Vibration Related Testing for Hermetic Compressor Development

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INTRODUCTION

Hermetic compressor vibration is often interpreted as the steady state motion exhibited by the compressor housing during continuous operation. However, in reality, the most objectionable forms of compressor vibration occur during starting and stopping. During compressor startup, in some compressor applications, significant quantities of liquid refrigerant may be present in the compressor housing in the vicinity of the compressor running gear. The interaction of this liquid with the rapidly accelerating running gear can cause large unbalanced forces which result in a severe compressor vibration, as much as three to four times the amplitude of steady state vibration. When compressor shutdown occurs, the compressor running gear decelerates to zero speed in approximately three to four crankshaft rotations. This rapid deceleration causes the compressor to undergo angular accelerations resulting in a torsional "kick" to the compressor housing. If suspension components are not properly sized to absorb this reaction, two possible consequences exist. First, if the suspension is too flexible, the compressor may strike its housing and second, if the suspension is too stiff, the compressor torsional reaction will be transmitted to the attached system chassis. To better understand and minimize the above types of vibration, experimental test procedures have been developed to provide quantitative data to aid in the evaluation and selection of compressor components.

Closely related to the stop reaction vibration problem is the fatigue life of the suspension components selected to control compressor vibration at shutdown. Depending on the application, a spring cycle life of from 100,000 to 500,000 starting and stopping test cycles may be required to insure no spring failures during the life of the compressor. Because of the many experimental test cycles necessary to verify spring life, the number of spring designs tested extensively must be limited. To aid in selecting acceptable spring designs, an experimental method using comparative strain gage measurements has been employed as outlined below.

When the compressor is installed in a refrigeration system, vibration due to excessive discharge pressure pulsation may become important. To control this vibration, discharge mufflers must be designed to control gas pulsation amplitudes without seriously affecting compressor efficiency. Therefore, gas pressure pulsation must be accurately measured if optimum muffler designs are desired. To accomplish this, a measurement system is recommended which employs a semi-anechoic termination to minimize the erroneous affect of standing waves in the discharge line. With this measurement system, accurate, repeatable results have been obtained.

VIBRATION RELATED TESTS

In the following sections of this paper, four specific vibration related tests are described which can aid in the design of compressor components for both reduced vibration and increased reliability. Although these tests are most helpful in the design of single cylinder compressors, they may also serve as an aid to the vibration reduction of multi-cylinder compressors.

Compressor Starting Vibration

Compressor startup in certain applications can result in high vibration. One application where this problem exists is the room air conditioner in which the compressor may be exposed to cool evening temperatures during an extended off cycle. Since crankcase heaters are rarely employed in this application, significant quantities of liquid refrigerant will migrate from the relatively warm indoor system components to the cool compressor housing located outside. At startup, severe compressor vibration can occur until the liquid refrigerant is cleared from the housing.

To better understand the compressor design variables which can minimize this type of vibration, a repeatable test with quantitative data is required. To obtain a repeatable test, a laboratory calorimeter for measuring compressor...
capacity is recommended for use as the test vehicle. The test procedure is initiated by charging the compressor with its proper oil charge and a specified charge of liquid refrigerant. Two test variables, the housing bottom temperature and calorimeter condenser pressure are then adjusted to be consistent with a typical ambient temperature of 60°F to 65°F. Just prior to compressor startup the discharge line valve is opened with the suction line valve remaining closed throughout the duration of the test.

To measure the resulting vibration, an accelerometer with low pass filter is employed as shown in Figure 1. Then, using the storage mode of the oscilloscope, a permanent record is obtained for compressor acceleration versus time. Since the filter allows only the measurement of the fundamental running frequency of the compressor, the measured housing acceleration is proportional to housing vibration.

Figures 2 and 3 illustrate differences in the starting vibration characteristics of two different compressor designs, each charged with four pounds of R-22. Compressor A of Figure 2 has extreme difficulty in clearing and has yet to reach a steady state amplitude after the twenty second duration of the oscilloscope record. In contrast, Compressor B of Figure 3 has reached a steady state vibration level after only 8 - 10 seconds of operating time. The peak vibration amplitudes shown in both test results correspond physically to a low rumble sound.

The compressor startup vibration test has been used to compare different compressor models as well as design variations of a specific model. Tests made in actual room air conditioners have also correlated well with the calorimeter based tests described above. However, from the standpoint of testing convenience and high repeatability, the calorimeter based procedure is recommended.

Compressor Stop Reaction

Compressor stop reactions are of two basic types; those which contain metallic impact noise and those which do not. If metallic noise is present, the designer must first stiffen or redesign the compressor suspension system before a valid measurement can be obtained for compressor stop reaction. In the test procedure which follows, the presence of metallic impact noise was sufficient cause for both a discontinuation of the test and the disqualification of a specific suspension design.

To evaluate compressor stop reaction, a measurement system is required which allows both a comparison of different compressor types and design variations of a given compressor model. A key element of this measurement system is the 'standard' measurement platform shown in Figure 4. Basically, this consists of a compressor mounting plate attached to a heavy base plate with a standard rubber grommet mounting kit which includes steel sleeves to limit platform rotation. To measure the angular accelerations occurring during compressor shutdown, an accelerometer is attached to the platform in the tangential direction shown. Using the measurement system electronics of Figure 1, an oscilloscope record of stop reaction acceleration is obtained as shown in Figure 5. The maximum amplitude is then determined and testing continued until fifty stop reaction amplitudes can be averaged. This number of tests is necessary due to high variations in the severity of the stop reaction. Typical test data, for example, gave a minimum stop reaction amplitude of 0.4 g's, a maximum amplitude of 2.8 g's and an average amplitude of 1.3 g's.

