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A Test Facility for Determining Interactions Between a Compressor and System

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INTERACTIONS BETWEEN A COMPRESSOR AND SYSTEM

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INTRODUCTION

As the mathematical simulation models of compressors become more refined, and with increased demand for improved performance and reliability from existing compressor designs, the interactions between the compressor and its associated air conditioning system become more important. Described herein is a test facility and instrumentation for determining interactions between a compressor and air conditioning system.

TEST FACILITY DESCRIPTION

Test Facility Requirements

In order to determine the interactions between a compressor and the air conditioning system, it is necessary to be able to measure both dependent and independent system variables. In addition, it is necessary to be able to change and control the independent variables. In discussing the test facility requirements, it will be helpful to review a typical air conditioning system and the variables involved. Figure 1 presents a schematic of the typical residential split-system air conditioner, selected for investigation by the Carrier Research Division. In operation, high temperature, high pressure refrigerant vapor leaves the compressor and enters the outdoor coil or condenser where it condenses into cool high pressure liquid by rejecting heat to outdoor air flowing through the condenser. The high pressure refrigerant liquid then flows through an interconnecting tube into the indoor section, where its pressure is reduced through an expansion device. The low pressure refrigerant liquid then flows through the indoor coil or evaporator where it absorbs heat from indoor air circulated through the evaporator, and evaporates into low pressure refrigerant vapor. Finally, the low pressure vapor returns through a second interconnecting tube to the outdoor section or condensing unit, where it enters the compressor and is again compressed into high temperature, high pressure vapor.

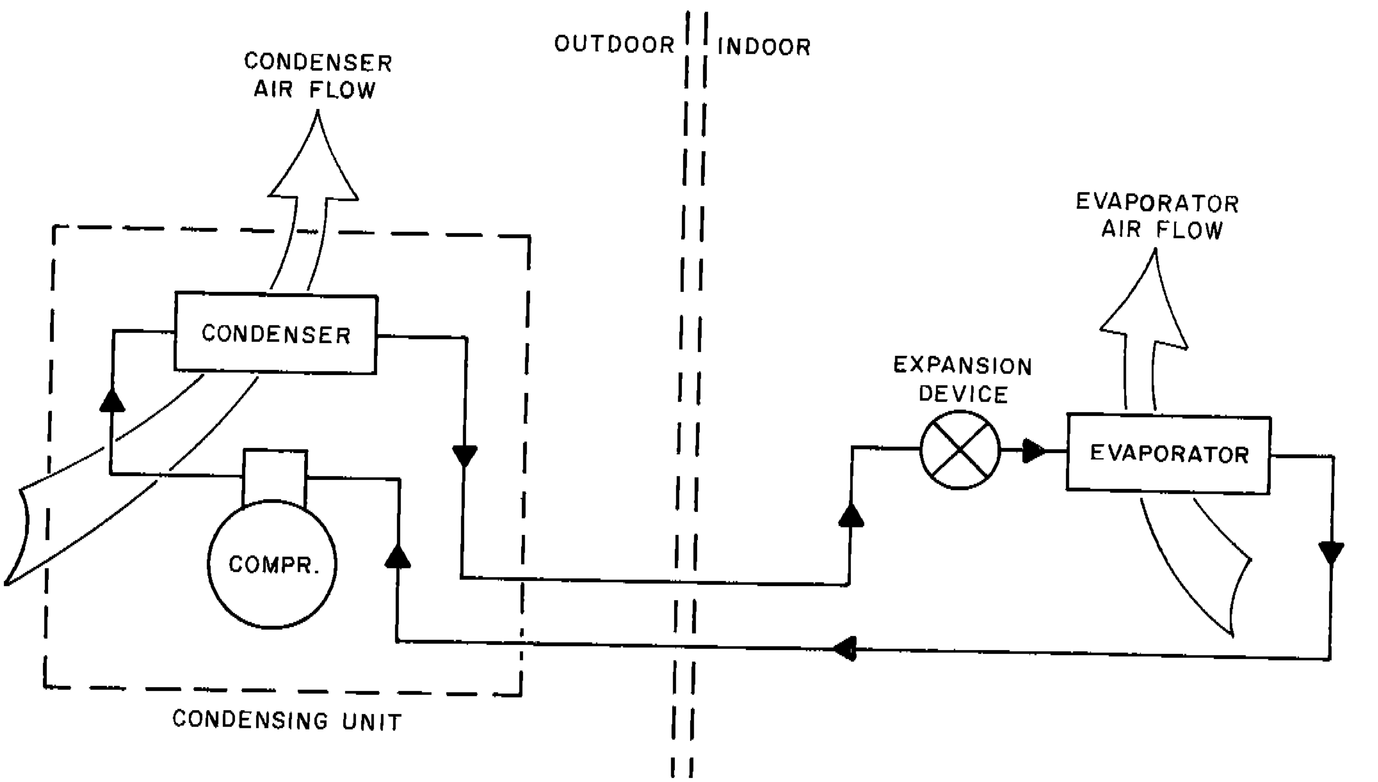

Figure 1. Typical Components and Arrangement for Residential Split-System Air Conditioners

