1990

Development of an Operator-Controlled Compressor Load Stand for Liquid-Chiller Systems

R. W. Andrews
Purdue University

J. D. Jones
Purdue University

K. L. Koai
Purdue University

W. Soedel
Purdue University

F. Peacock
Purdue University

See next page for additional authors

DEVELOPMENT OF AN OPERATOR-CONTROLLED COMPRESSOR LOAD STAND FOR LIQUID-CHILLER SYSTEMS

R.W. Andrews, J.D. Jones, K.L. Koai, W. Soedel,
F. Peacock, J. Wood, J. Baer, R. Brown

The Ray W. Herrick Laboratories, School of Mechanical Engineering
Purdue University, West Lafayette, IN 47907 USA

ABSTRACT

A fully-condensing compressor load stand was recently designed and constructed at the Ray W. Herrick Laboratories of Purdue University for the purpose of loading a test compressor for noise and vibration studies. The load stand enables self-contained medium scale to large scale liquid-chiller systems to be operated at standard capacities for a variety of compressor operating conditions. Using automatic and manual instrumentation, the system parameters can be directly controlled to establish and maintain a variety of compressor operating conditions. Also, at a fixed operating condition, individual system parameters can be independently varied to incorporate sensitivity testing. Because of its high degree of stability, the load stand has enabled repeatable measurement of the acoustic and gas pulsation levels of the test compressor during steady-state operation of the liquid-chiller system. The load stand can also be used to examine the thermodynamic characteristics of the compressor (e.g., the influence of gas pulsations on compressor efficiency).

INTRODUCTION

Interest in screw compressor technology for liquid-chilling and refrigeration applications has steadily increased in recent years. The interest is motivated by the knowledge that screw compressors are of smaller size and weight, greater durability, and lower long term cost than the majority of current commercial compressors [1]. Yet due to the comparatively recent development of screw compressors, little is known about their sound and vibration characteristics.

The objective of this study is to design and construct a load stand that enables liquid-chiller systems to be operated at steady-state with a high degree of stability and repeatability. The salient objective is to identify the sound and vibration characteristics of semi-hermetic twin-screw compressors. A repeatable and controllable load stand is necessary to enable accurate measurement of the the system parameters and the compressor's sound and vibration characteristics. In addition, the load stand must be capable of varying individual operating parameters in the system at steady-state. This allows for sensitivity testing, which enables a correlation between a change in the system output and a change in the system operation condition.

DESCRIPTION OF THE LOAD STAND SYSTEM

There are in general two methods available for loading liquid-chiller systems: the fully-condensing load stand and the hot gas load stand. Regardless of the type of load stand used, the design must allow for a steady-state operating condition to be reached and held for the duration of an experiment. Currently, both hot-gas load stands and fully-condensing load stands are in use at the Herrick Laboratories. The fully-condensing type was judged to be superior for use in the present application because the large buildup of thermal momentum in this type of load stand results in increased system stability [2]. Increased stability was judged to be more important than reduced system response time, the major asset of the hot-gas load stand. It was not a primary concern to rapidly change the compressor operating conditions during testing. During sensitivity testing, the compressor operating conditions were periodically changed from one steady-state condition to another, but the transition time involved was not judged to be excessive.

