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TWO-PHASE FLOW TURBINES AS STAND-ALONE THROTTLE REPLACEMENT UNITS IN LARGE 2000-5000 TON CENTRIFUGAL CHILLER INSTALLATIONS

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ABSTRACT

This paper describes the development and commercial introduction of stand-alone two-phase flow power recovering turbo-expanders for the HVAC market. The units are designed to be installed in parallel to existing throttle valves of large 2000-5000 ton water-cooled chillers. A first unit has recently been installed at a commercial building in Manhattan.

INTRODUCTION

A recent development in refrigeration, cryogenics, geothermal power and oil and gas production and processing is the replacement of two-phase flow throttling valves and Joule-Thomson valves with two-phase turbines. The benefits which have been demonstrated are the generation of useful power from previously wasted energy and added cooling effect, producing more cold liquid product, reference 1.

Commercial units have now been demonstrated for geothermal power, oil and gas production and refrigeration. For refrigeration two-phase turbines have been incorporated into a commercial centrifugal chiller line, reference 2. Over 70 units have been deployed and are currently being operated in a wide range of industrial and commercial applications.

Application of two-phase turbine generators to existing large chiller installations to improve the operational efficiency has also been initiated. The first project, retrofit of a 2500 Ton centrifugal chiller in a commercial building in Manhattan has been started. A description of the two-phase turbine design and performance and the installation for that project is given in this paper. In addition, performance for chillers of other sizes is presented.

SYSTEM DESCRIPTION

A simplified schematic diagram of a centrifugal chiller with a two-phase turbine generator is given in figure 1. Cold refrigerant is evaporated by the heat load of the chilled water in the evaporator. The vapor is compressed to a higher pressure and temperature by the compressor. Hot vapor is condensed by cooling tower water in the condenser. In the existing installation the condensate is flashed through the throttling valve producing a two-phase stream of cold refrigerant which enters the evaporator. The two-phase turbine generator is added externally to the existing installation by adding piping connections and isolation valves. To generate power the throttling valve is closed and the isolation valves and turbine control valve are opened, admitting the condensate to the two-phase turbine where it is flashed, producing power and additional liquid refrigerant. The power produced may be used directly to offset compressor power for electric motor drives or it can be used to service other loads or, as is the case for the first installation, to reduce the building power consumption. The cold refrigerant is subsequently returned through the isolation valve to the condenser of the existing system. In the event the two-phase turbine generator is shutdown, the throttling valve automatically opens to enable non-interruptible cooling by the existing chiller.

The simplified P&ID of figure 2 shows the control strategy. The throttling valve position is normally controlled by a pneumatic signal from the level indicator. When the turbine is actuated the signal is diverted to a sensor whose signal is measured by a micro-processor. The micro-processor opens the turbine inlet valve while closing the throttling valve to maintain a constant level in the condenser. When the turbine speed is within 50 rpm of 1800 rpm the micro-processor closes the circuit breaker, locking the induction generator into the frequency of the grid. The inlet valve continues to open while the throttling valve closes until the maximum flow enters the turbine. If the chiller conditions are such that the turbine can not swallow the entire flow a portion is bypassed through the throttling valve to achieve level control. If the conditions are such that the turbine would swallow too much flow the inlet valve is partially closed to maintain the condenser level.

Other control strategies have been formulated which are simpler. They will be evaluated during the operation of this project. The most promising is the use of different actuation ranges in the two valves, e.g. 3-9 psig for the inlet valve and 9-15 psig for the throttling valve. This method eliminates the level control function from the microprocessor. However, for the first installation it was decided to start with active control of the important parameters.

The electrical intertie utilizes utility grade protective relays. The microprocessor reads any electrical faults, turbine overspeed, or reverse power and automatically shuts down and isolates the turbine, restoring flow through the throttling valve. The system is fail safe producing a closed turbine inlet valve and open throttling valve, under the control of the level signal.