From Figure 1 and the above explanation, it should be clear that the major requirement of the test facility is to supply the correct quantities of measured and controlled air flow to both the condenser and evaporator over the range of conditions of interest. In regard to a range of interest, it was determined that the facility described herein would be restricted to a nominal three-ton capacity, but would simulate both normal air conditioning operation and heat pump, or reverse cycle, operation. Heat pump operation, as intended here, refers to reconnecting the compressor refrigerant piping such that the refrigerant flow direction is reversed and the role of the indoor and outdoor coils as evaporator and condenser, respectively, are thereby reversed. In terms of facility requirements, the option of air conditioning or heat pump operation means that the facility must be capable of supplying the outdoor coil with a controlled and measured air flow ranging in temperature from -10°F to +115°F. In addition, the indoor coil requires a controlled and measured air flow ranging in temperature from 60°F to 100°F. The references to controlled and measured air flows are meant to indicate that in addition to dry bulb temperature, the wet bulb temperature and air flow quantity are also controlled and measured. That portion of the test facility which provides the controlled and measured air flows is defined as air-side apparatus, and will be described in more detail in a later section.

Having established the general operation in regard to the air-side requirements, for the typical residential split-system air conditioner, there remains the subject of the vapor compression cycle and the refrigerant side requirements. The PH (pressure-enthalpy) diagram for the air conditioning vapor compression cycle is presented in Figure 2. In analyzing an air conditioning system, it is necessary to know the state point of the refrigerant entering and leaving the various system components, i.e., to basically know the pressure and temperature of the refrigerant in the system at points corresponding to the four corners of the cycle shown in Figure 2. In setting up the refrigerant-side conditions, the pressure at which the condensing and evaporating processes occur are determined by the air-side conditions at the condenser and evaporator, respectively. However, in addition to setting up the refrigerant circuitry so that the state points may be physically measured, it is possible to determine the refrigerant flow rate, and also have control over the amount of system subcooling and superheat. A method for determining the refrigerant flow rate and controlling subcooling and superheat will be described in a later section.

The remaining requirement of the overall test facility is to measure and record the system data as accurately as possible. An instrumentation scheme which is used in the Carrier Research Division to record the various system data will be presented in a later section.

Air-Side Apparatus

The air-side portion of the test facility consists of two separate test loops to permit independent simulation of indoor and outdoor conditions. Both

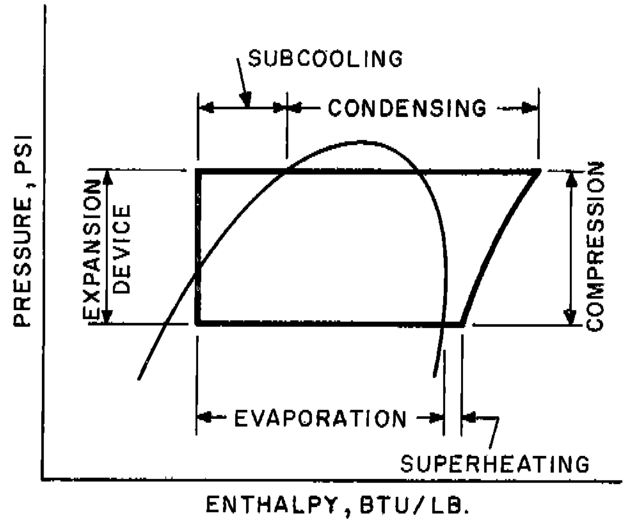

Figure 2. Pressure-Enthalpy Diagram for Air Conditioning Vapor Compression Cycle

of the test loops contain an auxiliary blower, electric heaters and brine coils to heat or cool incoming air, steam injectors for humidification, measuring stations to determine entering and leaving system air temperatures, and flow nozzles to determine air flow rates. The electric heaters and brine coils were selected and applied such that the air flow sees nearly uniform temperature planes perpendicular to its direction of flow. In addition, the air flow passes through mixing sections as described by Wile[1], before entering the measurement sections. In regard to flow measurement, the flow nozzles are set up in accordance with the AMCA[2] standard for multiple nozzles in inlet chamber, with diffusing plates included in both halves of the measurement sections.

The test loops may be operated "open loop" with the laboratory as the return plenum, or "closed loop" for heat pump operation or overnight system soaks. The overall air-side simulation capability ranges from heat pump operation at -10°F ambient to air conditioning operation at a 115°F ambient. Air-side schematics of the condenser and evaporator test loops are shown in Figures 3 and 4, respectively. A photograph of the actual test loops is included as Figure 5.

Refrigerant Circuitry

The refrigerant circuitry is set up such that the conditions for any one component may be fully specified, and in addition, the entering and leaving conditions of all components may be measured. Certain control components, such as the reversing valve, accumulator, and suction pressure regulator are options which may be employed for special tests. The general refrigerant schematic is shown in Figure 6.

