Industrial On-site Vibration Measurements: Some Practical Observations and Comparison of Time Domain RMS Peak Average to 3rd Octave Data

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Abstract

Industrial production plant on-site vibration surveys present many challenges, especially if performed in environments with additional constraints such as cleanrooms. This paper gives an overview of some of the main challenges from the point of view of the practitioner, including comments on the VC guidelines for floor only measurements, a selected ISO standard for machine measurements, and the combination and conflict of the two for the case of simultaneous floor and machine measurements. An unexpected outcome from the practical work, was the observation that for cases of floor only measurements and no observable 50Hz power supply noise signal, the average of the peak maximum RMS and peak minimum RMS time domain values matched the 3rd Octave peak value quite closely. The error was less than 5% for 93% of the cases, 5-10% for 4% of the cases, and over 10% for 3% of the cases. This may offer an advantage when needing much shorter sampling times or when limited analysis capability is available. For the case of machine measurements or an observable 50Hz power supply noise signal, the error was much higher, even over 100%, and could not be a useful or reliable alternative analysis tool to replace the 3rd Octave.

Keywords: Vibration surveys, standards.

1. Introduction

Vibration is an ever present phenomenon in production plants, with a wide range of sources (such as rotating machinery, impulsive loads, turbulence, and even human action), transmission paths (such as air borne noise, building structural elements, machine feet to or from the ground) and manifestation locations (such as production components, laboratory test equipment and building floors). The presence of vibration is not a concern unless it results in energy loss, reduced production quality, reliability, increased maintenance costs, or human work place discomfort. The Authors personal experience and contact with industry in Thailand during the last decade suggests that these issues are becoming a greater concern, partly due to raising the awareness of industry of such issues, but also due to real technical requirements such as the improvement of production precision and/or reduction of maintenance costs [1] for specific machines, or the overall reduction in vibration levels measured on the building floors as an indicator of transmission and building infrastructure quality that is fit for various ranges of sensitive equipment.

This paper presents some practical considerations, some comments on standards, or the lack thereof, a key observation of some results, based on real on-site test experience amassed from over 1200 measurements in industrial production plant environments including open production lines, cleanrooms, laboratories, offices, machines and floors.

At this stage, it is important to mention that all details must be desensitize for confidentiality reasons, and as such, this means the usual level of detail cannot be included, such as company identification, photographs of the environment, test set up, specific data, or any other potentially sensitive information.

Therefore, the focus of the paper is to share the experience of the shortcomings of the standards as well as the key final technical observation which is based on data reduction and normalization to mask all the details that precede the key final technical result. In addition, this paper also aims to 1. Promote an awareness of the growing importance of vibration in industry. 2. Indicate the difference between theoretical University based vibration lab experience compared to industry based experience, and 3. Highlight the need to make implementation decisions based on sound conceptual and technical knowledge to achieve final practical engineering outcomes that have meaning and value to the industrial stakeholders.

2. Standards and measurements

Two standards were used, referred to in this paper as “VC curves” [2] and “ISO 8569” [3].

The use of VC curves was a requirement from industry. It is not a standard, in the sense of being formally approved by any recognized international body, seems to have been generally accepted as a useable guideline. A brief summary is given here. Vibration measurements are taken in three axes, being one vertical and two horizontal, between 4-80Hz, processed into 1/3 octave bandwidths, in amplitude units of μm/s RMS. The bandwidth with the highest amplitude determines the “VC level”, using a letter coding of A to E, given by $0<E\leq3$, $3<D\leq6$, $6<C\leq12.5$, $12.5<B\leq25$, and $25<A\leq50$ μm/s RMS. A value of 4.7 μm/s RMS would therefore be stated as a level of VC-D, for example. There are other categories above VC-A, as stated in the article, but for this work, these were not important as such high vibration levels were deemed an environment vibration failure. In a relatively constant vibration environment, such as normally continuously running production machinery and plant equipment, levels can be measured at many locations across a large area and the final building area level being calculated from the “average plus one standard deviation” level at each frequency. Finally then, an entire floor of a building could be reported to be “VC-D”, for example. In general, industry that has sensitive equipment, either as part of their production process or as part of performance or quality control testing, would use such a method to

classify main floor areas, and as product specifications require continued miniaturisation or higher vibration related performance, so there is a trend for building to move from A down towards E levels.

