FEW ISSUES RELATED TO AN ELECTRODYNAMIC EXCITER CONTROL

Martin Čala
Doctoral Degree Programme (1), FEEC, Brno University of Technology
E-mail: xcalam00@stud.feec.vutbr.cz

Supervised by: Petr Beneš
E-mail: benesp@feec.vutbr.cz

Abstract: There are multiple problems to solve when controlling an electromagnetic exciter for vibrations generation. Main challenge is to straighten a frequency response of an exciter which is normally not uniform due to resonances resulting from the mechanical construction of an exciter, specimen to test, or mounting fixture. This paper describes number of aspects to consider, which arose during implementation of the control system for small electrodynamic exciter on the Department of Control and Instrumentation.

Keywords: Vibration generation, electrodynamic exciter, accelerometer, inverse filter, system identification, controller

1 INTRODUCTION

In vibrations testing are used electrodynamic exciters to create vibrations with strict parameters to stress the specimen and prove whether it is capable to work during transportation, normal working conditions, or critical (faulty) situations which may occur. That tests can last many hours and stability of generated vibrations must satisfy the limits. Very important property of the control system is versatility to be able to keep signal stable on different equipment or specimen types.

Simplified exciter model shown in Fig. 1 has a resonance given by an equation

$$w_0 = \sqrt{\frac{k}{m}}, \tag{1}$$

where k denotes spring constant $[\mathrm{kg} \cdot \mathrm{s}^{-2}]$ and m denotes moving mass [kg]. This resonance is always present and causes non-uniform frequency response. It means that for different frequencies, different signal amplitude must be provided to measure uniform acceleration on particular working range. This is main challenge to be investigated in the paper. There are many authors who dealed with this challenge. According to a [2], [3], [4], [5], and [6], best way is to identify controlled system and change drive signal amplitude inversely to the calculated frequency response.

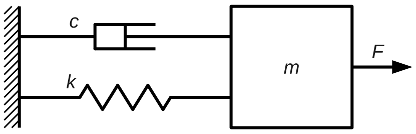

Figure 1: Mechanical model of an electrodynamic exciter

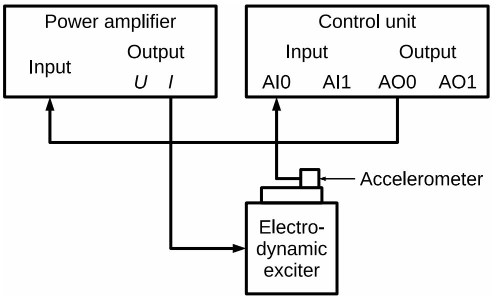

Figure 2: Vibration system components

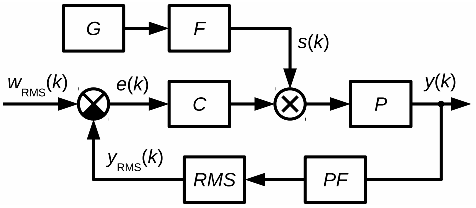

Figure 3: System control scheme

2 THE SYSTEM DESCRIPTION

The system is usually capable of generating multiple signal types. In this case, only sine signals are considered. Signal properties, as well as test scenarios, are described in the international standard IEC 60068-2-6 [7].

Vibration system components are showed in Fig. 2. Control unit implements all algorithms. Depending on the signal from an accelerometer and wanted signal properties, the system generates a drive signal amplified by the power amplifier with current output proportional to the supplied voltage. The electrodynamic exciter generates mechanical movement distorted by its frequency response. Purpose of the control algorithms is to adapt a drive signal in order to measure desired signal on a test specimen. Fig. 3 shows control scheme of the proposed system. Filter F changes signal amplitude from generator G inversely to the identified frequency response. If the frequency response is identified properly, filter F should equalize whole spectrum and controller C only adjusts tiny differences. The open loop (denoted as P) is identified once in the beginning using a white noise signal.

Vibration testing usually uses a chirp signal with one octal per minute frequency change to ensure that test specimen is exposed to all frequencies in the range sufficiently long time. If an acceleration amplitude leaves $\pm 6\,\mathrm{dB}$ tolerance, test must be stopped and if leaves $\pm 3\,\mathrm{dB}$ tolerance, warning is generated.

2.1 DELAY OF AN DELTA-SIGMA AD CONVERTER AND FREQUENCY RANGE

Vibrations are usually measured using a cards with 24-bit resolution delta-sigma analog-to-digital converter (ADC). Such principle brings a delay in order of tens of samples. This is reason why point-by-point control is not possible. Instead, controller works with data blocks. If input and output sampling frequencies (Fig. 2) are set reasonably high (e.g. $50\,\mathrm{kHz}$) to ensure signal smoothness, delay introduced in blocks of 5000 samples is negligible. It is possible to create also point-by-point control but different successive approximation ADC must be used. Delay introduced into a control loop by these ADCs is usually much lower than length of one sampling period and thus insignificant for control algorithms. Commercial systems use delta-sigma ADCs because whole inputs are usually adapted to the accelerometers and contains also current source for ICP sensors.

