Intercooled recuperated 1400-kW genset has an 8000-Btu heat rate

By Robert Farmer

Initial testing of the intercooled, recuperated, sequential combustion prototype Heron engine has been completed—genset to be installed next year at a customer site for base load CHP demonstration and validation tests.

A unique 1.4 MW reheat gas turbine with intercooling and recuperation providing an outstanding 42.9% LHV thermal efficiency burning natural gas fuel has completed its initial phase of testing in The Netherlands.

The H-1 turbine was developed by Holland's Schelde Heron BV with design assistance from Fern Engineering in the United States.

☐ **Intercooled.** Simplified water-to-air intercooler reduces the gas turbine working fluid temperature (heat of compression) between stages of compression. This increases the mass flow through the compressor and reduces the compressor work (losses).

☐ **Recuperated.** Integral recuperator helps provide nearly 43% thermal efficiency in base load power generation, with enough exhaust heat remaining to produce process steam, heat or air conditioning for combined heat and power applications.

☐ **Reheat.** Operates with two separate combustor sections. Fuel ignited in the upstream combustor drives the gas generator turbine. Hot gases leaving this stage are reheated in a second combustion section prior to entering the power turbine. Combined sequential combustion drives the power turbine.

According to the project design engineering team, the unusual combination of cycle design features gives the small engine a heat rate matched only by some advanced aeroderivative gas turbines 30 times its size.

The Heron H-1 is a two-shaft recuperated gas turbine. Its gas generator features a 2-stage centrifugal (radial) compressor section driven by a single-stage axial turbine. A radial free power turbine on a separate shaft drives the electric generator via a reduction gearbox.

Modular construction is applied. The recuperator is located at one end of the package and the intercoolers are located above the engine.

Each of the two radial compressor sections has a design pressure ratio of around 3.0 to 1. The discharge from the first compressor passes through a water-cooled intercooler, which lowers the pressurized air temperature back to within 10°C of ambient.

Intercooling reduces the amount of the power consumed by the second compressor section, and also provides a relatively low temperature from the compressor discharge.

According to Fern designers, this low temperature allows the cycle to take full advantage of the recuperator, which preheats the combustor inlet air by recovering thermal energy from the power turbine exhaust.

Hot water produced by the intercooler makes the H-1 an ideal engine for combined heat and power applications, they maintain. It is also possible to convert some of the low-grade intercooler heat into air conditioning (cooling) with the use of an absorption chiller.

The H-1 uses twin shell and tube type intercoolers built of CrNi alloy stainless steel. These are horizontally mounted above the power turbine-generator section of the engine.

At design point, compressor operates at a relatively low 8.78 to 1 overall pressure ratio with an inlet airflow of 5.15 kg/sec at ISO base load output (11.3 lb/sec). Competitively sized engines, says Fern, typically have compression ratios ranging between 12 and 20 to 1.

Due to its low pressure ratio, the H-1 engine can operate on only about 10 bar (146 psi) fuel supply pressure. This means that at most site locations it can do without the need (or cost) of an extra fuel gas compressor.

Recuperated for efficiency

The H-1 has a shell and tube type recuperator constructed of chrome-molybdenum alloy steel.

The recuperator provides operators with very good system heat rates for a small machine in this size range, without going to the complexity and cost of a combined cycle system.

In a simple cycle design, compressor discharge air flows into the combustor where it is mixed with fuel and burned to raise its temperature. Typically, only about one-quarter to one-third of the heat energy is turned into mechanical energy.

The recuperator recovers some of this unused heat energy from the turbine exhaust and transfers it to the compressor discharge air, preheating the air before it enters the combustor.