Refrigerant flow rate is determined through a heat balance on the liquid refrigerant and brine heat exchanger. This type of flow determination was selected because of its negligible pressure drop, and insensitivity to transients and type of refrigerant. In addition, the liquid refrigerant and brine heat

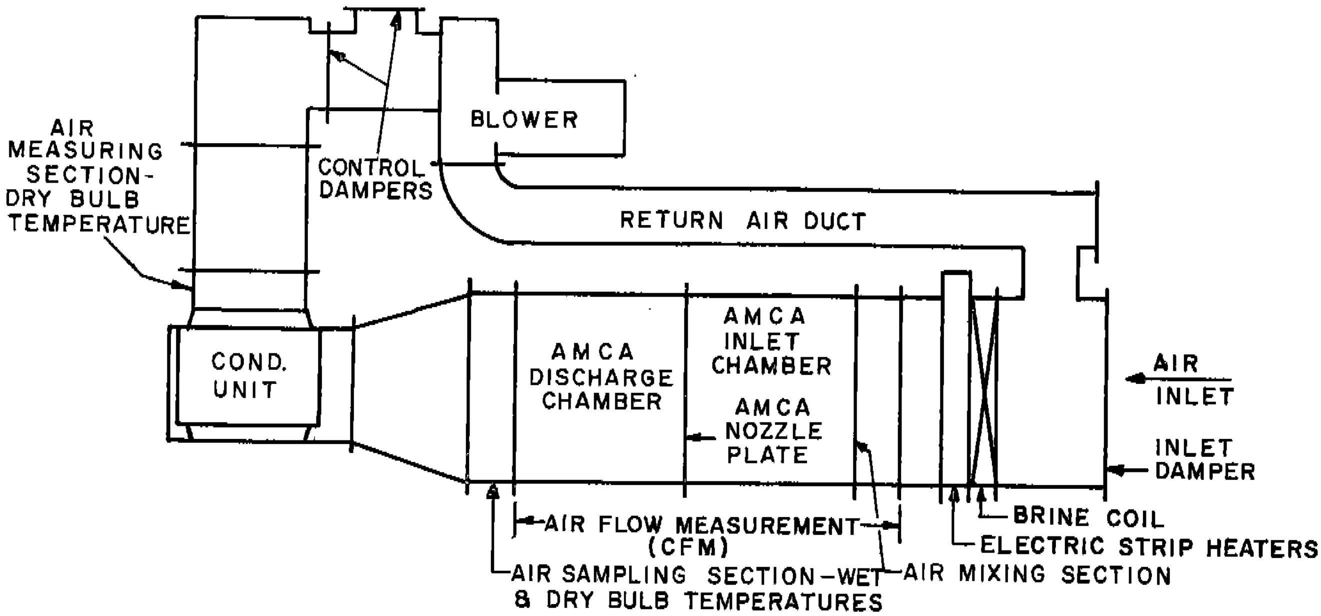

Figure 3. Condenser Test Loop

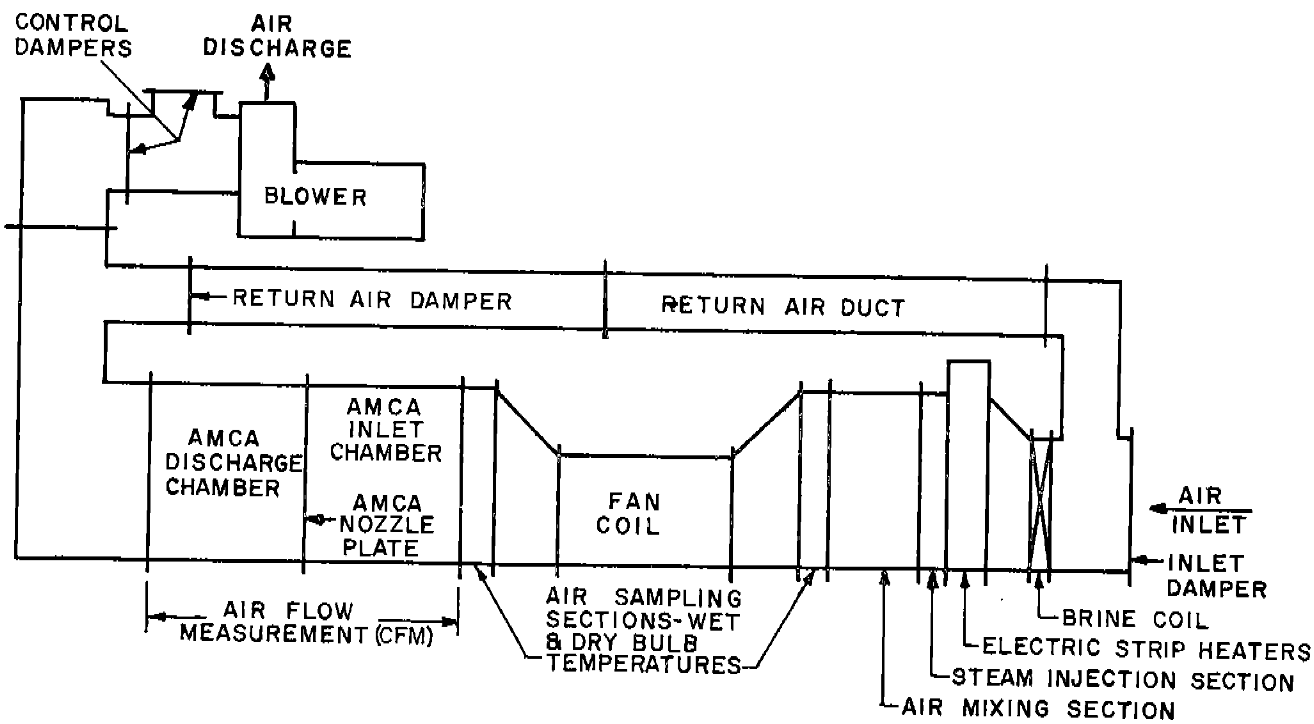

Figure 4. Evaporator Test Loop

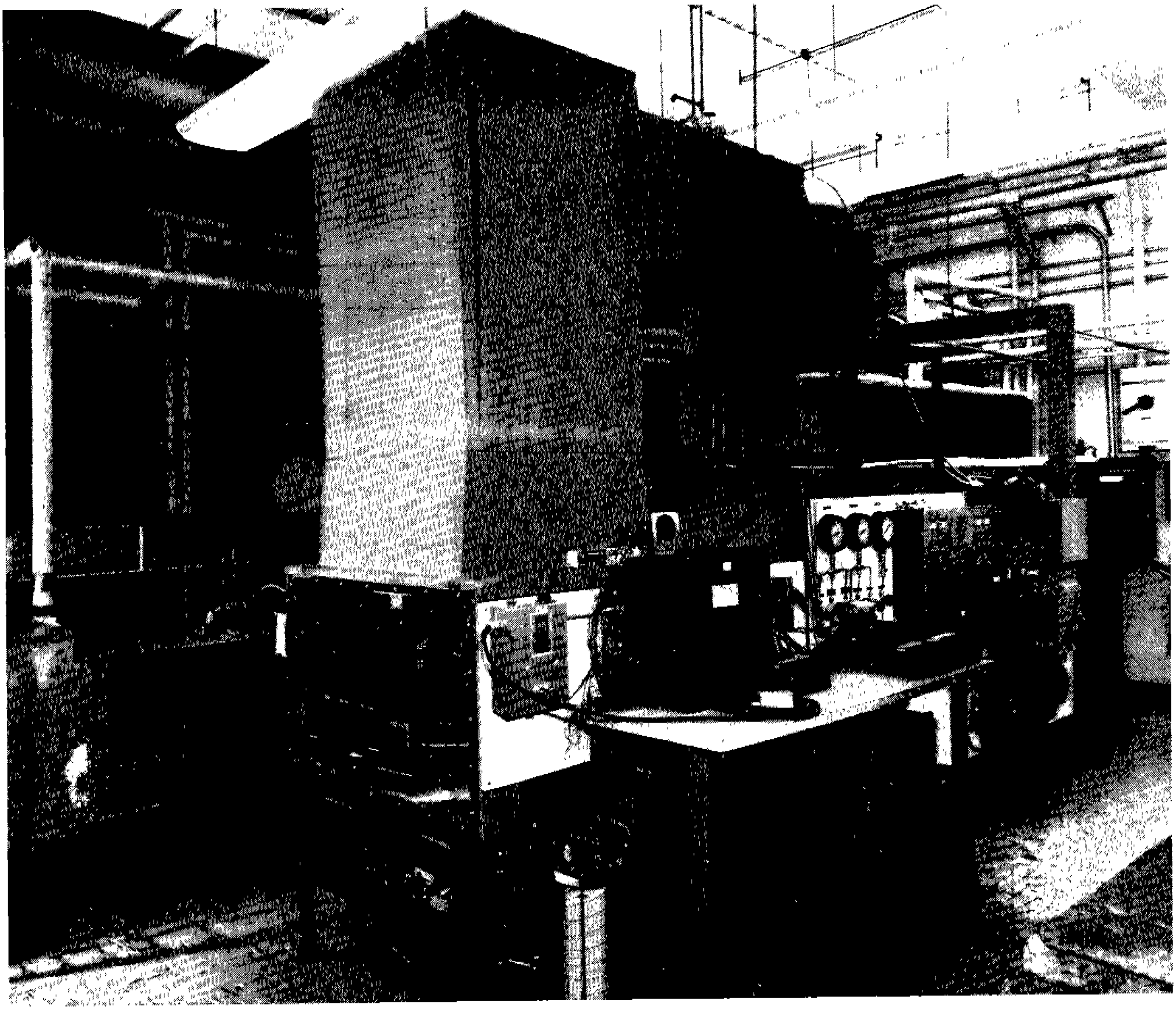

Figure 5. Actual Air-Side Test Loops

exchanger permits refrigerant flow in either direction and provides a method of controlling refrigerant subcooling. Suction superheat may also be controlled, either increased by means of a 20-foot section of suction line which is electrically heated, or decreased by injecting a measured stream of liquid refrigerant. A photograph of the evaporator loop, showing the coiled liquid refrigerant-brine heat exchanger and the coiled suction line heat exchanger, is attached as Figure 7.

