Chapter 8
Conclusions

This book focused on the design optimization of application oriented electromagnetic vibration transducers. An essential part of the book considered the dimensioning of the magnet, the coil and if existent the back iron components in eight different commonly applied coupling architectures. With the established optimization procedure the optimal dimensions can be determined either for maximum output power or maximum output voltage generation. The results lead to an overall comparison of the coupling architectures. It was shown that the architectures inherently have different output power and output voltage generation capabilities. The best architectures have been identified and should be preferred in application whenever possible. An application oriented prototype development was realized to show how the optimization procedure can be integrated in the design–flow. The research in this book leads to further results which are summarized in the following.

8.1 Overview of Main Findings

In general the following conclusions can be drawn from this book:

- For the design of electromagnetic vibration transducers the task is to find optimal dimensions of the coupling architecture components (magnet, coil and if existent back iron components) rather than optimizing damping factors as stated in the analytical theory. This is due to the volume constraint condition which is the regular case in applications but has not explicitly been considered in the analytical theory so far.
- There are different optimal dimensions for maximum output voltage and maximum output power generation. Power optimization should of course be preferred except perhaps for cases where the output voltage may be too low (e.g. <1V because of small construction volume, small vibration amplitudes, …) where an output voltage optimized design is recommended.

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- Many different coupling architectures have been applied in literature. The comparison of the optimized output performance (for each architecture) allows an overall comparison. There are definitely architectures which should be preferred in application because of the high output performance capability.
- Of the eight architectures investigated the one with the highest output power performance is A V. With optimized dimensions the output power can be increased by a factor of 4 with respect to the architecture with the lowest output power performance (A III).
- The architecture with the highest output voltage performance is A II. With optimized dimensions the output voltage can be increased by a factor of 1.8 with respect to the architecture with the lowest output voltage performance (A VI).
- In comparison to the architectures without back iron the investigated coupling architectures with back iron have a general advantage (especially for output power generation) and should be preferred whenever possible.
- Another advantage of back iron based architectures is that they are insensitive against unwanted nonlinear magnetic forces and eddy current losses in operation environments with ferromagnetic materials and materials with nonzero conductivity.
- Beside the optimal dimensions of the coupling architecture components there are different optimal form–factors for output power and output voltage generation.
- The established coil topology optimization can be used to define a coil which maximizes the output power for fixed cylindrical magnet dimensions. However, for the fixed construction volume condition in most applications the topology optimized coils are not advantageous. Nevertheless, if there is unused space left in the housing of the transducer the topology optimization approach can be used to maximize the output power.
- Nonlinear hardening springs have the potential to maximize the output power (up to 25% compared to optimal linear spring). For the evaluation the vibration characteristic, the desired resonance frequency and the available inner displacement limit need to be taken into account.

8.2 Suggestions for Further Work

The research results from the output power and output voltage optimization calculations as well as the design of the prototype vibration transducer presented in this book lead to several suggestions for further work that may be conducted in future. In summary, they are:

- This book considers the output performance as the optimization goal. However in the application other parameters like the packaging, power management, robustness or costs may be taken into account as well. Whenever it is proven that the output power of the vibration transducer is sufficient this leads to a multi objective optimization.

- Using transient simulations it is shown that nonlinear hardening springs have the potential to increase the output power. Moreover it is shown how nonlinear hardening springs may be realized. However, because in the end a linear spring has been implemented in the prototype development, the verification and further investigation of this result should be performed.
- In this book eight different commonly used coupling architectures have been optimized. But there are even more architectures that could be investigated. However, it is assumed that the possible increase of the output performance of further architectures is not appreciable.
- There is a great demand for the implementation of tunable devices. Based on electromagnetic conversion, these devices contain also a certain coupling architecture that may require optimization as shown in this book.
- In most of all cases it is rather challenging to provide the demanded power and voltage level even with miniaturized fine–mechanical transducers. As long as the output power is the limiting factor the reduction of construction volume is counterproductive for any application oriented development.