Maximum vibration amplitude during run-up of a Jeffcott rotor at parametric anti-resonance

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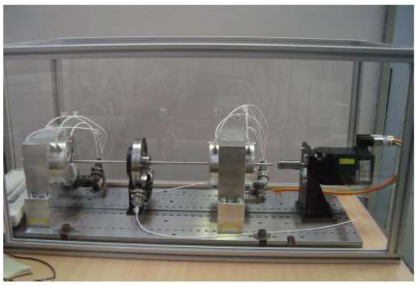
Summary. During run-up of a rotor, transient vibrations are introduced when passing through critical speeds which excite the corresponding vibration mode. It was shown recently that a modal interaction is achieved artificially by employing a parametric anti-resonance via a time-periodic bearing controller. Due to this mode coupling, a modal energy transfer is triggered which decreases the maximum amplitude at the first critical speed since some vibration energy is transferred to the highly damped second mode. An analytical approximation is derived for the maximum vibration amplitude. This result allows a physical interpretation of the paramtric anti-resonance in the context of passage through resonance and reveals the physical parameters and its dependencies for engineering an efficient bearing controller.

Problem description

The beneficial effect of a parametric anti-resonance on self-excited vibration was discovered by Tondl in his pioneering work [1]. This concept was first transferred to self-excited systems [2,3], then to general dynamic systems [4], was interpret physically as an energy transfer between the vibration modes of the original system and was validated experimentally for simple systems including a flexible rotor [5]. A parametric anti-resonance is a specific parametric combination resonance which does not lead to a parametric instability but enables an increased dissipation of vibration energy. Active magnetic bearings as discussed in the present contribution offer the possibility to apply a desired time-periodic variation of the bearing characteristics with an accuracy that enables a parametric anti-resonance phenomenon. In rotating machines fluid film bearings are commonly used which inspired investigations on applying a variation of the fluid film bearing characteristics via a bearing shell of variable geometry [6].

In the present investigation, the flexible rotor supported by bearings as discussed in detail in [7] is revisited. The dynamic properties of the active magnetic bearings (AMB) are controlled semi-actively. Such a concept was proposed for active magnetic bearings in [5] and validated numerically and experimentally in [7]. The present work focuses on the analytical approximation of the maximum amplitude achieved during the run-up characteristic of the rotor: the interaction between parametric anti-resonance and passage through resonance at constant run-up acceleration.



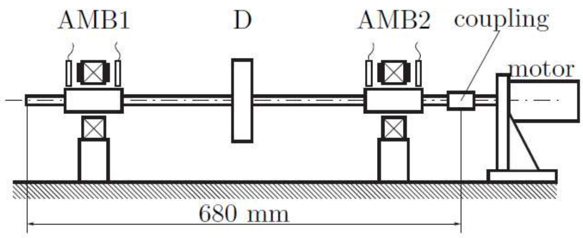


Figure 1: Jeffcott rotor supported by two magnetic bearings [5]: (left) experimental test rig, (right) corresponding dynamic model (taken from [7]).

The passage through resonance at a specific, constant accelerations are shown in Fig. 2 for light and intermediate bearing damping. At constant, nominal AMB characteristics, the maximum deflections are reached during passage through resonance. This maximum is a function of the run-up acceleration and the modal damping of the corresponding mode. The maximum displacement can be reduced in two independent ways (see [8]): by increasing the bearing damping and/or by increasing the run-up acceleration (faster passage through resonance).

At constant run-up acceleration, the first critical speed is passed showing a major peak displacement and the second critical speed a small peak displacement. Activating the optimum parametric anti-resonance, modal coupling is introduced which activates an energy transfer between the corresponding modes of the flexible rotor system. This coupling leads to an equal distribution of the maximum amplitudes at both critical speeds during run-up, see Fig. 2.

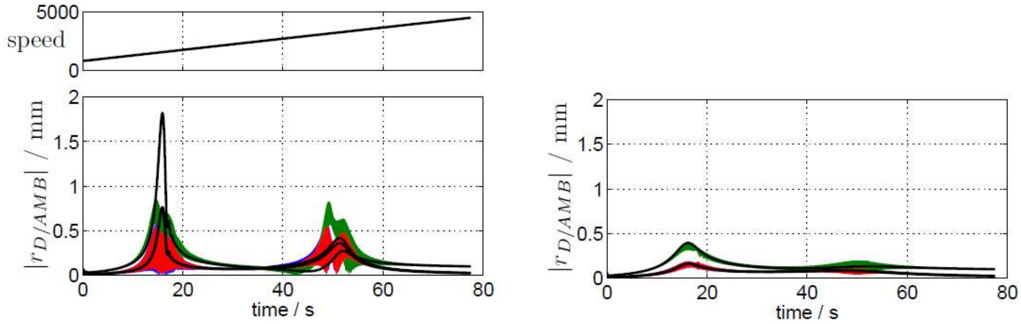


Figure 2: Passage through resonance at constant acceleration 5 rad/s2: (top) speed characteristic, (bottom) time histories of radial deflections at nominal bearing characteristics (black lines) and for induced parametric anti-resonance at 170 rad/s and a bearing stiffness varation of 10% (green: disc, blue/red: bearing studs) for small (left) and medium (right) bearing damping (taken from [7]).

The dependency of the maximum disc displacements on the run-up acceleration and the bearing damping is summarised in Fig. 3. The maximum displacement at nominal bearing characteristic (without PE) shows a large deflection at first critical speed. For the AMBs with periodic proportional action (with PE), the maximum displacements at the critical speeds are brought to a comparable level. It has to be highlighted that the parametric anti-resonance is most effective at low system damping. The method of averaging is applied in order to have an analytical expression at hand for predicting the maximum amplitude. This approximation also allows to explain the different trends in Fig. 3 for constant and time-periodic bearing stiffness characteristic.

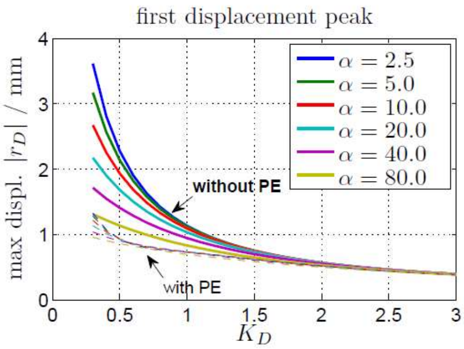


Figure 3: Dependency of the maximum displacements of the rotor disc on the run-up acceleration and the damping at nominal bearing characteristics (without PE) and time-periodic proportional action (with PE): peak displacement at first critical speed (taken from [7]).

Conclusions

During run-up of a rotor, transient vibrations are introduced when passing through critical speeds which excite the corresponding vibration mode. A time-perioidic bearing controller is capable of triggering a modal energy transfer between two vibration modes of a flexible rotor system. The main benefit of this is the decrease of the maximum amplitude at the first critical speed since some vibration energy is transferred to the highly damped second mode. An analytical approximation is derived for the maximum vibration amplitude. This result allows a physical interpretation of the parametric anti-resonance in the context of passage through resonance and reveals the physical parameters and its dependencies for engineering an efficient time-periodic bearing controller.

References

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