Experimental Study for Fault Diagnostics on Refrigeration Systems using the Acoustic Emission Technique

M. M. Abo Elazm, M. F. Shehadeh, A. Arabi

Abstract— This paper investigates the utilization of Acoustic Emission "AE" systems for monitoring faults of fans in refrigeration system. In this paper the AE counts analysis technique was implemented. A relation between Amplitude and AE hits (density of emission) was obtained in order to determine the behavior of the fault. The results showed that the fault noises are directly proportional to the AE emission with respect to the time. The results also showed that the measured AE energy produced during the fault is lower than that at the ideal case.

Keywords: Acoustic Emission, Experimental Study, Fault Diagnostics, Refrigeration.

I. INTRODUCTION

Refrigeration and air conditioning play a major part in the world economy. In the United Kingdom, for example, it accounts for around 15% of the total electrical energy consumption at a cost of £2500 million per year [1]. The environmental impact of refrigeration systems can be reduced by operation at higher efficiencies and minimum operating and maintenance costs.

Most of the large commercial and industrial refrigeration systems as well as the household refrigerators use the vapor-compression system (VCS). The basic components of VCS are the evaporator, compressor, condenser, and expansion device [2]. Evaporators are made in many different shapes and styles to fulfill specific needs, the most common style is the forced convection evaporator in which the refrigerant evaporates inside finned tubes, extracting heat from air blown through the coil by means of a fan.

A forced convection air evaporator is made up of a direct expansion coil, mounted in a metal housing. The coil is normally constructed of copper tubing supported in metal tube sheets with aluminum fins on the tubing to increase heat transfer efficiency. One of the most common faults in refrigeration systems is the sudden stop of the evaporator fan, which may result in an extreme damage for the food products, especially during transportation. Large commercial refrigerators usually hold tons of food products with extremely high cost, which raise the importance of the fast prediction of this fault [3,4].

In the last two decades, great progress has been made in the areas of condition monitoring techniques. The most convenient online monitoring technique is the Acoustic Emission [3-5].

Acoustic Emission (AE) technique has been demonstrated not only in inspection, but also in monitoring, detecting incipient failure and correlation between AE parameters and the different types of fault sources. This technique offers a great potential as a laboratory tool for the investigation of mechanisms under many circumstances. This paper is focusing on monitoring the fan of refrigeration systems.

II. ACOUSTIC EMISSION TECHNIQUES

Acoustic Emissions are stress waves produced by a sudden movement in stressed regions. The traditional emission sources are defect-related deformation processes such as crack growth and plastic deformation (Pollock, 2003) [5]. Typically, an AE system consists of one or more AE sensors, and a preamplifier (per channel), filter, and amplifier, along with measurement, display and storage equipment (AE processor). Acoustic emission is generally transient in nature, occurring in discrete bursts. AE systems process these bursts as AE "hits" by analyzing various aspects of the waveforms associated with each hit, one at a time.

The wave propagation throughout the structure can be listened and that technique is used worldwide for detecting and locating defects as they occur, across the entire monitored area, providing early warning of failure, in a timely and cost effective manner [5-7]. Acoustic emission (AE) is one of many technologies for health monitoring and diagnosis of rotating machines such as gearboxes. An experimental investigation was carried out to assess the effectiveness of AE in identifying seeded defects on helical gears. Additionally vibration analysis has been performed to study the effect of seeded defect on the vibration signature of the meshing gears [8].

III. EXPERIMENTAL PROGRAM AND METHODOLOGY

All the experiments were carried on an advanced commercial refrigeration trainer, shown in Figure 1. The trainer allows continuous refrigeration with the respect to smaller horsepower range. This trainer consists of three main sections: (1) Refrigeration Circuit, (2) Controls, and (3) Instrumentation. Moreover, the trainer is provided with fault switches that simulate different types of faults.

