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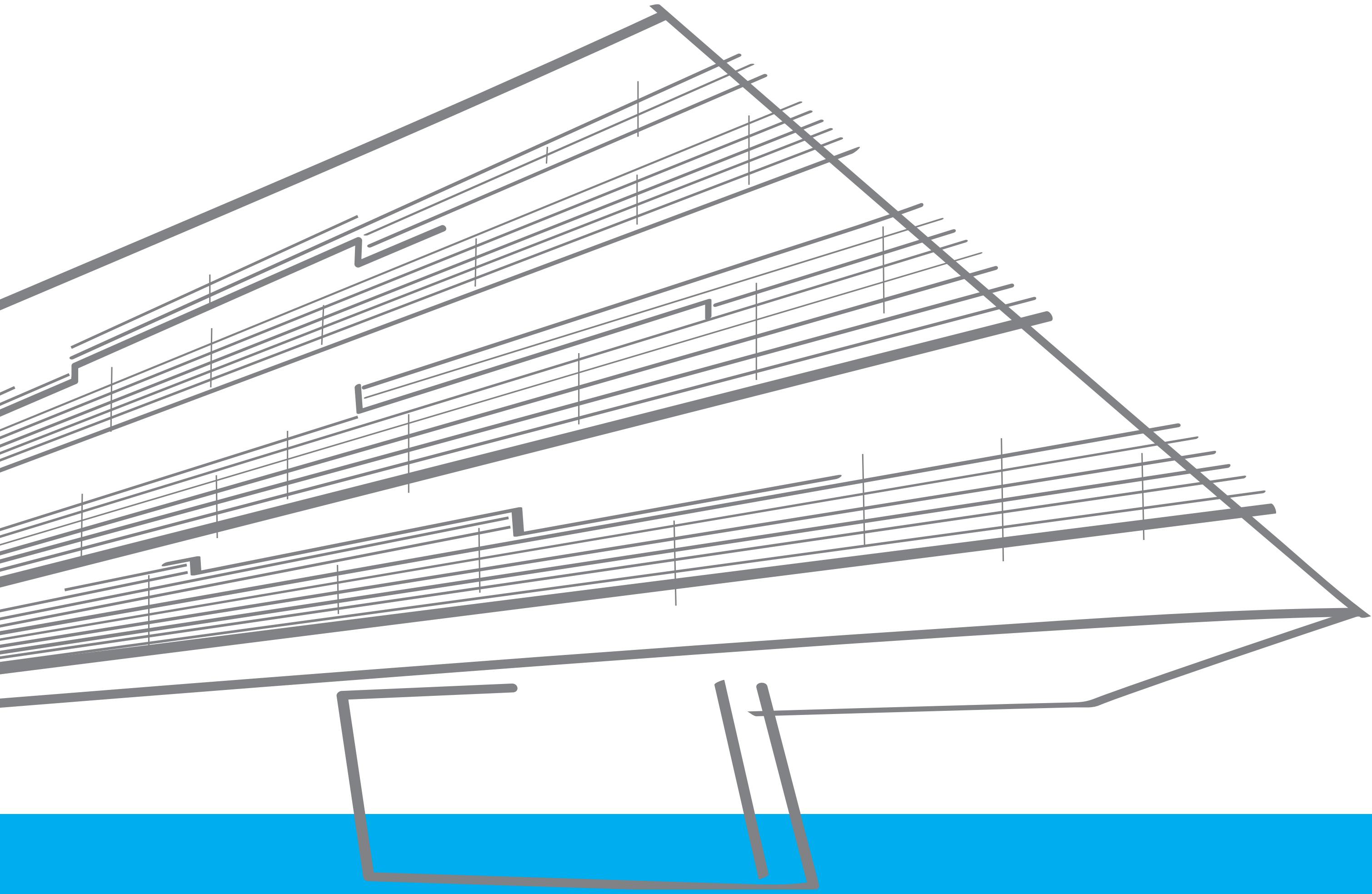