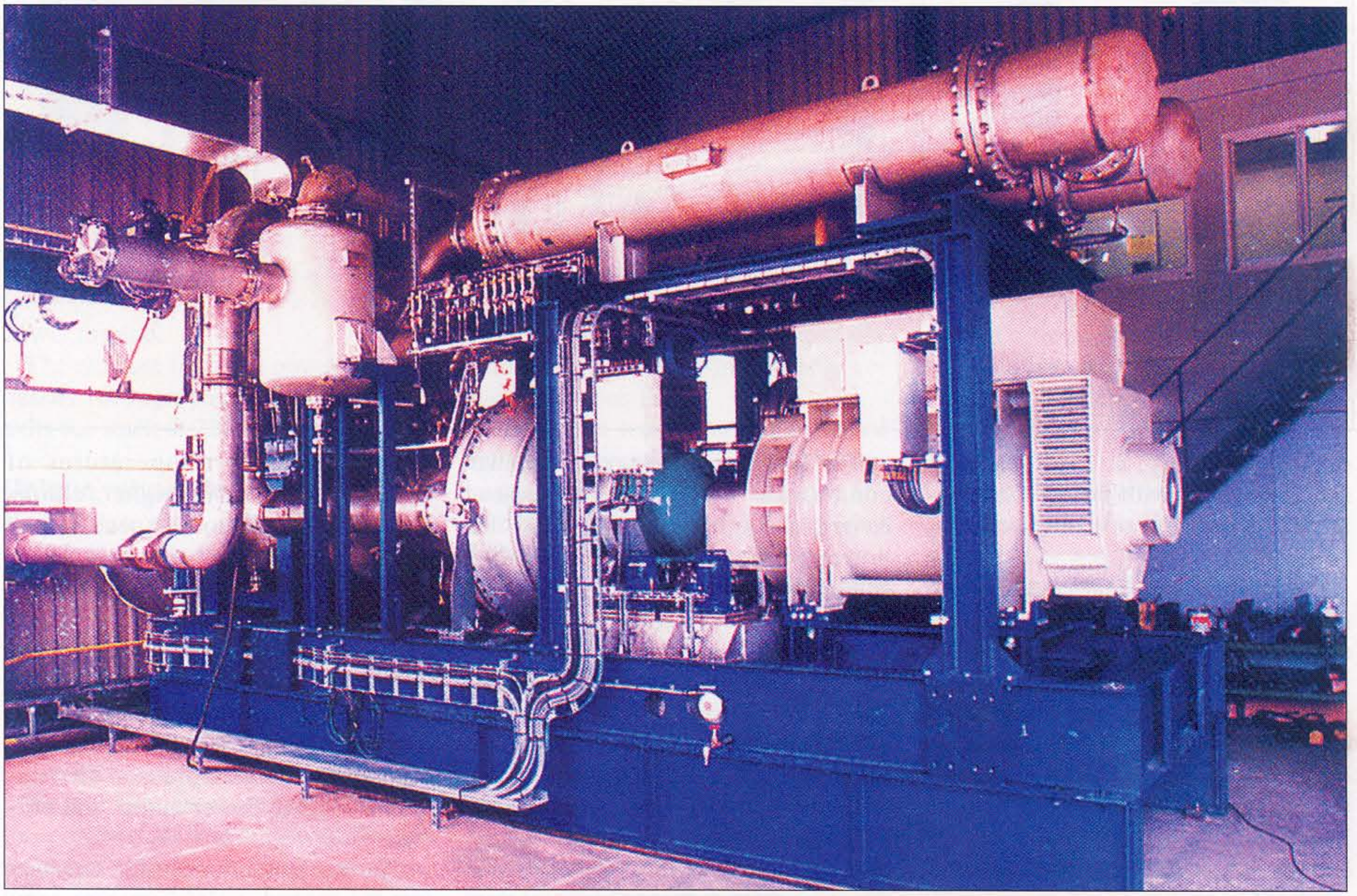
This reduces the amount of fuel otherwise needed and increases overall thermal efficiency.

As a result, the Heron H-1 genset package is rated 1.4 MW continuous with a net heat rate of 7953 Btu/kWh

Design performance of Heron H-1

Net performance, with losses, at full rated load burning natural gas fuel for a packaged generator set at 15°C (59°F) ambient air temperature, 60% relative humidity, sea level site conditions.

