Development of Measurement and Tracing of Vibration for the TPS Utility System

Presenting author: Zong-Da Tsai
Organisation: National Synchrotron Radiation Research Center

Corresponding author: Zong-Da Tsai
Organisation: National Synchrotron Radiation Research Center
Email:zdtsai@nsrrc.org.tw

Co-author(s): Ching-Wei Hsu
Organisation: National Synchrotron Radiation Research Center

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Abstract:

The civil construction and utility system of the 3-GeV Taiwan Photon Source (TPS) at NSRRC are expected to be ready for machine commission in 2013. Because various accelerator facilities are sensitive to vibration, its control and the design should be considered carefully. The specification provides the design necessary for the construction of architectural, mechanical, process, electrical and structural systems due to both the operation of machinery or equipment and the turbulence-inducing vibration in piping and ductwork.

The utility system is a major and severe source of vibration, because the system has much rotating mechanical equipment and turbulent flow. The vibration induced at the tunnel sites is propagated through the main path of the piping, ductwork and ground or rigid contact with the building structure. For the purpose of tracing the source of vibrations and to prevent failure of the facility, a system to measure and to trace vibration has been developed, incorporating a programmable automation controller with a field-programmable gate array (FPGA) function to perform data acquisition with its algorithms. To prevent the transmission of vibration and noise to the building structure, the cross-talk effect of vibration should be clarified. We propose a new method that we combine with a time-frequency spectrogram and feature extraction algorithms to distinguish the cross-talk effect of vibration. It is helpful to specify the path of vibration propagation in the large and complicated accelerator system.

1-Introduction

Much evidence has shown that an accelerator is sensitive to vibration signals [1][2]. There are many mechanical rotary or moving parts, such as pumps, fans, compressors etc. among the utility facilities; some vibrational phenomena have a significant influence on the beam stability. Vibration is always suspected to propagate along paths in piping, ductwork and ground or rigid contact with the building structure. To clarify the situation, the development of the measurement and tracing of vibration is required, especially in such a comprehensive TPS utility system. These conditions have encouraged us to construct an on-line system of vibrational measurement for the utility facility [3]. A convenient interface provides on-line analysis and traces the source of vibration via a network, anywhere and anytime. Monitoring these data allows us to predict a failure early and to schedule appropriate maintenance. In general, this information can provide a lead time three months before an actual occasion of failure. It is helpful to prevent unscheduled outages, to optimize the machine performance, and to decrease the repair time and maintenance costs. Analysis of the relations among multi-channel and on-line vibration data then occurs within 1 s and shows simultaneously on the display, which can enable tracing all vibrational signals and clarify the paths of propagation.

To prevent the transmission of vibration and noise to the building structure, the cross-talk effect of vibration should be clarified, but the on-line vibrational data show only the relation at a particular time and the historical data cannot be compared with each other automatically. If the source of vibration has an almost constant frequency at the stage of commission, it is difficult to clarify in such a comprehensive system. A new method combines a time-frequency spectrogram and feature extraction to distinguish the effect of vibrational cross-talk. The time-frequency spectrogram can faithfully record the vibrational signal with time when the inverter frequency of the facility is switched with time. These measures can provide vibrational information sufficient to separate other sources of vibration and noise signal; the feature extraction makes effective use of image processing to characterize the main frequency spectrum. Furthermore, the correlation function can be applied to obtain quantification of the relation. It is thus helpful to specify the path of vibrational propagation in the large and complicated accelerator system and to evaluate impacts from the utility facility.

2-Data acquisition and recording of vibration signal

The PAC (National Instrument, NI) with real-time controllers and FPGA are adopted for all distributed data acquisition. We must first choose two positions of detection, one for the source of vibration such as the location of pumps or fans, and the other for the neighboring ground or remote ductwork with induced vibration. The proper accelerometers must be carefully selected for individual sensitivity. This FPGA function possesses an ability of rapid data acquisition to accept packets of data with a sampling rate 1 – 2 kHz, and then to use a direct memory access (DMA) and interrupt function to transfer data into the real-time controller without delay. The real-time controller transmits the native time waveform to Ethernet. The exchange server located on the same network can access these data via a NI published subscribe protocol (PSP) to conduct rapid data storage.

A TDM streaming-data model defined by NI has been adopted. This TDM streaming is designed to write real-time data quickly and efficiently to a disk and also to have an auto-generated binary index file to provide consolidated information on all attributes in the bulk data file, which facilitates its search. All data for vibrational signals can be saved periodically. According to various requests of time and signal, these data can be accessed via the FTP protocol. It is helpful to trace fully the trend as historical information about the machine commission conditions, but historical information is chaotic, requiring human intervention to clarify according to individual experience. The best way is to model this experience mathematically, as shown in the following description.

