OVERALL FACTORY VIBRATION LEVEL: THE NEED FOR GLOBAL INDICATORS IN CBM

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Summary

When we do predictive maintenance, including vibration analysis, rotating machinery, we anticipate many times a catastrophic failure that without this technology, would be difficult to locate and make unsafe our system functionally. This analysis is done individually machine to machine, point to point which prevents us from having a parameter that quantifies the overall status of all rotating machinery of a plant or department.

Key words: vibration, speed, acceleration, predictive maintenance, CBM, data collector, indicator.

INTRODUCTION

It is very common, the uses of non-destructive testing for diagnosis of machinery, which failure modes are not enough to file a hidden pathology visible to the operator. The non-detectability of these faults has extended the use of these technologies in particular the analysis of vibration, very successful in rotating machinery. This has made large investments in equipment gauges, many hours of training to operators and engineers to interpret data and a radical change in the planning of maintenance. Breakdowns are reduced significantly and the non planned actions too, being replaced by interventions result of the predictive inspections. It is therefore important the correctness of these predictions because of the high cost is an intervention in labour, parts and lost production. It is considered a successful program that avoids costs of intervention with these inspections, but unfortunately in most cases repairs are made useless because of false alarms. The dynamics of the systems tells us that a perfect rotating machine must not vibrate, being this failure mode an anomaly. But this statement is partially true in the industrial world. Most machines suffer from failures from the day of their operation due to:

- installed incorrectly machines
- poor operating conditions
- poor design or machine manufacturing defects
- adjacent machinery with problems transferred to the reference machine.

This means that in the case of vibration, we find machines, which since its installation vibrate due to faulty benches, incorrect installation, improper piping design, hydraulic imbalances by use products are not allowed to pump etc. In the case of machines with spent operating time, the above issues have been able to generate a vibration pattern hardly changed and that we must contemplate when planning any repairs because the inherent level of reliability has been reduced in the machine. The values of vibration of such equipment are therefore not zero and comparative analysis we can create false alarms, being higher than the other machines in environment or are in gangs of dissatisfaction if we follow vibration standards. We therefore created in the analysis of the plant a distorting element, because we think the machine is in poor condition when vibration due to a defective bench can be sustained over time with minimal damage to the machine itself and almost never justifies the investment that often has little impact. It is therefore proposed in this article, an average parameter value of vibration for rotating machinery, so that we can display the severity of the vibration of machines, groups of machines or entire plants, with an overall indicator, without false alarms that we can create with the strict application of the standard point to point.

1. POINTS OF MEASUREMENT AND CALCULATION OF AVERAGE MACHINE VIBRATION

The intention of the indicators described in this article is to obtain a set of parameters and templates easy to reach without a specific diagnosis, to detect an anomaly in the operation of a plant or an area with a number of rotating machines. That is why we calculate the average level of machine vibration, and then calculate the average level of vibration of the plant. In the case of machines composed of elements that rotate at a speed only, as in Figure 1, the parameters to consider are:

- power (in kw)
- speed (usually measured in rpm or revolutions per minute)
- average vibration of the points of measurement (mm / s)

The points of vibration measurement, to collect data easier to analyze, are proposed by [1] with special emphasis on the collection of data in horizontal, vertical and axial. The orientation of each point of measurement is an important consideration in configuring the database for analysis. There is an optimal orientation for each measurement point of the machine in a predictive maintenance program. If only we could take a radial measurement, must be oriented in the plane (vertical or horizontal) that provides the highest vibration amplitude. For continuity, each machine must be clear of the train the shaft of entry and exit of driver and driven machine. The measurement points should be numbered sequentially starting with the main driver. This is illustrated in Figure 1. Any numbering convention may be used, but must be consistent in this way will provide the following benefits:

1. Immediate identification of the location of a point during the analysis and diagnosis.
2. The cluster of points per axis allows the analyst a clear view of the problems in each component.

In the case of electric motors, we will have two points of measurement, corresponding to the housing of the bearings. At each point, it is normal to take two measurements, in a horizontally and vertically, reflecting different pathologies vibration obtained in two different directions, despite being the same pocket. It allows the analyst a clear view of the problems in each component.

