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Machinery Vibration Signal Transmitters, a Discussion

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1. Introduction

Over the past few years industry has seen the growth of the vibration signal transmitter in the form of the loop powered accelerometer delivering 4-20mA signal specifically for PLCs as demanded by the Control and Instrumentation market. Unfortunately this apparent logical solution has severe negative consequences for effective vibration monitoring of rotating machinery. This paper discussed the benefits and risks of the concept and offers recommendations for a more appropriate way of achieving the same result at an economic cost with additional vibration analysis capabilities.

2. The Market Requirement

The Control and Instrumentation (C&I) signal architecture is primarily based on the 4-20mA direct current standard while the more recent field-bus standard (digital equivalent of 4-20mA) is still to gain wide usage. Unlike the process instrumentation DC architecture, machinery vibration sensors generate an alternating current (AC) signal and pose quite different signal handling needs than the simpler 4-20mA signal. As a result vibration measurement systems are generally set apart from the main control instrumentation network. However, since all data is generally centralised in the DCS (Distributed Control System) computer that accepts the 4-20mA format, the vibration signals are required to be converted to suit.

Most vibration on-line protection monitoring systems convert the AC signal to the 4-20mA DC signal. Apart from this basic need, sending DC signals requires lower specification cabling, regards screening than the more complex AC signal. In recent years C&I engineers have been asked to include more vibration signals into their control systems as the benefits of condition monitoring gains greater recognition. In order to drive down costs and utilise existing PLCs (programmable logic controllers) which have warning, alarm and trip capabilities, generally duplicated in vibration monitoring systems (VMS), the market has demanded a simpler signal conversion system. The sensor manufacturers have met this demand by developing loop powered accelerometers that internally convert a pre specified vibration signal range to 4-20mA, the sensor usually comes with integral cables. This solution appears ideal as it meets the needs of the C&I engineers, it does not occupy any front panel space nor duplicates relays or other specialist features in standard VMS. Unfortunately from a sustainability and vibration engineering aspect it has considerable short comings.

3. Vibration Measurement, the basics

Vibration is the cyclic or oscillation motion of a body or component from its position of rest or its neutral position. Whenever vibration occurs there are four forces involved that determine the characteristics of vibration. They are:

1. The exciting force such as unbalance, misalignment, looseness etc created by the rotating shaft.
2. The mass of vibrating system
3. The stiffness
4. The damping characteristics

The characteristics that define vibration, and are needed to understand the behaviour of vibrating machinery, are illustrated in the figure below (Fig1):

1. **Amplitude** (how much?) i.e. Displacement (microns), Velocity (mm/sec), Acceleration (g)
2. **Frequency** (how often the signal moves back and forward)
3. **Phase** (the time relationship between vibrating forces).

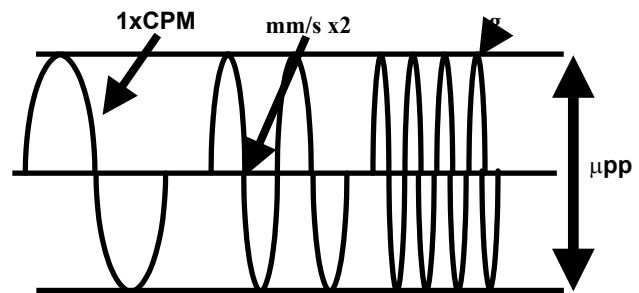


Figure 1 – Types of Vibration Measurement

For simplicity, frequencies are stated in Cycles Per. Minute or CPM as this is easier than calculating in Hz when identifying orders or harmonics of a fundamental frequency related to the rotating machinery elements. When the three prime parameters are

coupled with a machine's speed, load and effects of the process, a more precise diagnosis becomes essential for complex machinery. When applied to case mounted sensors on rotating machinery, the selected measurement unit is determined by the rotor speed or frequency of the machinery elements. A general guide is as follows:

| Measurement Unit | Definition | Units | Machine Element Speed or Frequency Range in CPM |
|------------------|---|--------------------|---|
| Displacement | The total distance a mass travels back and forth as it vibrates | peak-peak microns | <600 |
| Velocity | A measure of how fast the mass is moving back and forth. | peak or RMS mm/sec | 600 - 120,000 |
| Acceleration | The rate of change of velocity | g's | >120,000 |

Vibration can be represented in the Time or Frequency Domain that enables the analyst to identify suspect machinery elements. **Figures 2 and 3** are typical representations of the same data.