TWO-PHASE TURBINE GENERATOR DESIGN

A vertical shaft turbine design was selected to facilitate removal of the leaving flow. Figure 3 is a cross section of the unit. HFC-134a condensate enters a plenum through a side inlet. The plenum feeds the flow to six two-phase nozzles. The flow is expanded in the nozzles, producing two-phase jets. The jets impinge upon impulse blading and a separating shroud which is provided for inventory control and to minimize liquid windage. For some applications direct impingement is not feasible due to blade erosion. However, the relatively low impact velocities (~100 feet per second) for most refrigeration applications eliminate erosion as a concern.

The two-phase flow leaving the blades and shroud flows downward through the exit port to the evaporator.

The turbine was designed using a two-phase nozzle code and a two-phase turbine code. The nozzle code is a one-dimensional equilibrium code which includes droplet breakup; vapor-liquid heat transfer and slip; and wall friction. It has been verified for HFC-134a as well as many other fluids. The two-phase turbine code is a two-dimensional code which includes impact momentum losses and liquid friction losses on the blading. This code also has been verified for the commercial HFC-134a turbines. Table 1 provides a summary of the turbine performance for typical measured conditions of the chiller.

Table 1

Two-Phase Turbine Generator Performance with HFC-134a for 2500 Ton Chiller

Inlet Pressure	124 psia
Inlet Temperature	86 ^{0}F
Flowrate	417,000 lb/h
Exit Pressure	54 psia
Exit Temperature	44 ^{0}F
Power	54 kWe
Speed	1800 rpm
Isentropic Power	85 kW

The turbine rotor for this application is compared to the rotor for a 500 ton chiller in figure 4. The larger diameter, 13 inches, is required because of the higher flow requirements of the large chiller. The rotor shown can be used for a chiller size up to about 4500 tons. Above that size a larger rotor or the use of two of the present turbines is required. Figure 5 is a photograph showing the nozzles and their inlets, which are inserted into the plenum. A press fit into the retaining structure is used. The assembled two-phase turbine and generator are shown in figure 6, prior to shipment to the site. Controls and electrical intertie were tested prior to shipment using air and water to simulate the refrigerant. The unit was synchronized automatically with the grid and all trip functions were verified with the microprocessor.

PERFORMANCE FOR OTHER APPLICATIONS

An estimate of the power generated and additional liquid produced was prepared as a function of refrigerant flow rate and condenser temperature for an evaporator temperature of 44 ^{0}F, assuming no internal pressure drop in the evaporator. Shaft power was calculated since there may be cases where the turbine is used to directly drive a pump or other mechanical load. The results are provided in figure 7. The power at 86 ^{0}F condenser temperature ranges from 15 kW for a 500 ton chiller to 180 kW for a 6000 ton unit.

Pressure drop within the evaporator, such as due to the inlet manifold, must be taken into account by correcting the exit pressure of the turbine. The power output is nearly proportional to the pressure ratio across the turbine so the results of figure 7 may be corrected by multiplying the ratio of the actual pressure ratio to the value plotted. If the turbine is used to drive a generator the values of figure 7 must be multiplied by the generator efficiency.

The installed cost of the first unit is approximately $1000/kWe which includes one time tooling and programming costs. Additional units in this size range will cost approximately $ 550/kWe. Application to a 4500 ton chiller will see the specific cost drop to about $ 400/kWe. Since the previously wasted energy ("fuel") generating this power is free, the economics of retrofitting large chillers with two-phase turbines should be very good.

FUTURE PLANS

The two-phase turbine generator has been installed at the first site, the Bell Atlantic building in Manhattan. It will be operated during the summer peak season and during the rest of the year.

Based on the successful experience of the commercial units to date it is expected that retrofit two-phase turbines will be offered commercially for existing chillers by the fall of 1998. In addition they will be offered as accessories for new large chillers to realize the same benefits as the chiller line already incorporating two-phase turbines.

REFERENCES

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2. Brasz, J.J., "Improving the Refrigeration Cycle with Turbo-Expanders", Proceedings of the 19th International Congress of Refrigeration, Volume IIIa, pp. 246-253, 1995.

