Condition monitoring of screw compressors and induction motors in a food processing industry

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Abstract - *In this paper, we measured the vibration level of various critical machinery in the food processing industry. Vibration analysis is an effective tool for detecting and diagnosing machine and equipment faults in the early stages. Maximum research found that a periodic measurement program detected several potential failures before a breakdown. Screw compressors and induction motors are widely used in the food processing industry for refrigeration. As these types of machinery must run for 24 hours in a dairy/food processing industry and most food items are perishable, breakdown maintenance could be more cost-effective. A periodic vibration monitoring system is required to detect critical parts' failure. So, an attempt is made for fault detection in earlier stages to reduce breakdown maintenance. Vibration severity as per ISO 10816 is measured in terms of $V_{r.m.s.}$ (mm/sec) using SKF Microlog Analyzer CMXA 75. The collected data was then processed and analyzed, and corrective actions were taken according to the vibration severity.*

Key Words: **vibration measurement, screw compressor, condition monitoring, induction motor, velocity measurement**

1. INTRODUCTION

In the food processing industry, various types of machinery are present. The majority of these machines have rotating parts. Machines must perform according to their designed specifications and installed capacity for an industrial plant to have high production rates. The machine must be in good working condition to ensure no significant downtime. Machinery condition monitoring is concerned with the maintenance of these machines based on their current and previous conditions. To determine the machine's condition, sensors are installed around it so that relevant information about the machine's condition can be collected and analyzed. Decisions are made about the appropriate maintenance or corrective actions to be taken so that the machine can perform as intended.

Machines generate information or signals during operation through the noise, vibration, temperature, lubricating oil condition, quality and quantity of motor current drawn, and so on. These machine signals are obtained by installing transducers to measure the mechanical parameters of the machine. The signals received in this manner are usually analog and are always present. An analog-to-digital converters convert the signals into the digital domain to generate meaningful information. Software is available to efficiently store and handle large amounts of digital data collected from machines. This data is then used in the algorithms designed to detect machine faults. Once a machine fault has been identified, corrective measures can be implemented to ensure that the machine has a long useful life and that the plant is more productive.

1.1 vibration monitoring

Vibration analysis is the most well-known condition-monitoring technology for rotating equipment. The type of sensor used is determined by the frequency range that is being monitored:

Position transducers for the low-frequency range, Velocity sensors in the middle-frequency range, Accelerometers in the high-frequency range, and SEE sensors (Spectral Emitted Energy) for very high frequencies (acoustic vibrations).

The vibration monitoring method can detect the following defects: misalignment, eccentricity, cracked shaft, bowed and bent shaft, unbalanced shaft, looseness, defects in bearing, gear faults, etc.

It is a parameter that gives the best information about the health condition of the machine and helps to diagnose the problems of the machine. The vibration parameter has a definite relationship with types of mechanical fault which are typical characteristics. Advances in instrumentation have made measurement and analysis easy and simple. About 70% of the machinery faults can be detected using vibration monitoring.

The vibrations must be measured axially, vertically, and horizontally as shown in Fig - 3.

2. METHODOLOGY

The objectives of this study were achieved through the following steps:

We studied the refrigeration system in the food processing (dairy) industry. The refrigeration system is designed to handle 15 lakh liters of milk daily. It is a fully automated system using PLC-based automation and SCADA. The system consists of the following elements: Screw compressors, evaporative condensers, economizers to increase efficiency, expansion valves, and various evaporators such as plate heat exchangers (PHE) chillers and air-cooling units for different applications. The primary function of the refrigeration section is to provide chilled water for various processes in the dairy and maintain the temperature of different cold rooms present according to the norms. The system operates at three different evaporation temperatures, which are -2 °C, -5 °C, and – 30 °C.

Compressor type: Screw compressor

Allowable pressure: 28 bar

Maximum speed: 3600 rpm

Refrigerant used: Anhydrous ammonia (R717)

Motor type: 3-phase induction motor

Motor KW: 315

Maximum speed: 2985 rpm

Various operating parameters such as suction pressure and temperature, discharge pressure and temperature, oil pressure and temperature, oil filter pressure, compressor rpm, and motor current were observed for more than a month and recorded. An example of the same is given below:

Suction pressure: 2.56 bar, suction temperature: -2.4 °C, discharge pressure: 10.5 bar, discharge temperature: 62.5 °C, oil pressure: 13.38 bar, oil temperature: 40.4 °C, capacity: 100%, motor speed: 1862 rpm, motor current: 342.3 amp.