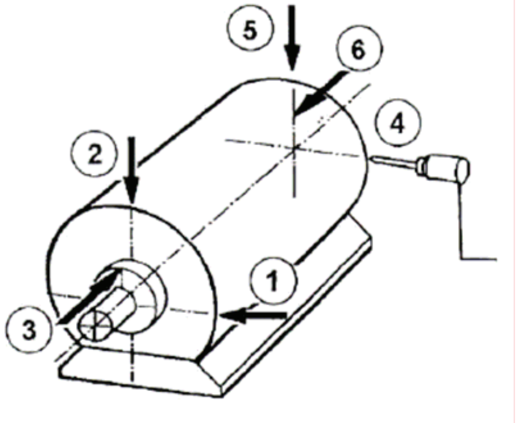


Fig. 1. Measurement points in an electric motor

Point 1 is also called NCS measure (acronym Non Coupling Side). In Section 1, we have measures in 1H Horizontal and Vertical 1V.

In Figure 2 correspond to:

- 1H: Point 4
- 1V: Point 5

Section 2 will be called the CS (acronym Coupling Side). Again we find 2H and 2V whose correlation:

- 2H: Point 1
- 2V: Point 2

Respect to the axial measurement, reflected in the figure, can be taken in 1 or 2 in the graph represented by 3 and 6 (because the measure is the same) but by accessibility of the sensor is used in point 6 of the figure, which is commonly known as 1A, to be located at the cashier and 1 being the axial direction of rotation. Besides an important detail of the measure 1A, which is no risk to the operator that measures the vibration, not to approach any mobile device discovered. Which measure 3, which would be called 2A, it is close to the motor shaft and the coupling and the risk of entrapment and amputation. In an electric motor therefore average vibration is:

$$V_{average} = \frac{V_{1H} + V_{1V} + V_{2H} + V_{2V} + V_{1A}}{5} \qquad (1)$$

Where $V_{1H}, V_{1V}, V_{2H}, V_{2V}, V_{1A}$, the values of vibration velocity (measured in mm / s) at the points previously selected. In the case of more complex machines, that is coupled to fan motors or pumps, but having a single speed, it would act similarly, but taking into account that the two points of the engine are joined by two other housings for the pump bearings of the same, which will call 3 and 4.

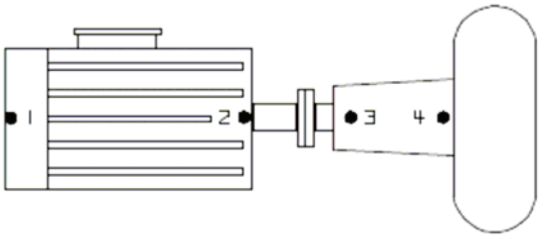


Fig. 2. Measurement points in an electric motor coupled to a centrifugal pump.

Again, we find the 3H and 3V and the 4H and 4V. It will be interesting to take the measurement 4A for a coupling in the middle of the train. The reason to take 4A, instead of 3A, is the safety of the operator, knowing that we are talking about the same vibration.

Therefore, the average vibration machines such a coupling and four bearings operating at the same speed will be:

$$V_{average} = \frac{V_{1H} + V_{1V} + V_{2H} + V_{2V} + V_{1A}}{10} + \\ + \frac{V_{3H} + V_{3V} + V_{4H} + V_{4V} + V_{4A}}{10} \qquad (2)$$