VIBRATION PROBLEMS

Whitepaper

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CONTENT

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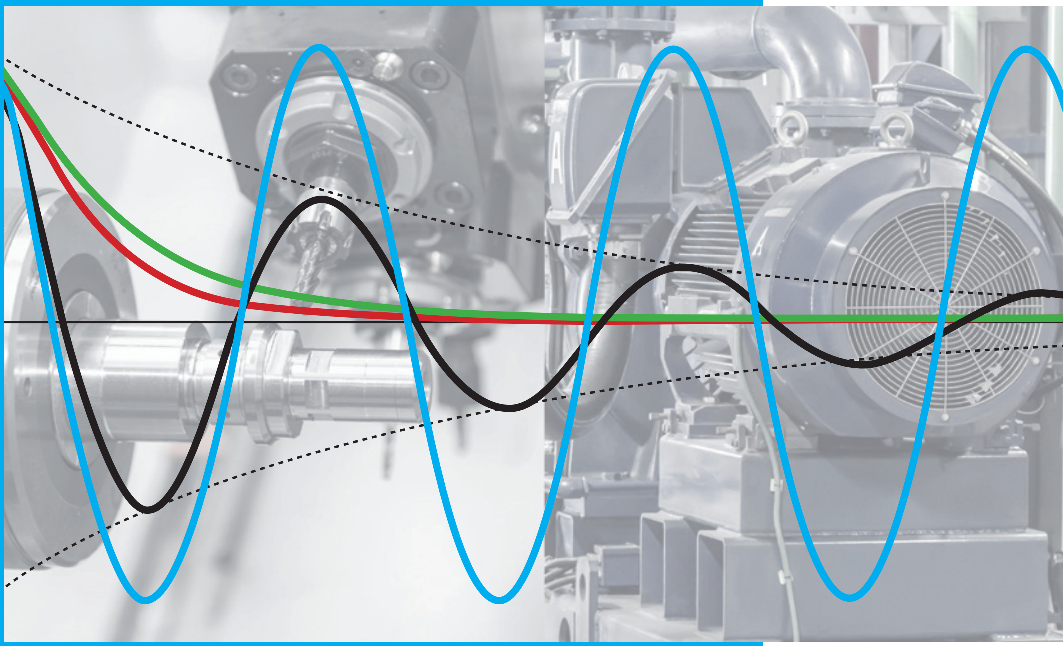
HOW TO SOLVE VIBRATION PROBLEMS?



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Shorter cycle times and lightweight construction also in classical plant and machine construction often lead to an increase of unexpected mechanical vibrations. Depending on the application these vibrations can lead to quality problems, noise or even safety-relevant vibrations of buildings.

In this short white paper, a basic guideline how to solve or avoid vibration problems is presented. This paper explains the 2 main factors for vibrations

- Vibrating structure (stiffness, eigenfrequencies, passive damping, …)
- Excitation (periodic, impulse, active damping, …)

and their interrelation to each other.

VIBRATING STRUCTURE

(including passive damping)

Every mechanical structure has frequencies in which it tends to vibrate, so called eigenfrequencies. These frequencies mainly depend on the mechanical design (mass, length, thickness …) of the structure as well as the used materials. (Strike a bell and you will hear its first eigenfrequency) Each of these frequencies is related to a vibration mode, the geometrical description of the motion. If a structure has been excited to vibrate and the excitation is removed, the vibration will decrease over time due to damping. Higher damping leads to a faster decrease of the vibrations and smaller vibration amplitudes even if the excitation is present permanent.

It is possible to design mechanical structures in such a way, that they will not tend to vibrate in a frequency range of interest. According to the basic estimation

$$f = \frac{1}{2\pi}\sqrt{\frac{c}{m}}$$

the first eigenfrequency mainly depends on the stiffness c and the mass m. Increasing mass usually helps to avoid vibrations in high frequencies whereas an increase in stiffness leads to higher eigenfrequencies.

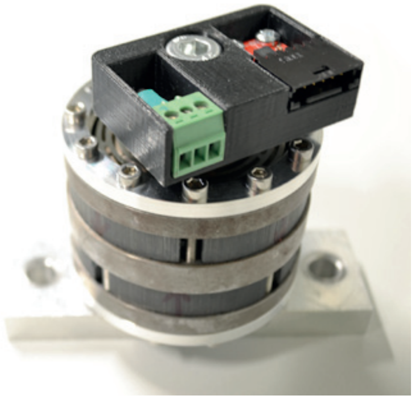
If a change in excitation is not possible, changes in the vibrating structure are the only way to decrease the vibrations.

If the excitations or the planed operation movements are known a priori, it is strongly recommended to include this knowledge already in the design process and design the structure such that these excitations do not lead to unwanted vibrations. During the design process simulations help to improve the vibrating structure. Typical basic simulation analyses are e.g. modal analysis, operational modal analysis or harmonic analysis, which are often already integrated in the tool-chain of CAD providers and result e.g. in a list of eigenfrequencies or waterfall plots. In some cases however more complex simulations are necessary to analyse e.g. the interaction of the mechanical structure with electronic components, fluids, complex bearings or the control of the system.

In many cases the mechanical structure or machine already exists and the vibration problem shall be solved with some “add-on” afterwards. If this worst case cannot be solved with a change in excitation, a variety of mechanical solutions are possible. The easiest ones are increases in damping or mass. Tuned mass-dampers can be designed to damp specific single frequencies whereas passive damping devices like damping mats or rubber elements are designed for a broader frequency range. If the excitation is changing, adaptive damping devices may become necessary. In this case the vibrations are measured with sensors and the passive damping device is adapted to change e.g. its eigenfrequency. In any of these “add-ons” it is crucial to have an understanding of the vibrating structure and the excitation. If no simulation models are available or suitable, measurements are a good option. Based on the specific situation and a priori knowledge the measurements may include e.g. modal analysis, operational modal analysis or sound source location.