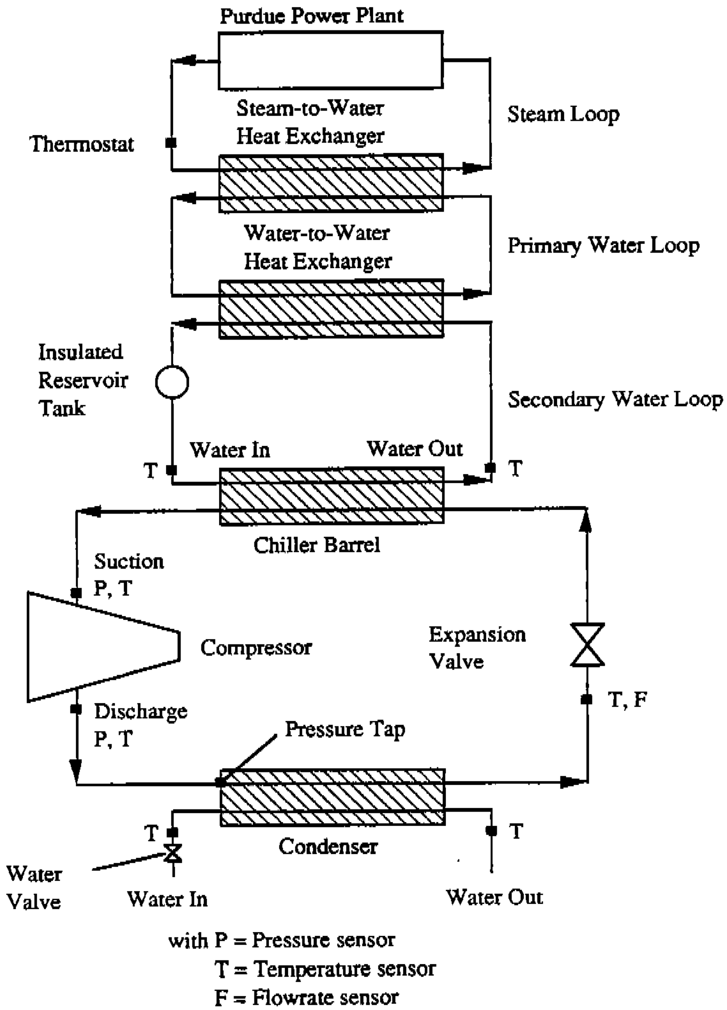

Figure 1. Schematic Diagram of Liquid-Chiller, Load Stand and Measured System Parameters

A schematic diagram of the load stand is shown in Figure 1. Two water loops were constructed to load the condenser and chiller barrel, respectively. The water loops were independent to eliminate the complex control problem encountered in single loop systems associated with cross-coupling between the condenser and chiller barrel. The water loop for the condenser was simple in principle and construction. As the compressor began operation, a pressure tap in the refrigerant system sensed the need for energy removal from the condenser. Consequently, a direct acting water valve upstream of the condenser automatically metered the water flow rate to maintain a preset condenser pressure. City water provided a virtually stable inlet temperature to the condenser, and the condenser pressure conditions could easily be modified by manually adjusting the direct acting water valve.

The chiller loop used to load the chiller barrel was necessarily more sophisticated in design. Steam from the Purdue power plant entered the load stand system and travelled through a steam-to-water heat exchanger. For safety and stability considerations, steam was not used to load the chiller barrel. In the steam-to-water heat exchanger, steam energy was transferred to a closed primary water loop, and the steam leaving the heat exchanger entered a steam trap before returning to the power plant.

The water in the primary loop left the steam-to-water heat exchanger and in turn transferred energy to the closed secondary water loop via a water-to-water heat exchanger. The bulk of the water in the secondary loop was stored during the cycle in an insulated reservoir tank which minimized energy losses and helped maintain a constant inlet water temperature to the chiller barrel. The water in the two loops was circulated by pumps, one for each loop.

OPERATION OF THE LOAD STAND SYSTEM

Initially, operation of the compressor and load stand involved activating the single phase power of the compressor's control circuitry. All safety features in the system became operable at that time, including low temperature control on the chiller barrel. The pumps in the primary and secondary water loops were then activated to initiate water flow through the chiller barrel. Activation of the compressor motor (utilizing three phase power) allowed both motor operation and the flow of water through the condenser. With motor rotation, compression and liquid chilling automatically commenced.

The operating capacity of the compressor conventionally is dictated by the load. The test compressor of the current study was hard wired with manual switches on the compressor's control panel that were used to maintain a specific compressor loading condition. Changes in capacity were accomplished inside the compressor using a slide valve. The valve position controlled the refrigerant flow rate. As the flow rate was reduced, the compressor load was correspondingly reduced.