Being $V_{1H}, V_{1V}, V_{2H}, V_{2V}, V_{1A}, V_{3H}, V_{3V}, V_{4H}, V_{4V}, V_{4A}$ vibration speed in the points. In the case of machines with multiple speeds, it is interesting to ponder the vibration of each point depending on the speed at which the element rotates at the same treadmill. It should be remembered that the frequency of rotation of the machine is an important parameter, since the acceleration of the vibration increases with the square of the frequency of rotation and speed of vibration increases linearly with increases in the frequency of rotation, [2]. Therefore, the most common machines with different speeds, i.e. motor-gear train fans and pumps with pulleys and belts, we calculate a speed weighted average, for obtaining an average value that reflects the criticality of element that we look and do not mask high-frequency amplitudes with low frequencies which clearly do not pose the same risk factor. How to perform measurements on trains coupled machines is described in ISO 7919-3 [3], this policy helps us in the case of rotating machines that have a relatively rigid casing and / or heavy compared to its rotational mass, often considering which has a flexible shaft rotor. In this case, the vibration should be assessed with greater sensitivity if the measures are carried out on rotating elements and not on the static components of the machine.

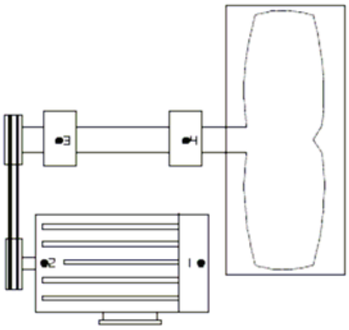


Fig. 3. Fan belt driven

In the simple case of a fan driven by belt where:

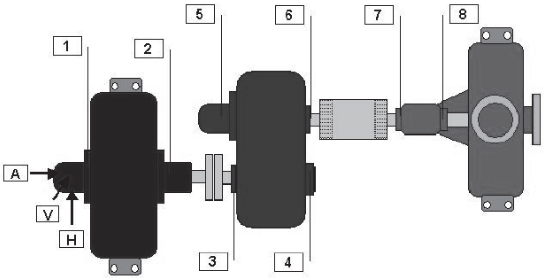
v_{motor} is the speed at which the motor rotates

v_{fan} is the speed at which the fan rotates.

Assuming that the transmission through the pulleys is different from 1:1, i.e. the pulleys are of different size and thus the speeds are also different, the vibration is:

$$V_{average} = \frac{v_{motor}(V_{1H} + V_{1V} + V_{2H} + V_{2V} + V_{1A})}{5v_{motor} + 5v_{fan}} + \\ + \frac{v_{fan}(V_{3H} + V_{3V} + V_{4H} + V_{4V} + V_{4A})}{5v_{motor} + 5v_{fan}} \tag{3}$$

In this case, we are again with a four-bearing machine. Some configurations have more points of measurement; it is the case of a driver (motor or turbine) with a gearbox and pump. In this configuration, we find eight bearings, with their pockets as shown in Figure 4:



1	Turbine Non Coupling Side	5	Gearbox Low Speed Non Coupling Side
2	Turbine Coupling Side	6	Gearbox Low Speed Coupling Side
3	Gearbox High Speed Coupling Side	7	Pump Coupling Side
4	Gearbox High Speed Non Coupling Side	8	Pump Non Coupling Side

Fig. 4. Details of the measuring points on a machine train: turbine-gear-pump

In the case of the figure, a turbine coupled to a gearbox and a pump to this, we measure the following points:

- Turbine 1A, 1H, 1V, 2H, 2V
- Gearbox 3H, 3V, 4^a, 4H, 4V, 5^a, 5H, 5V, 6H,6V
- Pump 7A,7H,7V,8H,8V

Naming:

$v_{turbine}$, is the speed at which the steam turbine rotates

v_{pump} , is the speed at which the pump rotates.

Therefore, average vibration of this machine is:

$$V_{average} = \frac{v_{turbine}(V_{1H} + V_{1V} + V_{2H} + V_{2V} + V_{1A})}{10v_{turbine}10v_{pump}} + \\ + \frac{v_{turbine}(V_{3H} + V_{3V} + V_{4H} + V_{4V} + V_{4A})}{10v_{turbine}10v_{pump}} \\ + \frac{v_{pump}(V_{5H} + V_{5V} + V_{6H} + V_{6V} + V_{5A})}{10v_{turbine}10v_{pump}} + \\ + \frac{+v_{pump}(V_{7H} + V_{7V} + V_{8H} + V_{8V} + V_{7A})}{10v_{turbine}10v_{pump}} \tag{4}$$