AE sensor type WSA sensors was mounted on the outer case of the evaporator as shown at Figure 2, the "a" stands for Alpha series of sensors.

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These sensors have a built-in amplifiers and a fairly flat frequency response but with two bands of relatively high sensitivity at around 100 kHz and 1000 kHz and they have an operating temperature from -65 c to175 oC. The surface was kept smooth and clean and silicone grease was used as couplet to fill any gaps caused by surface roughness and eliminates air gaps, which might otherwise impair AE transmission.

Figure 1a: Advanced Commercial Refrigeration Trainer (overview)

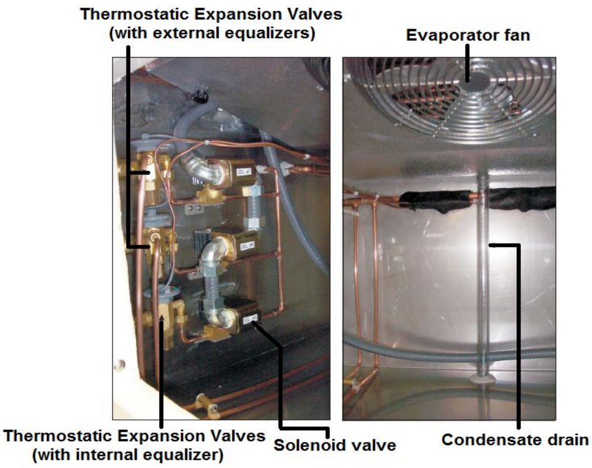

Figure 1b: Advanced Commercial Refrigeration Trainer (internal view)

The AE noise readings through the normal state of ideal running of the evaporator (Fan ON) were recorded with 10 MSPS during the all period of the test. The fault switches were used to simulate the fan stopping and the AE noise reading were collected with the same sampling rate. USB-AE Node acquisition systems have been used to collect these data. The USB-AE Node system shown in Figure 2 is a high performance, computerized Acoustic Emission (AE) system packaged in a small-anodized aluminium case. This USB-AE Node system has all the performance features (e.g, AE bandwidth, speed, AE features, sampling rates and waveform processing capabilities). In addition, the USB-AE Node system possesses one channel of AE with its internal 18-bit A/D conversion, up to 20 MSamples/second and 1.0 MHz signal bandwidth.

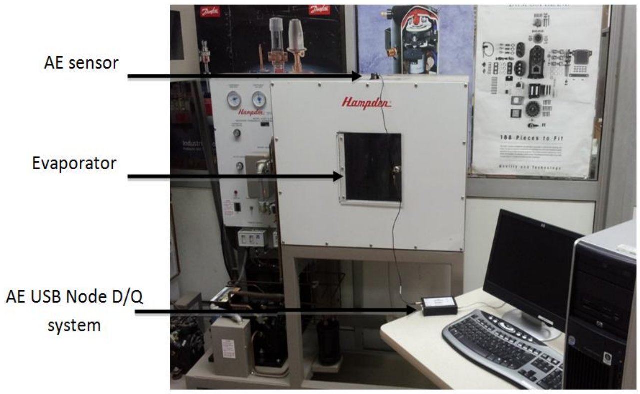

Figure 2: Experimental setup

IV. RESULTS AND DISCUSSIONS

The recorded data in the two cases were compared and analysis techniques are developed to extract significant features of the AE signal associated with real sources, based mostly on techniques using energy, time and frequency domain, AE count and conventional analysis.

A typical AE waveform is recorded for the AE noise and the FFT magnitude for the signal in the two cases, Figure 3. A Chebyshev I band-pass filter was applied at 10 kHz to 200 kHz to have good identification for the required signal. Figure 3 and figure 4 show that the two conditions have the same frequency band but with different amplitude amount. Figure 3 show that the ideal case (Fan on) gives higher amplitude than the other condition when the fan is off, as shown in Figure 4. As the level of noise decreases a secondary activity was noticed, some peaks are present at 150 kHz as shown in Figure 3b.

