FIR FILTER RESONANCE COMPENSATION FOR RANDOM VIBRATION GENERATION

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Abstract: This paper deals with a random vibration generation on vibration shakers using a FIR filter. Every shaker has its resonances and anti-resonances which causes troubles in random vibration generation, for instance in presented shaker the difference between maximum and minimum in frequency characteristic is nearly 50 dB. Therefore, we decided to create a FIR filter with inverse characteristic with respect to the shaker to minimize those differences. To design such a filter a freqeuncy characteristic of the shaker has to be measured, then the characteristic is simplified using Ramer–Douglas–Peucker algorithm. Finally, the characteristic is inverted and FIR filter is designed using Remez algorithm. Using this FIR filter the difference in frequency characteristic drops from 50 dB to less 2 dB.

Keywords: Mechanical vibration, random vibration, FIR filter, resonance

1 INTRODUCTION

Mechanical vibrations are essential part of environmental testing procedure, because everything is, during its lifetime, exposed to vibration. Different equipment are exposed to different types of vibration based on their purpose and destination. For this reason, there exist many different testing procedures, for instance for industrial equipment, cars, aerospace, etc. However all these procedures are using sine, sweep sine, or random vibration to test the devices. Therefore generation of such a signal is necessary for the testing. Moreover, mechanical vibrations are also used in other areas, such as modal analysis, energy harvesters characterization, and mechanical sensor testing.

The vibrations are usually performed on electrodynamic shakers, which can be easily driven by electrical signal. On the other hand, the description of electrical and mechanical parameters and their mutual influence is complex and can be found in [1]. In general, the parameters and their mutual influence results in resonances and anti-resonances, which has to be taken into account when driving these shakers.

Traditional approach to control random vibrations is based on narrowband filters and control of the effective value (rms) of the vibrations [1]. Nowadays, with increased computational power new algorithms and methods have been developed, for instance robust methods [2], precision methods [3], or energy efficient methods [4]. Unfortunately, these methods are not suitable for low computational power systems.

Commercially available vibration driving software firstly identifies the system to find their main resonances and anti-resonances and then uses sophisticated control algorithms to keep the amplitude of the vibration within specified range. Therefore, these control systems are expensive and does not allow further modifications. So, this solution is not suitable for occasional testing and research. For this reason we decided to develop our own vibration control system.

We have already developed a control system capable of sine and sweep sine vibration control, where signal effective value is controlled via PID controller [5]. This system is working quite well if the resonances and anti-resonances have lower quality factor and are sparsely distributed. Otherwise, the system is not able to control the amplitude properly.

Nevertheless, the resonances can have a high quality factor and especially resonance and anti-resonance can be very close to each other. Moreover, the need for simple vibration noise control system still lasts. For these reasons, we have decided to develop a new control system.

2 RANDOM VIBRATION CONTROL

Random vibrations are usually defined as a vibration with constant power spectral density on specified frequency range, the maximal amplitude error is usually $\pm$ 3 dB. This is quite challenging to achieve, due to resonances and anti-resonances in the system.

A recommended way how to achieve a white noise on vibration shakers, is to divide the frequencies spectrum to several narrower ones, where the amplitude is controlled independently [6]. This attitude is versatile, but require a lot of computational power to filter input and output data. Therefore, this algorithm is not suitable for distributed systems like NI CompactRIO.

For this reason, we decided to create a FIR filter with inverse characteristic of the vibration system and using it to filter the input data for the shaker so, the system should have a constant frequency characteristic. Then, a PID controller can easily control the amplitude of the vibration. This system is less computational demanding than the aforementioned method, so it can be used on NI CompactRIO. Moreover, this filter can be also used in our current sine control system to improve its properties. On the other hand, for a different shakers, or load on shaker a new filter needs to be created.