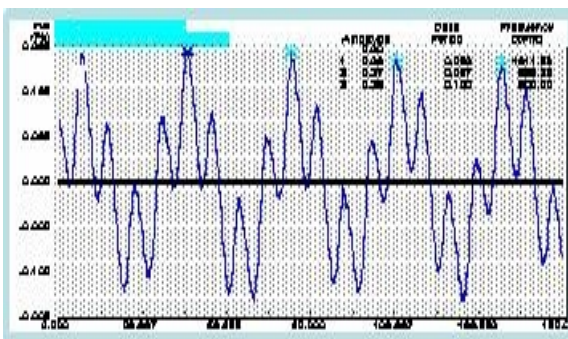


Figure 2 - Time Domain (Waveform)

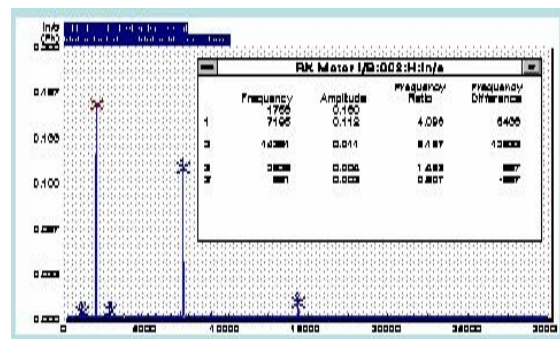


Figure 3 - Frequency Domain (FFT Fast Fourier)

The Time Domain format requires more skill to analyse but is indicative of repetitive vibration characteristics where complex signals illustrate a pattern. The frequency domain or vibration spectrum is easier to understand by the relationship between rotating machinery elements based on their speeds, base frequencies and associated harmonics.

As can be seen in **Figure 4**, the overall vibration AC signal is complex and a summation of the signals from all the individual vibrating elements. When converted to the frequency domain the individual frequencies identify the condition of the machine's components. **When this signal is converted to 4-20mA DC, the ability to analyse a machines vibrations is restricted only to the overall vibration level.** Typically the lower frequency signals from unbalance, looseness and alignment generate the most energy whereas the higher frequencies from bearings etc generate much lower energy.

Those signals converted to 4-20mA reflect the overall level of vibration which most vibration protection monitoring systems use as the base indicator.

For strategic machinery, more sophisticated vibration systems use high and low pass filtering for specific fault trending. Often the AC data is transmitted to a multi-channel diagnostic system that employs intelligent alarming using FFT band enveloping techniques and phase analysis.

This powerful capability enables discrete machinery element's condition to be reported to operators. The actual cause of the problem, such as unbalance, alignment, looseness, defective bearings, gear meshing etc is highlighted. Thus better operational decisions can be made based on qualitative information than in the past.

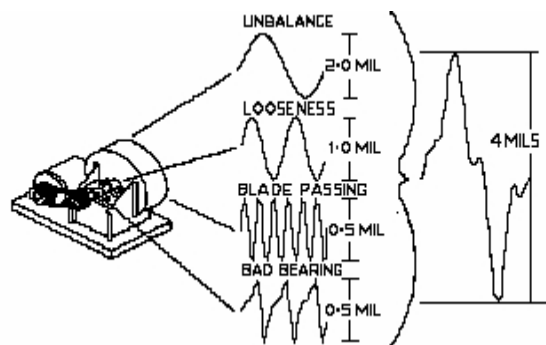
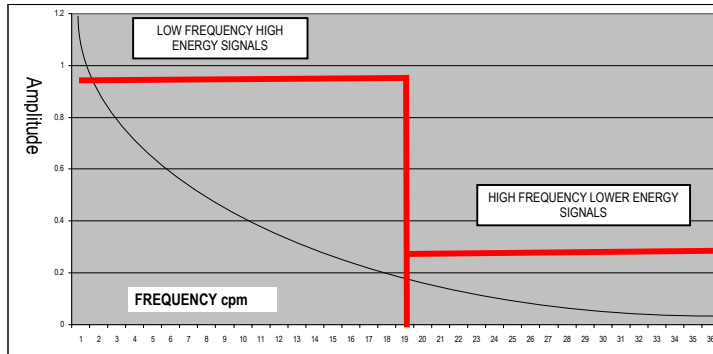


Figure 4 – Complex Vibrations

4. On-Line Vibration Measurement – The Industrial Challenge

Over the past 50 years the method for on-line vibration measurement for rotating machinery has hardly changed. All vibration standards are basically the same calling for overall measurements of vibration (un-filtered signals); they are based on the original belief that a defective machine will generate an increase in the overall vibration level. While this is true for basic machinery, the measurement method has failed to keep pace with modern machinery where prime movers are associated with high frequency bearing signals and sub systems.