3-Tracing analysis of a vibration signal

Once the vibrational signals become recorded faithfully, the off-line tracing algorithm becomes applicable to clarify the relation of the main path of the vibration. For example, if the fan of an AHU suddenly becomes a vibrational source, the neighboring ground and remote ductwork become concurrently monitored dynamically. An analysis algorithm that characterizes the main frequency is subsequently applied to the raw vibrational data. The processes include a band-pass filter, integration of a signal with a running RMS average, power spectrum with RMS average, time-frequency spectrogram, feature extraction, and correlation analysis as depicted in Figure 1. All processing is as follows.

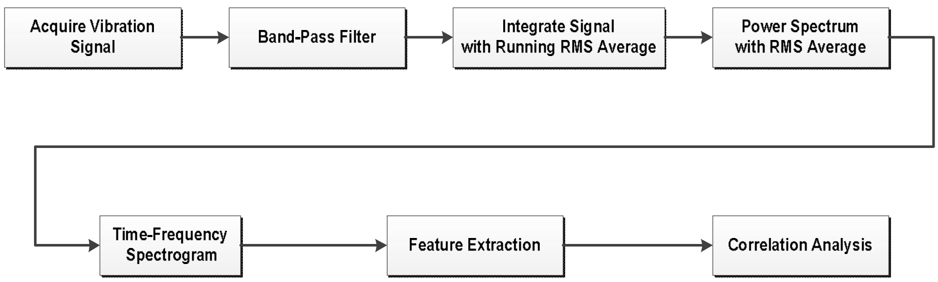

Figure 1: Flow chart to trace analysis of vibration

Band-Pass Filter

Because the mechanical vibration frequency appears almost invariably below 1 kHz and the general accelerometers have superior performance above 10 Hz, a Butterworth band-pass filter has been implemented to remove the other spectrum unrelated to the mechanical vibration.

Integration of Signal with Running RMS Average

The integration algorithm integrates the acceleration value from accelerometers into a velocity value. In general, the utility facility has a guideline using a velocity value as definition, including the ASHRAE standard, ISO 2372 and Gordon presentation in 1991, which are readily comparable with these standards, and the high-frequency noise can be eliminated. The running RMS average is applicable also in this step to decrease the signal fluctuation and to enhance the main waveform of the vibrational signal in the time domain.

Power Spectrum with RMS Average

We use a FFT [4] to transform the signal in the time domain into the frequency spectrum to separate all frequencies, as shown in Figure 2. A Hanning window is applied to avoid a windowing effect. The noise signal in the frequency domain is also minimized with a RMS average.

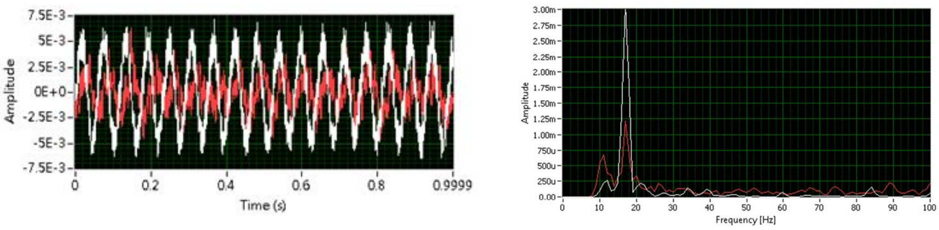

Figure 2: Time waveform and the corresponding power spectrum of the vibrational signal

Time-Frequency Spectrogram

When the power spectrum signal has been obtained and recorded, the inverter frequency of pumps or fans will be switched with time programmatically. When the frequency varies sequentially with time, all power spectra will be recorded with time to shape a time-frequency spectrogram as shown in Figure 3. The left time-frequency spectrogram shows a source of vibration from a fan of the AHU. The right time-frequency spectrogram shows vibration induced from the neighboring ground.

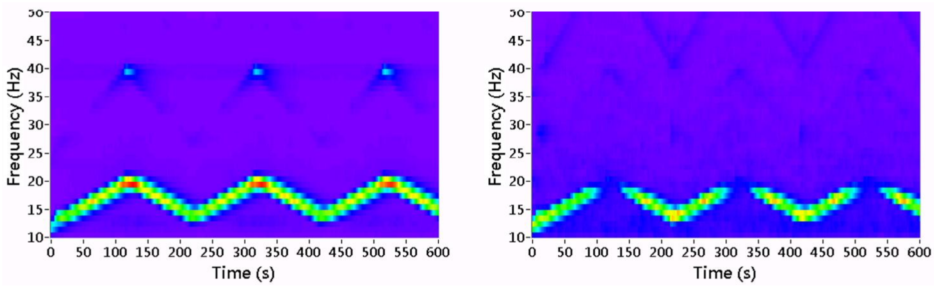

Figure 3: Time-frequency spectrograms

Feature Extraction

The time-frequency spectrogram is a 2D image with many maxima and slopes. The feature extraction has three steps of image processing [5], including ridge detection, binary thresholding and a size filter, to characterize the variation of the main frequency with time. The ridge detection removes the sidebands for every maximum. The binary thresholding converts a grey image into a binary image for the following processing as shown in Figure 4, and the size filter removes small particles, which is a kind of induced frequency without continuous variation with time as shown in Figure 5. The main maxima can thereby be clarified clearly.