Sr.No	Time	Suction Pressure (Bar)	Suction Temperature (°C)	Discharge Pressure (Bar)	Discharge Temperature (°C)	Oil Pressure (Bar)	Oil Temperature (°C)	Diff Oil Pressure (Bar)	Capacity (%)	Motor RPM	Motor Current (Amp)	Eco (-2) Evap Pressure (Bar) PT01-EC02	Accu Pressure (Bar) PT01-PKG02	Chilled Water Inlet Temp (°C) TT01-WC02	Chilled Water Outlet Temp (°C) TT02-WC02	Operating Hours	COP	Economiser (-2°C) Temp (°C) TT02-RL
1	08:02	2.56	-2.4	10.5	62.5	13.38	40.4	2.88	100	1862	342.3	5.42	2.74	2.89	0.21	17536	5.5	14.49
2	08:07	3.03	-1.7	10.26	62	13.2	39.6	2.94	100	1586	332.9	5.86	3.28	5.85	3.42	17536	5.8	13.96
3	08:12	3.36	0.6	10.52	62.6	13.44	38.5	2.92	100	2348	342.5	5.92	3.59	12.32	6.98	17536	5.2	15.06
4	08:17	2.9	-3	10.63	65.2	13.55	41.3	2.92	100	2678	356.5	5.48	3.17	14.27	3.49	17536	5.3	15.28
5	08:22	2.84	-3.6	10.56	62.2	13.53	42.9	2.97	100	2517	341.3	5.51	3.06	13.23	3.1	17536	5.2	14.68
6	08:27	2.8	-3	10.55	61.5	13.45	42.4	2.9	100	2281	333.9	5.44	3.14	12.52	3.53	17536	5.4	14.96
7	08:32	2.87	-3.2	10.56	63.2	13.56	41.7	3	100	2272	341.3	5.48	3.19	11.5	2.92	17536	5.4	15.85
8	08:37	2.78	-2.7	10.65	61.1	13.51	41.7	2.86	100	2335	335.4	5.43	2.97	10.87	2.73	17536	5.5	15.21
9	08:42	3.04	-2.7	10.67	60.9	13.59	42	2.92	100	2348	334.7	5.43	3.28	13.12	3.71	17537	5.4	15
10	08:47	2.57	-4.4	10.6	61.4	13.61	42.3	3.01	100	2259	334.7	5.46	2.77	8.01	0.71	17537	5.6	14.75
11	08:52	2.95	-2.9	10.64	60.3	13.49	41.8	2.85	100	2222	332.3	5.42	3.13	10.86	2.61	17537	5.5	14.57
12	08:57	3.04	-1.6	10.72	61.4	13.68	41.8	2.96	100	2296	337	5.44	3.28	12.96	4.48	17537	5.5	14.81
13	09:02	2.96	-2.1	10.75	61.1	13.67	42.1	2.92	100	2302	338	5.44	3.2	12.94	4.01	17537	5.5	14.96
14	09:07	2.8	-3.6	10.85	61.6	13.87	42.8	3.02	100	2275	340.3	5.46	2.99	11.36	2.15	17537	5.3	15.22
15	09:12	3.25	-0.8	11.14	63.4	14.08	42.8	2.94	100	2535	349.5	5.77	3.58	15.35	6.13	17537	5.3	16.22
16	09:17	2.8	-2.5	10.44	61.8	13.31	40	2.87	100	2566	331.5	5.42	3.08	9.52	4.03	17537	5.8	15.23
17	09:22	2.82	-3.2	10.67	62.5	13.48	42.5	2.81	100	2577	355.6	5.46	3.1	10.59	3.55	17537	5	15.4
18	09:27	2.73	-3.5	10.52	61.6	13.39	42.5	2.87	100	2458	335.4	5.43	2.92	9.04	3.15	17537	5.5	15.06
19	09:32	2.79	-3.3	10.41	60.3	13.31	41.7	2.9	100	2302	330	5.49	3	8.58	2.86	17538	5.7	14.53
20	09:37	2.89	-2.7	10.49	60.5	13.31	41.3	2.82	100	2262	330.4	5.46	3.07	8.75	3.33	17538	5.5	14.76
21	09:42	2.79	-3.5	10.39	59.6	13.21	41.3	2.82	100	2177	327	5.42	2.98	7.86	2.22	17538	5.5	14.78
22	09:47	2.71	-3.7	10.47	60.3	13.41	41	2.94	100	2095	328.8	5.41	2.89	6.64	1.51	17538	5.6	14.75
23	09:52	2.84	-3.2	10.37	59.9	13.16	41	2.79	100	2009	326.6	5.48	3.02	6.66	2.11	17538	5.6	14.26
24	09:57	3.07	-2	10.49	60.3	13.39	40.5	2.9	100	2042	326.8	5.46	3.25	8.24	3.37	17538	5.6	14.5
25	10:02	2.95	-2.1	10.47	60.2	13.33	40.6	2.86	100	2072	326.3	5.53	3.12	8.03	3.1	17538	5.7	14.73
26	10:07	2.78	-3.9	10.32	59.4	13.3	40.7	2.98	100	1969	325.9	5.43	2.94	5.52	0.69	17538	5.7	14.51
27	10:12	3.04	-1.9	10.46	60.3	13.44	40	2.98	100	1870	326.4	5.48	3.23	8.02	3.46	17538	5.7	14.34
28	10:17	3.03	-2.5	10.52	60	13.47	40.5	2.95	100	1891	328	5.53	3.22	6.74	2.07	17538	5.7	14.51
29	10:22	2.96	-2.3	10.46	60	13.31	40.5	2.85	100	1892	327.2	5.45	3.15	7.48	2.76	17538	5.6	14.4

