Vibration Measurment And Analysis of Two Reciprocating Machines

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Abstract

Vibration analysis is used as a predictive maintenance tool in a wide variety of industrial areas, especially for rotating and reciprocating machines. In this paper fault diagnosis of the reciprocating air compressor in factory for furniture and the radiator of the diesel engines for generating electricity is presented. The reciprocating air compressor had failures in the outlet pipe of stage one. The radiator of diesel engines was subjected to leakage caused by vibrating forces. In order to detect the faults, some vibration measurements were taken and vibration analysis was accomplished. Finally, according to measurements and vibration analysis results some remedial actions were recommended.

ملخص

يُعتبر قياس و تحليل الاهتزاز أحد أهم أدوات الصيانة بمراقبة الحالة CBM، التي هي من ضمن الصيانة التنبئية ، الصيانة المطبقة بشكل واسع في معظم أنواع الآلات الهامة ذات الحركات الدورانية و ذات الحركات الترددية . فمن خلالها يمكن تحديد مصادر الخلل في الآلة و في مرحلة مبكرة منه و قبل استفحال العطل ، مما ينعكس إيجاباً على المردود الاقتصادي للمنشأة التي تُطبق هذا الأسلوب من الصيانة على معدّاتها ذات الأهمية الخاصة . في هذا البحث تمّ تطبيق مفهوم الصيانة بمراقبة و قياس الاهتزاز بهدف تشخيص و تحديد سبب التسرب الحاصل في ضاغط هواء "ثلاثي المراحل" ، موجود في معمل كبير لتصنيع المفروشات . كما تمّ تشخيص و تحديد سبب العطل في مبرد الماء الخاص بمحرك ديزل لمولدة تيار كهربائي لدى أحد المصانع. خلال البحث تمّ قياس و تحليل الاهتزازت عند مجموعة من النقاط وفقاً للمعيار الدولي ISO 10816 . نتيجة لذلك فقد أمكن تحديد مصادر الخلل في كل من الضاغط والمحرك و بناءاً عليه تمّ اقتراح بعض الحلول الفنية التي من شأنها تخفيض الاهتزاز و بالتالي إزالة سبب المشكلة .

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1. Introduction

A major focus of industry is to gain the maximum working life of machinery and also minimize maintenance and operating costs [1]. It has long been accepted that condition-based maintenance is the most effective and cost-efficient approach to maximize the life of industrial machinery [2].Condition monitoring provides information on the health and maintenance requirements of industrial machinery and is used in a wide range of industrial applications. Parameters such as vibration, temperature, lubricant quality and power consumption can be used to monitor the mechanical status of equipment [3].

Vibration monitoring is the main condition monitoring technique for machinery maintenance and fault diagnosis that is used widely in predictive maintenance programs. Vibration signature of an operating machine provides far more information about the inner working of the machine than any other types of non-destructive test [4]. By measuring and analyzing the vibration of a machine, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure [1]. The overall vibration signal of a machine is originated from different machine parts and nearby machines to which it may be coupled. However, different mechanical defects produce characteristic vibrations at different frequencies, which can be related to specific machine fault conditions. By analyzing the vibration signals in time and frequency domains and using signal processing techniques, both the defects and natural frequencies of the various structural components can be identified.

In this paper, failures in outlet pipe of the reciprocating air compressor and leakage of the radiator of a diesel engine is investigated.

2. Fault Diagnosis of the Compressors

There are many types of compressors in common use, and their vibration signatures vary over a wide range. When monitoring compressor vibration, it is important that the operating conditions are uniform from one measurement to the next to assure consistent signatures.

In reciprocating machines, the piston rate (usually 1X) is dominant. Camshaft gear problems are also common, and can be seen by looking for the tooth mesh frequency. If harmonics of the piston rate are present in significant levels, it usually indicates a piston drive linkage problem [4].

2 – 1 Machinery Specifications:

The main machinery in the units are electromotor, compressor and cooling fan. The compressor has three stages with 115 cm stroke. The cooling fan has four blades. Other specifications are given in Table (1).

Table 1. Rotational Speed and Power of Electromotor, Compressor and Cooling Fan

Unit	Rotational Speed (rpm)	Power Hp(KW)
Electromotor	1500	180(132)
Compressor	900	-
Cooling fan	1200	10(7.5)

2 – 2 Vibration Measurement:

To evaluate the vibration in compressors measurements are carried out in 11 recommended points by the manufacturer. For evaluating the machine behavior vibration has been measured in another four points too. These points include compressor stages 1, 2 and three plus flange of stage 1 outlet piping. Some points are shown in Figures (1) .