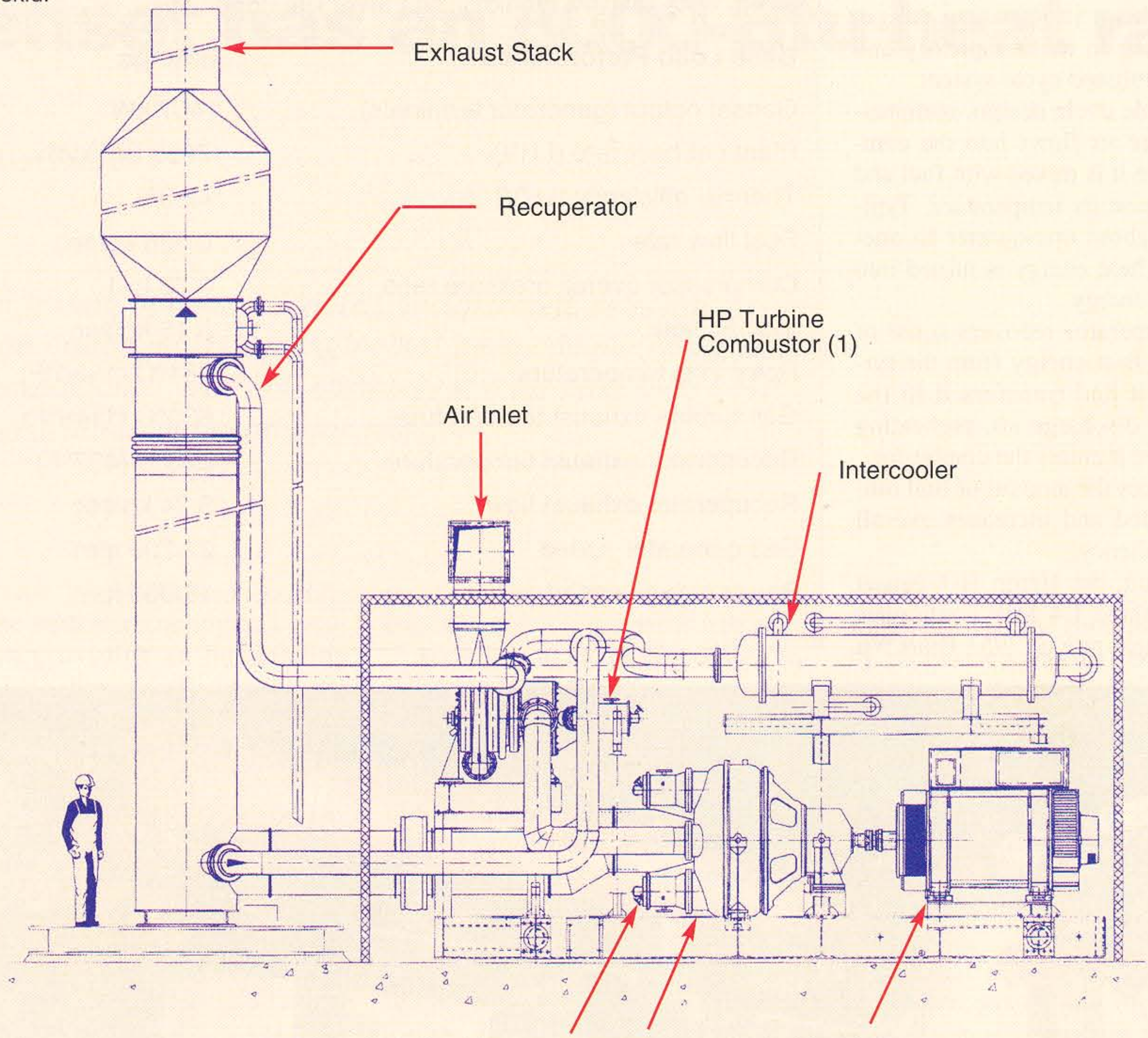
Base Load Performance	Ratings
Genset output (generator terminals)	1407 kW
Plant net heat rate (LHV)	7953 Btu/kWh
Thermal efficiency (LHV)	42.9%
Fuel flow rate	0.086 kg/sec
Compressor overall pressure ratio	8.78 to 1
Inlet air flow	5.15 kg/sec
Rotor inlet temperature	861°C (1580°F)
Gas turbine exhaust temperature	620°C (1148°F)
Recuperator exhaust temperature	225°C (437°F)
Recuperator exhaust flow	5.24 kg/sec
Gas generator speed	22,700 rpm
Power turbine speed	18,000 rpm