Knowing the state and flow rate of the refrigerant leaving the evaporator, it is also possible, by injecting a measured stream of liquid refrigerant, to create a known two-phase condition at the compressor entrance. Included in the suction line just external of the compressor shell is a 10-inch long glass section, so that any two-phase flow condition may be observed visually. Sight glasses are also located at various points on the compressor shell so that the action of any liquid refrigerant entering the compressor shell may be observed. A photograph showing the suction line and compressor shell sight glasses is included as Figure 8.

Instrumentation

Several different instrumentation schemes are used for data acquisition, depending on intended data usage and necessary instrumentation response time. For steady-state information, such as system air temperatures, the data are recorded and monitored via thermocouples and a multi-channel recorder. For steady-state, high accuracy temperature requirements such as the heat balance to determine the refrigerant flow rate, .1°F accuracy mercury-in-

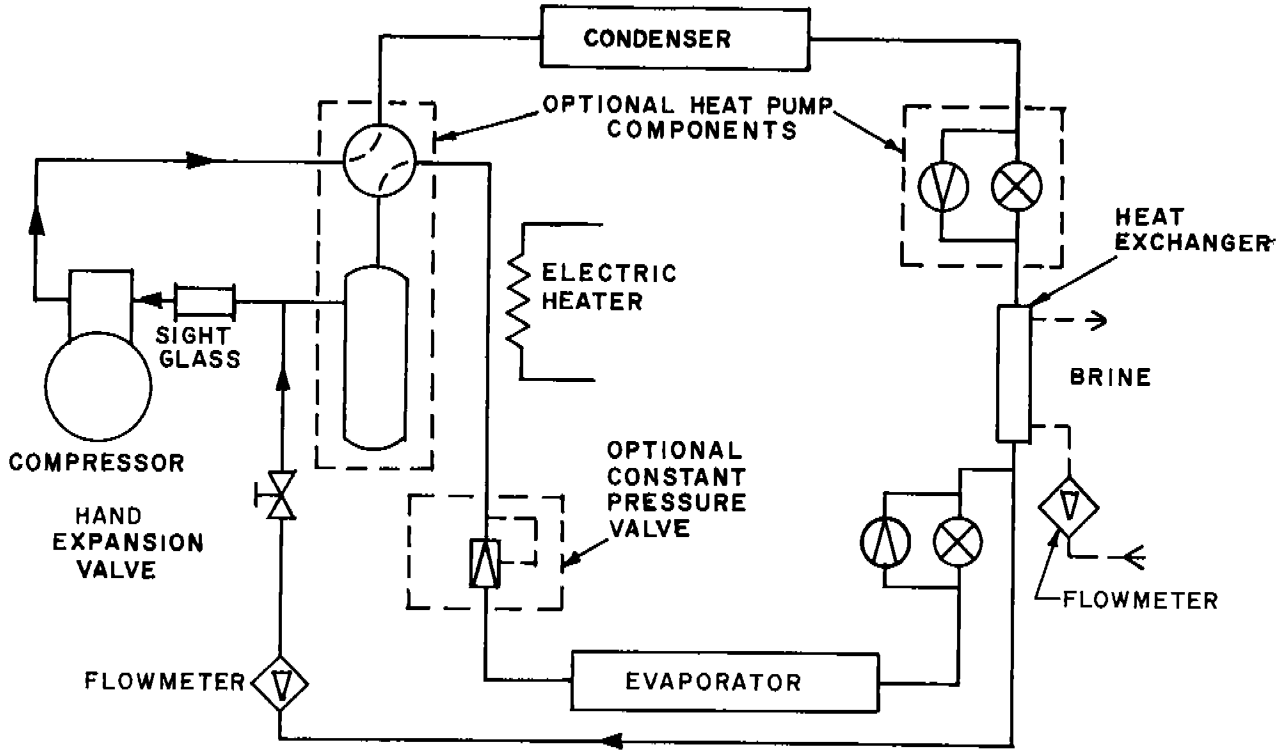

Figure 6. Refrigerant Piping Schematic

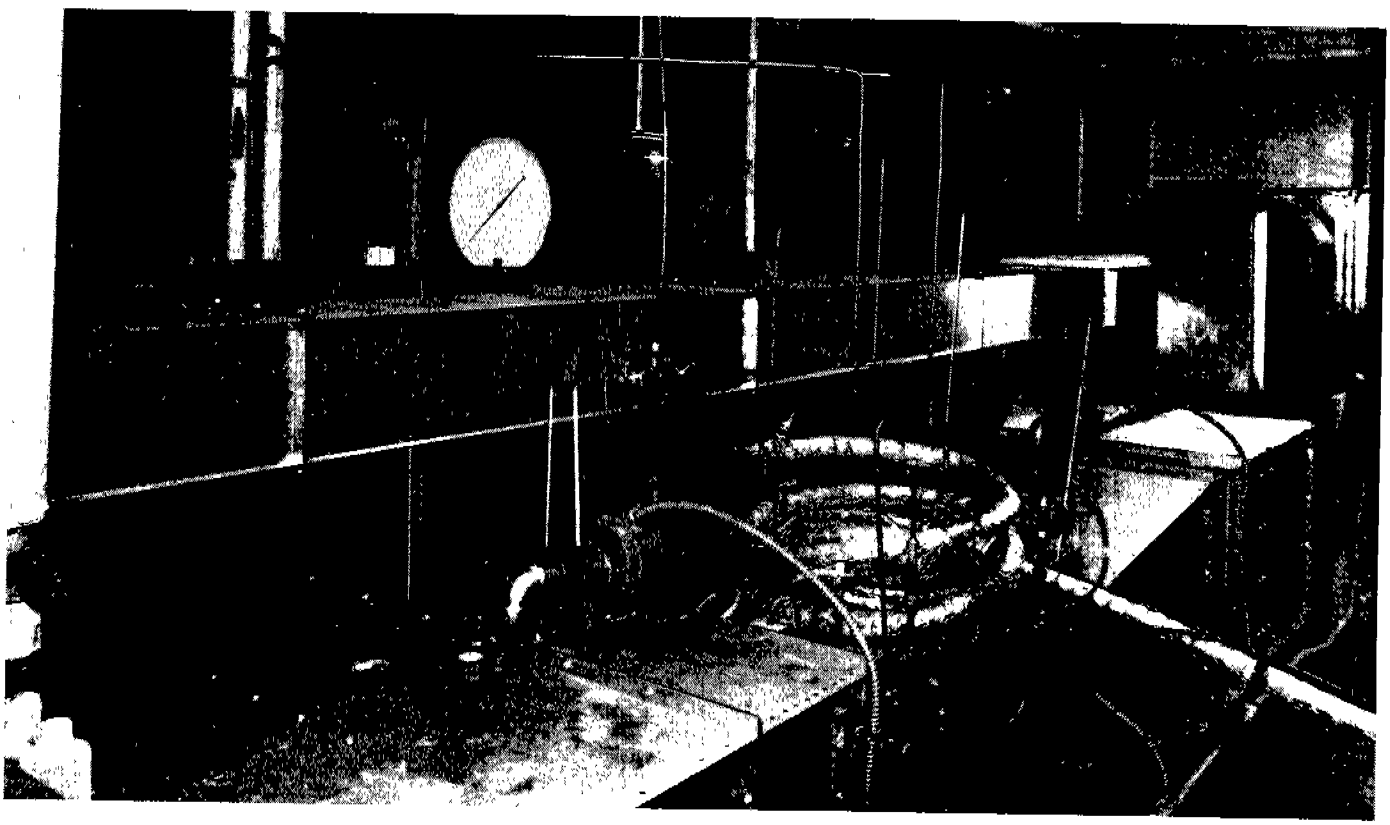