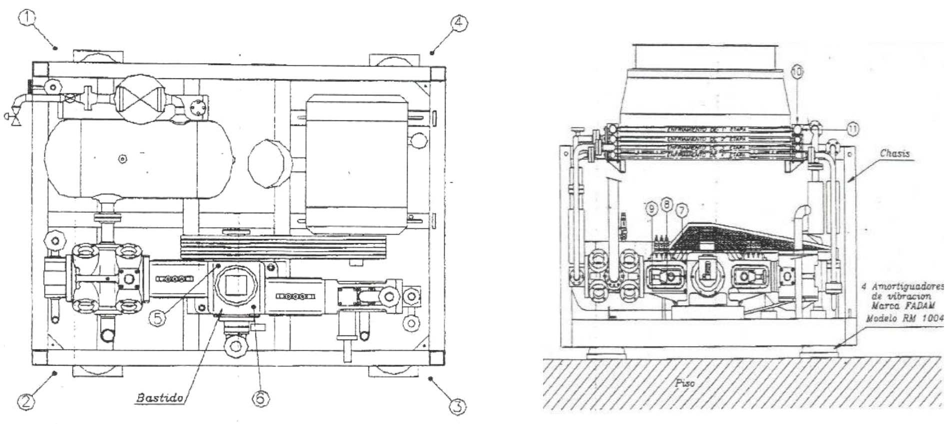


Figure (1) Measurement points recommended by the manufacturer

The measuring device was recording the values of velocity in mm/sec and the frequency spectrum of the mentioned velocity .

According to the manufacturer recommendations, vibration velocity of 1X in the first nine measuring points and 2X amplitude for points 10 and 11 were required.

The vibration values requested by the manufacturer and four other points are measured and vibration values of a unit is given in Table 2 for instance. The last column in this table gives the permissible values (recommended by manufacturer). The vibration spectrum was measured for 1 to 1000 Hz.

Table 2. Vibration velocity values in reciprocating air compressor

Point No.	Direction	Frequency (1/min)	Dominant Component Velocity (mm/sec)	Pemissible Value (Recommended by manufacturer) (mm/sec)
1	V	900	Negligible	0.75
2	V	900	Negligible	0.75
3	V	900	Negligible	0.75
4	V	900	0.066	0.75
5	V	900	4.511	4.6

6	V	900	3.562	4.4
7	H	900	9.251	11.8
8	H	900	7.512	13.4
9	H	900	4.994	6.3
10	V	(2X)900	**6.863**	2.4
11	H	(2X)900	**25.37**	8.6
12	V	900	24.2	-
13	A	900	10.807	-
14	A	900	8.04	-
15	A	900	281.46	-

H: Horizontal, V: Vertical, A: Axial

According to the measured values the amplitude of 1X component is less than the recommended values, but 2X frequencies of the points 10 and 11 are higher than the recommended values. However the dominant frequencies of the measuring locations occur in 4X and in some cases 2X too. This indicates that the main source of vibration can be the reciprocating parts of the compressor. Because 4X and 2X components are much higher than 1X component, the vibration assessment according to 1X component seems not to be correct.

2 – 3 Effects of New Added Support on the Vibration of Stage one

Outlet Piping:

In order to evaluate the effect of adding a support to the stage one outlet piping vibration first the vibration on the flange of the original design was measured. The vibration values are given in Table 3.

To decrease the vibration of stage one outlet piping an extra support has been mounted . Then the vibration with this new configuration has been measured in three directions which are given in Table (3).

Table 3. Vibration Values of Point 15 Before And after Adding the Support

	Normal Design	After piping modification
Direction	V (mm/s)	V (mm/s)
Axial	281.46	175.47
Vertical	96.7304	133.9344
Horizontal	102.3643	132.0351

From data given in Table 3 one can conclude that adding the support has decreased the vibration in axial direction however the vibration has increased in other two directions. Therefore adding the support seems not to be a right decision to decrease the vibration in this case.

2 – 4 Conclusions and Recommendations:

According to the vibration survey in 15 points measured for a frequency range of 1-1000Hz in the reciprocating air compressor under a pressure change of 210 to 250 bar focusing on velocity , the conclusions and recommendations are:

According to measurments the 1X component of the first 9 points are very small and the 2X component of points 10 and 11 are also very small compared with the maximum values given for a similar unit by the manufacturer. However there are some dominant components in other frequencies such as 2X for points 7,8,9,12 and 4X for points 6,10,11,13,14 and 15. This makes the overall vibration to have a considerable value. The dominant frequencies of the velocity are mainly located in the range of 2X and 4X. By the fact that the vibration values remained high after adding the support , this remedy will not help as a long term solution.

