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HOW THE DESIGN OF THE SUCTION RETURN AFFECTS COMPRESSOR EFFICIENCY

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ABSTRACT

This paper describes a flow-visualization technique that was employed to qualitatively evaluate the gas flow pattern inside a small, low side, hermetically sealed, reciprocating refrigeration compressor. The applicable compressor designs are those in which the suction gas from the evaporator is dumped into the compressor shell, and is then drawn through a muffler into the suction plenum of the compressor. The physical separation of the muffler inlet from the suction gas inlet serves to reduce compressor noise and also provides an easy and convenient means of separating any liquid (compressor oil or liquid freon) from the freon gas.

For the flow visualization studies the compressor housing was replaced by a clear plastic shell. Atmospheric air, seeded with white smoke was the working fluid. The suction inlet and muffler were from a representative compressor. The flow pulsations were modeled by connecting the muffler outlet to the input plenum of an auxiliary compressor. The flow patterns in the vicinity of the muffler inlet were recorded with a video camera. The mixing of the inlet gas with the gas circulating inside the muffler was studied. The effect of alignment and offset of the muffler inlet relative to the suction inlet, the effect of muffler size, and the effect of a shroud around the muffler were studied. The results were used to guide a companion study of detailed temperature and pressure measurements inside an actual working compressor (see Ref. 2).

INTRODUCTION

This paper deals with the operating efficiency of small, hermetically sealed, low side refrigeration compressors. More particularly, it concerns the design of the refrigerant flow passages between the suction line leaving the evaporator and the intake manifold to the compression cylinder.

Theoretically, a simple, well insulated, direct connection between the suction line and the intake manifold would be the most efficient design. However, other considerations make the direct connection undesirable. Those considerations include noise propagation, the need to separate the compressor oil from the refrigerant gas, and slugging problems associated with start-up. In addition, the suction gas is used to cool the electric motor and compressor in some designs.

One popular design technique that is the base line for this study is to dump the suction gas into the compressor shell. The gas is then drawn into an acoustic muffler, through flow passages, and into the intake manifold. This design has the desirable characteristic of damping the compressor noise. The design also provides an easy solution to the liquid-gas separation need, and to the slugging problems.

For this design only a part of the suction gas entering the shell goes directly into the muffler. The remainder is "spilled," and circulates inside the shell, and is superheated by the relatively hot motor and compressor. Part of the superheated gas is drawn into the muffler on each intake stroke of the compressor, and is mixed with the unspilled flow. Theoretical estimates show that for the small compressor considered here, a 10F increase in suction gas temperature results in approximately a one percent decrease in compressor efficiency.

To study the flow pattern of the suction gas in transit between the suction inlet and the muffler inlet, flow-visualization was used. The flow pattern was recorded on video tape and compared for the following cases:

1. The muffler inlet in alignment with the suction inlet,
2. The muffler inlet misaligned relative to the suction inlet,
3. Different offset between the aligned muffler inlet and suction inlet,
4. The use of a shroud around the muffler to partially baffle the flow in the vicinity of the muffler, and
5. The use of a larger volume muffler instead of the standard muffler, with an increased inlet hole diameter and increased outlet passage diameter.

Reference 1 describes the flow-visualization study and also contains the video tape produced as part of that study.

In a companion study (Ref. 2), Meyer made temperature, pressure, flow rate, and power consumption measurements on a modified compressor to quantitatively evaluate the effects that are indicated by the flow-visualization study. That work evaluated the effect of misaligned muffler and suction inlet and the effect of a shroud around the muffler. A theoretical heat transfer and mixing model was programmed and the numerical results were compared with the measurements.

From the visualization results and the detailed measurements of Ref. 2, a flow mixing parameter, δ , is defined and estimated for the various geometries and flow conditions considered. δ is the fraction of unspilled flow so that a value of $\delta = 1$ represents no flow spillage (a direct connect). Measurements in Ref. 2 indicate that $\delta = 0.5$ is typical of off the shelf compressors. The flow-visualization studies indicate that values of 0.8 to 0.9 could be achieved by some design improvements.

