Prospects For A 1000 Mw(E) Nuclear Reactor/MHD Power Plant

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Abstract

A parametric study has been made of a 1000 Mw(e) nuclear reactor/MHD power plant operating on a closed Brayton cycle. Over-all efficiencies, i.e., ratio of net electrical output to thermal energy input, greater than 0.5 have been calculated for a regenerative, turbocompressor cycle. It is believed that if present estimated capital costs of a plant based on this cycle can be reduced, MHD power production may become competitive as a commercial power source by the 1980's. The economics, i.e., detailed capital costs, fuel costs, maintenance, etc., are beyond the present scope of this study, but recent estimates of some of the components yet to be developed indicate high capital cost compared with conventional power plant equipment.

A schematic of the cycle is illustrated in Fig. 1 along with results from preliminary calculations of representative conditions. For the parameter study, the expansion through the MHD duct was assumed to be isentropic with efficiencies from 60 to 75 percent. The inlet stagnation temperature and pressure were held constant at 3590°F and 118 psia. The duct outlet temperature was allowed to drop below that of thermal equilibrium ionization with the hope of deriving benefit from ion recombination. The conducting medium is helium, seeded with 0.5 mole-percent cesium. The cycle efficiency, being a function of $1-T_C/T_R$, is increased by lowering the compressor inlet temperature and increasing the high temperature recuperator outlet temperatures. The choice of "boot-strap" turbocompressors was made to increase the over-all efficiency and to utilize machines with lighter rotors than electrically coupled compressors. Although efficiencies are lowered by using multiple turbocompressors, their use was considered necessary for this cycle because of the large shaft horsepower requirements for one machine (in the range of 0.5 to 1 million horsepower). The study included the use of two, three, and four turbocompressors with a water-cooled heat exchanger between each compressor. The ranges of efficiencies for the turbine and compressor were, respectively, 80 to 90 and 75 to 85 percent.

Within the scope of these studies, the only parameters for reactor design are core geometries necessary for heat transfer and pressure drop calculations. No consideration has been given to neutronics, control problems, or necessary internal ducting of the coolant.

In using conventional shell-and-tube heat exchanger designs for the water-cooled exchangers and the low temperature recuperator, pressure drops become prohibitive. Unique designs will be necessary to provide large flow cross-sectional areas and short lengths to achieve pressure drops less than 10 psi at the low pressures in the loop (less than 100psi). The high temperature recuperator operates at temperatures beyond present metal heat exchanger technology. The cold side outlet temperature ranges from 2200 to 2500°F. This temperature level will require refractory materials such as graphite or refractory metals like tungsten or molybdenum. Other practical problems associated with such a plant are the effects and removal (if necessary) of the cesium seed and the effects and control of trace impurities such as oxygen in the high temperature portions of the loop. Present technology of graphite heat exchangers is sufficient for the design of the high temperature recuperator, but knowledge of the effects of cesium on graphite is insufficient to predict the lifetime of this component. The effects of high temperature cesium on refractory metals is negligible, but the present fabrication costs with these metals are not competitive with the costs of graphite.

The operation of this loop with the possibility of fission product contamination requires that loop components be reliable and leak tight. This requirement in present reactor coolant loops has led to the development of compressors with hydrodynamically lubricated gas bearings. These machines can be totally "canned" and do not require the periodic maintenance of grease-lubricated bearing machines. The MHD cycle requires a large, high-powered machine for a high pressure ratio and low density fluid. In the Present "state-of-the-art", large, gas-bearing machines have been developed with centrifugal impellers for low pressure ratios and high density fluids. For efficient operation, the requirements for an MHD cycle are better met by a staged-axial flow compressor, and gas-bearing axial flow compressors have only been developed for high density fluids. There are, however, active programs in existence for the development of gas-bearing "boot-strap" turbocompressors. The development of such a machine appears necessary for this cycle to be competitive for future power production.

The foregoing examples indicate only some of the problems in the design of a nuclear reactor /MHD power plant. To be competitive even with present conventional (fossil-fueled or nuclear) power plants, major developments, particularly in high temperature technology and turbomachinery, will be necessary.

