# Time delay controllers and compensators for vibration suppression - neutrality, spectral design and applications

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**Biography**

Tomáš Vyhlídal (1974) received MSc in Automatic control and engineering informatics in 1998, and Ph.D. in control and systems engineering in 2003, both from the Faculty of Mechanical Engineering (FME), Czech Technical University in Prague (CTU). Since 2000, he has been with the Department of Instrumentation and Control Engineering, FME - CTU, professor since 2012 and the department head since 2019. Currently, he is also with the Czech Institute of Informatics, Robotics, and Cybernetics, CTU, where he leads research group Machine and process control. He has been a member of the Technical Committee for Linear Control Systems of IFAC since 2013, vice-chair on industry since 2017.
His research interests include applied control theory, mathematical modelling, analysis and control of time delay systems, numerical methods, mechatronic control system design, modelling and control of industrial processes. His key results were achieved in the spectral analysis and synthesis of time delay systems, quasi-polynomial spectrum computation (author of QPmR), analysis of strong stability of neutral systems, pole-placement techniques, application of time delay algorithms in input shaping and vibration suppression of mechanical systems.

**Abstract**

In the talk, I will present research path which took me from spectral analysis of time delay systems to development of time delay algorithms for vibration suppression and control of flexible mechanical systems. The talk will start with an outline of an 'easy to apply' **QPmR** routine for computing spectrum of quasi-polynomials including analysis of spectral properties of **retarded and neutral time delay systems**. Interestingly, the undesirable closed loop neutrality can arise if time delay algorithms are applied to vibration suppression and control of flexible mechanical systems. This phenomenon will be targeted for several case study applications with the aim either to make the neutrality 'safe' or to remove it by structural adjustment of the controller (compensator).

The **state derivative feedback** will be targeted as the first case study motivated by control of mechanical systems where accelerometers are used to monitor the system motion, including vibration. In theory at least, the neutrality of such closed loop may arise if an arbitrary communication delay is present in the feedback path. The aim of the proposed control design is to make the closed loop strongly stable, i.e. stable under such emerging small delays. The acceleration feedback is also applied in **delayed resonator**, which forms the second case study. After the neutrality analysis for the original resonator feedback with a lumped delay, an adjustment of the control algorithm is proposed consisting in substitution of the lumped delay by a **distributed delay**. Next to the signal filtering by the distributed delay, the main benefit of the feedback adjustment is the retarded spectrum of the closed loop.

Analogously to the delayed resonator adjustment, substitution of the lumped delay by a distributed delay proved useful in the design of **input shapers** used to pre-compensate the oscillatory modes of flexible mechanical systems. The retarded spectrum of zeros of the distributed delay shaper is particularly important in its **inverse application** within a feedback loop – the concept proposed to pre-compensate the oscillatory modes induced by both reference and disturbance changes. Interestingly, the inverse shaper resembles the compensator in the **repetitive control** concept to handle the periodic inputs of the feedback loop. Also in this case, the closed loop neutrality needs to be removed to turn the feedback to an applicable form. Next to theoretical analysis of the given case studies, experimental results will be presented in the talk.