Axial Turbine for Low-Grade Heat Source: 
Vapor Expansion Turbine Has Been Developed 
for Organic Rankine Cycle Applications That Operate 
in the 500kw to 5mw Range

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Interest in low grade heat recovery has grown over recent years. A number of approaches have been proposed to capture and convert low grade heat energy, traditionally viewed as not commercially useful, into productive electric power. Among the proposed solutions is the use of Organic Rankine Cycle (ORC) technology.

ORC is a vapor power cycle named for its use of an organic, high molecular mass fluid with a liquid-vapor phase change taking place at a lower temperature than the traditional fluid of water-steam. This lower temperature phase change is what allows for the capture and conversion of low grade heat from wasted thermal energy to useable electrical energy.

Aside from the use of an organic compound as the working fluid, it functionally resembles the steam cycle power plant: a pump increases the pressure of condensed liquid; the high pressure liquid is pre-heated via a recuperator exchanger; the liquid is then vaporized by extracting waste heat from the heat source through a heat exchanger; the high-pressure vapor expands in a turbine that drives a generator thus producing power; and the low-pressure vapor leaving the turbine is de-superheated through the recuperator and condensed via a condenser before being sent back to the pump to restart the cycle.

A key component of the cycle is the vapor expansion turbine. The maturity of this turbomachinery, in large measure, defines the commercial viability of an overall ORC solution. Today, small scale positive displacement units in the tens or few hundreds of kW capacity are available to function as the ORC driver. Additionally, oil and gas providers can, with little modification, supply commercially viable turboexpanders suitable for ORC applications at the larger sizes (>5-7MW). However, many of the available heat sources do not line up with this supply and as a result, ORC applications that are in the middle scale of the above ranges have struggled to find their footing in the market place.

To satisfy this market need and supply ORC solutions in the 500kW to 5MW range, an axial turbine has been developed which is capable of supporting applications with low grade heat sources found in geothermal projects, as well as moderately higher temperatures found in industrial waste heat segments (Figure 1).

ORC’s appeal in tackling the low grade heat problem is largely due to its broad applicability. With minor modifications, the technology applies to geothermal, biomass, solar-thermal, reciprocating and gas turbine exhaust, and industrial process heat. The design process followed the Design for Manufacturability and Assembly (DFM/DFA) method which aims to yield product designs with reduced part count, simple manufacturing techniques, and standardized parts and materials. Process conditions required that the turbine be suitable for applications at the previously stated power ranges, using TAS Energy’s primary ORC working fluids (R245fa and R134a), at application-defined temperatures (200°F – 500°F). These conditions create a large range of flows, enthalpy drops, pressure ratios, and optimal design speeds which is problematic for a standard design compliant with DFM/DFA principles. The range of flows is covered with two cast turbine plenums – one for low flows and one for high flows. The plenum...
castings include three optional inlets regardless of actual project design requirements. Thus, with two plenum designs, six increments are available for optimal flow distribution into the plenum by machining out the required number of inlets. The plenum’s stiff design reduces the need for expansion joints.

The varying temperature range and fluid selection tend to trend together and this range of requirements is solved by having a single-stage or two-stage turbine that fits within the plenum castings. The single stage is applied to the lower to moderate temperature ranges, and the two-stage units cover the higher temperatures. Low turbine thrusts enable the use of off-the-shelf rolling element bearings. The bearing design eliminates the need for thrust bearings in the gearbox which improves gearbox efficiency to greater than 98%.

When needed the second stage is mounted on a shaft extension designed into the common subassembly. The subassembly is fixed for all units and houses a standard set of bearings, seals, and shaft. The blades are electro-chemically milled (ECM) on the rotor disk and the shroud is an electron beam welded. The turbine rotors are slip-fit and locked to the shaft with tapered locking devices to allow rapid removal/replacement.

**Geothermal Deployment**

One installation utilizing this technology was a result of the U.S. Department of Energy’s (DOE) Geothermal Technologies Program (GTP) at Terra-Gen Power, LLC’s operating geothermal flash plant at Beowawe, near Battle Mountain, NV. The goal was to prove the technical and economic feasibility of electricity generation from nonconventional geothermal resources using a 199°F heat source, and became the first commercial use of a low temperature bottoming cycle at a geothermal power plant. This ORC plant generates ~2.5MW gross and has been running for more than two years. It augments the original flash steam power plant by 10% without consuming additional geothermal resources (Figure 2).

This axial turbine was also incorporated into the design of an ORC project in Western Turkey. However, this particular site (comprised of two plants) is a high temperature mixed enthalpy resource (steam and hot water), typical of most geothermal systems in Turkey. Each plant is ~7.0MWe gross capacity which is achieved by providing two turbines, each driving through their respective gearboxes, to both ends of a common generator. This requires the turbines to rotate clockwise and counterclockwise. The first plant is due to be commissioned in the Spring of 2013 with the second soon afterwards.