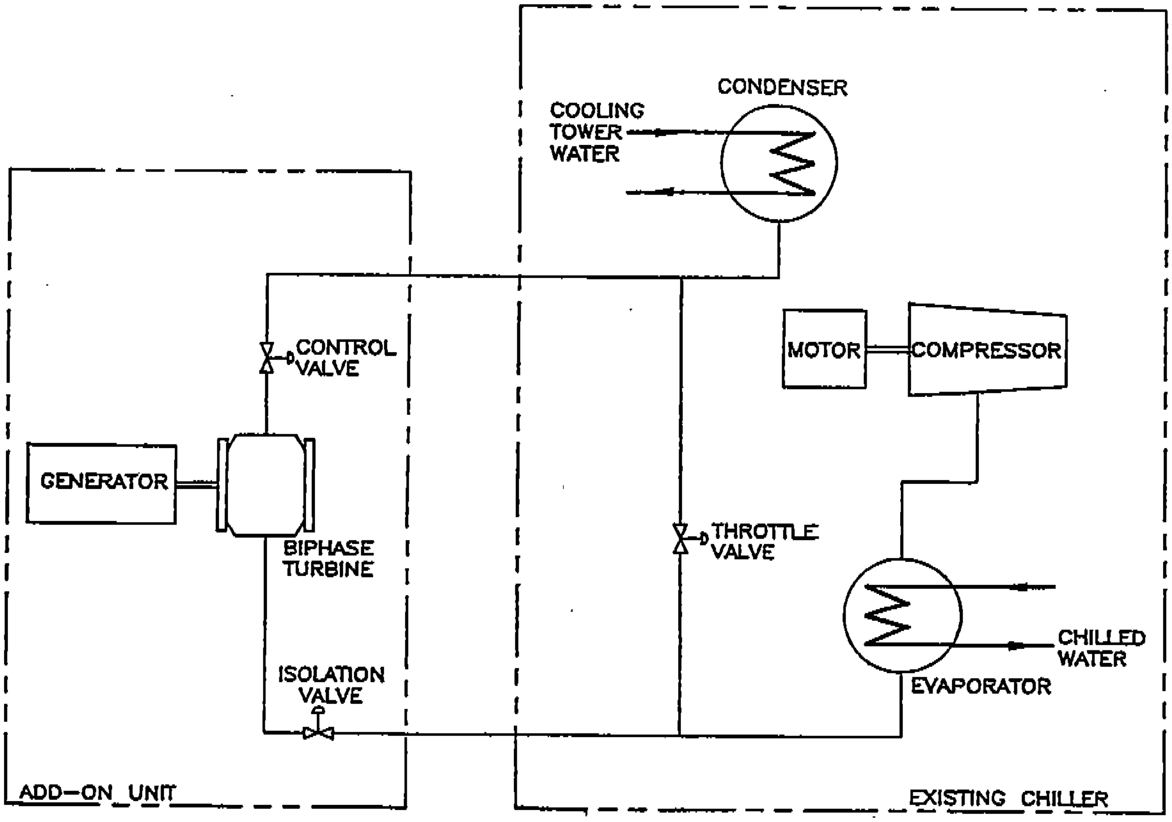

Figure 1. Schematic of Retrofit of Two-Phase Turbine Generator to Existing Centrifugal Chiller