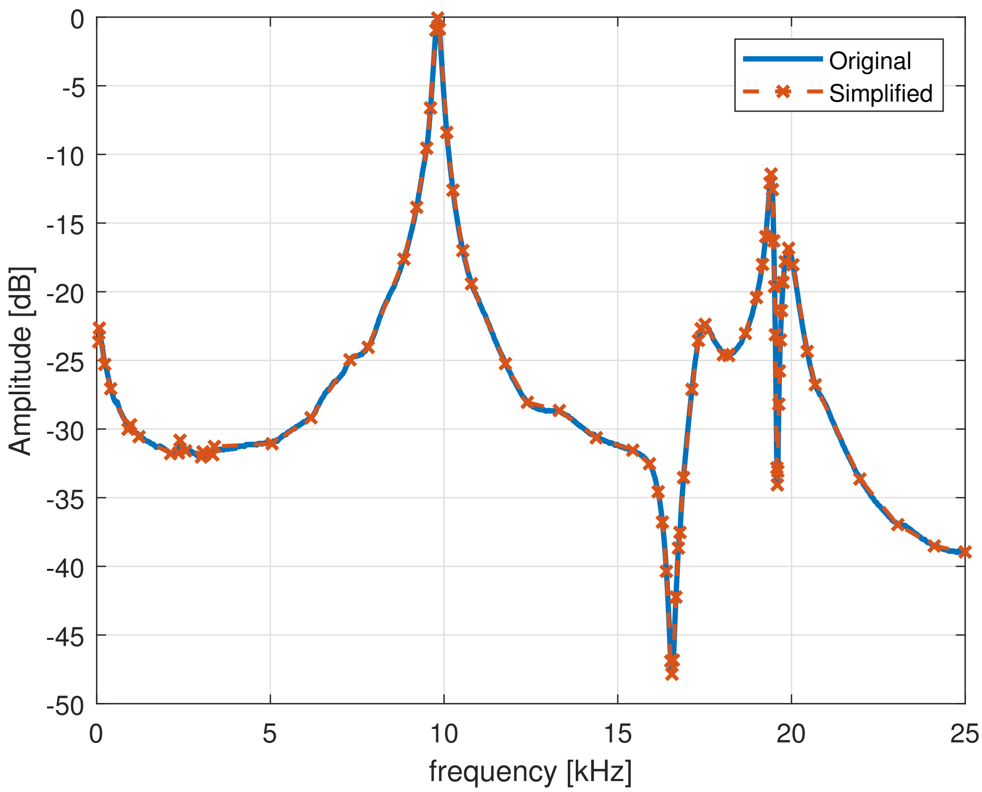

Figure 1: Frequency characteristic of vibration shaker - measured and after simplification using Ramer–Douglas–Peucker algorithm

2.1 Inverse Filter

The frequency characteristic of the shaker is created using ratio of frequency spectra of the output and input signal with 1 Hz resolution. The data are generated and measured using NI PXI 6363 card. To minimize the error, the characteristic is created by averaging 1000 measurement. Nevertheless, the resulted spectrum were still quite noisy therefore, a spline filter was used. The filtered frequency characteristic is visible in the figure 1.

To create a FIR filter according to specific frequency characteristic a Remez exchange method was selected [7]. There has to be enough input data to interpret the shape properly, however there cannot be too much of the data due to numerical stability. In our case, the algorithm is stable if the input data are a few hundreds samples long. And the maximum distance between samples is 100 Hz, otherwise the algorithm creates peaks or notches between those points. For this reason, it is necessary to process the data to describe the shape properly, but contain only a few hundreds of samples.

For this reason, the frequency characteristic was simplified using Ramer–Douglas–Peucker algorithm [8]. This algorithm remove points which can be replaced by line segment within a specified tolerance. This method simplified the frequency characteristic to 84 points (figure 1). However, this method keeps some wide areas without any point. Therefore, if there is an area larger than 100 Hz without a point, one is added. The resulted characteristic is described by 298 points.

Then, the data are inverted to create the inverse filter and the FIR filter is created using aforementioned Remez algorithm. The length of the filter was determined experimentally to 2001 samples. The frequency characteristic of the filter is visible in the figure 2.