Simply measuring the area under the rectified signal envelope and adding the batches of energy for each of the relevant files together can calculate the AE energy. Accordingly, Figure 5 shows the AE energies for the entire test versus the rise time, and that gives a good definition of the system behaviour. Taking the steady zone shown in Figure 5, it can be noticed that, the AE energy is constant during the all period of the zone. But, it can be observed that the AE energy calculated at the ideal case is higher than the AE energy when the fan is not operating (fault condition).

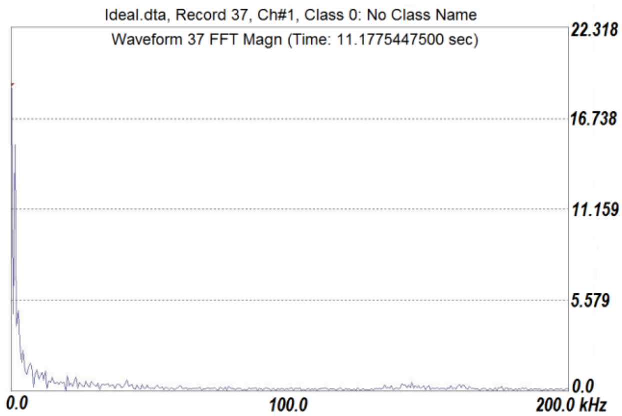

Figure 3: Waveform FFT magnitude for the ideal case (Fan on)

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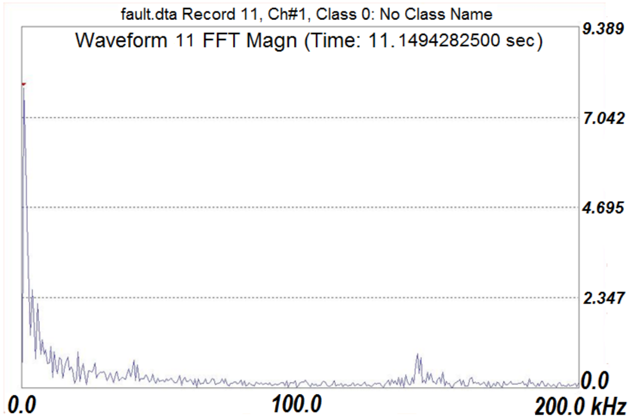

Figure 4: Waveform FFT magnitude for the fault case (Fan off)

Another worth mentioning note, a delay at the rise time for the AE signal in the fault case is observed comparing to the rise time at the ideal. The rise time is applied to classify the type of fault or eliminate noise signals as can be noticed at the other zones. The observed behaviour at the other zones is due to the noise of the operation of different components of the refrigeration system (e.g. solenoids, compressors and the condenser).

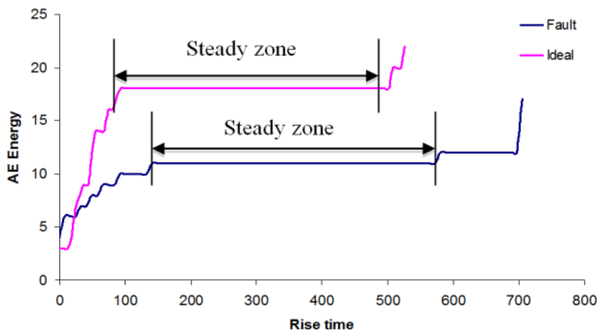

Figure 5: AE energy versus Rise time

In practice another characteristic is used more often which is called the AE distribution of counts as shown in Figure 6. This Figure shows the AE emission activity during the whole test and it can be observed clearly that the cumulative AE counts for ideal running case shown in Figure 6 are higher than the counts number produced by the fault case. That indicates that the AE emission at the first condition is greater than that of the second condition.