The major problem of the VC curves is that there is no well defined detail on the implementation, such as measurement location (floor, machine) or measurement density (how many measurements per unit area of floor). The final decision of such detail must therefore start by considering the detailed purpose and motivation of industry, such as specific suspected problems or general long term building performance trending, as well as the most practical considerations such as budget and available time. Although not explicitly stated in the guide, it makes most sense when used for floor only measurements due to its bandwidth average approach. However it is possible to argue a case to even include measurement on machines, if wanting to correlate floor to machine measurements to some type of trending behaviour as opposed to any specific machine orientated problem or enquiry. The practitioners conclusion is to take as many floor only measurements as possible for the given budget and time constraint, aiming for as even a floor distribution as possible, with local deviation from such a grid to be close to either suspected hotspots, machine feet or to avoid permanent unmovable obstacles.

In contrast, the ISO 8569 is a true standard and is applicable to machines, but is a private article accessible only upon payment of a fee. There is not space here nor legal permission to detail all aspects of the standard, so only some key information will be broadly discussed. The standard require three axis measurements in velocity units, as for the VC curves, but for a slightly wider frequency range, and gives more detail on the location requirements at least for a general purpose test case, including a floor measurement on the true solid floor, another floor measurement on any raised floor, and measurements on the machine contact to the floor and/or isolation equipment and the machine working equipment itself, with all these in a vertical line. The analysis requires looking at peak and average values (over given time intervals) in the time domain, and the dominant frequencies in the frequency domain. If possible, some comparison should be made between operating and non-operating modes.

The major problem with the ISO 8569 standard is when there is either an industry driven specific enquiry or a feature of the machine that needs some special case particular attention. It is not possible for a single reasonable length document, written as a standard, to cover all possible cases, so there will always be a need for on-site interpretation in order to meaningfully implement or adapt the standard. An example industry driven enquiry could be if there is a wish to compare the performance of two generations of machine, and old and a new design, that perform the same function, with the key question being if the new machine design has better vibration performance. If the machines are very different in the detailed design or even the conceptual design level of how they deliver the same function, there is no obvious clear or fair way to compare vibration performance in terms of the final selection of the location of the sensors. It is possible to choose measurement locations on a given machine, that record very different vibration behaviour. So the judgment of where to locate sensors on each machine will greatly affect the conclusion of which machine is better in terms of its vibration performance. An example of machine feature could be the presence of a fast and intermittent moving robot arm, conducting processes that require very accurate positioning of small production components. In such a case, the sensor location should be chosen to pick up the effect of the arm motion on the sensitive positioning of parts, hence the vibration transfer from robot base to somewhere near the part positioning station working surfaces, which will normally not be in a vertical line and hence violate the standard's requirements. Furthermore, the measurement start and end time must reasonably match the motion cycle, so as to fairly capture the main energy input pulses. In the absence of precise electron triggering systems linked to the control of the robot, the practitioner can only then measure for a time period than includes at least one major cycle, and then look carefully at the resulting time trace. This kind of detail on the implementation is missing from the standard, and therefore again requires expert on-site interpretation.

It is possible to set up a single test using multiple sensors to take raw time domain data that can be processed to achieve both standards from the same test data. The test data from real on-site work was derived from such an approach, using a fully portable system, and hence as a result of using the two standards, there was an opportunity to compare the VC curve 1/3rd octave results to the ISO 8569 time domain RMS average results, hence the technical observation reported in this paper.

3. Practical challenges

Some of the practical challenges in the context of implementing the standards have been briefly mentioned in the previous section, but there are many other practical challenges which emphasise the difference between University laboratory and industry on-site test environments and experience. Some key examples are briefly presented here.

These tests require sensitive sensors capable of measuring the vibration even when located on heavy granite blocks with isolation systems, making the best practice of calibration become difficult on-site. Even in an office environment, there was usually a measureable background level of vibration, meaning on-site calibration includes the error of such background noise. Therefore true calibration cannot be done on-site, except for the setting of a DC zero offset, which is usually required for such sensitive sensors when they have a frequency range from DC upwards.

Eliminating ground loops and/or electrical power supply 50Hz noise can be a problem, either due to poor quality grounding in the available power supply or in the case of operating off batteries, having a fully electrically isolated contact between sensor and machine.

Cleanrooms present a particular challenge all to themselves, requiring all equipment to be cleaned and statically isolated upon entry, suitable clothing which can severely limit motion, vision and handling of equipment, all of which acts as a large time sink.