The steam inlet thermostat shown in Figure 1 was then set to a desired temperature. The thermostat adjustment controlled the steady-state temperature of the water in the secondary loop which entered the chiller barrel. Raising the thermostat setting also allowed steam to enter the steam-to-water heat exchanger. This means of control allowed for a constant energy exchange across the chiller barrel during operation at any operating condition. With energy into and out of the system at a constant rate, the system could hold steady-state conditions indefinitely.

Adjustment of the discharge valve of the pump in the secondary water loop was able to vary the suction pressure from 65 to 85 psig. Unfortunately, by the time the system reached a steady-state, the maximum suction pressure was 75 psig. No higher pressures could be held because the system was unable to provide sufficient energy through the energy exchange system. An adjustment of the city water inlet valve was able to vary the discharge pressure from 140 to 310 psig. The lower limit was attained when the condenser was not taking any energy from the system, while the upper limit was based on safety considerations. Steady-state conditions in the system were defined as the time at which the system parameters (pressures, temperatures and the flow rate) varied about a fixed value within a tolerable range. In general, it took approximately 30 minutes to reach a desired operating condition.

MEASUREMENT SETUP

The present application of the load stand involves loading a 70 ton (840 kBtu/h) semi-hermetic twin-screw compressor at discrete load capacities of 50%, 75%, and 100%. Figure 2 shows a photograph of the test compressor.

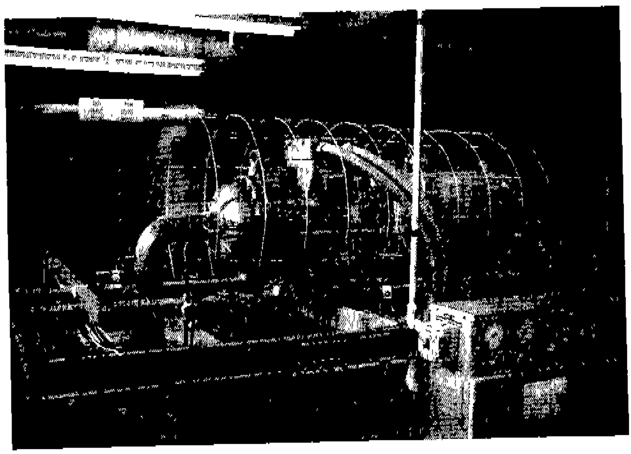

Figure 2. Photo of Test Compressor

During compressor operation, the liquid-chiller system's parameters were held at a steady-state for sufficient time (approximately 30 minutes) to perform two-microphone sound intensity measurement at 99 points in the compressor's acoustic near field. A conformal wire grid around the compressor segmented the surface area into 99 equal subareas to help facilitate the intensity measurements. Also, single system parameters of the load stand were varied during sensitivity tests.

Temperatures, pressures, and the refrigerant flow rate were measured at the locations in the system shown in Figure 1. Static pressure transducers were used to measure the suction and discharge pressures of the compressor. Thermocouples were used to measure the inlet and exit temperatures of the fluids in the compressor, condenser and chiller barrel. A Micromotion flow measuring device was placed in the chiller liquid line just before the expansion valve to measure refrigerant flow rate. The flow meter was able to verify proper operation of the compressor and also to detect a hunting phenomenon, which occurred when the system was undercharged.

RESULTS

Figure 3 shows the values of the refrigerant flow rate, the suction pressure and the discharge temperature of the compressor for a test at an operating capacity of 100% capacity. Each parameter reached the same independent steady-state value, dependent on capacity and the energy exchange in the system, regardless of the test run. This demonstrates the highly stable characteristics of the load stand. Note that it took approximately 60 minutes to reach steady-state from a cold startup.