Figure 7. Evaporator Test Loop, Showing Coiled Liquid and Suction Line Heat Exchangers

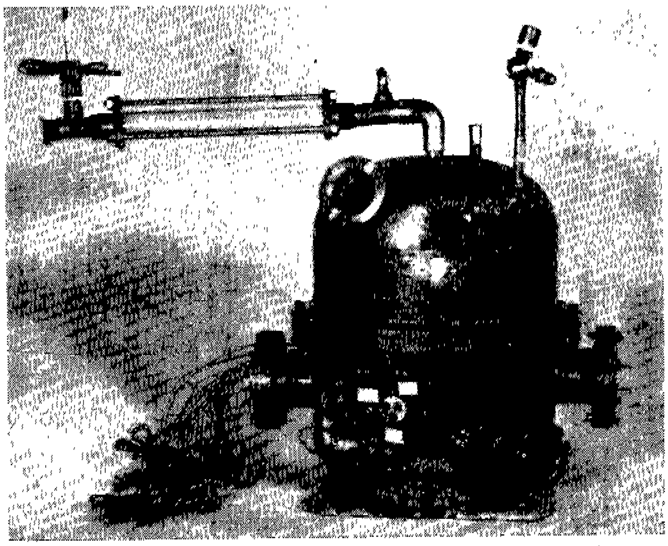

Figure 8. Test Compressor with Shell and Suction Line Sight-Glasses

glass thermometers are used and read visually. The high accuracy thermometers are immersed in 3-inch deep oil-filled wells, and are visible in Figure 7. Continually-varying refrigerant system pressures and temperatures are sensed via strain-gaged diaphragm pressure transducers and thermocouples, respectively, and recorded on a multi-channel high-speed oscillograph. For high frequency information such as cylinder pressures and manifold temperatures, the data are obtained using piezoelectric pressure transducers and fast response thermocouples, respectively; then, following signal conditioning, the data are recorded at high tape speed on a multi-channel FM tape recorder. The tape speed is then reduced to 1/10 or 1/100 of record speed, and re-played into a multi-channel oscillograph. A schematic of the instrumentation arrangement using the FM tape recorder is shown in Figure 9, and a sample of cylinder pressure data is shown in Figure 10. Figure 10 shows two cycles of the expanded data on the left, and several cycles of the real time data on the right.