According to these facts, it is recommended that pulley alignment and the compressor reciprocating and rotating parts performance and balance be checked .

3 - Fault Diagnosis of the Diesel Engine Radiator

Diesel engines are a common source of power, both for vehicles and for static equipment like electricity generators, as they are fuel efficient, robust and reliable [5]. Impact excitations, time-varying transfer properties and non-stationary random response are typical characteristics of the reciprocating engine vibration. These characteristics of the engine vibration make its dynamic analysis and signature extraction much more difficult than that of the rotational machinery [6].

Table (4). Common sources of Vibration in Diesel Engines [4]

Vibration Source	Exciting Frequency	Comments
Cylinder Misfiring	0.5 X	No diagnostics can be done until all misfiring is corrected
Imbalance, Misalignment Torque Reaction, Weak Foundation	1X	1X and No. of firing strokes per revolution are caused by torque reaction, which in turn can cause misalignment
Harmonic Balancer	2X	Correct by rotating the balancer
Cylinder Combustion Forces	1.5X, 2.5X, etc	Normal operating levels

In analyzing vibration spectra from rotating and reciprocating machines, it is important to note that there isn't a single fault and always a combination of various faults is present in the vibration signature. Care must be taken in the interpretation of vibration signatures since some faults produce spectral components at the same frequencies. When a gearbox has multiple shafts, each pair of gears will generate its own tooth mesh frequency. Different types of gear teeth will generate greatly different levels of vibration. Spur gears are inherently the noisiest, followed by bevel gears, hypoid gears, helical gears, herringbone gears, and worm gears [4]. Some common sources of vibration and their specifications are given in Table 4.

The radiator has a key role in diesel engines which has the task of removing the generated heat. In regard to its key role in diesel engines, considering vibration monitoring of radiator as a part of a condition monitoring program for a diesel engine can provide more reliable information and brings significant cost benefits [7].

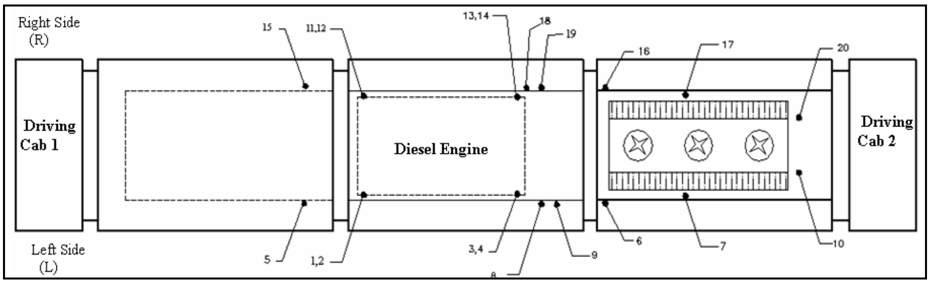
In this section, unexpected damage and leakage of the radiator of a diesel engines group is studied. In order to locate the source of the fault, vibration measurements have been done and compared with standard values and with vibration values of a healthy diesel engines group.

3 – 1 Vibration Measurement:

To find the source of vibration several measurements were taken at different points according to ISO 10816-6 and some more points for gathering more information. Measurement points are shown in Figure 2. According to ISO 10816-6 and assuming severity grade 45, the acceptable vibration level is 45 mm/sec (RMS) between 2 and 1000 Hz for the engine [8].

In order to compare vibration values of the faulty diesel engine group with a healthy one, vibration of a healthy diesel engine group were measured too. Vibration measurements were carried out for root mean square (RMS) values of velocity in three directions for both overall values and frequency spectrums.

Vibration measurements were taken in both conditions unloaded (idle) and loaded condition.



