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Monitoring of Vibration in Vibration-Sensitive Facilities

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ABSTRACT

Vibration monitoring is a valuable tool in the operation of facilities which house vibration-sensitive equipment. Monitoring can detect trends in the vibration environment that may signal the need for remedial action before vibration-related problems are encountered. Monitoring is invaluable in situation where construction work is carried out within, or close to, the facility. The monitor can alert the construction team to particular events that exceed a set vibration threshold.

In this paper we describe our experience with the long-term use of a multi-channel monitoring system. This experience has provided insights to the problems that can be encountered and the ways in which these can be remedied.

1. REQUIREMENT

We were contacted by a contractor who was responsible for the refurbishment of a 22 story office building. The contractor wanted to provide a means of protecting the tenants from the effect of the construction generated vibration. One of the tenants was a telecommunications company providing cellular telephone service throughout the southwest region of the United States. This telecommunications company had large computer hard drives located on the third and fourteenth floors of the building which were used to operate and control the satellite up-link process of the system. We were asked by the contractor to recommend, install, and maintain a vibration monitoring system that would give the contractor an early warning that the vibration levels at these two critical locations were approaching levels that may interrupt the telecommunications service or damage the equipment. An interruption of service would create a large financial liability that the contractor would like to avoid.

2. MONITORING SYSTEM

We had previous experience with a floor vibration monitoring system which could be adapted to this task. The system consisted of six accelerometers, a signal conditioning chassis, and software to display and record the accelerometer outputs. The time domain data from each accelerometer was filtered into 4 bands. The frequency of these bands were determined by interpreting the hard drive manufacturers maximum allowable vibration specification with respect to spectrum resolution, bandwidth, and frequency range. The maximum level, minimum level, mean level (average), standard deviation level, and instantaneous level from each of the filtered time domain signals are recorded at user defined intervals. The software also allows the un-filtered accelerometer signal to be used in generating FFT spectrums. The number of averages used to generate the spectrum and the interval at which the spectrum will be generated and recorded is user definable. Each of the filtered time domain signals had two alarm set points available for a total of 24 yellow and 24 red alarm outputs. The system is programmed to record all time domain levels at the time an alarm occurs It can be also programmed to generate FFT spectrums upon an alarm event. Trend plots for the filtered time domain signals and stored FFT spectrums can be displayed without interrupting the monitoring functions of the system.

We customized the monitoring system by adding a modem card and software to the computer that would allow us to remotely monitor and control the system from our office. Additionally, the alarm outputs were connected to a telephone auto-dial system and a computer sound card with a speaker attached. The auto-dial system would call a designated phone number and would output a recognizable tone. The auto-dial system would alert the local system operator that an alarm had occurred.

The external speaker that was attached to the sound card was placed in the building security office. In the event of an alarm the building security office was to contact the construction foreman and have all construction activity stopped.

Before the system was installed in the building we conducted controlled tests where several types of construction tools were operated and the structural response was measured. During these tests FFT spectrums were recorded for future comparisons in the event of an alarm condition. This data and the manufacturers maximum allowable vibration levels were used to determine the yellow and red alarm set points for each filtered time domain channels in each axis being monitored at each location. Three accelerometers were mounted on the third and the remaining three accelerometers were mounted on the fourteenth floor. In each location the accelerometers were arranged in a tri-axial configuration to monitor vertical, North/South horizontal, and East/West horizontal vibration levels.

After the system was installed in the building an "end to end" calibration was conducted to compensate for any signal loss due to cable lengths. The alarm operation was verified for each channel as well. We monitored the system daily via the computer modem and printed reports weekly which included observations and data.

3. UNKNOWN LOCAL VIBRATION SOURCES

The monitoring system was installed in the building during the winter months and the pre-construction demolition was started. We were able to determine from looking at the maximum level trend data the daily and weekly activity cycles. In one of the weekly data reviews the daily cycle had disappeared and was replaced by a steady-state level. This occurred on all three accelerometers located on the third floor. We were immediately concerned that maybe the system was malfunctioning. We went through the steps of exchanging circuit cards, accelerometers, and accelerometer cables. None of the changes corrected the suspected malfunction. We came to the conclusion then that it must be real vibration levels. We then started looking for possible sources of the vibration levels on the third floor. We found a large air conditioning unit located on the third floor that provided extra cooling for the computer room during warm summer months. Since the system was set-up and started in the cooler months the supplemental air conditioning unit was not operating and we were unaware of its existence.