The signal conditioning typically consists of amplifiers and D.C. suppression networks so that the full dynamic ranges of the tape recorder and oscillograph are utilized, yielding minimum noise and maximum accuracy. A photograph of the actual instrumentation set-up is included as Figure 11.

Use of the FM tape recorder permits accurate reproduction of high frequency signals, plus allowing one to record data over a long time span, but only transcribe to paper that data containing an unusual or important event.

FACILITY-RELATED TESTING

Testing with the facility includes such standard tests as determination of compressor capacity and power curves, and in addition, has been used to investigate the effect of liquid return on compressor operation. Included in the test facility is a variable voltage power supply for the compressor so that the effects of the line voltage variations can be factored into the determination of compressor characteristics.

Two types of liquid return have been investigated--continuous return as a two-phase suction flow with the compressor operating, and migration of liquid into the compressor shell with the compressor idle. The two-phase suction flow is obtained as previously mentioned, by injecting a continuous stream

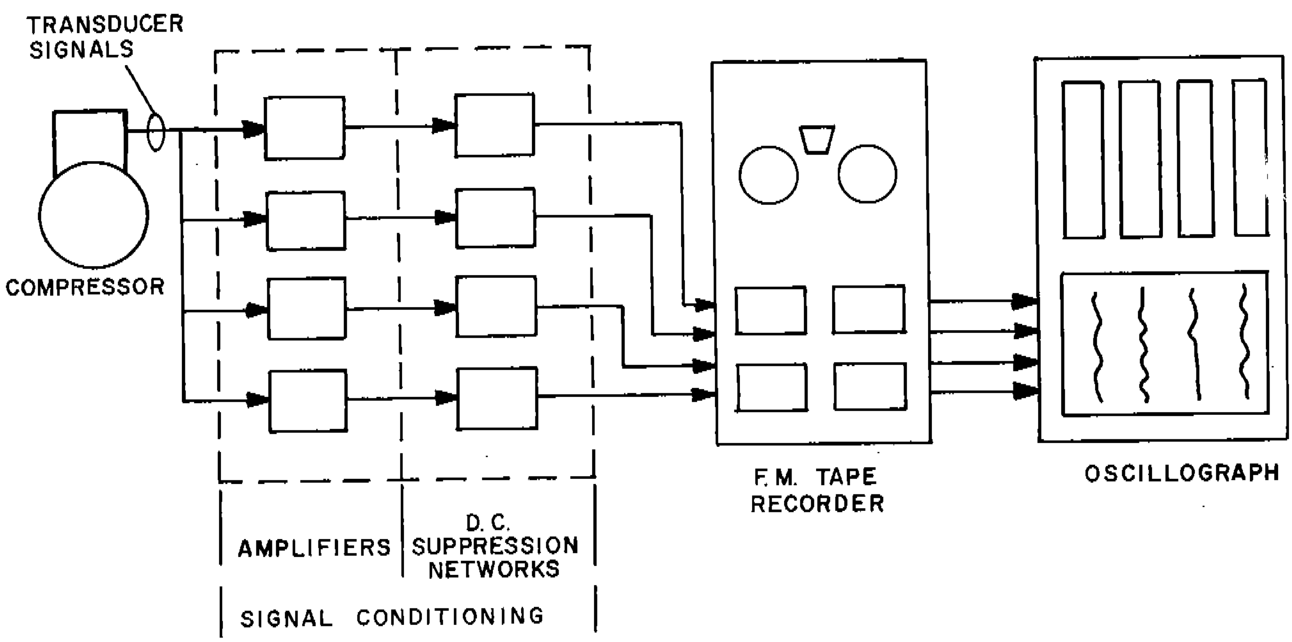

Figure 9. Instrumentation Schematic

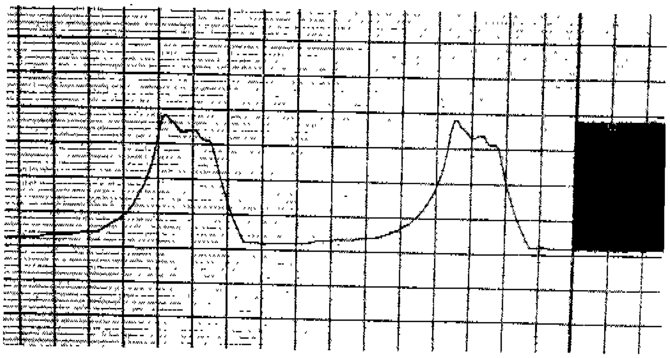

Figure 10. Example of Cylinder Pressure Data, Comparing Expanded Data on the Left to the Real Time Data on the Right

of liquid into the suction line. The quality of the two-phase mixture entering the compressor is determined by knowing the enthalpy and mass flow rate of both flows before mixing. The migration of refrigerant into the compressor shell on the off cycle is accomplished by reducing the temperature of the condenser air stream 10 to 15°F below that of the evaporator, and allowing the system to "soak" overnight. After the soak period, the condensing unit will be at a uniform temperature and will contain all of the available liquid refrigerant. By quickly raising the condenser air stream temperature a few degrees, all of the available liquid refrigerant will be driven into the compressor because of the compressor's large thermal mass, and, therefore, long time constant. Sight glasses in the compressor shell provide an indication of the amount of liquid stored in the compressor at start-up. Typical data recorded when the compressor is operating with liquid present might include motor winding temperatures and cylinder pressures. Additional testing performed with the facility involved