Prototype on test: First H-1 installed at Schelde Heron facility in Vlissingen, The Netherlands has completed initial shakedown testing. Following mods, will be retested, then installed next year at the Dutch Institute for Public Health and Environment office building in Bilthoven where it will provide heat and power for base load operational testing.

Packaged 1.4-MW generator set

H-1 turbine in enclosure measures about 8 x 2.5 x 3.7 meters LWH (26 x 8 x 12 feet) to the top of the enclosure. Power equipment is mounted on a steel skid baseplate with the external recuperator/stack (at left) mounted outside on a separate skid.



(42.9% efficiency) at 15°C sea level site conditions, with 3-inch water inlet and 6-inch exhaust duct pressure losses.

In comparison, heat rates for the most efficient 1.2 to 1.8-MW simple cycle non-recuperated gas turbine gensets range from around 13,000 Btu to 15,000 Btu/kWh (23% to 26% efficiency).

Reheat cycle

The two-stage sequential combustion design concept is sometimes referred to as reheat, after-burning or inter-heating. It is akin to high performance jet engines with afterburner or reheat.

The H-1 design features sequential combustion with the gas generator having a single combustor and the power turbine having two parallel combustors.

The intercooler also plays a role. By preheating the combustor inlet air to 565°C (1050°F), the fuel flow required by the high-pressure combustor (HPC) is greatly reduced, according to Heron design engineers.

The moderate combustor exit temperature (turbine rotor inlet temperature) of 860°C (1580°F) allows for the use of low-cost turbine section components that do not need cooling.

Competitive machines this size have combustor temperatures of 1100°C (2012°F) or higher, claims Fern, which are more expensive and do require cooling.

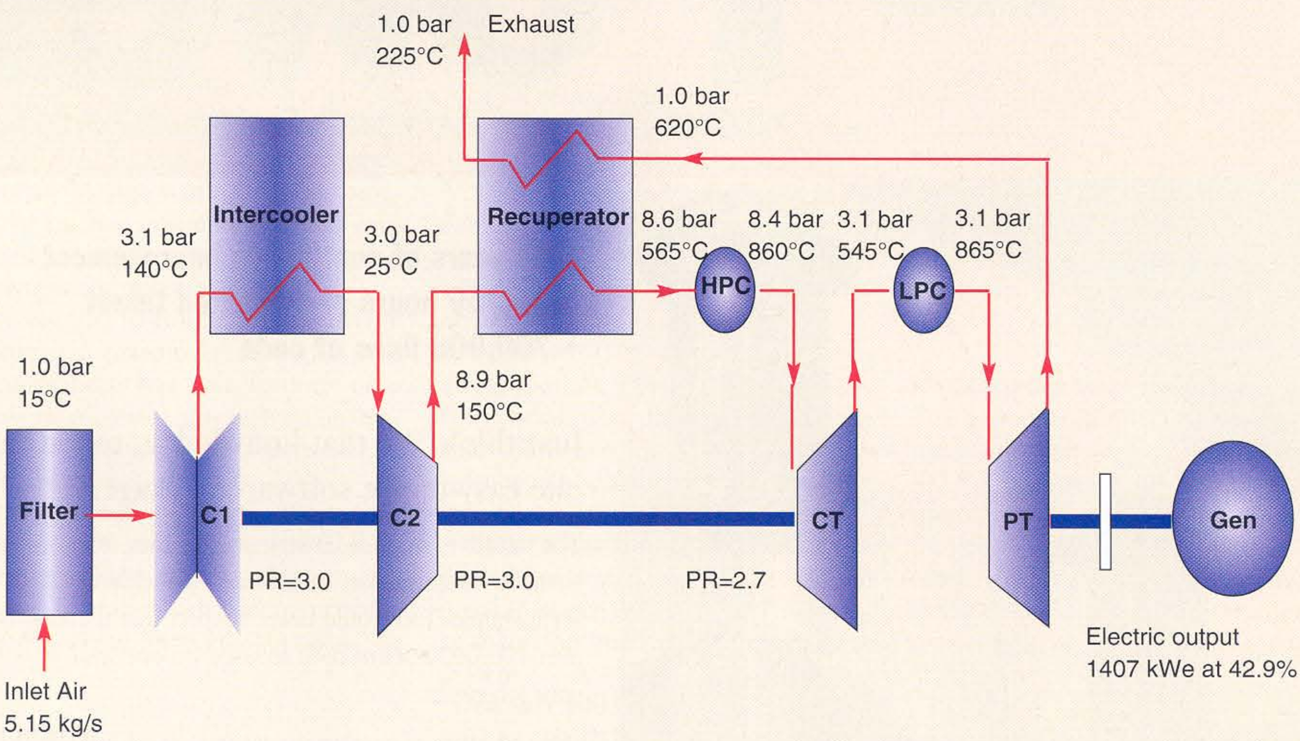
Cost savings in hot section components, materials and coatings should help offset the (expected) increased production costs of the more complex inter-cooled recuperated reheat cycle.