Production lines or individual machines cannot easily be stopped or paused, as this affects production efficiency and someone's job performance criteria. Setting up measurements and the timing of measurements often must be fitted around operational needs, as well as other factors that limit machine access, such as maintenance downtime.

Equipment malfunction can severely impact on project time, especially if in a remote location far away from any viable source of replacement. Taking spares is the obvious solution, but this has cost implications.

Human fatigue can be a surprising factor, having to undertake highly repetitive actions, such as bending down to floor level to place/remove sensors, can cause various strain injuries.

Unexpected plant shut down, failures or any abnormal operational conditions that are outside of the practitioners control can delay all testing by several hours or even days.

A systematic process and cycle for each measurement set-up is needed, and roles must be assigned when performed by a team.

There are numerous other details, such as having indicators to highlight the presence of sensors on floors so staff do not kick or trip over the sensors or cables. Coming prepared with the necessary small tools, including cleaning sensors from bees wax and dirt build up, enough backup data storage, calibration sheets for set-up, tape measures to set-up the measurement grid and locations, power cable extensions, maps of the plant layout, pre-prepared spreadsheets and standardized push of the button data post-processing to check quality of data at the end of each test. All this must be pre-prepared. Failure to do so will heavily impact on the time.

In general, there should be an overall systematic plan to take all measurements during the project specified total number of days, resulting in a target number of measurements per hour. Monitoring this performance indicator is crucial, as is monitoring the impact on the plan due to the above or other factors, and a daily modification to the plan. Identifying risk is an important part of the overall process when planning the number of measurements, their locations, the on-site project number of days and the resulting required number of measurements per hour.

All the above can easily be solved or avoided in a University lab setting, where time is not so much of an issues, the lab can be under the full control of the practitioner, all spare equipment is instantly available, and there are generally no other overriding objectives or interests other than the experimental work being undertaken, making everything predictable, controllable, in essence, very one dimensional. In an industrial environment, the opposite is true, and if something can go wrong, it usually will.

4. Results

It is important to re-emphasise that specific data cannot be presented here due to confidentiality reasons.

Based on the application of the two standards, to real on-site test situations, the key technical observation reported in this paper compares the ISO 8569 time domain RMS average (meaning the average of the RMS peak maximum and RMS peak minimum values) data to the VC curves 3rd Octave RMS peak values (meaning the amplitude value of the 3rd Octave bandwidth which has the highest vibration level, corresponding to the definition of the VC level). For one set of measurements taken on-site, for floor only measurements and ignoring any effects of power supply 50Hz noise and its harmonics, the time domain RMS average and the 3rd Octave RMS peak values were surprising similar, with the difference error being less than 5% for 93% of the cases, 5-10% for 4% of the cases, and over 10% for 3% of the cases.

This is a surprising result because the comparison is between time domain results and frequency domain results, where there is no single frequency that contains the vast majority of the vibration energy. Besides being a scientifically interesting observation, there is potential value for the practitioner, in that if many tests are required, and the final VC level for a large floor area is based on a statically averaging of all VC levels form each single test, then the time domain approach can save measurement time (shorter sampling times needed), with a slightly simpler set-up, and the errors mentioned above could be reduced due to the statistical averaging applied to give the single final VC level result.

However, this may become void if industry demands that the VC curve method be strictly applied, and expect data to be processed into 3rd Octave format. In addition, as part of the data quality check, both the time domain and frequency domain formats are useful, such as for example, when identifying the presence of any 50Hz noise or its harmonics.

For the case of machine measurements, this comparison has large differences, and the proposed shortcut method of testing cannot be applied.

5. Conclusions

On-site vibration surveys offer challenges to the practitioner that require careful planning and the accumulation of experience, to avoid project time overrun and to be able to make key decision on the measurement set-up detail, to extract meaningful data especially in the case of machine measurements.

The mentioned standards are generalized and require a great deal of on-site interpretation, and hence detailed logging of decisions and final chosen conditions, which must be justified against either the industrial client's specific enquiry or machine specific features or problems.

Empirical evidence shows the VC level approach for floor only measurement can be made redundant by using only the ISO 8569 time domain RMS peak average data, depending on the occurrence of 50Hz noise and/or its harmonics, and the strict requirements of the industrial client, which must be agreed prior to any tests.

Further work is required to investigate why this result occurs, including any detailed limitations of other possible analysis methods of short sampling time domain data.

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7. References

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