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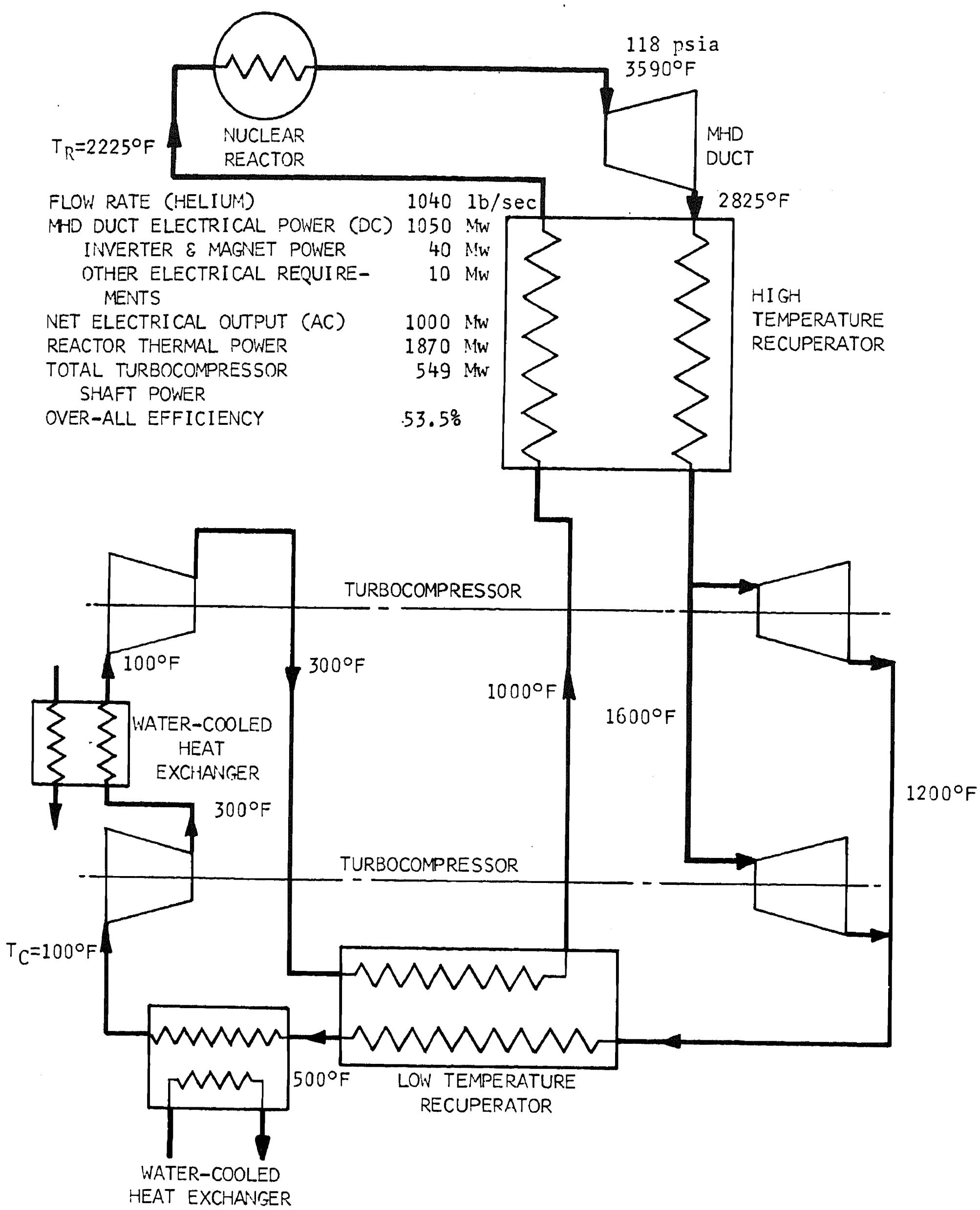

Fig. 1 - Schematic of a 1000 Mw(e) Nuclear Reactor/MHD Power Plant.