FLOW-VISUALIZATION

Through flow-visualization, fluid flow patterns are made visible. Visualization of flow patterns in complex geometries can be extremely useful both for determining the regions where more detailed measurements are needed, and for evaluating the effect of geometry modifications.

Flow patterns of transparent fluids can often be observed, photographed, or recorded for detailed study by adding small, light scattering tracer particles to the fluid. Considerable creativity, skill, and experience are often required to select the tracer particles and introduce them into the flow so that they will faithfully follow, but not alter the flow and will illuminate the areas of the flow that are of interest.

The following items need to be carefully considered and are discussed below:

1. Choice and generation of tracer particles,
2. Method of introducing the tracer particles into the flow,
3. Method of recording the flow pattern, and
4. Flow similarity between the model and the actual flow situation.

The tracer particles should be visible to the detectors (usually the human eye and a recording camera), easily generated, and neutrally buoyant. Colored dyes are commonly used tracers in liquids whereas white smoke generated by vaporizing mineral oils are common in studying flow patterns in gases. Further considerations are discussed in Reference 3.

Introducing the tracer into the fluid flow requires control of the quantity, place, and method of adding the tracer particles to the flow. In this study, oil sprayed over a strip heater from a pressurized container vaporizes on contact with the heater, generating smoke.

The flow patterns were recorded on VHS video tape. The advantages of recording on video tape are:

1. The results are obtained without photographic delay,
2. The quality of the recording is determined immediately and may be repeated or recorded over if necessary,
3. Time dependent flow behavior for moderate speeds can be captured easily, and
4. It is relatively inexpensive.

The flow-visualization study was conducted on a qualitative model of the actual compressor in order to study the flow pattern between the suction inlet and the muffler inlet. The model consists of a rectangular, clear plastic shell that houses a non operational compressor motor and a standard muffler. A mixture of atmospheric air and white smoke is the working fluid, instead of freon used in the actual compressor. The discharge line from the muffler is connected directly to the suction plenum of an auxiliary compressor located external to the model.

The system is operated at atmospheric pressure. The auxiliary compressor draws air through the system at approximately the same volumetric flow rate as the actual compressor, and also simulates the pulsating flow conditions of the actual compressor.

Similarity considerations are an important part of all model testing. Geometric similarity between the model and the actual compressor is local, and is limited to the positioning of the muffler, the alignment of the muffler inlet with the suction inlet, and the design of the suction line leading to the suction inlet. The scaling is one to one in this case. Local geometric similarity is of primary importance especially for observing the effect of the muffler geometry on the flow pattern and flow mixing.

The flow through the suction inlet in both the model and the actual compressor was turbulent and unsteady. The average Reynolds number in the suction line was about 5,600 for the model and about 11,200 for the actual compressor. The frequency of pulsation of the suction valve is 60 cycles per second and is the same for the auxiliary compressor and the actual compressor. Also, fluctuating pressure exists at the muffler inlet in both the model and the actual compressor. Hence, a qualitative comparison can be made between aligned and misaligned components of both the model and the actual compressor and the effect of geometric changes can be qualitatively evaluated.

EXPERIMENTAL SETUP

The flow-visualization setup consists of the following components:

1. The clear plastic (lexan) shell and contents,
2. Dividing head,
3. Smoke generation box,
4. An auxiliary compressor, and
5. Video system.

A photograph of the setup is shown in Fig. 1, and a schematic diagram is illustrated in Fig. 2. The suction inlet is located on the front face of the lexan shell. The shell can be moved horizontally by operating the wheels of the dividing head. The movement is possible front to back and vice versa, and left to right and vice versa. The muffler support is independent of the shell. By moving the shell, the alignment of the suction inlet relative to the muffler inlet can be changed. Vertical alignment can be varied by moving the muffler up or down.