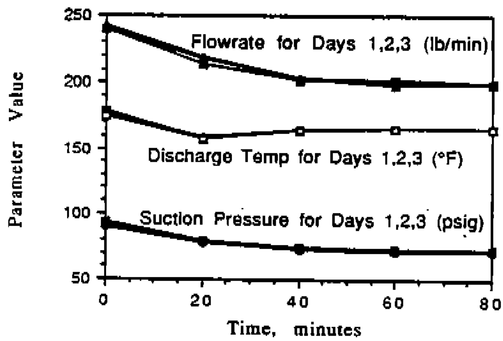

Figure 3. Selected Load Stand Parameter Time Histories at 100% Capacity

To further examine the performance of the load stand relating to acoustic repeatability, the sound power radiated by the compressor was measured at a representative load condition (75% capacity) in two identical tests. Figure 4 shows the sound power levels in 1/3 octave bands for the frequency range 315-2500 Hz and for the summation of all 1/3 octave bands. The sound power level levels were generated from a summation of the 99 sound intensity spectra measured over the grid surface. The measurement sets were performed on separate days to ensure that the measurements were independent. There was excellent repeatability in the sound power levels, especially the overall power, for the two tests.

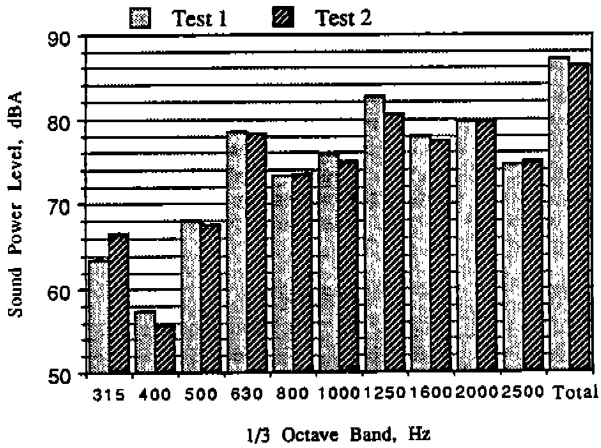

Figure 4. Acoustic Repeatability at 75% Capacity

The ability of the system to vary a single operating condition is shown in Figure 5. During one set of sensitivity tests, the discharge pressure was varied from 170 to 270 psig at 75% capacity. However, the flow rate, suction pressure, and suction temperature were maintained essentially constant even though the discharge pressure was varied substantially.

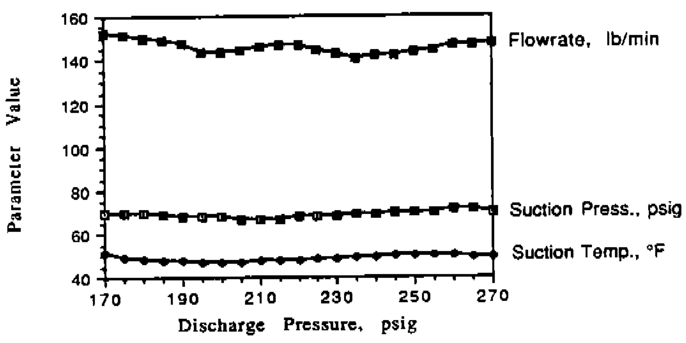

Figure 5. Parameter Sensitivity Test at 75% Capacity

CONCLUSIONS

A unique load stand system has been designed which enables large-scale liquid-chiller systems to be operated under a variety of desired steady-state operating conditions. The primary advantage of the load stand is that it provides the operator a controllable loading system in which select parameters can be varied independently to study their effects on the test compressor's radiated sound field. Also, the fully-condensing load stand has a high degree of stability due to the added thermal momentum of the refrigerant, which reduces fluctuations in the compressor operating conditions and subsequently the radiated sound field. Furthermore, although the current application focuses on sound and vibration considerations, the load stand could be easily further instrumented to study the influence of compressor operating parameters on the thermodynamic characteristics of the compressor (e.g., the effect of discharge gas pulsations of compressor efficiency).

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of this research by the Carrier Corporation, and the technical assistance of John Jacobs, Jack O'Brien, and Erric Heitmann of Carrier.

REFERENCES

[1] Ernst, S., Advantages of Screw Compressors. Heat Piping Air Cond (59) n 11.

[2] Hamilton, J.F., Measurement and Control of Compressor Noise. Ray W. Herrick Laboratories, School of Mechanical Engineering, Purdue University, West Lafayette, IN, 1988.