While this occurrence was not the result of a system malfunction it does represent a deficiency in the set-up procedure. A thorough investigation of potential vibration sources must be carried out at each monitoring location and should identify equipment that may not be running at the time of the system installation but may be turned on during the monitoring period. This event also initiated a discussion on methods of troubleshooting the monitoring system. The important points of this discussion were a means of displaying the accelerometer power supply voltage and current as well as a method of verifying the accelerometer cable continuity. These features would enable the system operator to quickly determine if accelerometers or accelerometer cables are operating properly and reduce the down time on the system caused by trial and error trouble shooting methods.

4. FFT SPECTRUM GENERATION UPON AN ALARM CONDITION

The system allows for FFT spectrum generation upon a yellow or red alarm condition. This is a useful capability for identifying the specific frequencies and spectrum shape of the vibration causing the alarm. As stated previously we had conducted several tool tests and had spectrums on file for comparison purposes. However, due to limitations of the software, this feature could cause a situation where the alarms would not function.

We encountered several yellow alarms during the first few months of system operation. Upon a detailed review of the recorded data it was apparent that in each case the maximum recorded level during an alarm was equal to the yellow alarm threshold level. We had configured the system so that it would gather FFT spectrums upon an alarm condition. The system recognized the yellow alarm and responded with the appropriate alarm outputs to the telephone auto-dialer and the audible alarm in the building security office. The monitoring system then went into the FFT generation mode. By the time all of the FFT spectrums had been generated and stored the vibration levels were below the yellow alarm threshold and the system had returned to the normal monitoring mode.

The monitoring system software does not use multi-tasking technology. If a yellow alarm occurs and the FFT generation is enabled the system acknowledges the alarm and goes into the FFT averaging mode. The system is locked into this mode until all averages for the spectrums of each accelerometer are completed. If the vibration levels are slow in developing but continues to increase during this FFT generation period to a level above the red alarm threshold the system would not acknowledge an alarm state. Similarly, if an alarm occurs during the normal interval FFT generation period the system would not acknowledge an alarm state unless the alarm event duration was longer than the time it takes to complete all of the FFT spectrums.

Our initial attempt at a solution to this conflict was to make a choice of what data is to be collected during either a yellow or a red alarm state. We decided that it was important to allow the system to go into a red alarm state from a yellow alarm state in order to stop the construction activities. We attempted to disable the FFT capabilities for any yellow alarm occurrence. During a yellow alarm event all of the construction activities would quickly be reviewed and they would be allowed to continue with caution. The FFT capability would be used during a red alarm condition. Under a red alarm condition all construction activities would be stopped and the FFT spectrum from the accelerometer going into alarm would be reviewed and compared to the previously recorded construction tool test spectrums. However we were unable to disable the FFT capability during a yellow alarm condition. We were able to demonstrate that if the vibration levels increased very quickly to levels that exceeded both the yellow and red alarms both alarm states would be recognized. Since our previous data showed that the construction tools that were being used generated vibration levels that quickly increased, similar to shock pulses, we determined that this system configuration would be acceptable in this situation.

The long term solution to this processing conflict is to develop the appropriate software and hardware that allows normal monitoring and alarm functions while FFT spectrums are being generated.

5. Time Domain Data During an Alarm Condition

As stated previously each accelerometer time domain signal is filtered into four channels. The maximum, minimum, mean, standard deviation, and instantaneous levels are recorded for each channel at pre-set intervals. Additionally each type of level for each channel is recorded when the vibration level of any channel exceeds either of the alarm thresholds and when that level decreases below the alarm threshold. A review of data collected from a yellow alarm event showed the maximum level for the preceding interval, the alarm initiation level, the alarm recovery level, and the maximum level for the following interval. Having only four recorded data points for and alarm event, and the two alarm levels representing the just the alarm threshold level, is insufficient to determine the peak level for the event and the time in which it took to reach the peak level. Here, again, the system software's inability to perform multiple tasks is at fault. While the system is acknowledging the alarm state and then recording the alarm levels the vibration event is continuing without being monitored.

There was no quick fix for this problem. We can conceive of a system where time history data is recorded a very fast rate concurrent with the normal alarm functions. A data buffer could be used to collect the time history data and write it to a file for review after the alarm event is over. You would be able to trend, in good detail, the vibration levels during the alarm event and also establish the peak level during the event.

6. Data Manipulation

The time history data and the FFT spectrum files stored by the monitoring system cannot be interpreted by common text editors or spreadsheet software. When we generated reports we displayed the time history data and the spectrum data within the monitoring system software and used a screen capture program to print them. We could not edit or format the displayed data. We have found it useful in other projects to be able to display data in different formats that are consistent with our clients needs such as velocity, acceleration, displacement, or one-third octave bands. This is usually done by converting the original data to the required format in a spreadsheet and then charting the modified data. This is not a critical feature for a floor monitoring system but is very useful when trying to convince your manger of the value of the system.