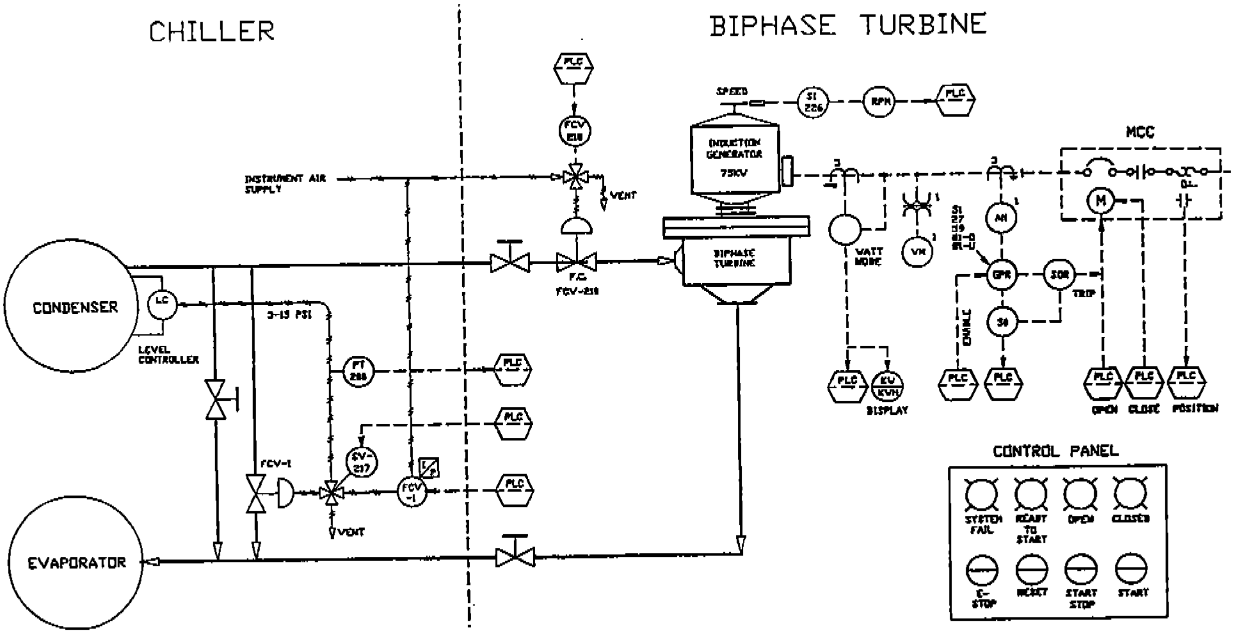

Figure 2. P&ID of Two-Phase Turbine Generator Installation on Existing 2500 ton Chiller