EXCITATION

(including active damping)



electromagnetic vibration damping device
Foto: LCM

Structures have to be excited to start vibrating, so if there is no (critical) excitation no vibration problem occurs. Classical examples for periodic excitations are marching soldiers on a bridge; unbalanced rotors in engines or periodic motion profiles in pick and place applications. Classical examples for impulse excitations are striking a bell, stamping processes or hard contact of a tool on a workpiece. Periodic excitations "just" excite vibrations with this single frequency and multiples of this frequency, so-called overtones. Impulse excitation in theory excites all possible frequencies.

If it is possible to avoid critical excitation, no changes in the vibrating structure or additional damping devices are necessary.

Concerning periodic excitations, in many cases already a small change of the frequency leads to a significant reduction of the vibrations as the frequency of the excitation does not match an eigenfrequency of the vibrating structure anymore, so-called detuning. If it is necessary to operate with frequencies higher than a critical frequency (super-critical operation) it is important to pass this operation mode fast enough during start-up and coast-down. Special control laws exist for this case out of the box.

A standard approach in robotics, but still not common in other branches, is to avoid unwanted (impulse) excitation by a suitable smooth design of the trajectories of moving parts in a machine. It is not sufficient to only avoid jumps in desired velocity or acceleration but also in the first derivative of the acceleration, the jerk.

Often it is not possible to access or change the control of the actuators or the external excitation. If changes in the vibrating structure are also not feasible, active vibration damping as an add-on can be used. Depending on the frequency range and necessary amplitudes different actuator concepts are in use, e.g. electrodynamic, piezoelectric, loudspeaker,… With these actuators forces are generated which counteract the unwanted excitations or damp the vibrations at desired positions of the structure. A variety of control laws is used in practice for active vibration damping, depending on the kind of excitation (impulse, periodic, single tone, broad band,…) and vibrating structure.

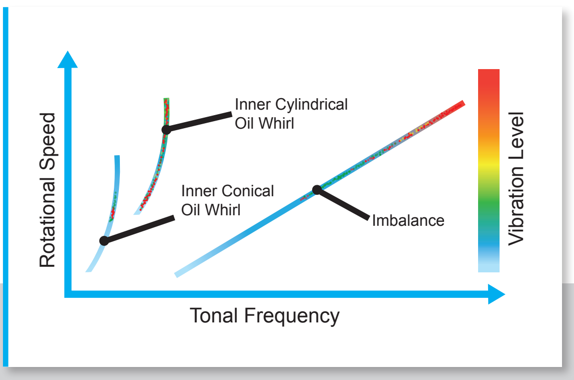


Figure 1: Vibration frequency and level strongly depend on the excitation, e.g. the rotational speed of an engine

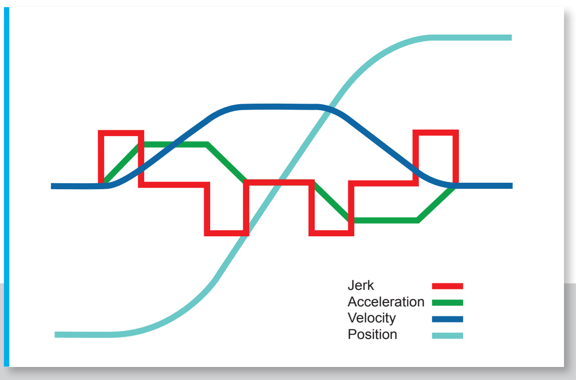


Figure 2: typical trajectory with jumps in the jerk (first derivative of the acceleration)

INTERRELATION OR SYSTEM APPROACH

If the actuators necessary and present for the original process are also accessible for vibration damping it is possible to improve the overall performance significantly. Motion profiles can not only be designed to avoid unwanted excitation (a priori, feedforward) but also to actively damp vibrations (feedback). Depending on the complexity of the vibrating structure, this is realized as simple add on in the original control law or e.g. as tailored model-based control.

With this system approach, it is possible to reduce mass and stiffness of the vibrating structure and reach higher speed at lower energy consumption compared to conventional "rigid" solutions. The resulting accuracies (e.g. of the trajectory) at least remain comparable to the original system. Reduction of the stiffness of e.g. a handling system also leads to reduced unwanted mechanical effects (vibration, wear, noise,…) when closing a mechanical loop like during approaching a workpiece with a tool or at an end stop.

CONCLUSION

As a brief conclusion, the following questions have to be answered to find a suitable solution:

- Is the knowledge about the vibrating structure and the excitation sufficient?
  NO: Additional simulations or measurements
- Is it possible to change the vibrating structure?
  NO: you have to change the excitation (incl. active damping)
- Is it possible to change the excitation?
  NO: you have to change the vibrating structure (incl. passive damping)
- Is it possible to use/access the existing actuators?
  YES: Great chance to improve the overall performance
  NO: some add-on is necessary

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Foto: privat