been reached at 8066 rpm. A characteristic of the RORT is that the mass flowrate increases with rotor speed (Fig. 4), and it is clear that the maximum plant flow capability was reached at the two highest speed runs. The lower performance of the turbine near 7500 rpm (Figure 3) is probably due to leakage past the inlet seal (Figure 4). Performance with leakage is degraded by the fluid lost and also by additional loading on the rotor thrust bearing caused by a pressure buildup on the inlet rotor face due to flashing of the hot fluid.

Conclusions

Other studies^{1,2} have indicated that the pure reaction turbine could probably be developed to obtain a 50% or higher engine efficiency. An engine efficiency of 40% or higher would be very useful for geothermal energy conversion. For example, even with a RORT efficiency of 40% the hybrid system composed of the RORT, a separator and one vapor turbine, will exceed the performance of the conventional two-stage flashed steam system for the expansion of a saturated liquid source. Thus the measured engine efficiency of 33% for the small experimental reaction turbine is very encouraging, especially since this performance does not represent the limit of the present machine.

The basic nature of this design is such that its cost per kilowatt may be considerably lower than a conventional turbine. Previous analyses^{1,2} indicates that a 50% RORT gives about 15% improvement to a conventional double-flash plant operating from a high-temperature fluid. A rough cost estimate for a 7.5 MW RORT is .5M\$ to 1.5M\$; hence, a 15% increase in overall plant output can be achieved for less than a 3% increase in capital cost, based on \$50 Million for a 50 MW plant.

The design concept has been proven with the present experimental pure reaction turbine. This means that the original goal of a 50% engine efficiency for the RORT is credible, and could be achieved if development were to continue on larger, improved designs. The radial outflow reaction turbine, if perfected, would be a significant addition in energy conversion technology for geothermal energy development, and for other applications involving expansion of hot liquids.

References

1. UCRL-50046-76, A. L. Austin et al., "The LLL Geothermal Energy Program Status Report, January 1976 - January 1977", (April 1977).
2. UCRL-52480, P. A. House, "Analysis of a Radial-Outflow Reaction Turbine Concept for Geothermal Application", (May 25, 1978).

FIGURE 1: Nozzle Configuration

Figure 2: Turbine Test Configuration

TABLE 1: Performance Data From Test Runs on 18 July 1978

Point	Inlet Conditions Temp. (°F)	Press. (PSIA)	Flowrate (LB/Sec)	Case Press. (PSIA)	Turbine Speed (RPM)	Brake Power (H.P.)	Brake Eng. Efficiency %
1	345.6	191.5	1.37	2.57	4161	13.36	22.11
2	361.6	200.1	1.33	2.54	4062	14.10	20.75
3	366.3	195.5	1.42	2.64	4489	16.65	22.46
4	367.3	188.2	1.44	2.64	4602	17.07	22.44
5	369.0	196.2	1.53	2.68	4927	19.59	24.02
6	369.7	191.1	1.54	2.77	5046	19.98	24.55
7	369.7	191.7	1.70	2.90	5587	23.74	26.74
8	369.7	195.5	1.71	2.90	5524	23.44	26.36
9	370.4	195.1	1.83	2.99	6022	26.42	27.82
10	370.8	195.8	1.85	3.00	6022	26.35	27.54
11	369.9	193.0	1.98	3.13	6552	29.18	28.99
12	370.0	193.2	1.99	3.16	6586	29.44	29.41
13	370.6	193.2	2.13	3.30	7085	32.34	30.42
14	370.2	194.3	2.14	3.31	7080	32.28	30.19
15	369.3	194.7	2.29	3.44	7549	34.25	30.76
16	369.3	193.2	2.29	3.47	7545	34.15	30.67
17	369.9	192.9	2.30	3.67	8043	36.05	32.59
18	370.6	193.6	2.30	3.67	8066	36.24	32.71

Figure 3 - Engine Efficiency

Figure 4 - Mass Flowrate

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