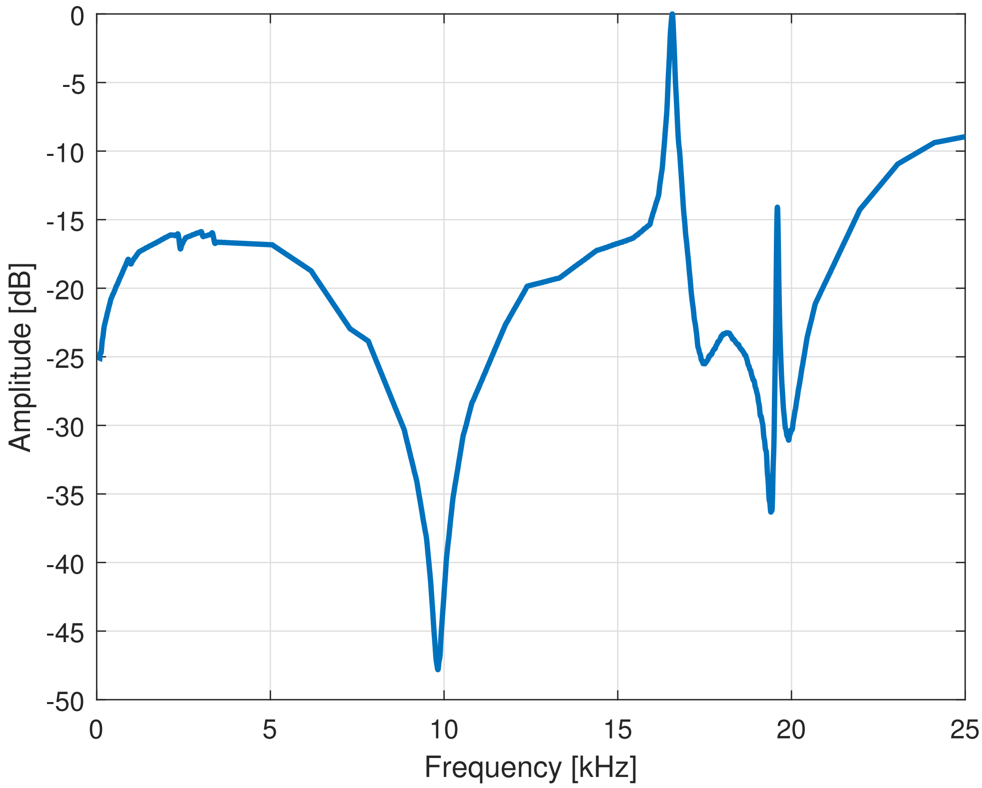

Figure 2: Frequency characteristic of the FIR filter

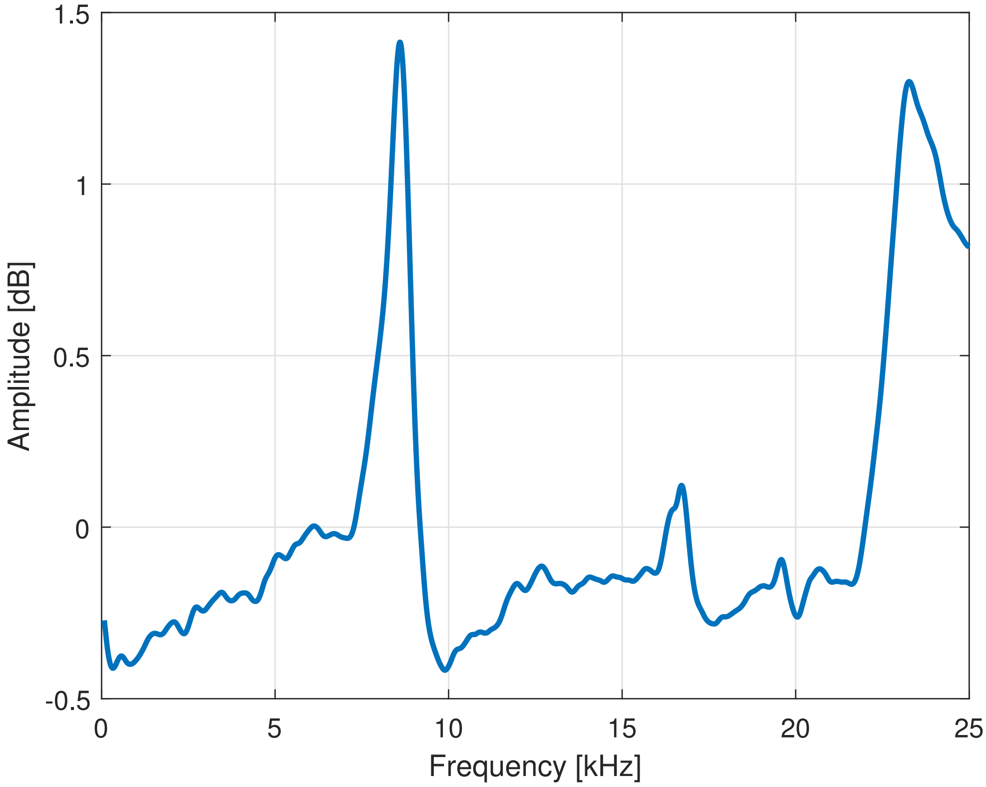

Figure 3: Resulted spectrum of the vibration

2.2 Vibration generation

The FIR filter is used to filter the input white noise data to the vibration shaker to minimize its resonances. The amplitude of the vibration is controlled using simple PI controller. The spectrum of the vibration signal on the vibration shaker is visible in the figure 3. In the resulted spectrum are still visible some traces of the original resonances, however the overall error is smaller than 2 dB, which is within the limits described by [6]. Therefore, this method can be used to generate random vibration.

3 CONCLUSION

In this paper we describe a method of generation a random vibration with constant power spectral density. To do that a shaker resonances has to be suppressed. In our case, we do this using FIR filter. To design such a filter we need the frequency characteristic of the shaker, which can be easily measured using the input and output signal spectrum ratio. Then, from the spectrum are using Ramer–Douglas–Peucker algorithm extracted important points, which are then inverted and used to design FIR filter using Remez exchange method.

The resulted FIR filter is then used to filter the input signal to the shaker. The resulted system has more or less constant frequency characteristic. The differences in the resulted spectrum are smaller than 2 dB, which is great improvement because the in the original spectrum were nearly 50 dB. The effective value of the vibration is then controlled by simple PID controller.

Moreover, this method can be used also in sweep sine vibration to overcome the resonances and anti-resonances. On the other hand, The FIR filter has to be designed for different vibration shakers and loads, as it can change the resonances. However, the FIR filter can be easily created, so this constrains does not cause much difficulties.

Unlike the standard approach, this method is not able to reflect runtime changes in the frequency characteristic of the vibration system, which can be caused for instance by temperature. On the other hand, it is possible to update the inverse filter during vibration generation, however this will largely increase needed lot of computational power, so in that case a standard approach seems to be a better option. Nevertheless, in applications with minor runtime frequency characteristic changes this method can be used.

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