1- Top edge of front of engine (L Side)
2- Bottom edge of front of engine (L Side)
3- Top edge of rear of engine (L Side)
4- Bottom edge of rear of engine (L Side)
5- Generator base (L Side)
6- Pump (L Side)
7- Radiator Chassis (L Side)
8- Radiator base (L Side)
9- Flexible joint No. 1 in outlet (L Side)
10- Basement of bogey fan motor (L Side)
11- Top edge of front of engine (R Side)
12- Bottom edge of front of engine (R Side)
13- Top edge of rear of engine (R Side)
14- Bottom edge of rear of engine (R Side)
15- Generator base (R Side)
16- Pump (R Side)
17- Radiator Chassis (R Side)
18- Radiator base (R Side)
19- Flexible joint No. 1 in outlet (R Side)
20- Basement of bogey fan motor (R Side)

Figure (2) Diesel engine group and measurement points

3 – 2 Data Analysis:

Some overall RMS values of vibration velocity in loaded condition are presented in Table 5 for both faulty and healthy diesel engine. Faulty diesel engine has higher values of vibration at some points, the faulty diesel engine shows high vibration values. According to standard, one can see that values of vibration at point (11) and point (13) on diesel engine are higher than the acceptable values.

In order to identify abnormal peaks, vibrations of two diesel engine groups have been compared. Some frequency spectrums are shown in Figures 3 to 6. It can be seen that there are two unusual peaks on two different points of faulty diesel engine group rather than healthy one: 366Hz and 733Hz. Radiator chassis is also affected by these two components. It implies that these components are the reason of radiator leakage and damage. The latter speed is approximately two times the former speed. This fact shows that the sources of these two peaks are identical, i.e. the peak on 366Hz is 1X component and the peak on 733Hz corresponds to 2X component.

Table (5). RMS Values of Vibration Velocity (mm/s) for Frequency Range of (1-1000) Hz in Loaded Condition

Measuring Point	Faulty diesel engine group			healthy diesel engine group		
	H	V	A	H	V	A
1(Engine)	4.93	6.18	4.02	4.72	6.94	3.37
2(Engine)	6.97	6.92	4.08	8.80	5.53	3.77
3(Engine)	6.25	10.29	4.37	6.13	16.29	3.16
4(Engine)	5.21	4.06	1.44	4.77	3.62	0.95
5(Generator)	10.71	11.53	4.67	7.43	12.39	5.65
6(Pump)	2.85	5.07	4.40	3.85	5.71	1.85
7(Radiator)	5.77	6.11	2.72	5.74	4.72	2.50
8 (Piping)	17.97	24.97	9.20	14.52	16.98	8.82
9 (Piping)	20.75	50.32	35.27	21.85	32.13	74.36
10(bogey fan)	6.98	5.46	1.91	5.18	5.80	1.71
11(Engine)	4.95	7.53	**55.15**	4.02	8.01	9.58
12(Engine)	7.67	8.99	7.87	8.44	9.52	5.96
13(Engine)	**36.17**	12.15	**57.26**	6.42	13.14	5.24
14(Engine)	10.60	4.27	20.43	11.05	11.08	5.67
15(Generator)	11.64	10.19	8.56	7.89	8.57	6.30
16(Pump)	2.99	8.41	2.63	6.80	5.55	1.95
17(Radiator)	5.99	4.52	2.83	6.97	4.26	3.69
Piping)	21.21	15.54	14.15	12.56	10.91	13.34
Piping)	50.00	42.53	28.76	72.04	45.19	18.34
ogey fan)	**12.77**	**9.04**	**3.14**	6.80	5.55	1.95

H: Horizontal, V: Vertical, A: Axial

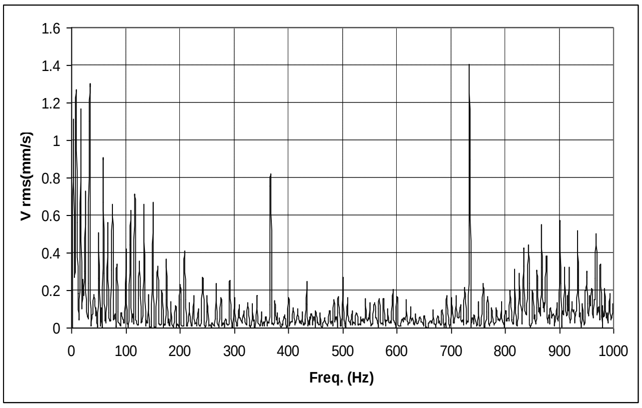


Figure (3). Axial velocity spectrum for point 13 (Engine), faulty diesel engine group