7. Hardware and Software Manuals

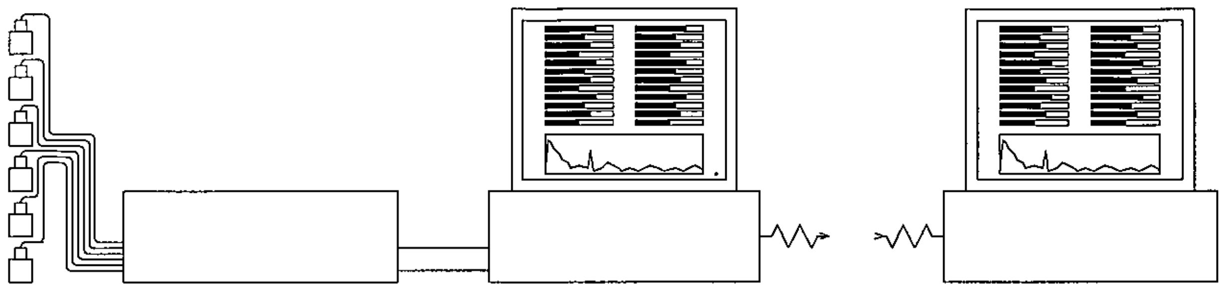
We found the operating manuals provided with the monitoring system were vague and incomplete. Many of details in system operation we had to discover ourselves. As we continued to use the system we found more features as well as faults. At the end of the project we had developed a good manual of our own that, unfortunately, could only be used for the situation we encountered during the project. A tool such as this is useful only when the capabilities are presented and the means to use them logically defined.

8. The Ideal Floor Monitoring System

In summary we describe an ideal floor vibration monitoring system, many of the details have already been discussed. The system would be multi-channel with accelerometers that have mounting plates that can be installed using adhesive to most any surface. This allows the accelerometers to be moved easily to new locations within the same facility as necessary. We may still be limited to hard wiring the accelerometers to the signal conditioning chassis due to restricted radio transmissions is some technical process areas. Filtering of the time domain signals should be user selectable depending of the specific requirements of the vibration sources and the specifications of the sensitive equipment being monitored. The computer should be configured to be as fast as possible due to the dynamic environment that it will be monitoring. Some vibration events take place in milliseconds and if the computer is still processing or archiving previous data a vibration event may not be recorded properly. It should be capable of collecting time history data very fast while quickly generating FFT spectrums. There should be built in alarm output devices such as a telephone auto-dialer and an external speaker port. A fast modem for remote system monitoring and control as well as data transfer should be standard. The data files should be usable in common text editors and spreadsheet software for customized report writing. The computer screen display should allow for all of the channels to be displayed at one time as well as being capable of displaying recorded trends and FFT spectrums concurrently. An alarm log should be created so that any alarm during an unattended period can be reviewed when the operator returns. Provisions for incorporating the vibration monitoring system into a facility's management systems should be standard. Many large facilities monitor many different facility parameters from one location. It may not be possible to locate the vibration monitoring system in that area, however, it in most likely possible to connect alarm output cables from the system to the central facilities monitoring system.

A system with these capabilities would be a useful tool for any facility with vibration sensitive equipment located in them. It can be used to monitor and control nearby construction activities so that they do not interrupt normal facility operations. It can also be used to monitor the condition of vibration isolation systems installed on building mechanical equipment. A baseline vibration level can be established when all isolation system are in good working condition. This baseline condition can be compared to trends plots generated by the monitoring system which could indicate the degradation of the vibration isolation systems or a new source of vibration that was recently installed. As certain technologies continue to grow the need for stable vibration environments also grows. A tool such as this can be used to monitor and control the vibration environment

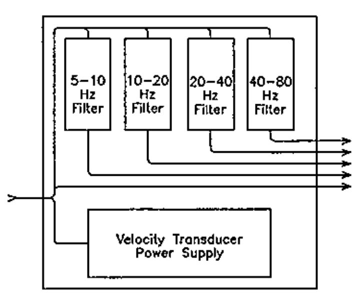
Figure 1 – Diagram of the Floor Vibration Monitoring System



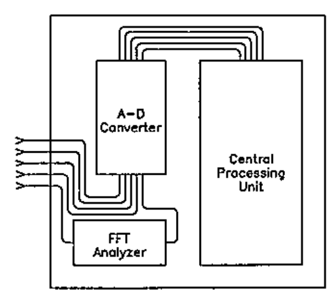
A) Velocity Transducers   B) Signal Conditioning Chassis   C) Local Computer   D) Computer Modem   E) Remote Computer

A) High sensitivity seismic–type velocity sensor. The system can use up to six of this type of transducer.