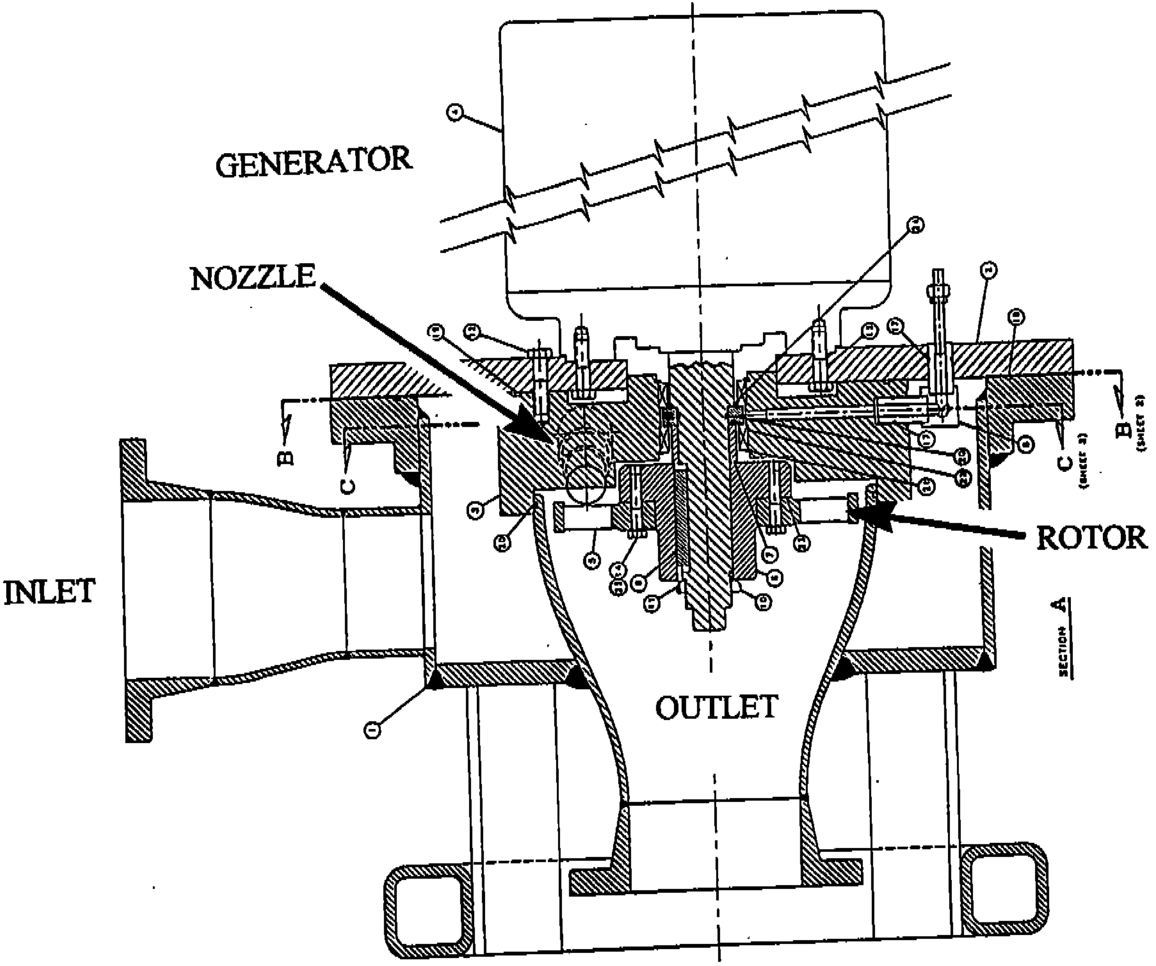

Figure 3. Cross Section of Two-Phase Turbine Generator for 2500 ton Chiller

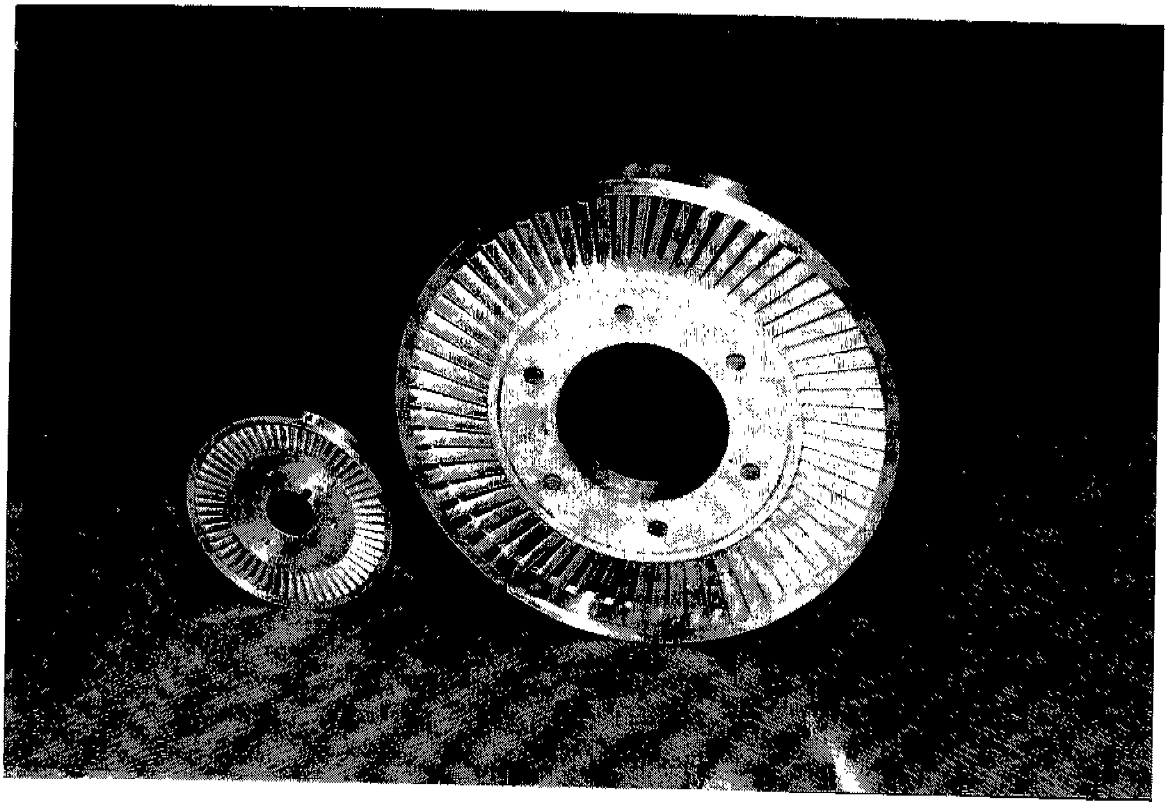

Figure 4. Comparison of Two-Phase