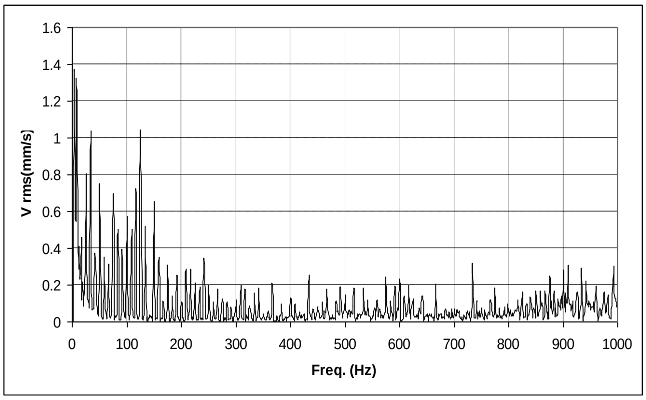


Figure (4). Axial Velocity Spectrum for Point 13 (Engine), Healthy Diesel Engine Group

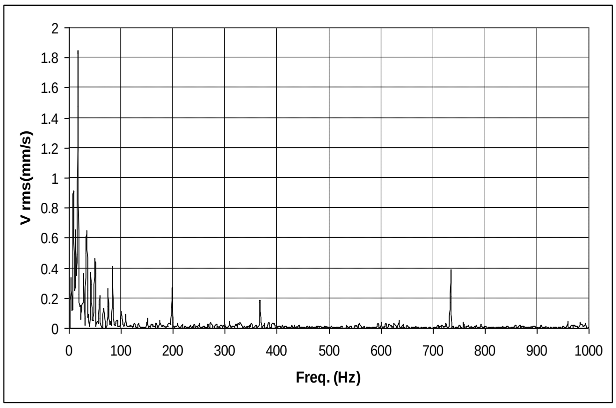


Figure (5) Axial Velocity Spectrum for Point 17 (Radiator), Faulty Diesel Engine Group

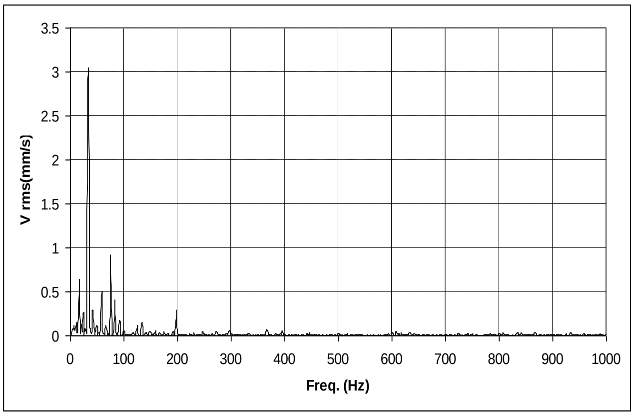


Figure (6) Axial Velocity Spectrum for point 17 (Radiator), Healthy Diesel Engine Group

At this point, vibration peaks have been detected and relating them to sources of vibration is of interest. Source of vibration is an element which produces vibrating force with frequency of 366Hz.

In loaded condition speed of engine is 1000 RPM (16.7 Hz) and the gear has 22 teeth, hence the tooth mesh frequency can be obtained as below:

$$f_{(t)} = \frac{Z * n}{60} \text{...........Hz}$$

Where:
$f_{(t)}$: tooth mesh frequency.
Z: number of teeth.
n: speed of engine .

$$\text{tooth mesh frequency} = \frac{22*1000}{60} = 366.67 \ \text{Hz} \tag{1}$$

Clearly, tooth mesh frequency equals 1X component. In order to find the gear problem, faults which produce tooth mesh frequency, should be studied. Evidently, it can be concluded that gear is the source of vibration in faulty diesel engine group and it must be repaired or replaced.

3 – 3) Conclusion:

In this paper, the fault diagnostic of the three stage reciprocating air compressors and radiator leakage in a diesel engine group has been presented. The three stage reciprocating air compressors had failures in the stage one outlet pipe. Vibration measurements confirmed that failures are due to excessive level of vibration. It is also shown that adding support did not reduce vibration impressively.

In order to find the reason of radiator leakage several measurements have been taken at some points according to ISO 10816-6 and some more points for gathering more information. According to standard the vibration values of this diesel engine group are higher than the acceptable values. In addition, comparing the vibration values of this diesel engine group with a healthy one shows abnormally high vibration in faulty diesel engine group. From both the standard and comparison with a healthy diesel engine group, it is ascertained that the radiator leakage is due to vibration. At this point, comparing spectrums of two diesel engine group vibrations shows some peaks in faulty diesel engine group which are significantly greater than corresponding peaks in healthy diesel engine group. Finally, it is shown that fault frequency corresponds to gear mesh frequency. Therefore it is recommended that the mentioned gear be replaced by a new one.

4. References

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