We can therefore generalize the expression of the average vibration as follows:

$$V_{average} = \frac{\sum_{i=1}^{n} v_i V_i}{\sum_{i=1}^{n} v_i} \tag{4}$$

Where v_i is the speed associated to the i point, V_i represents the speed of vibration measured at the point i, where n is the total points measured: horizontal, vertical and axial, not the pockets of the bearings. This overall vibration measure of a machine, allows a first assessment. In the above analysis, we obtained 20 measures vibration velocity at different points, which give us an idea of the deterioration of the elements located in these positions. Normally, when we classify a machine according to the degree of severity of the vibrations that suffers, we are guided by the highest vibration that appears, this being a serious error in the creation of false alarms. Many machines in its period of maturity or due to poor installation have bench problems or structures that support the joint, as can be seen in Figure 5.

Fig. 5. Rotating machines with a weak bench

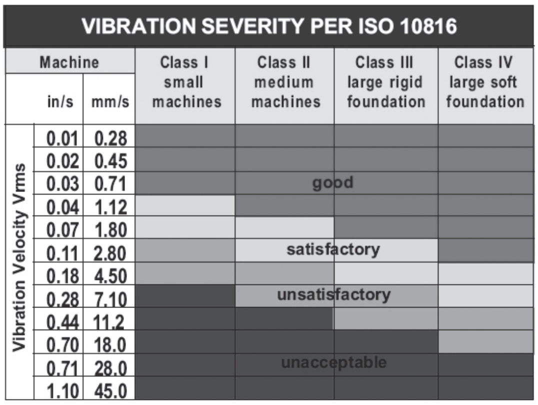
Therefore, when calculating the severity of the vibration by the highest value we are creating a false alarm almost permanent, because there are particularly critical points, as the supports of the pump on the side of the coupling, which normally vibrates from its installation. This support, in the analysis correspond to the points 3H and 3V (especially 3H) and lead a vibration much higher than the rest of the machine due to poor support or bolt, which by this vibration, are dropping. For that reason, the analysis of severity mentioned, this vibration partially masks the state of the machine, because despite being a vibration, it is very difficult to remove it in the machinery of a certain age. With the average vibration value of machine, this discordant, is softened by the rest of the machine measurements, and we obtain a value more in line with reality, with which to assess the severity of that vibration.

3. VIBRATION SEVERITY

The most common value used to display the severity are the peak and RMS, [5], being the second most widely used and included in the existing rules. Thus, ISO defines as "severity of the vibration, the higher value of the RMS amplitude of vibration velocity obtained in the frequency range 10-1.000 Hz and measured at predetermined points of the structure (usually measures at the top of the bearings or the supports). The most common rule is ISO 10816 [6], which is now considered to assess the status of machines. It applies to machines with rotating rigid rotors and flexible rotors with rotating machinery, where the vibration of the bearing cap is indicative of the behaviour of vibrating shaft. This rule is studying global vibration without bands. The data required for implementation, are the overall level of vibration at speed (effective value RMS) in a frequency range between 10 and 1,000 Hz (vibration severity to ISO).

The criterion for acceptable vibration severity in each class of machines referred to is reflected in Table 1.

Table 1. Severity of vibration according to ISO 2372/ISO 10816



VIBRATION SEVERITY PER ISO 10816

Machine			Class I small machines	Class II medium machines	Class III large rigid foundation	Class IV large soft foundation
	in/s	mm/s				
Vibration Velocity Vrms	0.01	0.28	good	good	good	good
	0.02	0.45	good	good	good	good
	0.03	0.71	good	good	good	good
	0.04	1.12	satisfactory	good	good	good
	0.07	1.80	satisfactory	satisfactory	good	good
	0.11	2.80	unsatisfactory	satisfactory	satisfactory	good
	0.18	4.50	unsatisfactory	unsatisfactory	satisfactory	satisfactory
	0.28	7.10	unacceptable	unsatisfactory	unsatisfactory	satisfactory
	0.44	11.2	unacceptable	unacceptable	unsatisfactory	unsatisfactory
	0.70	18.0	unacceptable	unacceptable	unacceptable	unsatisfactory
	0.71	28.0	unacceptable	unacceptable	unacceptable	unacceptable
	1.10	45.0	unacceptable	unacceptable	unacceptable	unacceptable