Turbine Rotors for 500 Ton Chiller and 2500 Ton Chiller

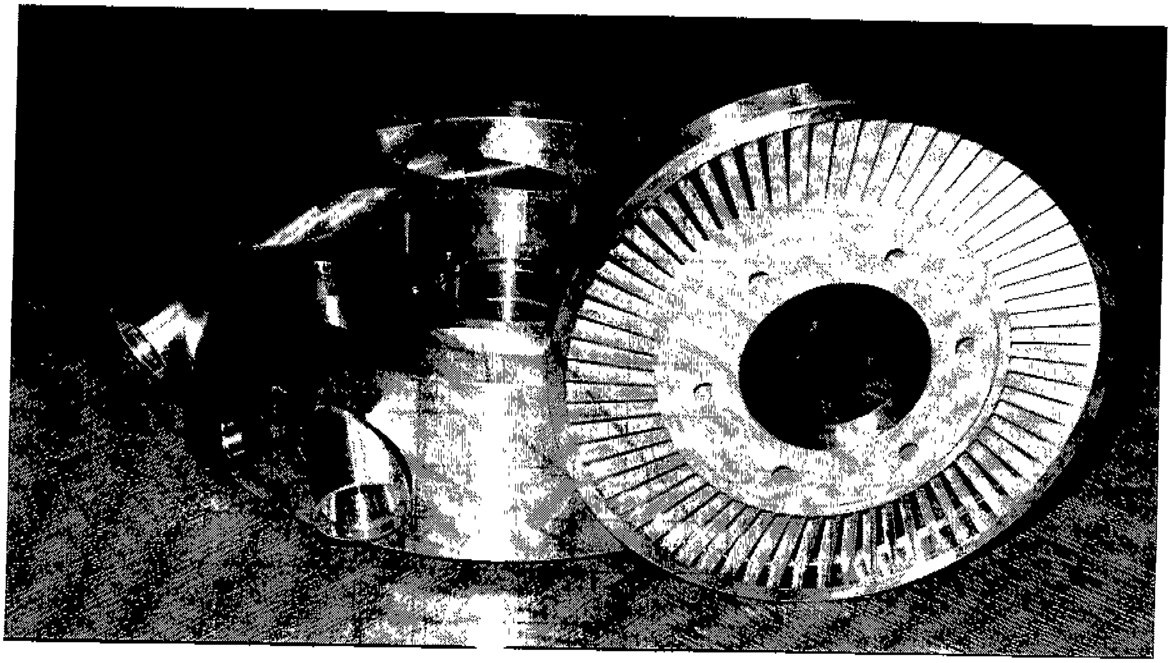

Figure 5. Nozzles, Manifold and Rotor of Two-Phase Turbine Generator for 2500 ton Chiller

