Small turbines need new approaches

CERAMICS ARE A DEAD END

It looks like the microturbine folks are not going to get past a net electric efficiency of 34-35 percent Lower Heating Value (LHV) in the near future, and that the promise of ceramics, long thought to be the critical enabling technology, will remain a distant objective. The basic problem is that these recuperated simple cycle designs cannot use the full Turbine Rotor Inlet Temperature (TRIT) potential because of material cost vs. life limitations on the recuperator materials. Un-cooled radial inflow turbine rotors are commonly applied at 950 C (1142 F), and in some cases up to 1000 C (1832 F). The recuperator cost goals, however, compel the use of stainless steel alloys, where the 40,000 life-in-service objectives limit Exhaust Gas Temperatures (EGT) to approximately 625 C (1150 F).

Turbine rotor inlet and exhaust gas temperatures are connected through turbine efficiency and expansion ratio. With a 90 percent effective recuperator and standard assumptions on pressure drop of 1.5 percent on the air side and 3.5 percent on the gas side, the cycle efficiency optimizes at a pressure ratio of 3.0:1. However, to mitigate cost impacts, these machines are commonly designed at 4.0:1 or slightly higher, thereby reducing component size and cost. Built into these optimizations are assumptions on compressor and turbine efficiencies, typically at 80 percent and 85 percent respectively.

With a TRIT of 950 C, and a compression/expansion ratio of 4.0/3.6, the cycle efficiency is 34-35 percent LHV net electric, but the EGT is 670 C and well beyond the application of SS347 cost recuperator alloys. Although cycle efficiency approaches 36 percent, the 1000 C TRIT is completely out of the question for stainless steel designs, which at these compression/expansion ratios reaches 700 C. This is, of course, why the Department of Energy at its Oak Ridge National Laboratory has been pursuing advanced stainless alloys capable of meeting the 40,000 life objective at 700 C. These efforts have been moderately successful and could lead to efficiency gains in the future.

Another choice is to raise the expansion ratio, but compressor efficiency limits this option. Not only does the efficiency of the compressor begin to roll off with the loss in component efficiency, but the temperature difference between EGT and compressor discharge temperature narrows as well, resulting in an additional loss to the cycle.

If we could improve compressor efficiency from 80 to 90 percent, it would shift the optimum pressure ratio higher as a result of the full utilization of the material limits on both the turbine rotor and the recuperator. At a TRIT of 950 C and compression/expansion ratio of 5.5/5.0, the EGT is a manageable 625 C, and the cycle efficiency could be as high as 38 percent. Boosting the EGT limit to 650 C and the compression/expansion ratio to 5.6/5.1 would allow full use of the 1000 C TRIT and result in a cycle efficiency of approximately 39 percent. This could be accomplished without the need for ceramics which, if they are ever practical, could even add an increment beyond.

There have been some interesting developments around the world that focus on compressor efficiency as a means of improving overall performance. One is worth mentioning.

GE introduced their LMS100 at PowerGen in December. In addition to improving turbine efficiency, the significant design concept was the use of an intercooled compressor to improve compression efficiency. The unit is advertised at 46 percent LHV efficiency at a pressure ratio of 42:1 and a TRIT of 1400 C

Compressor efficiency is one of those areas that should be revisited to see if recent advances can re-energize the interest in smaller gas turbines, as well. It is a mistake to leave this critical component as a simple assumption, buried beneath three levels in the cycle deck. TI

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