Better understanding of machines, improved sensors and signal processing now offers greater machinery protection and prediction capability; **Figure 5** below illustrates the prime challenge of basic vibration physics.

Lower frequencies generate considerably higher energy than higher frequencies. This means that the prime mover large mass rotor, affected mainly by unbalance or alignment etc, will generate the majority of the vibration signal energy. This will swamp those lower amplitude but very relevant signals at higher frequencies from low mass anti-friction bearings, gears etc.

Figure 5 - Low Frequency Higher Energy v Low Energy High Frequencies

In traditional monitoring systems the overall or total vibration energy signal is used to activate alarms. However, this is only really useful for the basic machine frequencies generating high energy at low frequencies (below 60kCPM). Figure 5 illustrates that at the higher frequency signals, that generate less energy, (a more sensitive level of alarming is needed. This is required to detect incipient faults that are easily disguised by the fundamental frequency and lower harmonics at higher energies. For example, if the higher frequency signal increases from 0.5 to 1 mm/sec (100% increase) this is likely to indicate a 25% increase in the overall level from say 2mm (Good) to 2.5 (seems OK) and would be ignored in most situations yet could be serious. In practice many industrial machines operate at 8mm/sec and so would only see a 6.3% increase even though the bearing has doubled its vibration level. Thus converting the overall vibration level to the 4-20mA DC signal has considerable risk if applied across all rotation machinery especially if one cannot analyse the time wave form (TWF) data for its frequency spectrum. Further It is important to establish the **F-max** (maximum frequency to which energy is likely to be generated) in a machine when setting a monitoring system alarm levels.

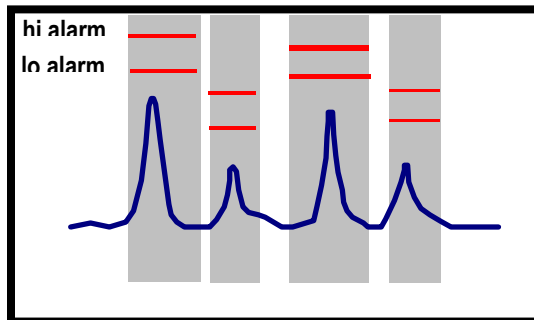


Figure 6 illustrates a typical vibration spectrum where intelligent alarming is only possible when the TWF signal can be accessed and processed with an FFT analyser.

When frequency band alarming in a software data management package is applied, the development of difficult to notice high frequency signals are soon brought to the attention of Operations. When configured with a thorough understanding of machinery fault frequencies, alarms can be generated that identify specific rotating element faults. Thus machinery health is better managed and proactive maintenance becomes practical.

Figure 6 - Frequency Bands Alarming

5. The Machinery Data Transmitter (Vibration)

Prior to the arrival of the low cost loop powered accelerometer on the market and where C&I design did not require the traditional 19" panel mounted Rack, the Machinery Data Transmitter (MDT) shown in **Figure 6** was the standard solution for distributed plant giving 4-20mA output.

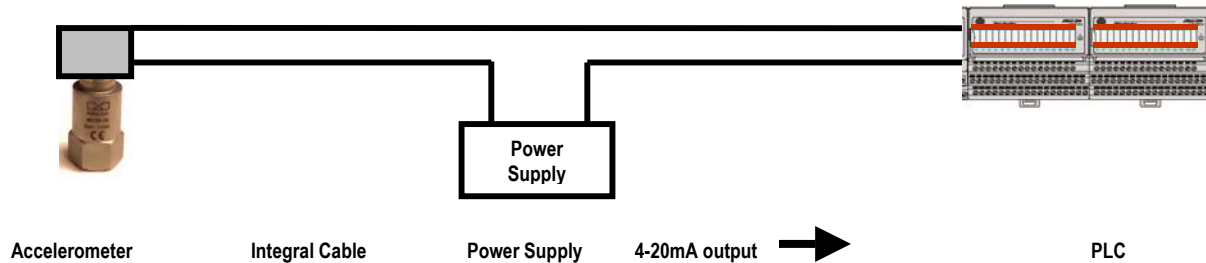
It still remains popular for many applications where local alarm and trip signals are required. The main difference between the MDT and the 19" Rack is that the MDT (IP65) can be mounted close to machinery on site. No control room or panel space is taken up; outputs are 4-20mA, with warning and trip relays. Whilst it offers high quality machinery protection, those plants with PLCs etc do not use many of trip relay features it more costly than the simpler loop powered accelerometer system.