Fig -1: Operating parameters of -2 °C compressor.

Sr.No	Time	Suction Pressure (Bar)	Suction Temperature (°C)	Discharge Pressure (Bar)	Discharge Temperature (°C)	Oil Pressure (Bar)	Oil Temperature (°C)	Diff Oil Pressure (Bar)	Capacity (%)	Motor RPM	Motor Current (Amp)	Economiser (-5°C) Pressure (Bar) PT01-EC02	Operating Hours	COP	Economiser (-5°C) Temp (°C) TT03-RL
1	08:02	2.39	-5.1	10.5	65.4	13.5	43.7	3	100	1781	351.6	5.57	17141	5.1	18.79
2	08:07	2.32	-5.3	10.28	64.6	13.37	43.6	3.09	100	1781	344.4	5.56	17141	5.2	18.66
3	08:12	2.44	-5.1	10.46	64.7	13.47	43.1	3.01	100	1781	348.5	5.56	17141	5.2	18.02
4	08:17	2.49	-4.8	10.53	64.7	13.58	43.4	3.05	100	1781	349.3	5.56	17141	5.1	17.35
5	08:22	2.66	-4.2	10.54	68.5	13.42	43.4	2.88	100	1910	386.6	5.76	17141	4.7	16.84
6	08:27	2.52	-4.4	10.57	66.1	13.47	44.4	2.9	100	2247	359.5	5.56	17141	4.9	18.61
7	08:32	2.4	-4.8	10.56	65.8	13.51	45.1	2.95	100	2247	359.1	5.58	17142	5.1	18.73
8	08:37	2.26	-5.3	10.64	67	13.58	45.6	2.94	100	2241	355	5.58	17142	5.1	18.4
9	08:42	2.33	-5.3	10.64	67.1	13.38	46	2.74	100	2130	354.6	5.58	17142	5.1	17.58
10	08:47	2.34	-5.2	10.6	66.9	13.53	45.9	2.93	100	2130	351.8	5.58	17142	5.2	16.98
11	08:52	2.59	-4.7	10.68	67.7	13.59	45.3	2.91	100	2156	390.1	5.77	17142	4.4	17.94
12	08:57	2.52	-4.7	10.72	65.4	13.59	45.6	2.87	100	2229	360.8	5.57	17142	4.7	18.5
13	09:02	2.52	-4.5	10.75	65.5	13.79	45.6	3.04	100	2229	358.5	5.61	17142	4.9	18.54
14	09:07	2.69	-3.9	10.93	67.1	13.81	45.8	2.88	100	2519	396.4	5.75	17142	4.5	18.3
15	09:12	2.56	-4.2	11.12	67.1	14.1	47	2.98	100	2689	370.4	5.59	17142	4.7	18.59
16	09:17	2.54	-4.1	10.46	65.2	13.5	45.9	3.04	100	2703	353.2	5.56	17142	5.2	18.61
17	09:22	2.51	-4.2	10.68	66.4	13.61	46.2	2.93	100	2792	363.4	5.58	17142	4.9	18.16
18	09:27	2.4	-4.6	10.54	66.7	13.33	46.7	2.79	100	2792	354	5.59	17142	4.9	18.38
19	09:32	2.34	-4.8	10.45	66.8	13.46	46.7	3.01	100	2792	353.8	5.57	17142	4.9	18.2
20	09:37	2.46	-4.8	10.54	66.6	13.63	46.2	3.09	100	2792	365.1	5.55	17143	4.7	17.93
21	09:42	2.38	-4.8	10.45	66.3	13.51	46.3	3.06	100	2792	351.8	5.58	17143	4.9	18.08
22	09:47	2.44	-4.8	10.57	66.5	13.34	46.4	2.77	100	2792	378.8	5.67	17143	4.7	16.85
23	09:52	2.31	-5.3	10.43	66.6	13.47	46.5	3.04	100	2792	352.8	5.58	17143	5.2	18.25
24	09:57	2.34	-5.3	10.54	69.2	13.44	46.5	2.9	100	2792	366.5	5.56	17143	4.8	18.04
25	10:02	2.23	-5.7	10.51	67.3	13.36	47	2.85	100	2731	350.5	5.58	17143	5.4	18.29
26	10:07	2.23	-5.8	10.36	67.1	13.22	46.7	2.86	100	2522	350.3	5.58	17143	5.1	18.08