Elimination of cooling air normally bled from the compressor also increases engine power output and efficiency.

The gas generator turbine exhausts into the second, or low-pressure combustor, where the flow is again heated to 860°C before passing through the

Cycle flow schematic

The H-1 engine is a two-shaft design, with two compressor sections (C1 and C2) and one turbine section (CT) on the gas generator shaft, and a power turbine (PT) driving an electric generator on the second shaft. Filtered intake air is compressed and passes through an intercooler (between stages) which reduces the temperature of the mass flow. Heat exchangers (not shown) mounted upstream of the intercooler provide up to 300 kW of heat. Mass flow is then preheated in a recuperator using power turbine exhaust heat, then fired in two sequential burners. Recuperator reduces exhaust flow temperature and recovers an additional 800 kW of usable heat.



power turbine.

The exhaust from the power turbine passes through the recuperator and exits the stack at 225°C (437°F).

Unique reheat design

Hector Bourgeois, Fern Engineering president, points out that the H-1 design is the only commercial gas turbine engine in this size range using a reheat system, although military jet engines have used reheat in the form of afterburners for many years

Land-based gas turbine designs must allow extra space between the high and low pressure turbine to fit the combustors and allow sufficient residence time for complete combustion.

Going to two separate but connected combustors 'stretches' the combustion residence time to chemically reduce NOx, he explains, thereby reduce emissions levels.

Initial H-1 testing has been carried out with conventional sequential combustion chambers and burners, according to Schelde Heron's managing director, Guido van Gerwen.

This will also be the case during the next phase of validation testing, says the company.

Once the mechanical design has been fully validated, engineering will concentrate on the low emissions combustor development program.

Emissions levels projected by the Heron design team are less than 20 g/GJ for NOx (approx. 10 ppm), less than 12 g/GJ for carbon monoxide (approx. 6 ppm), less than 6 g/GJ for unburned hydrocarbons (approx. 3 ppm).

That's for a dry low emissions design without steam or water injection for NOx control and without downstream catalysts.

Design development

The history of the H-1 can be traced back to the early 1980's when the Dutch company Thomassen, in cooperation with Fern Engineering, started developing a 10,000 hp (7.5 MW) gas turbine based on a cycle design similar to that now used in the H-1.

Development reached the stage of individual component testing before the overall poor market for gas turbines in the mid-1980's caused Thomassen to call a halt to the project.

Nevertheless, key individuals from the Thomassen development team kept working on highly efficient small gas turbine design, and eventually formed their own company, Heron Turbines BV, in the early 1990s.

They decided to reduce the size of the turbine to the range of 1 to 2 MW based on surveys that indicated a large potential market for turbines of that size in The Netherlands.