Although according to the [7] frequency ranges can be selected from multiple combinations, usually frequency range within $1\,\mathrm{Hz}$ and $2\,\mathrm{kHz}$ is used. It is important to acquire a block with at least one period of a chirp signal to be able to determine signal amplitude using a FFT. If the sampling frequency is $50\,\mathrm{kHz}$ and one block has 5000 samples, the sine signal must have the frequency at least $10\,\mathrm{Hz}$ when an amplitude is required to be determined reliably. Lower frequencies can be obtained by decreasing sampling frequency (limits signal shape at higher frequencies) or calculating signal amplitude from multiple blocks. This also adds significant delay to the control loop. Ratio of sampling frequency and block length defines controller sampling frequency to $10\,\mathrm{Hz}$.

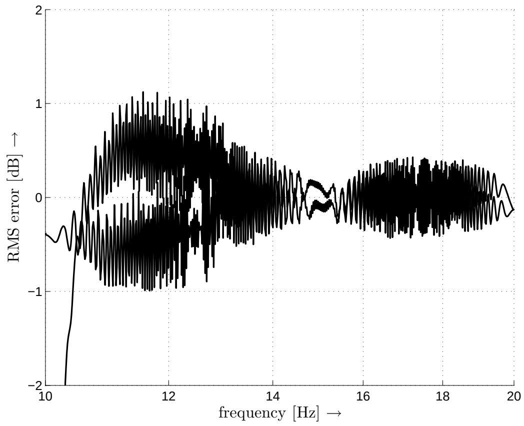

Figure 4: Fluctuations of an vibrations RMS over frequency change

2.2 RMS MEASUREMENT FLUCTUATIONS

Fig. 3 shows that the measured signal $y(k)$ is first filtered by a band-pass filter followed by the block for calculating the root mean square value *RMS*. Filter coefficients are calculated dynamically to keep the bandwidth in the range $[0.5f; 2f]$, where f denotes instantaneous frequency of the generated signal. Butterworth filter functions available in LabVIEW environment were used to calculate the coefficients. Potential noise or upper harmonics energy are suppressed.

If block size is fixed and instantaneous frequency is changing, the block will not always contain an integer multiple of the signal periods. Fig. 4 shows the progress of an RMS error in dB over the frequency change both upwards and downwards. Note the minimum values near 10, 15, and 20 Hz, which means that error is zero when there is integer multiply of half of the signal period. Other values cause an error up to 1 dB (difference about 12 %). This fluctuations can be compensated either by selecting only some cut-out from the block to maintain one or more periods or by multiplying fluctuated value by a factor dependent on the current signal frequency. Logarithmic frequency change makes both methods complicated but second one can be less complex to compute since it does not use an array operations which are usually time-consuming on the real-time operating systems.

These fluctuations influence the control quality because quick changes of the RMS show the same behavior as the noise. This is the reason why a PI controller is more suitable for this application. Using a derivative part would require a filter that would add significant delay.

2.3 THE FREQUENCY RESPONSE ACCURACY

The control algorithm employs the inverse filter based on the frequency response calculated from the measured signal while whole system was driven by a white noise. Frequency response contains a lot of noise which must be removed. Identified subject is mechanical system which contains resonances, often with high quality factor. It is very difficult to distinguish such resonances from noise. To use the response as inverse filter, response must be smoothed. Implemented method separates the whole frequency range to number of areas and computes an average from all points within an area. These average values are representing points of averaged frequency response. Example of such response is showed in Fig. 5. The method is very sensitive to a location of the resonance. Significant resonances (e.g. near 20 Hz) are located and the inverse filter makes control easier even though the frequency response change is over 20 dB. If the resonance is not located accurately, it is the PI controller that must adjust the drive signal amplitude but its speed is limited.

The control can fail when there is significant difference between reality and identified response, as

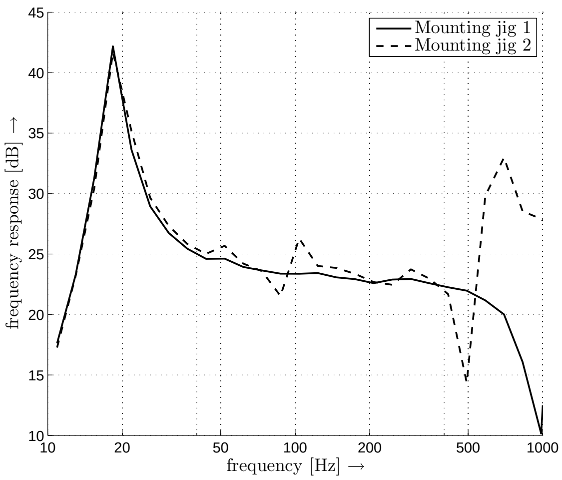

Figure 5: Identified frequency response used for prefiltering with the inverse filter