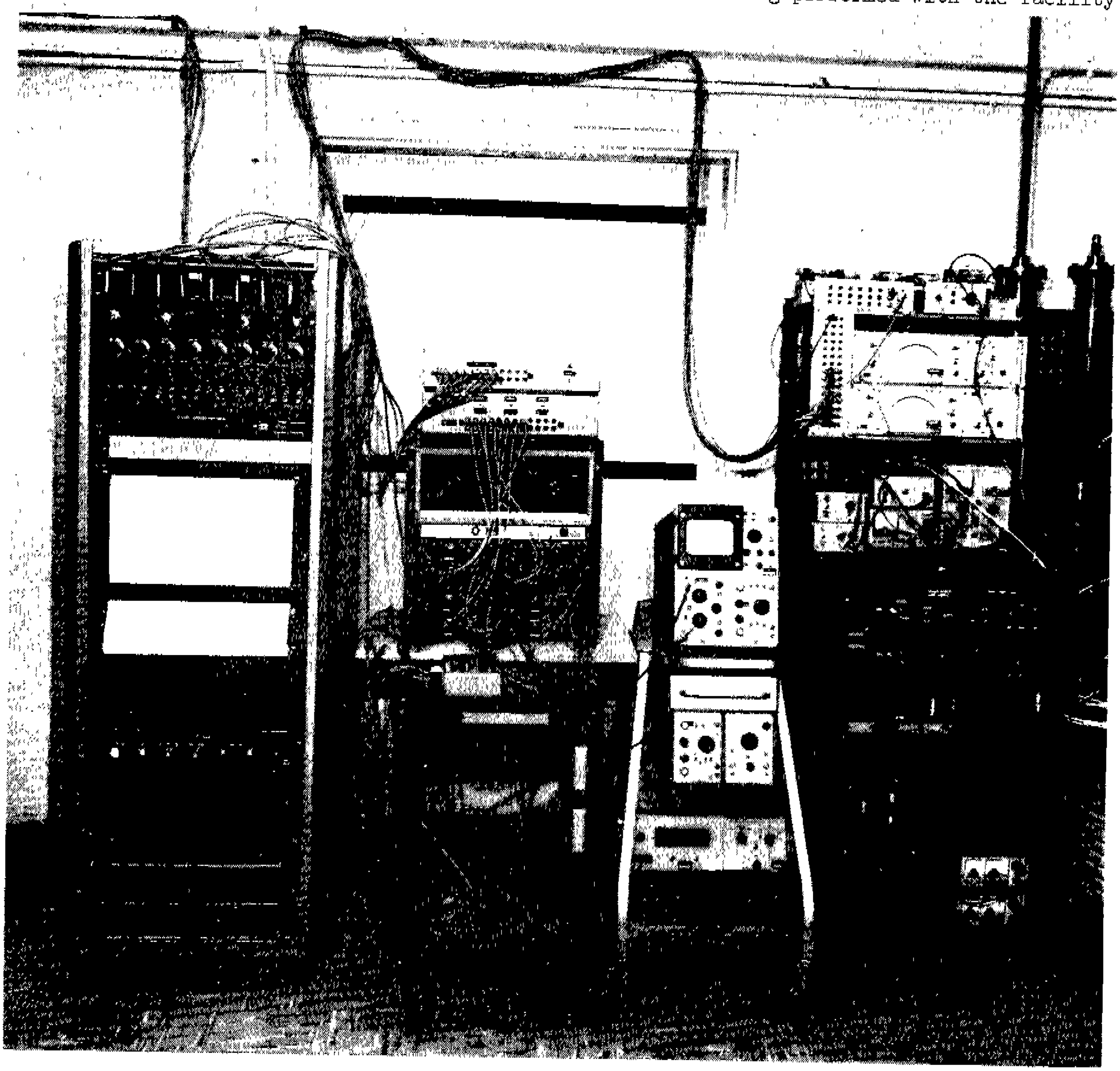

Figure 11. Photograph of Instrumentation Set-Up, Showing Signal Conditioning, FM Tape Recorder and Oscillograph

determining the time response characteristics of expansion devices. For instance, testing was performed to determine the time between compressor start-up and steady-state operation of a thermal expansion valve.

In general, the overall test facility has proven to be a useful and versatile tool. The facility provides accurate data, and while it is quite steady at any given operating condition, it is also quick to respond to new operating conditions. A last, but very important point, is the facility's ease of operation, so that new personnel are able to grasp its operation quickly.

REFERENCES

(1) Wile, D. D., "Air Flow Measurement In The Laboratory," Refrigerating Engineering, June 1947.

(2) AMCA Standard 210-67, "Air Moving and Conditioning Association," 1967.