Like Thomassen before them, Heron Turbines teamed with Fern Engineering to execute the development of the H-1.

Aerodynamic profiles for the H-1 were generated by the Von Karman Institute in Brussels. Fern performed all of the design work, detailed analyses of critical components, and produced a complete set of engineering drawings and specifications.

According to Bourgeois, the design effort was extremely cost-effective because Fern was able to draw on a network of senior gas turbine designers who participated in a series of design reviews.

"By taking advantage of literally hundreds of years of design experience, we were able to skip several stages in the development process without taking unacceptable risks," he observes.

Timetable

Once the design reached the point of manufacturing the first prototype, Heron Turbines joined with the Royal Schelde Group to form Schelde Heron, BV.

As noted, the prototype has been built and has completed initial shakedown tests. This unit is installed at Schelde's test facility in Vlissingen, The Netherlands.

During the tests, full, integrated operation of the system was achieved including operation of the reheat combustor.

The power turbine inlet temperature was brought up to within 35°C of the design value, and efficiencies of the various components were confirmed.

Efforts are now focused on making modifications to address deficiencies identified during the initial testing.

Scope of changes includes design and assembly procedure modifications to improve impeller tip clearance control in the gas generator compressor sections and further development of control and protection system software (e.g. bleed valve and blowoff valve operation).

It also includes modifying the power turbine casing to allow on-site removal of the bearing cartridge; providing extra borescope inspection ports; and simplifying the lube oil system and piping.

First installation

Once the modifications and additional testing are completed, the first H-1 will be delivered to the Dutch Institute for Public Health and Environment office building in Bilthoven where it will provide both heat and power.

While the DLE combustion design development work continues, this first installation may be fitted with water injection for NOx suppression to meet Dutch regulations of less than 65 g/GJ NOx.

This unit will also have two intercooler hot water heat exchangers to provide about 300 kW equivalent of heat for the building central heating system.

Another 800 kW thermal equivalent will be available from the exhaust stack downstream of the recuperator, also to be applied for central heating.

As noted, at ISO conditions, the gas turbine nominal exhaust at 225°C (437°F) 1.013 bar, 5.22 kg/sec (11.5 lb/sec) downstream of recuperator makes it a candidate for a variety of power and process heat cogeneration applications.

Future CHP installations are foreseen in large hospitals and medical facilities, office complexes and central energy facilities, universities and colleges.

Other typical candidate applications include refineries, chemicals, forest products, steel and pharmaceuticals, as well as food and agricultural processing plants.

Production schedule

According to Schelde Heron's business plan, the first installation at the Dutch Institute will operate during 2003 in the start-up phase of the project.

Here, complete type testing of the first H-1 will be done in order to meet predicted performance values.

During 2003-2004 the validation phase will be completed which involves "the manufacturing, testing and delivery of three additional demonstration/validation H-1 gas turbines to identified customers."

Successful completion of these two phases will lead to a planned expansion phase around 2005-2008. This phase will cover "the realization of series production up to 50 units per year at a cost level that will ensure penetration of the small scale power generation market in a profitable way."

Packaged power plant

The genset equipment mounted on a steel skid base plate measures about 8 x 2.5 x 3.7 meters (26 x 8 x 12 feet) overall.

Skid mounting supports all the major turbine systems to maintain the gas turbine engine, reduction drive gearbox, and generator in alignment.

Bare engines will ship skid-mounted with an inlet plenum and power turbine exhaust collector with flanged connections for bolt-up to inlet filtration systems and recuperator.

An outdoors enclosure fitted with package ventilation motors and fans is also available. The package is sound attenuated down to 85 dBA at one meter.

Woodward Governor's MicroNet system is used to control both the gas turbine and the generator. A direct-drive AC motor starter is standard.

The package also contains the integral triple-redundant lubrication system with pumps and reservoir.

The integral reduction gearbox from Allen Gears is an epicyclic unit with double helical gearing taking the 18,000 rpm power turbine shaft speed down to 1500 rpm for 50-Hz installations and to 1800 rpm for 60-Hz. ■