The use of a "standard" measurement platform allows the comparison of different compressor types with varied mounting arrangements. Because of the inertia of the mounting platform, measured accelerations are not true compressor accelerations. However, for the purpose of comparison, measured accelerations are considered representative of compressor torsional reaction.

The severity of the measured stop reaction is dependent on both the compressor operating condition and the specific compressor design. In general, the higher the power requirement for a specific operating condition, the more severe the stop reaction. For comparison purposes, a high load test condition of 360 psig/80 psig/95°F suction has been utilized as a standard test point. Compressor stop reaction could be very sensitive to relatively minor variations in the stiffness and preload used in suspension springs. Measured stop reactions varied as much as 50% to 100% with these simple changes. Thus, the optimal selection of suspension components can be very helpful for controlling compressor stop reaction.

Suspension Spring Fatigue Life

Closely related to the severity of compressor start and stop vibrations is the fatigue life of the selected suspension components. Once appropriate springs have been selected to control vibration, the fatigue life of these springs must be established according to design criteria which generally specify a number of compressor start-stop cycles at a specific compressor operating condition. If the spring life criteria is not met, an iterative process must begin in which spring selection involves the simultaneous satisfaction of both vibration criteria and spring fatigue life criteria.

To establish spring fatigue life, a test procedure has been employed which provides a preliminary evaluation of the success or failure of a given spring design. This is done to limit the number of suspension designs actually placed on continuous start-stop life testing. Often this involves a number of compressors, each tested at more than 100,000 start-stop cycles.
The first stage of this preliminary test procedure involves determining representative stress levels for a given suspension spring design. To accomplish this, a number of strain gages are first installed at various locations of suspected maximum strain. Then the compressor is started and stopped at a typical load point to determine the maximum strain location point on the spring. However, since no attempt is made to determine maximum principal strains for the spring coil, the strain measurements obtained are only considered representative of maximum strain for a specific type of spring design. This prevents a direct comparison of measured strain levels to the known fatigue life of the material used for spring wire.

Having established an appropriate location for the measurement of spring strain, a correlation is next obtained between measured spring strain and actual spring fatigue life in an operating compressor. One method for doing this involves measuring spring strain levels in compressors with acceptable spring fatigue life and similar suspension design. This is reasonable since spring design variations often involve only minor changes to wire diameter and the number of coils employed. Once acceptable spring strain levels are identified, numerous spring designs can be evaluated for predictable fatigue life.

A typical suspension spring strain measurement at compressor shutdown is shown in Figure 6. To obtain a legitimate test sample, data from fifty compressor shutdown tests is required in determining the average of the maximum strain amplitudes obtained from each test. If this average is equal to or below the average strain obtained for the reference compressor, the design is considered acceptable and further testing is initiated to verify the design fatigue life. Good correlation has been obtained between actual spring fatigue life and that predicted with strain gage measurements.

Discharge Pressure Pulsation

With the increasing importance of high efficiency compressor designs, optimal discharge muffler designs are necessary to achieve a near peak compressor performance while controlling discharge pulsations to acceptable levels. The accomplishment of this objective requires an accurate measurement of discharge pressure pulsations.

Discharge pressure pulsation measurements are often taken on calorimeter or flowrater measurement systems which contain shutoff valves or oil separator vessels in relatively close proximity to the location of the pressure measurement transducer. The potential effect of these elements is the creation of standing waves due to reflections of the discharge pressure pulsation. When standing waves are present in the measurement system, the pressure pulsation measurement becomes highly dependent on the exact location of the pressure transducer. It is interesting to note that this problem does not appear on many laboratory calorimeters or flowraters. However, to avoid measurement errors in general, a simple addition can be made to the calorimeter or flowrater to acoustically decouple it from the compressor.

The discharge pulsation measurement system employed to eliminate measurement errors is shown in Figure 7. The essential feature of this system is the 150 feet of coiled tubing inserted between the compressor and the calorimeter or flowrater to effectively provide a semi-anechoic (non-reflecting) termination for the discharge pulsation. The use of this system is illustrated in Figures 8 and 9, which show respectively the same compressor discharge pulsation measured with and without the special termination device. Based on this example, discharge pulsation measurement errors greater than 100% are possible with some measurement systems.

SUMMARY

Several vibration related tests have been presented to facilitate the design of hermetic compressor suspension components. Specifically presented were test procedures for use in controlling compressor startup and stopping vibration as well as a procedure for preliminarily evaluating the reliability of suspension components.

As an aid to the design of compressor muffling systems, a method was presented for eliminating potential measurement errors for discharge pressure pulsation.
Figure 1. Startup Vibration Measurement System

Figure 2. Startup Vibration - Compressor A

Figure 3. Startup Vibration - Compressor B

Figure 4. Stop Reaction Measurement Platform
Figure 5. Stop Reaction Acceleration

Figure 6. Suspension Spring Strain

Figure 7. Discharge Pulsation Measurement System

Figure 8. Discharge Pressure Pulsation With Semi-Anechoic Termination

Figure 9. Discharge Pressure Pulsation Without Semi-Anechoic Termination