Figure 6. MDT

6. The Loop Powered Accelerometer

The lower cost loop powered accelerometer system circuit architecture with main elements identified is shown below:



The illustration is a single channel unit; the power supply is usually in a junction box or the instrument panel. The output 4-20mA signal to the PLC is then used as required by the plant C&I engineers.

The loop powered accelerometer that converts vibration to 4-20mA signals has a number of advantages but perhaps more shortcomings as table below summarises:

| Sr. N | Advantages | Disadvantages |
|-------|--|--|
| 1 | No panel mounted monitoring instrument required, more space available | Sensor ranges need to be known in advance, once selected, no range changes are possible. Sensor ranges must be specified at time of order. |
| 2 | Warning, Alarm and Shutdown not duplicated; instructions can be handled by the PLC | Only velocity or acceleration can be converted, double integration for displacement is not practical but often needed |
| 3 | Output signals are sent direct to the PLC or DCS | Sensor accuracy is usually $\pm 10\%$ but calibration can change with age by as much as 20%; system accuracy may reduce with time. |
| 4 | Installation cost probably lower | Limited to operating temperature of 60 (100 max) degrees C due to internal electronics |
| 5 | Loop powered cabling costs reduced | Integral sensor cables lengths need specifying at time of order |
| 6 | Overall cost per channel lower by at least 33% | Replacement cost of loop sensors is double that of standard accelerometers |
| 7 | | Start-up attenuation can be difficult to achieve with PLCs |
| 8 | | During machinery maintenance, care must be taken with the sensors. If the integral cable is damaged a new sensor will be required |
| 9 | | Vibration analysis is not possible with the loop powered sensor system, only overall values are possible |

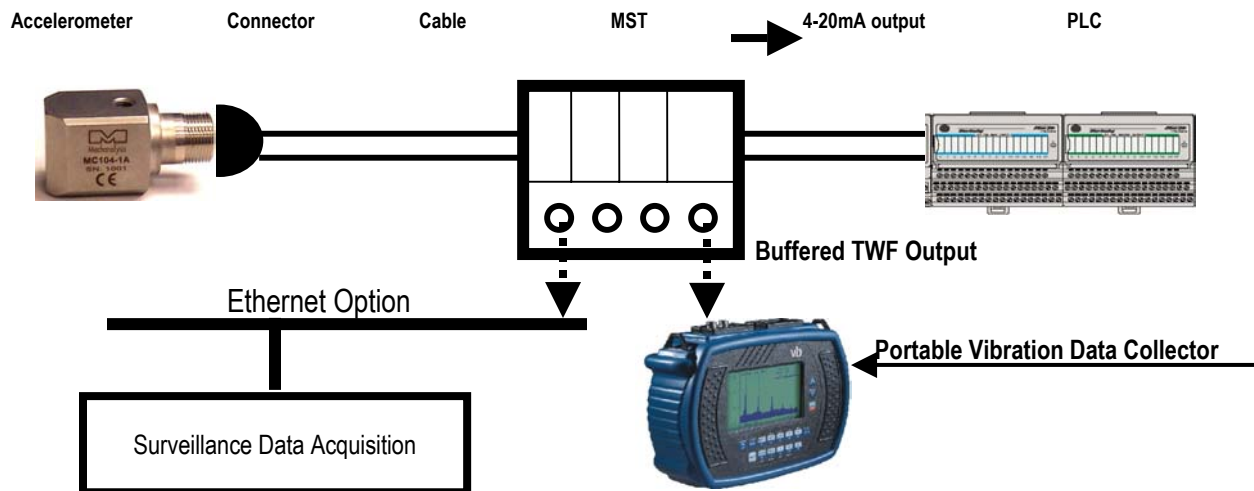
It can be seen that the disadvantages outweigh the advantages yet the market continues to install the loop powered accelerometer mainly based on price. Amongst other reasons, this remains a flawed strategy for the long term regards on-going maintenance in industrial plants. The main concern would be for enlightened companies, operating to ISO9000, is that sensors need to be calibrated on an annual basis. Logistics for a traceable certification calibration to National Standards make this almost impractical as they are installed with integral cables.