Smoke is generated by vaporizing W-D 40 oil, sprayed from a pressurized container, over a 300 watt, 1200F strip heater. The operation of the auxiliary compressor causes a mixture of smoke and air to be drawn in through the suction inlet from the smoke generation box via the suction line.

The video camera is positioned 2 to 3 feet from the setup and is focused on the vicinity of the muffler inlet. The flow pattern for each test is recorded on video tape for several smoke concentrations. The smoke is cleared from the lexan shell and a fresh mixture of air and smoke is generated for each recording.

Two mufflers of different sizes were used. The standard muffler was used in the first ten tests. A larger muffler was used in the remaining four tests. The larger muffler is geometrically similar to the standard muffler, but is approximately 2.5 times larger in volume. The inlet hole diameter is about 1.7 times that of the standard muffler. In both cases, the flow entering the inlet hole separates into two branches and flows downward toward the outlet passages as shown in Fig 3. In the actual compressor, any liquid freon and traces of compressor oil are separated from the gas by gravity during the process of branching. The separated liquid drains into the compressor oil at the bottom of the shell.

In the flow-visualization study, a clear plastic shroud around the muffler was used to partially contain the flow. The shroud is 3.875 x 3.0 x 1.0 in^3 in volume and covers the muffler on all but the bottom and front sides. In the operation of an actual compressor a smaller shroud made out of a chemically inert and heat insulating material was used (see Ref. 2).

TEST RESULTS

Fourteen different configurations were investigated in this study as listed in Table 1. The five different parameters that were varied are: the alignment of the muffler inlet and the suction inlet, the offset of the muffler inlet from the compressor shell, the size of the muffler, the use of a shroud to baffle the flow in the vicinity of the muffler, and the diameter of the muffler outlet passage. Table 1 lists the five parameters for each of the tests along with an estimate of the flow mixing parameter δ, defined as the fraction of the inlet gas that enters the muffler without mixing with the gas inside the compressor shell. Thus,

$$\dot{m}_{tot} = \dot{m}_{sp} + \dot{m}_{dir} \qquad (1)$$

$$\delta = \frac{\dot{m}_{sp}}{\dot{m}_{tot}} = 1 - \frac{\dot{m}_{dir}}{\dot{m}_{tot}} \qquad (2)$$

If it is assumed that the spilled portion of the gas is heated to the shell gas temperature before it enters the muffler, and that the specific heat of the gas does not vary over the temperature range, then from an energy and mass flow balance on the gas entering the muffler one obtains,

$$\delta = \frac{T_{circ} - T_{muf}}{T_{circ} - T_{suc}} \qquad (3)$$

where T_{circ} is the temperature of the gas circulating inside the compressor shell, T_{muf} is the temperature of the gas mixture entering the muffler, and T_{suc} is the temperature of the suction gas entering the compressor shell.

The values of δ were calculated from Meyer's measurements (Ref. 2) for test A, B, I and J. The δ values for the other runs, for which there is no data, are estimates based on the observed flow patterns. The higher the value of δ , the less the amount of spilled flow. Hand drawn sketches of the flow patterns observed for tests A, B, I, K and L are shown in Fig. 4, Fig. 5, Fig. 6, Fig. 7, and Fig. 8 respectively.

The flow patterns indicated less flow spillage for aligned than for misaligned components. The use of the shroud around the muffler proved to be an asset in further restricting the range of flow circulation. The larger muffler was seen to have less flow spillage when compared to the standard muffler.

