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CHANGES IN SOUND CHARACTERISTICS OF ROTARY COMPRESSOR WITH RUN TIME

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ABSTRACT
Whether or not compressor sound level changes with run time is of importance from quality control and field application standpoints. While it is a widely accepted notion that compressor run time normally helps improve sound, studies on this particular subject is scarce. This paper examines if rotary compressor sound indeed changes with run time and, if does, how does it change. Not only overall sound level but also change in different frequency bands are characterized in this study presented. Certain frequency bands are more sensitive than others to compressor run time. Significance of run time, life test condition, compressor sound with loss of performance and other parameters are discussed.

INTRODUCTION
As today’s consumers anticipate good product performance from air conditioners in the highly competitive industry, there is little room for marginally performing products. Thus, manufacturers face ever-increasing pressure in meeting the anticipation. It includes performance (capacity and energy efficiency ratio, EER) and sound among other things. While capacity and EER are readily comparable, sound comparison among different competitive compressors or units is not so. With this being the case, a particular consumer will normally not be able to judge cooling capacity or unit efficiency if the unit provides comfort to his satisfaction. As far as product performance is concerned, measurement yardstick is relatively objective. Manufacturers, industry association and government bodies are more specific in performance anticipated or required. In a simple term, performance criteria is objective while sound is subjective.

On the other hand, the yardstick for sound is a more complicated matter. As far as sound is concerned, the person makes the judgment either the unit sound is acceptable or not. This is the case despite the fact that it is not simple to define what constitutes an acceptable criteria. As compressor sound is altered - either attenuated or amplified when it is installed in the air conditioning unit in final job site, what was known as original compressor sound is not usually what the ultimate consumer hears.

SOUND CHARACTERISTICS & ACCEPTANCE CRITERIA
Many factors affect how a person reacts to particular sound of an air conditioner. House structure, size of the space to be cooled, internal condition such as carpet or hard surface and even people of different geographical parts make difference in threshold of tolerance in sound. Sound acceptable to one person may not be so to another. Thus, establishing absolute acceptance criteria that can be applicable to every person is complex to say the least and a dream of engineers.

Sound characteristics is determined by its frequency spectrum. While all-pass (AP) figure is an indicative of an overall measure of sound level, sound characteristics or frequency spectrum is often a more critical issue than AP value. Existence of pure tones normally disturbs human year more than absolute AP sound level and it can be a sufficient ground for objection. For this reason, compressor sound is normally checked in all-pass, third-octave and narrow-band along with vibration measurements.

COMPRESSOR RUN-IN EFFECTS ON COMPRESSOR SOUND
Compressor sound level often improves with “run-in.” This tendency can be verified by comparing initial sound level and that after running the compressor for a time period. In order to study the run-in effects on rotary compressor sound, a random population of 128 compressors with capacity range of 5,000 - 29,000 Btuh is examined here. The compressors have gone through a battery of reliability tests for “design-life-and-beyond.”

Out of 128 cases, 9 cases or 7% had no change. While 44 cases or 34% did see increase, the remaining 75 cases or 59% saw decrease. When measurement error of +/-0.5 or +/-1.0 dBA is taken into account, the classification respectively becomes:
These statistics indicates that majority of compressors show either no change or decrease in sound - 85% of cases and 91% of cases for assumed measurement error of +/- 0.5 and +/- 1.0 dBA respectively. Again, the compressors have gone through reliability testing for duration considered to be design life, and in some cases beyond the design life.

**CHANGES IN SOUND CHARACTERISTICS**

**No Changes in All Pass** - One of other interest is if sound characteristics changes even if AP sound level remains same, i.e., no change. To answer this question, the cases of “no change” are examined. In average, performance (capacity & EER) changes vary within 1% of the original, changes in third-octave bands fluctuate mostly within +/-0.5 dBA, certainly within +/-1.0 dBA. Slight increase in 200-800 Hz bands and decrease in 1,000 - 10,000 Hz range do not constitute a definite tendency.

**Decrease in AP** - The group of compressors which showed AP decrease after life testing show more clear change. While the change tends to be equal or slight increase (<0.5 dBA) below 500 Hz band, there is clear tendency for decrease at 500 Hz and higher frequency bands. The change in the 1,000-8,000 Hz is about 1 dBA decrease in all frequency bands in the range [Fig. 1]. If we examine only those compressors which exhibited more than 1 dBA AP decrease, the tendency becomes more enhanced. The change in magnitude becomes almost doubled [Fig. 1A.]

**Increase in AP** - A small number of compressors which increased in AP sound level after life testing contrasts very well with those decreased AP sound level. There is general tendency to increase in most of bands. If we select only ones with more than 1.0 dBA AP change, the spectrum change in frequency bands is enhanced [Fig. 2] similarly as seen in Fig. 1 vs. Fig. 1A.

**LIFE TEST CONDITIONS & CHANGES IN SOUND CHARACTERISTICS**

To examine effects of life test condition on changes in sound characteristics, three among various life test conditions were selected: Blocked Fan (condenser fan off, cycling on overload protector); High Load (high suction, high discharge pressure); and High Delta Pressure (high pressure differential). Under the test conditions, test duration tends to enhance, in general, the extent of changes.

**Blocked Fan** - Under blocked fan condition tested for one week, decrease of 0.5 - 1.0 dBA in sound level occurred in 400 Hz and higher frequencies [Fig. 3]. The reduction further enhanced to 0.5 - 2.0 dBA for long (four-week) tested compressors in 160 Hz and up to 4,000 Hz bands. There is a tendency, though minimal, to increase for very low frequency.

