

A Multivariable Experiment Design Framework for Accurate FRF Identification of Complex Systems

Citation for published version (APA):

Dirkx, N., van de Wijdeven, J., & Oomen, T. (2020). *A Multivariable Experiment Design Framework for Accurate FRF Identification of Complex Systems*.

Document status and date:

Published: 01/01/2020

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

A Multivariable Experiment Design Framework for Accurate FRF Identification of Complex Systems

N. Dirkx^{1,2}, J. van de Wijdeven¹, T. Oomen²

¹ASML, The Netherlands

²Eindhoven University of Technology, The Netherlands

nic.dirkx@asml.com

Abstract

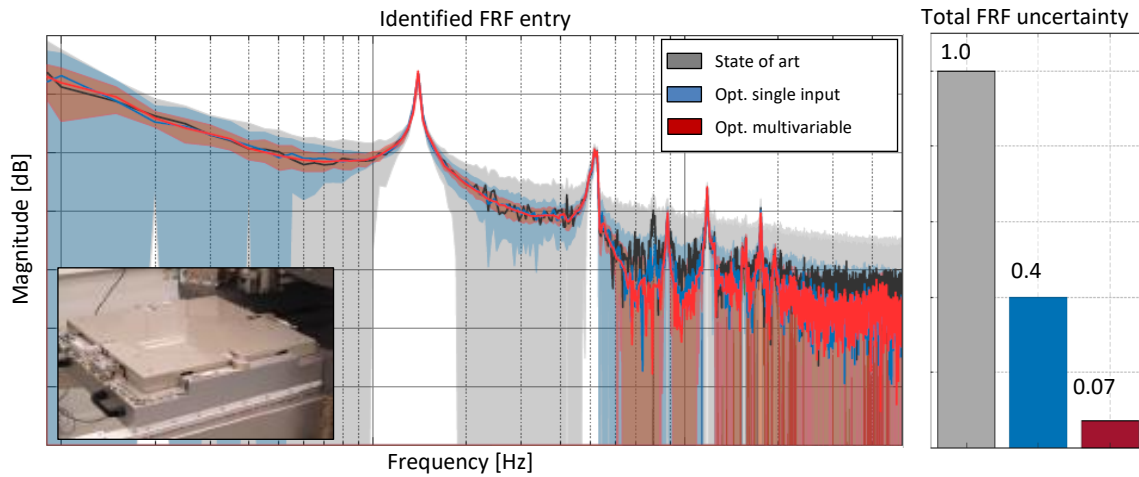
Accurate Frequency Response Function (FRF) identification is essential in high-precision mechatronics. To meet the ever-increasing performance requirements, there is a need to identify FRFs faster and more accurately. The quality of the identified FRF depends on the excitation signals used in the identification experiments, hence these must be designed carefully. Ideally, such design maximizes signal-to-noise ratio, while respecting the system limitations to guarantee safe operation. State of the art excitation methods in the industry address these items conservatively, since typically:

- 1) the spectrum is designed conservatively, e.g., uniform spectrum/ white noise,
- 2) physically relevant system input and output constraints are addressed implicitly,
- 3) only a single input is excited at a time, also for MIMO systems.

Consequently, the FRF quality is non-optimal.

In this research, a systematic framework is developed to optimally design multi-sine excitations for the FRF identification of mechatronic systems [1]. Herein, items 1) and 2) are addressed through a 2-step design approach: in step 1, a preliminary experiment is performed to acquire prior system knowledge. Step 2 involves an optimized-based synthesis of custom excitation signals that maximize the FRF quality within the system constraints. Particularly, for MIMO systems, item 3) is addressed through full multivariable and directional excitation design that exploits the plurality of the actuator inputs [2].

The techniques are applied to a 7 x 8 wafer stage and compared to the industrial state of art (uniform spectrum). The resulting FRFs and their total uncertainty are shown in the middle and right figure, respectively. The optimized single input design (**blue**) outperforms the state of art (**grey**) by a factor 2.5, while the optimal multivariable excitations (**red**) achieve an improvement factor of 14.2. This demonstrates the power of the developed techniques.



Left: Wafer stage and FRFs, incl. 95% uncertainty region (shades). *Right:* Total FRF uncertainty.

References

- [1] Dirkx N, van de Wijdeven J, Oomen T. Optimal experiment design for multivariable motion systems: with application to a next-generation wafer stage. In Proc. of 8th IFAC Symposium on Mechatronic Systems. 2019.
- [2] Dirkx N, Oomen T. Multivariable Experiment Design with Application to a Wafer Stage: a Sequential Relaxation Approach for Dealing with Element-Wise Constraints. Submitted. 2019.