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Self-Excited Vibrations in Mechanical Systems: Old Observations and New Results

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In mechanical engineering systems self-excited vibrations are in general unwanted and sometimes dangerous. There are many systems exhibiting self-excited vibrations which up to this day cannot be completely avoided, such as brake squeal, the galloping vibrations of overhead transmission lines, the ground resonance in helicopters and others. The flutter of an aircraft wing is of the same type, but fortunately can be avoided by appropriate design methods. Most of these systems have in common that in the linearized equations of motion the self-excitation terms are given by non-conservative, circulatory forces. The presentation will discuss some recent results linear and nonlinear systems of this type.
Self-excited vibrations have of course been mathematically modelled and studied at least since the times of Balthasar van der Pol. The van der Pol oscillator is a one degree of freedom system; its linearized equations of motion correspond to an oscillator with negative damping. Sometimes also other self-excited systems present negative damping, which can be made responsible for self-excited vibrations. In all the engineering systems mentioned above however, the self-excitation mechanism is mainly related to the interaction between different degrees of freedom (modes) and the linearized equations of motions contain circulatory terms. This is the main excitation mechanism discussed in this paper. Destabilization by ‘negative damping’ will not be considered. Also stick-slip phenomena are not in the focus of this presentation; they also do not seem to play an important role in all the examples given above. The systems analyzed in this presentation therefore are characterized by the M, D, G, K, N matrices (mass, damping, gyroscopic, stiffness and circulatory matrices, respectively). In the unstable case, additional nonlinear terms do of course limit the vibration amplitudes (e.g. limit cycle in the van der Pol oscillator). Different types of Hopf bifurcations relevant for these systems and recently studied in the literature and will also be discussed.
For a long time it has been well known, that the stability of linear MDGKN-systems can be very sensitive to damping, and also to the symmetry properties of the mechanical structure being studied. Recently, several new theorems were proved concerning the effect of damping on the stability and on the self-excited vibrations of the linearized systems. The present paper discusses the importance of these results for practical mechanical engineering systems. It turns out that the structure of the damping matrix is of utmost importance, and the common assumption, namely representing the damping matrix as a linear combination of the mass and the damping matrices, may give completely misleading results for the problem of instability and the onset of self-excited vibrations.

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