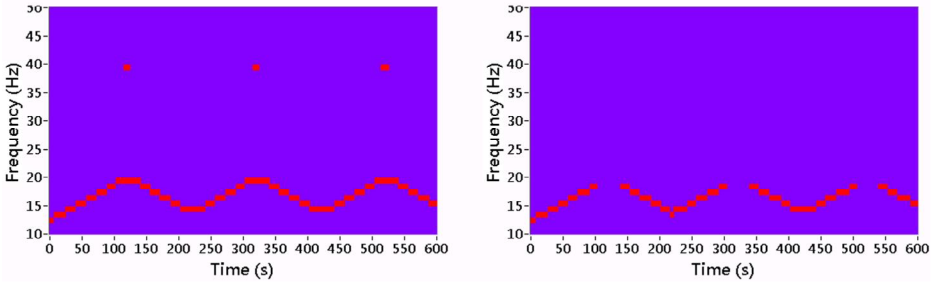

Figure 4: Binary images with processing of ridge detection and binary thresholding

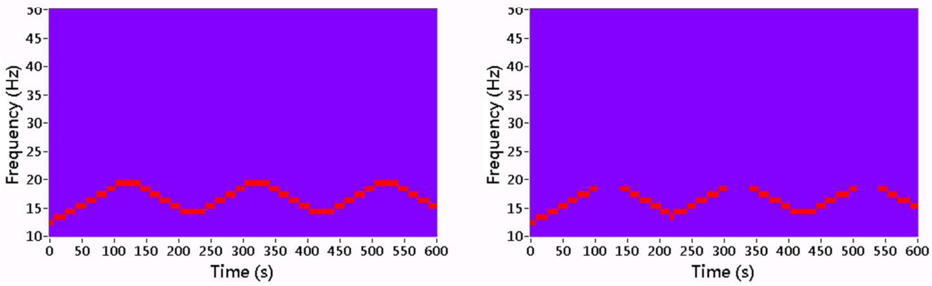

Figure 5: Binary image with processing of the size filter

Correlation Analysis

Once the main frequency becomes distinguished and preserved in the binary image, the correlation analysis is implemented easily. We select a portion of a time-frequency spectrogram with characteristic patterns as a match mask in the left image of Figure 5. The mask is applied into the right image of Figure 5 with image processing of pattern matching as shown in Figure 6. The figure shows that there are 3 similarity patterns between two detected positions of vibration. Therefore, the tracing analysis can be achieved.

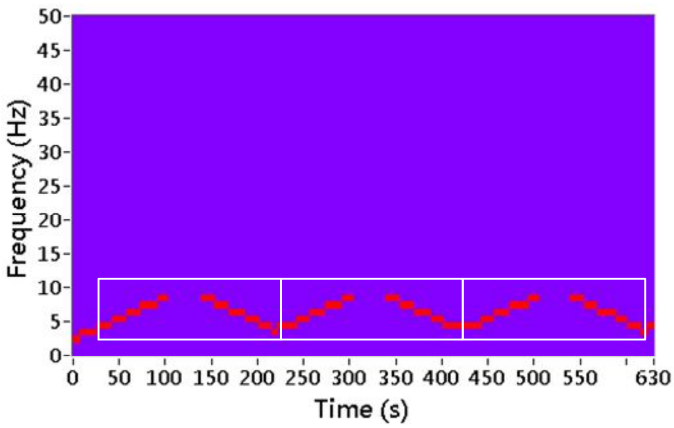

Figure 6: Correlation image with processing of pattern matching

4-Conclusion

Our effort is devoted to develop the measurement and tracing of vibration for the TPS utility system. The system combined with the previous development adopts a PAC with embedded FPGA chips to acquire the distributed vibration signal. The PSP and FTP protocol transmits the on-line and off-line data to the exchange server, and the client software accesses all distributed vibrational signals. The software currently provides an on-line comparison of similarity and an off-line historical analysis. A new method has been incorporated into the system to distinguish the cross-talk effect of vibration using a time-frequency spectrogram and feature extraction algorithms. It is helpful to specify the path of vibration propagation in the large and complicated accelerator system and to diagnose the failure status of the utility facility.

5-Acknowledgement

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