As shown in the table, the severity of vibration is divided into four ranges: Good, Satisfactory, Unsatisfactory or Unacceptable and four types of machines depending on the power installed, CLASS I, II, II and IV. To use ISO 2372, simply classifying the machine to be considered within the relevant class and, once obtained, the total value (RMS) vibration between 600 and 60,000 RPM (that band of 10 to 1000 Hz), we can locate in the table the level of severity of your machine. In general, it is generally considered that the severity of vibration of the machine remains unchanged if you have the same value of RMS velocity amplitude of vibration in the frequency range 10 - 1000 Hz. To illustrate the applicability of this indicator and its relationship with the severity of the vibration, take a machine like described one above, consisting of a steam turbine of 400kW, a gearbox (4000RPM speed input and output rate 1300 RPM) and a centrifugal pump coupled to the gearbox.

The values obtained by data collectors, can be of two types, the first is the peak value, useful if the subject of the sensor and the measure is not contaminated, otherwise, the collectors estimate the root mean square value of velocity vibration during the exposure time to the sensor (which also value and support the relevant regulations). This value is known as quadratic value RMS (Root Mean Square). If we look, the two highest steps on the machine are 23.6 and 35.5 mm / s. With these values taken to the 10816 standard for machines greater than 75kW, as is the case (CLASS III) we find the power of this machine, much in the unacceptable range, almost the full scale. Looking in depth at the location of these measures so alarming, we see that occur in the 7H and 8H, which correspond to the horizontal of the pump, excessive measures which are not equivalent in their vertical 7V and 8V, so imbalances that are discarded and other pathologies of a certain severity. It is therefore clear that it is due to a bench defect or minor structural rigidity.

Table 2. Data from vibration of the machine

	DATA CBM turbopump				
	Rotation Speed (RPM)	Equipment	Measurement point	Units	Value
Steam turbine	4000	Turbine	1A	$^{mm}/_{s}$	2.3
	4000	Turbine	1H	$^{mm}/_{s}$	1.8
	4000	Turbine	1V	$^{mm}/_{s}$	2.4
	4000	Turbine	2H	$^{mm}/_{s}$	2.8
	4000	Turbine	2V	$^{mm}/_{s}$	2.2
Gear Box	4000	Reductor	3H	$^{mm}/_{s}$	4.7
	4000	Reductor	3V	$^{mm}/_{s}$	9.4
	4000	Reductor	4A	$^{mm}/_{s}$	16.7
	4000	Reductor	4H	$^{mm}/_{s}$	9.1
	4000	Reductor	4V	$^{mm}/_{s}$	16.0
	1300	Reductor	5A	$^{mm}/_{s}$	11.9
	1300	Reductor	5H	$^{mm}/_{s}$	6.6
	1300	Reductor	5V	$^{mm}/_{s}$	8.9
	1300	Reductor	6H	$^{mm}/_{s}$	15.0
	1300	Reductor	6V	$^{mm}/_{s}$	18.1
Pump	1300	Pump	7A	$^{mm}/_{s}$	13.9
	1300	Pump	7H	$^{mm}/_{s}$	23.6
	1300	Pump	7V	$^{mm}/_{s}$	5.9
	1300	Pump	8H	$^{mm}/_{s}$	35.5
	1300	Pump	8V	$^{mm}/_{s}$	7.4