Fig -2: Operating parameters -5 °C compressor.

Vibrations were measured per ISO standards using SKF Microlog Analyzer CMXA 75 horizontally, vertically, and axially on the driving end (DE) and non-driving end (NDE) in terms of r.m.s. Velocity and compared with the Vibration severity chart. After comparing and analyzing the vibration severity values, corrective actions were taken according to the findings during the initial vibration measurement, described in detail in the results section.

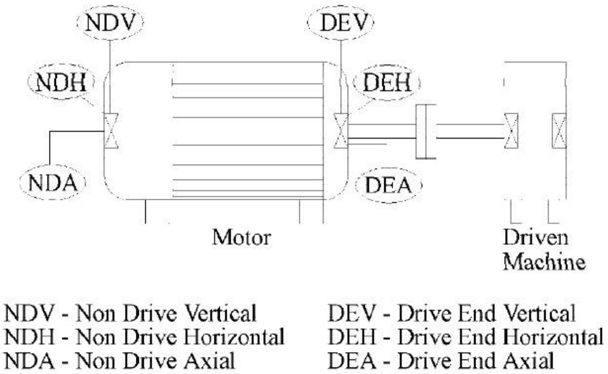

Fig -3: Positions where vibrations were measured.

We measured the vibration severity again after taking the corrective actions. This is necessary to confirm that the fault diagnosis and corrective actions we took were correct and that no other faults are present in the machine.

3. RESULTS AND DISCUSSION

3.1 Measurement of vibration according to ISO 10816

According to ISO 10816, the system's root mean square (r.m.s.) velocity under consideration was measured. The velocity was measured vertically, horizontally, and axially at the driving end (DE) and non-driving end (NDE).

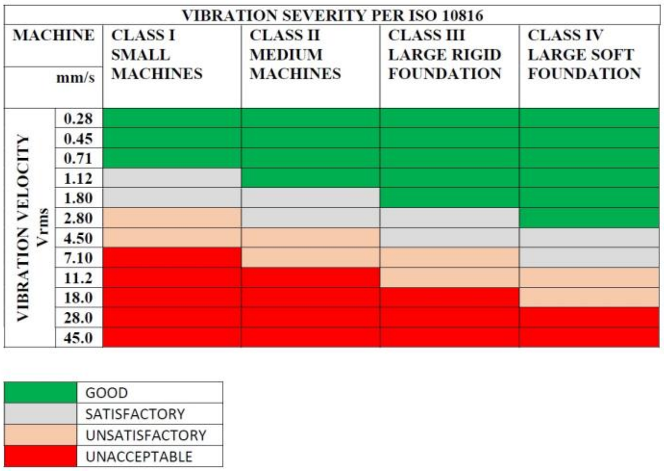

Fig -4: Vibration severity as per ISO 10816

The system under consideration falls under Class III, i.e., large prime movers and other large machinery with rotating masses mounted on rigid foundations. The results of the measurement are stated below:

Ammonia compressor No. 1:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	2.8	2.51	NA
Motor DE	3.10	2.43	2.89

Table -1: Measured velocity of ammonia compressor No. 1

Ammonia compressor No. 2:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	3.16	1.59	NA
Motor DE	2.62	5.70	7.2

Table -2: Measured velocity of ammonia compressor No. 2

Ammonia compressor No. 3:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	3.14	2.83	NA
Motor DE	3.20	2.53	3.02

Table -3: Measured velocity of ammonia compressor No. 3

Ammonia compressor No. 4:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	3.10	3.40	NA
Motor DE	2.78	3.35	2.58

Table -4: Measured velocity of ammonia compressor No. 4

Ammonia compressor No. 5:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	1.96	2.4	NA
Motor DE	2.87	3.17	3.05

Table -5: Measured velocity of ammonia compressor No. 5

Ammonia compressor No. 6:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	2.04	2.3	NA
Motor DE	2.56	3.01	3.02

Table -6: Measured velocity of ammonia compressor No. 5

Analysis of measured data and corrective actions are taken:

Compared the recorded values with the vibration severity chart per ISO 10816 (Fig -4).