CONCLUSIONS

From a qualitative analysis and comparison of the observed flow patterns the following conclusions are drawn:

1. There is a significant amount of spilled flow, turbulent mixing, and heating of the suction gas in the compressor under normal operation,
2. Any relative misalignment of the suction and muffler inlets greatly increases the amount of spilled flow and suction gas heating,
3. A simple shroud around the muffler can be effectively used to contain the suction gas spillage in the vicinity of the muffler inlet for either aligned or misaligned components,
4. Increasing the size of the muffler and the diameter of the muffler inlet hole are effective in reducing spillage, and
5. It appears that the flow spillage can be almost eliminated by a combination of a larger muffler, a larger muffler inlet hole, and a well designed shroud. The effect of those changes on compressor noise was not investigated.

RECOMMENDATIONS

The three design changes that would reduce the flow spillage in a compressor of the type studied here are:

1. A larger hole diameter at the muffler entrance,
2. A larger muffler (volume), and
3. A well designed shroud around the muffler.

Any one of those changes should produce some improvement. A well designed shroud that closed-off the flow area between the muffler and the bottom of the compressor shell should yield additional benefits.

ACKNOWLEDGMENT

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REFERENCES

1. Srikanth, Ramanujam, "How the Design of the Suction Return Affects Compressor Efficiency", MSME, Purdue University, 1987

2. Meyer, W.A., "An Investigation into Heat Transfer Processes in a Small Hermetic Refrigeration Compressor", MSME, Purdue University, 1987.

3. Merzkirch, W., Flow Visualization, Academic Press, 1974.

Test	Alignment	Offset in.	Muffler	Shroud	Outlet in.	δ est.
A	Aligned	0.276	Std.	No	0.125	0.50*
B	Muffler L by 0.4 in.	0.276	Std.	No	0.125	0.25*
C	Muffler R by 0.4 in.	0.276	Std.	No	0.125	0.25
D	Aligned	0.787	Std.	No	0.125	0.40
E	Aligned	0.157	Std.	No	0.125	0.55
F	Muffler U by 0.4 in.	0.276	Std.	No	0.125	0.25
G	Muffler D by 0.4 in.	0.276	Std.	No	0.125	0.25
H	Muffler D by 0.4 in.	0.276	Std.	Yes	0.125	0.70
I	Aligned	0.276	Std.	Yes	0.125	0.80*
J	Muffler L by 0.4 in.	0.276	Std.	Yes	0.125	0.72*
K	Aligned	0.276	No. 2	No	0.250	0.70
L	Aligned	0.276	No. 2	Yes	0.250	0.90
M	Aligned	0.276	No. 2	No	0.125	0.65
N	Aligned	0.276	No. 2	Yes	0.125	0.87

* computed from measured Temperatures in Reference 2.