B) Signal conditioning chassis contains the adjustable analog filters and the velocity transducer power supply. Each velocity transducer signal is filtered into 4 frequency bands, typically set in ranges from 5 to 10, 10 to 20, 20 to 40, and 40 to 80 Hz. Each filtered signal is sent to the analog to digital card located in the local computer. A parallel path to the filters provides an un–filtered velocity signal to the FFT analysis card also located in the local computer. (see drawing below)



Signal Conditioning Chassis



Local Computer

C) The local computer contains the FFT analysis card which processes the un–filtered velocity signal. The FFT spectrum output is then fed to the analog to digital converter card located in the local computer. (see drawing above)

D) The computer modem allows the remote computer to monitor the display of the local computer, take control of the local computer, and down–load data files from the local computer.

E) The remote computer can be located in an office remotely located from the facility that is being monitored.

Figure 2 – Monitoring System Configuration in Office Building

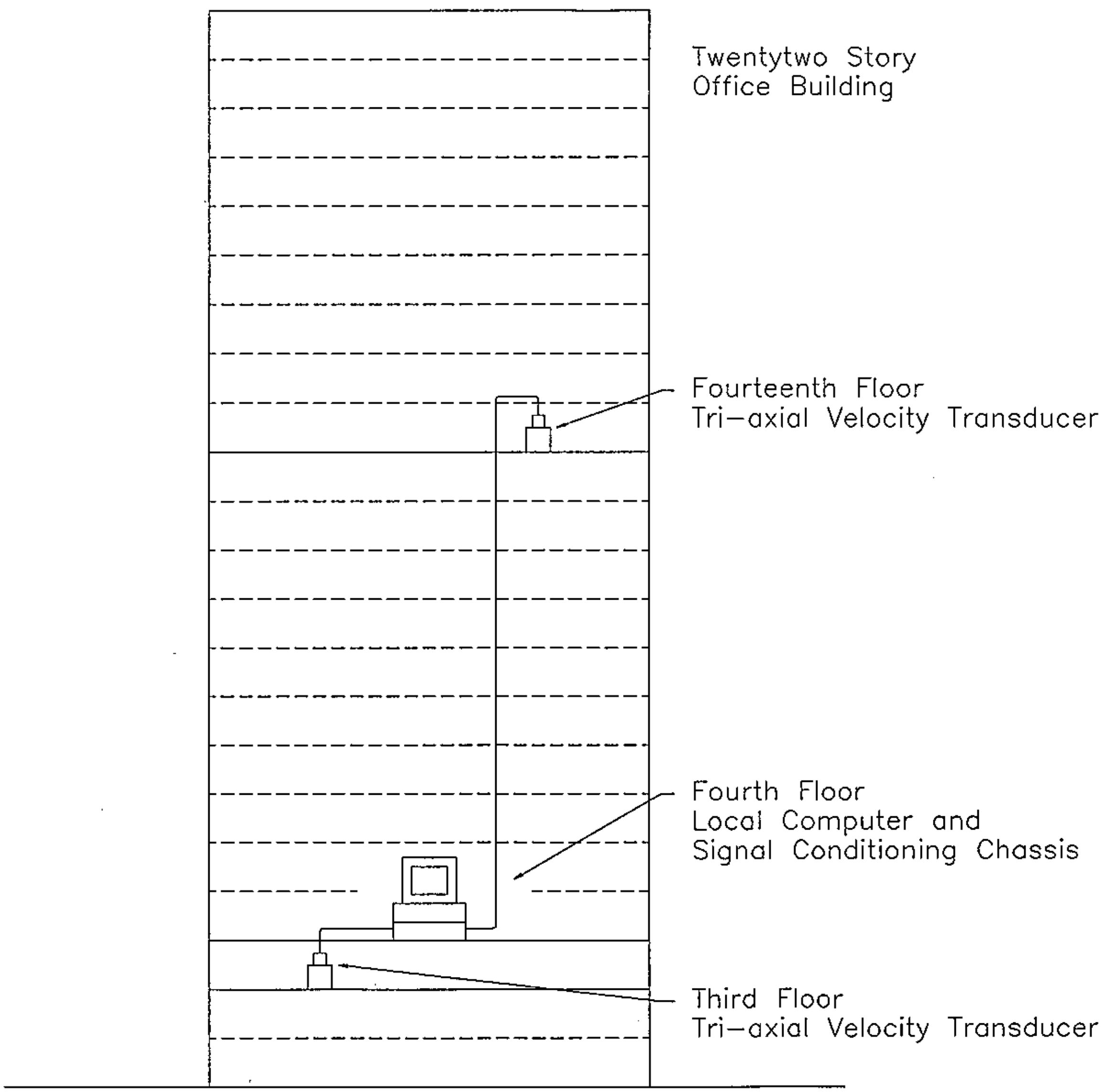


Figure 3 – Typical Time History
Data Format for Reports