**High Load** - Under high load, decrease of 0.5 - 1.5 dBA in sound level occurs in 500 Hz and higher frequencies. The reduction further enhanced to 0.5 - 2.5 dBA for long tested compressors [Fig. 4.]

**High Delta Pressure** - Under high delta pressure, decrease of 0.5 - 1.5 dBA in sound level occurs in 800 Hz and higher frequencies [Fig. 5.]. The reduction further enhanced with longer run time [Fig. 5A.]. Figure 5A compare reductions at 500, 1,000 and 2,000 hours of the testing.

**SOUND CHARACTERISTICS AT SMALL INCREMENT OF RUN TIME**

Sound characteristics being run time-dependent, we are interested in changes in frequency bands as well as in AP level. In order to examine the sound characteristics at different lengths of compressor run time, a 60 Hz/17,000 Btuh rotary compressor was sound tested at every 100 hours under the high load condition for a total of 2,000 hours.

Experiencing no change in capacity but gaining 2% in EER following 2,000 hours of running, sound level for selected frequency bands were examined. Sound level continues to drop at fast rate until 500 - 800 hours run time has been accumulated.

Considering test and measurement errors at every 100 hours for 2,000 hours, it is necessary to look at the changes from a macroscopic point of view. This can be done with trend analysis, example as shown also in Fig. 6. Basically the analysis takes out fluctuations. The trend analysis curves for the four peak frequencies are shown on Fig. 6. The curves shows earlier steep
changes followed by slower rate of changes, but they show continuous sound drop as time elapses. From the analysis, it can reasonably be seen that sound improve with run time.

**SOUND CHARACTERISTICS CHANGES FOR “FAILED” COMPRESSORS**

When a compressor degrades in performance, it is reasonable to expect changes in sound characteristics, but the question is how. Let's examine two cases where compressor performance degraded excessively - more than +/-5% of the original performance.

**Case No. 1** - In this case the 22,500 Btuh-50 Hz compressor ran under the blocked fan condition for a period of four weeks, which is considered to be at least several times of design life for the condition. Tear-down inspection of the compressor revealed heavy build-up of copper plating in all internal parts; roller ID/OD, bearing cap faces, shaft eccentrics and journals. Also upper bearing cap face showed gouging marks. This phenomena was a result of loss of moisture control in test unit along with exposure to excessive temperature. This hardware condition resulted in 17% capacity loss and 23% EER loss from the original performance. Though AP sound level did not increase (actually lowered by 0.6 dBA) sound spectrum changed drastically. There were as much as 5 dBA changes in certain frequency bands in opposite direction; -5 dBA reduction in one frequency bands and +5 dBA increase in another [Fig. 7.] Frequency bands 200 Hz above are all affected. Reduction is 400 - 3,150 Hz bands and increases are seen in high frequency bands, namely 4,000 Hz and above.

**Case No. 2** - In this case, the compressor (9,500 Btu-60 Hz) ran under high delta pressure condition for 500 hours, and failed due to loss of control in maintaining the required test condition. Bearings were scored resulting in 12% capacity loss and 13% EER loss from the original performance. Though AP sound level did not increase (actually lowered by 1.2 dBA) sound spectrum changed [Fig. 7A] more drastically than the previous Case No. 1. There were as much as 5 dBA changes in certain frequency bands in opposite directions; over 6 dBA reduction in one frequency band and over 6 dBA increase in another.

In both cases [Fig. 7 & 7A], the scale of vertical-axis has been changed by a factor of two or three to illustrate magnitude of the changes. Two cases cited here have shown that AP level does not necessarily tell the condition of a compressor. It is suspected that test condition does not determine how sound characteristics change, but hardware condition does.

**MECHANISMS FOR SOUND IMPROVEMENT**

The sound improvement results likely from smoothing out of rough machining edges, “shake-down” of mechanical assemblies, and better fitting of mating parts. Gas leakage through a generous passage and lowering over-compression of gas tend to help reducing sound. Compressor assembly with tight build-up tolerance increases sound.

**CHANGES IN SOUND vs. CHANGES IN COMPRESSOR EFFICIENCY**

Interest here is relationship between change in sound with time and that in EER. Figure 8 shows the relationship from the random samples examined, and insignificant correlation factor is readily seen in the figure.

**CONCLUSIONS**

Criterion for judging sound is relatively subjective than that for performance. Examining rotary compressors that have been life tested, the majority of compressors shows either no change or decrease in AP sound level. Compressors showing changes, either increase or decrease, exhibit certain pattern across the frequency spectrum. For different life test conditions, high frequency bands tend to decrease, and the changes enhance as testing accumulates more run hours. When a compressor is sound tested at every 100 hours for a total of 2,000 hours, sound is decreased most in the first few hundred hours. And sound improvement in high frequency bands seems to be a common thread for the majority of compressors examined in the study.
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**Fig. 1** Change in Sound Level for Group of Sound-Decreased Compressors

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**Fig. 1A** Change in Sound Level for Group of Compressors With More Than 1.0 dBA All-Pass Decrease

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**Fig. 2** Change in Sound Level for Group of Compressors With More Than 1.0 dBA All-Pass Increase
Fig. 3  Change in Sound Level After Blocked Fan Testing

Fig. 4  Change in Sound Level
After 2,000 Hours' of High Load Testing

Fig. 5  Change in Sound Level
After Testing Under High Delta Pressure

Fig. 5A  Effects of Run Hours Under High Delta Pressure
on Sound Level Change
Fig. 6 Sound Level Changes With Run Time at Different Frequency Ranges

Fig. 7 Change in Sound Level After Failing Under Four-Weeks' Blocked Fan Test

Fig. 7A Change in Sound Level After Failing Under High Delta Pressure

Fig. 8 Correlation Between Sound Level Change and EER Change