The vibration severity values for ammonia compressors No.1,3,4,5 and 6 were within acceptable levels. All the operating parameters were within the limit; no abnormal sounds were present while operating at various loads.

For ammonia compressor No. 2, the measured axial and vertical velocity values (axial: 7.2 mm/s, vertical: 5.70 mm/s) at the motor's driving end were in the Unsatisfactory (Alert) zone. Axial vibration > Horizontal vibration.

The motor current of this compressor was observed slightly more as compared to that of other motors running at similar loading conditions.

Hence, Misalignment is indicated between the motor and compressor.

The alignment of the motor and compressor was checked, and the following results were found:

As the manufacturing company prescribes, the permissible axial and radial alignment values are 0.10 mm.

Both axial and radial values were found out of limit when the alignment between the motor and compressor was measured.

The bolts of the compressor foundation were retightened with the torque values given in the manufacturer's manual.

Realignment was done using dial gauges as prescribed in the manual, and the results of before and after alignment are given in the following table:

	Measured value	After alignment
Axial	0.21 mm	0.05 mm
Radial	0.18 mm	0.07 mm

Table -7: Measured alignment of ammonia compressor No. 2

Lubrication to the motor bearing was done.

The vibration measurement was done after alignment:

Location	$V_{r.m.s.}$ (mm/s)		
	Horizontal	Vertical	Axial
Motor NDE	2.56	2.12	NA
Motor DE	2.32	2.25	3.21

Table -8: Measured velocity of ammonia compressor No. 2 after alignment.

The measured values were found within the limit.

4. FUTURE SCOPE

As current vibration measuring monitoring systems present in the market are very expensive, research must be done to design a reliable, low-cost continuous vibration monitoring system. This should justify the cost of installing the continuous vibration monitoring system concerning the cost of breakdown maintenance. This can be done using microcontrollers and various accelerometers present in the market. An in-depth study should be done using multiple low-cost microcontrollers and accelerometers to ensure the accuracy and reliability of the same.

5. CONCLUSIONS

Periodic vibration measurement must be done in the food processing industry to avoid significant breakdowns of critical machinery. A periodic vibration monitoring system detected several potential failures before the occurrence of a major breakdown. In this study, excessive vertical (5.70 mm/s) and axial (7.2 mm/s) vibrations were present for one compressor rig. Therefore, the misalignment was detected between the compressor and the motor. We were able to realign the compressor and motor, after which horizontal (2.25 mm/sec) and axial (3.21 mm/s) vibrations were found within the limit. Because of this, premature failure of bearings, couplings, and shafts is avoided.

A continuous vibration monitoring system is required to detect sudden changes occurring in the machinery. To detect the fault accurately, the system must measure the acceleration continuously and plot the acceleration vs. frequency graph.

6. REFERENCES

[1] Amiya R. Mohanty, Machinery Condition Monitoring Principles and Practices, CRC Press, Taylor & Francis Group, LLC, 2015.

[2] D.N.Brown & J.C.Jorgensen, Machine-Condition Monitoring using Vibration Analysis A Case Study from a Petrochemical Plant, Briiel & Kjsev.

[3] Gupta, K.N. Vibration — A tool for machine diagnostics and condition monitoring. Sadhana 22, 393–410 (1997). < https://doi.org/10.1007/BF02744480 >

[4] N. Tandon, G.S. Yadava, K.M. Ramakrishna, A comparison of some condition monitoring techniques for the detection of defect in induction motor ball bearings. Mechanical Systems and Signal Processing, Volume 21, Issue 1, 2007, Pages 244-256, ISSN 0888-3270, < https://doi.org/10.1016/j.ymssp.2005.08.005 >

[5] Andy C.C. Tan, Katie L. McNickle & Daniel L. Timms, A practical approach to learning vibration condition monitoring. World Transactions on Engineering and Technology Education Vol.2, No.2, 2003. < http://www.wiete.com.au/journals/WTE&TE/Pages/Vol.2,%20No.2%20(2003)/Tan30.pdf>

[6] Saravanan, S., Yadava, G.S. & Rao, P.V., Condition monitoring studies on spindle bearing of a lathe. Int J Adv Manuf Technol 28, 993–1005 (2006). < https://doi.org/10.1007/s00170-004-2449-0 >