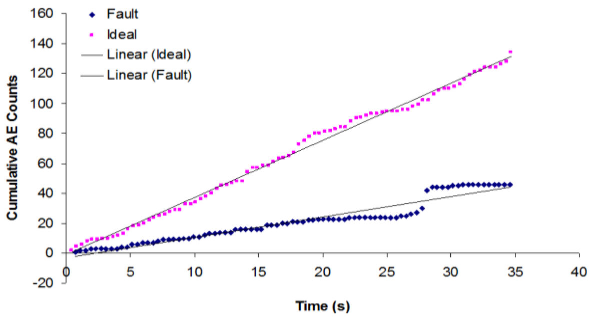

Figure 6: The cumulative AE counts versus Time

Figure 7 shows the relationship between the AE signal amplitude and vector (Hits). At the ideal running condition, two row of activity can be noticed. The first one has relatively low amplitude (about 35-40 db) with large number of hits. This activity refers to the operation noise produced by different components at the refrigeration system. On the other hand, the other activity has a higher amplitude level (about 70db) with high number of hits. This activity gives a good identification for the fan noise. Comparing the fault running condition behavior with the ideal condition as shown in Figure 7, it can be noticed that there is only one row of activity appears. The fan noise with the (70 db) amplitude disappears and the AE activity with the (about 35-40 db) only remains but with lower number of AE hits. At the fault case, lower level of noise emitted and that describes the remarkable decrease in the AE activity.

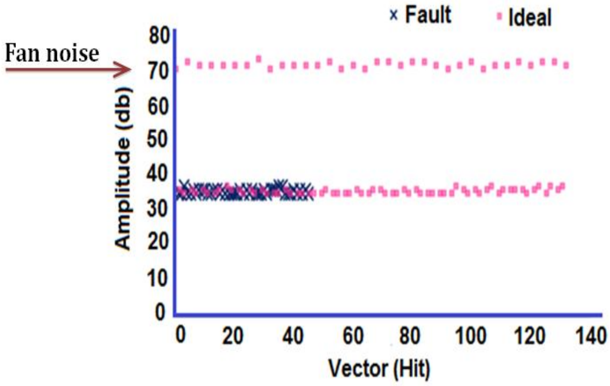

Figure 7: Amplitude versus Vector (hits)

Figure 8 shows that the two monitored readings are over lapping at the 35-40 db intervals. So, more investigations for these amplitude intervals were conducted as shown in Figure 8. At this figure a relation between the amplitude and the AE count were obtained. For these intervals, the AE counts are inversely- proportional with the amplitude. Moreover, the AE counts at the ideal case are greater than the number of counts at the fault case.

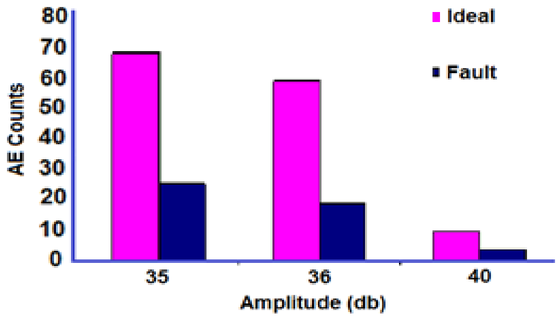

Figure 8: AE Count versus Amplitude

V. CONCLUSIONS

Acoustic Emission technique can be used as a successful monitoring technique for refrigeration storerooms as well as small commercial refrigeration systems. In the refrigeration system investigated it was observed that higher energy levels were produced under the ideal running conditions, this is due to the running of all elements in steady state, while the lower energy levels were produced by the fault condition case, i.e., the fan stop condition. A good classification for the fault type was maintained as a remarkable delay at the rise time for the AE signal was observed.

At the ideal running condition, two rows of activity were monitored (40 db and 70 db) while in the fault case only one raw of activity was observed (40 db). The density of the emission at the ideal case is higher than the density of the emission at the fault case and it is inversely proportional with the amplitude.

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