Table 1: Summary of Flow-visualization Tests

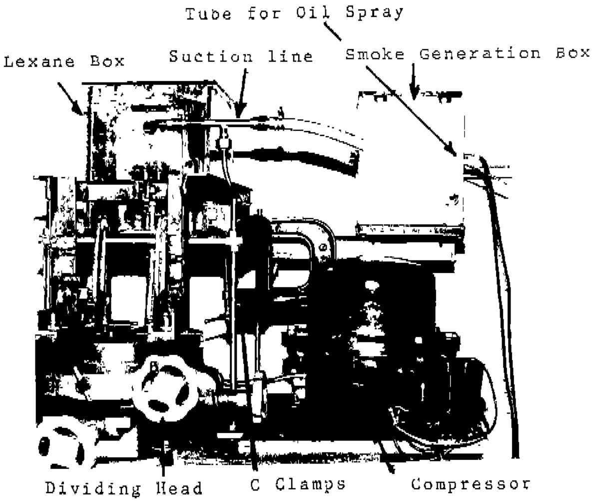

Fig. 1 Experimental Setup

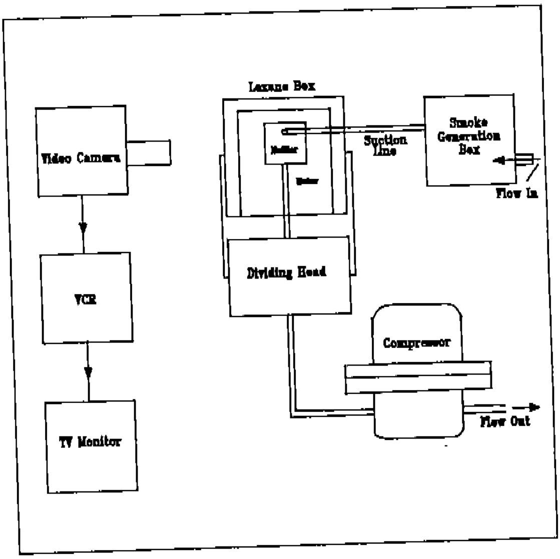

Fig. 2 Components of the Flow-visualization Setup

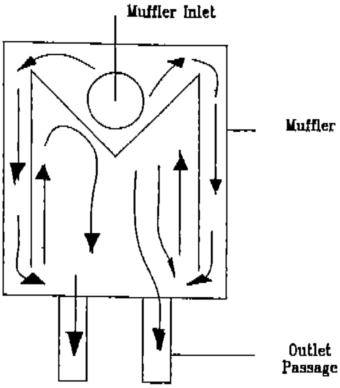

Fig. 3 Flow pattern inside the Muffler

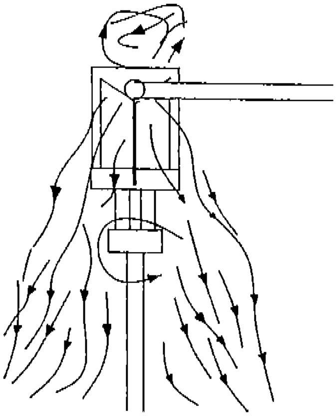

Fig. 4 Test A- Muffler Inlet aligned with the Suction Inlet

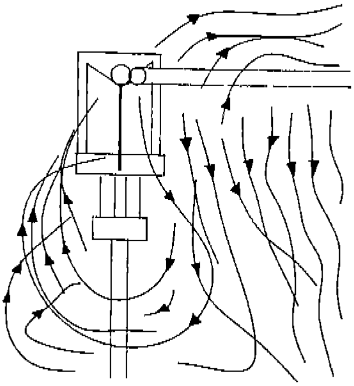

Fig. 5 Test B- Muffler Inlet left of the Suction Inlet horizontally

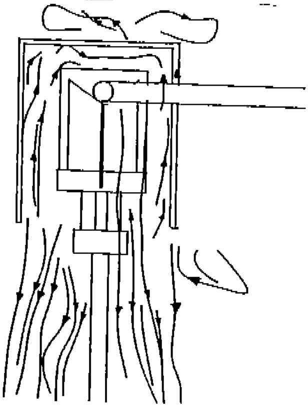

Fig. 6 Test I- Muffler Inlet aligned with the Suction Inlet with the Shroud around the Muffler

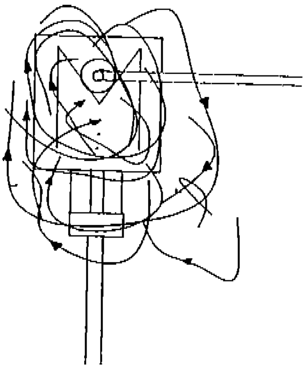

Fig. 7 Test K- Larger Muffler with Inlet aligned with the Suction Inlet

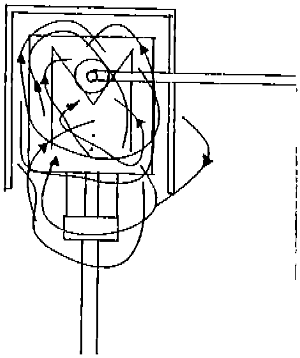

Fig. 8 Test L- Larger Muffler, Inlet aligned with the Suction Inlet, and Shroud around the Muffler