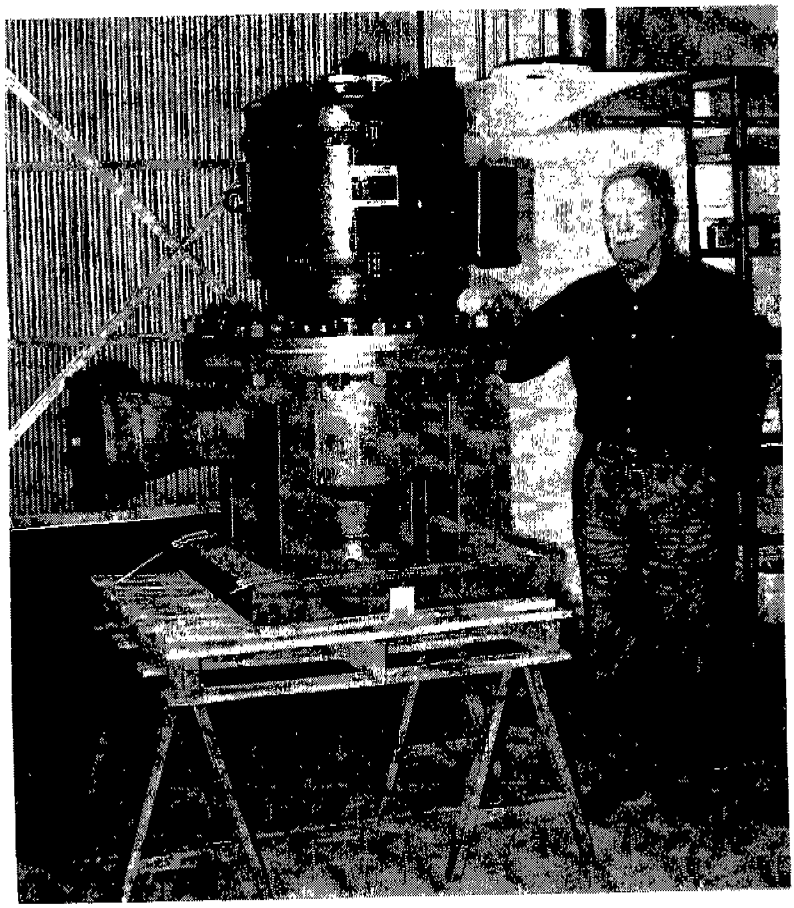

Figure 6. Assembled Two-Phase Turbine Generator

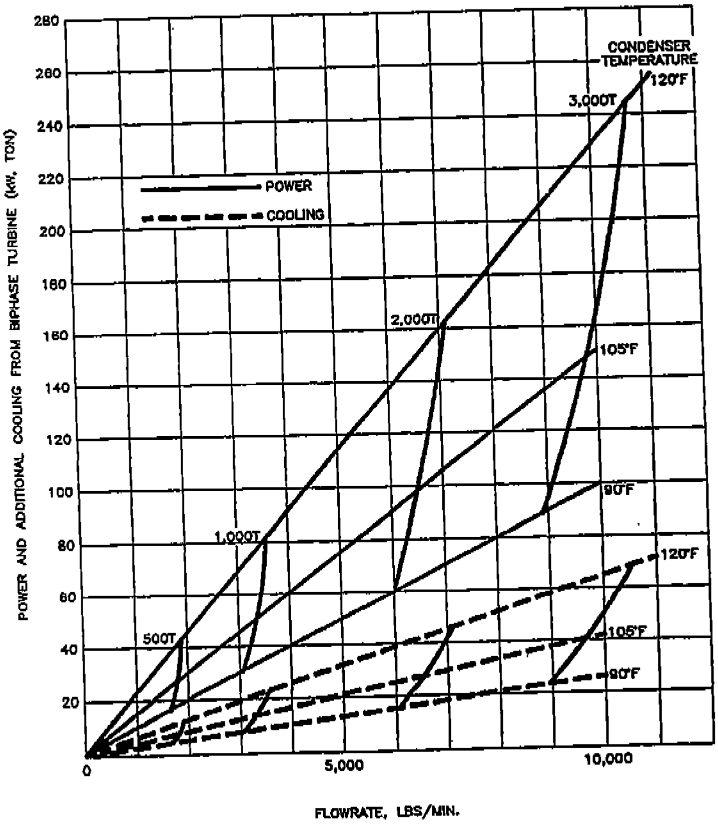

Figure 7. Performance of Two-Phase Turbine Generators for Retrofit of Existing Chillers