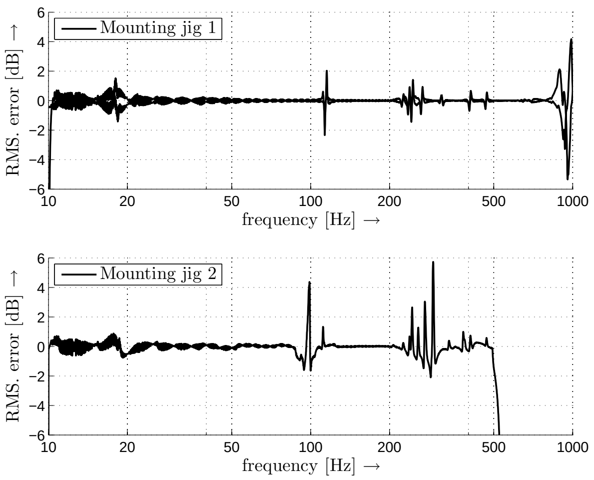

Figure 6: RMS error during the one test cycle related to the desired acceleration setpoint value $10\mathrm{ms}^{-2}$ for different loads

showed in Fig. 6. The resonance near 500 Hz was not identified properly thus controller was not fast enough to adjust the drive signal amplitude and 6 dB limit for stopping was reached. The frequency response accuracy plays important role in the whole system functionality since better frequency response makes the PI controller less important during a control.

2.4 THE LOSS OF A FEEDBACK

The forces during the tests are very high. With combination of long duration, there is high probability of system failure during a test due to components fatigue. For control is important to keep in mind that any damage during a test anywhere in a feedback (accelerometer, cabling, mounting) will produce only a little acceleration signal. The PI controller will then increase the drive signal to a maximum value that can damage or destroy an exciter or a specimen. The system must be able to detect such a risk by monitoring the drive signal changes. If the change is abnormally big, the test must be terminated.

3 CONCLUSION

The paper presented few issues that occurs when developing the control system for a small electrodynamic exciter. The most important is to care about the fidelity of the frequency response of all closed loop components, mainly about noise suppression while all significant resonances are preserved. Real constructions or specimens commonly contains severe resonances. Although there is extensive effort to reduce that resonances mainly in the fixtures, need for systems capable of dealing with the resonances is increasing. Implemented control system demonstrates importance of mentioned issues and shows several aspects for the future development. Despite the simplicity of an approach the control system can work similarly as the commercial systems available on the market. This was proved by number of experiments made on the realized system.

ACKNOWLEDGEMENT

This research work has been carried out in the Centre for Research and Utilization of Renewable Energy (CVVOZE). Authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports of the Czech Republic under NPU I programme (project No. LO1210)

REFERENCES

[1] P. Noskievič. *Modelování a identifikace systémů.* Ostrava: Montanex, 1999, 276 p. ISBN 80-7225-030-2.

[2] S. Salehzadeh-Nobari et al. Implementation of frequency domain adaptive control in vibration test products. *In proceedings of the 5th International Conference on Factory2000*, Imperial College, England, pp. 263-268, 1997. ISSN 0537-9989.

[3] T. H. Chen and C. M. Liaw. Vibration Acceleration Control of an Inverter-Fed Electrodynamic Shaker. *In Mechatronics*, IEEE/ASME Transactions. Vol. 4 (1). 1999, pp. 60-70. ISSN 1083-4435.

[4] L. D. Flora and H. A. Gründling. Acceleration Control of an Inverter-Fed Electrodynamic Shaker. *In Power Electronics Specialists Conference*. 37th IEEE. Santa Maria, Brasil. 2006, pp. 1-7. ISSN 0275-9306.

[5] Y. Uchiyama and M. Fujita. Robust Acceleration and Displacement Control of Electrodynamic Shaker. *In Proceedings of the 2006 IEEE, International Conference on Control Applications*. Munich, Germany. 2006, pp. 746-751. ISBN 0-7803-9797-5.

[6] H. M. Gomes et al. An Automatic System for Electrodynamic Shaker Control by Acceleration Power Spectral Density. *In Mecánica Computacional*, Vol XXVI. Córdoba, Argentina. 2007, pp. 2959-2970.

[7] IEC 60068-2-6 ed7.0 *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*. 2007.

[8] IEC 60068-2-64 ed2.0 *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*. 2008.

[9] T. Ödestrom and P. Stoica. *System Identification*. Prentice Hall, 1989 Cambridge. 612 p. ISBN 0-13-881236-5.