When accelerometers are manufactured, the casing can is hermetically sealed by micro welding. When the item is calibrated will it be known that it meets a certain design standard. Those rejected are not discarded but manufacturers offer them as 'low cost' sensors which have an accuracy of >10 or 15% and are priced according. Most loop powered sensors are marketed with an accuracy of $\pm 10\%$.

It is a well known fact that accelerometer's age since their outputs can reduce by as much as 20%; this needs to be taken into consideration against the required accuracy range. Further, since the cables are integrated with the sensors, they are susceptible to damage, especially when maintenance is carried out. Instead of replacing the relatively low cost cable the complete sensor system will have to be replaced when damaged. **However, the main concern from a condition monitoring point of view is that the loop powered sensor cannot be used for effective vibration analysis!**

7. The Mechanalysis Signal Transmitter (MST)

It is accepted that C&I Engineers and End Users will continue to demand a low cost vibration measuring system for lower duty machinery that offers the 4-20mA signal. A more technically acceptable design is now available that has the flexibility of overcoming many of the objections and disadvantages stated earlier. The machinery signal transmitter (MST) architecture is shown below:



The illustration shows one input of 4 channels of an MST system with integral power supply and four BNC sockets in an accessible IP65 enclosure with optional connectivity to manual or surveillance vibration spectrum data collection. The output 4-20mA signal to the PLC is then used as required by the plant C&I engineers. The Mechanalysis Signal Transmitter (MST) is summarised as follows:

1. Accepts virtually any case mounted vibration sensor that meets the machinery type related to speed, frequency and temperature
2. Separate cables with connectors are available and can be made to any length required
3. A 2 channel or multi DIN rail mounted signal converter version accepts the vibration signal and functions as follows:
 - a. Adjustable to sensor sensitivity
 - b. Converts inductive velocity sensors giving displacement signals in microns
 - c. Field adjustable for measurement ranges: 0-10, 20, 30 mm/sec
 - d. Available for measuring in acceleration with ranges: 0-1, 5, 10g
 - e. System calibration in the field is easily checked
 - f. 4-20mA output
4. BNC buffered sockets for vibration analysis from the time wave form (TWF) signal

The flexibility of the MST ensures that machinery vibration monitoring is not compromised yet is a very economic solution for low priority condition monitoring applications. The MST matches or betters the cost of the loop powered accelerometer and is completely customisable. It overcomes the longer term aging issue by being able to adjust the sensitivity to match the accelerometer's degrading output

Separating the sensor and cable reduces the high replacement costs and the inevitable damage that occurs on site. Annual calibration and sensor exchange is a simple matter. System selection based on exact measurement ranges is not an issue as on site adjustments are possible. At any time the vibration analyst can collect vibration FFT data which, in intrinsically safe installations, is a major advantage as analysis is done remotely.

Should the vibration sensor network be expanded to a multi-channel diagnostic system then the buffered TWF signals can be captured without any interference or additional cost to the installed system. The same applies to the use of periodic vibration data collection or surveillance systems where detailed analysis and band alarming is available.

8. Summary

In heavy industrial plant with high cost strategic machinery, the simplistic view that all that is required is to convert vibration to 4-20mA signal and C&I will do the rest is false economy and technically ill advised. The main concern is that machinery is at risk where complex vibrations with a high F max are monitored.

The current practice of installing loop powered sensors that internally convert the AC vibration signal to the DC 4-20mA standard is limited and will create long term maintenance costs far exceeding the original investment. The inability to use the DC signal for anything more than an overall level of vibration is also a waste of investment when at least 33% of the useable data is thrown away or ignored.

It is a well fact that by only observing overall vibration levels machinery failures continues to occur. However, by a small change in system architecture, at almost no extra cost, the system becomes far more useful and offers greater flexibility for configuration to limitless applications. The MST design is more sustainable in the long term as well as offering TWF data via buffered BNC sockets for detailed spectrum band analysis and even automated intelligent alarming.

Vibration monitoring continues to be a specialist activity and C&I engineers should discuss applications and signal management with companies with expertise in the technology rather than those with an agenda to sell product regardless of the longer term consequences.

The loop powered accelerometer has applications in low duty non strategic plant where there is one prime and dominant vibration signal that can be easily trended. Building Services Heating and Ventilation applications come to mind but in the opinion of the author the loop powered sensor is not suitable for heavy industrial plant with complex vibration signals.

If the requirement is for converting the vibration signal to 4-20mA then selection of independent accelerometers with a processing system that provides the AC buffered output for vibration analysis and data collection is advisable.

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