Conversely, if we calculate the parameter proposed average vibration, with appropriate weighting for the speed in each zone so far obtained is 8.68 mm / s, much more rational and placing the machine in the range limit between satisfactory and unsatisfactory, while minimizing the effects of structural vibration and eliminating false alarms in the monitoring. Hence, we can generalize the use of the average vibration parameter for a full factory or area of analysis. The expression of the parameter proposed OFVL (Factory Overall Vibration Level) therefore is:

$$OFVL = \frac{\sum_{i=0}^{n} P_i V_i}{\sum_{i=0}^{n} P_i} \tag{5}$$

Where V_i is the average of the vibration machine i has been calculated as above, P_i the power on the i-machine and n the number of machines included in the search for the global average value of vibration. With these data we can also calculate the average power installed per machine:

$$P_{media} = \frac{\sum_{i=0}^{n} P_i}{n} \tag{6}$$

4. CALCULATION OF OFVL

This parameter is easy to calculate manually, but when the plants take on a certain size and the number of rotating machines is high, should be made systematic and automated as far as possible. All plants that have a predictive program perform measurements with three different types of equipment, [7]:

- Collectors of absolute value.
- Collectors and spectrum analyzers.
- Continuos monitoring.

The measurement equipment is automatically connected to the computer system in the post-measurement and downloaded all data. Being better the quality of monitored continuously vibration by the repetitiveness of the process. The basic vibration meters, do not often have memory or is very small, so there are values to be scored in the appropriate medium. After entering all the data, the calculation of the parameter is very simple, because the datasheets in the machine analysis software, often have the power and frequency of rotation of the elements and they are capable to make rapid exports to spreadsheets where speeding up the process. Measurement systems in companies with high level of monitoring, due to the criticality of some elements can certainly achieve a complex structure, which can include several pieces of equipment described, with several dozen accelerometers as described by [9]. These systems respond to the need to measure acceleration, velocity or displacement, in a very large fleet, with different criticality, rotation speeds and power. This is where you need a connection or interface between the entire system of CBM and CMMS installed in the plant, necessarily existing, as proposed by [8]. This gives us the OFVL parameter is calculated by the CMMS, and incorporated into the indicator panel control of maintenance team. This parameter is not for immediate intervention, because that is the task of continuously monitor or routes that will yield the state machinery and the necessity of stopping, repairs or replacements. This parameter will allow us to see the trend of the vibration and thus the overall success of the predictive, reaching as far as possible to the minimum levels of the same or what is the status of reliability inherent in the system. Obviously, this parameter plant has some correlation with the indicators with the indicators proposed by some authors as [10], to measure the success of implementing a predictive maintenance program. So at the beginning of the program, while the overall vibration decreases, the number of hours spent PMP (Predictive Maintenance Programme) increasing to stabilize these two parameters. Also reducing the overall vibration plant will strongly correlates with the reduction of failures and thus the frequency of the same. Simplifying, we can observe that as decreases the overall value, increases the MTBF to be both achieved in the so-called reliability of the system, aiming to achieve the same inherent reliability.

5. CONCLUSIONS

The need for indicators, appear when we try to use a score card, as a way of management different than the current one. As organizations use indicators in the maintenance function, they realize that they can be used to define the strategy and achieve consensus on it, communicate the strategy throughout the organization, align personal goals and the departments, aims to link long-term and annual maintenance budgets, identify and align strategic initiatives, regular and systematic reviews, and obtain feedback for the strategy and improve it. The indicators serve to refocus the management system and link short term with long-term strategy, linking the maintenance function with other functions of the organization, especially, production. The results should eventually translate into financial technical achievements, leading to the maximization of the value created by the company. The proper use of maintenance indicators, allows you to select an optimal frequency of maintenance and inspection, inventory levels, management and optimization of budgets, contracts and technical proposals. It will help us to consider, objectively, the impact they bring with them different modes of failure on operations, production, safety and environment, thus helping to reduce production costs and maximizing the value of the cycle equipment life, increasing the benefits. The OFVL is configured as one indicator of high importance when assessing the success of PDM, and the quantification of the tendency of the state machinery. The OFVL, basic numerical indicator will allow us to compare the value of vibration of the plant with the specific machine or with the same manufacturing plant, for analysis or sectorial comparative tests of different machines for the same purpose. We are also permitted under current regulations, documenting the overall state of the plant and set a trend that marked the PM policy, corrective and overhauls, and we can relate this parameter with other parameters controlling the maintenance function.

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