Rotordynamics of Automotive Turbochargers

Hung Nguyen-Schäfer

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Linear and Nonlinear Rotordynamics - Bearing Design - Rotor Balancing

Springer

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Preface

This book has arisen from my many years of experience in the automotive industry, as a development engineer and a senior expert of rotordynamics of automotive turbochargers. It is intended for senior undergraduates and graduates in mechanical engineering, research scientists, and practicing engineers who work on the rotordynamics of automotive turbochargers. It could be also used as a rotordynamic textbook in colleges and universities, and practical handbook of rotordynamics in the automotive turbochargers.

The topic of rotordynamics of automotive turbochargers is a widely interdisciplinary working field, firstly involving *rotordynamics* to study dynamics of rotating machines at very high rotor speeds and as well as to balance the rotor. Secondly, it involves *thermodynamics* and *turbo matching* to compute working conditions of the turbochargers. Thirdly, it involves *fluid and bearing dynamics* to compute the acting loads in the bearings at various operating conditions, and to design the hydrodynamic oil-film bearings. Lastly, it involves *applied tribology* to reduce bearing friction and wears of the journal and bearings. In order to understand the rotordynamic phenomena, readers are assumed to have some mathematical requisite backgrounds for modeling and simulating nonlinear rotordynamics of turbochargers. The author tries to keep the mathematics requirement as simple as possible in this book; however, without any mathematical background, it is quite difficult to comprehend and thoroughly understand the rotordynamic behaviors of the turbochargers.

Exhaust gas turbochargers used in the automobiles of personal, commercial vehicles, and off-road engines have some important discrepancies to the heavy turbomachines applied to the power plants, chemical, and aeroplane industries. The automotive turbochargers are much smaller compared to the industrial turbomachines. Therefore, they generally work at very high rotor speeds in various dynamically operating conditions, such as highly transient rotor speeds, variable pressures, high temperatures of exhaust gas, and as well as unsteady-state mass flow rates of the intake air and exhaust gas. The industrial turbomachines are larger and heavier, and often operate at a nearly stationary condition. Due to the large compressor and turbine wheels, they operate at relatively low rotational speeds from 3,000 rpm (Europe) or 3,600 rpm (US) in the power plants for the electrical frequency of 50 Hz or 60 Hz up to about 15,000 rpm in the chemical industries and aeroplanes. On the contrary, the exhaust gas turbochargers mostly work at the high rotor speeds from 150,000 rpm to 350,000 rpm in the automotive applications. Therefore, the unbalance force is much larger than the rotor weight, leading

to nonlinear characteristics of the oil-film bearings used in the automotive turbochargers. As a reason, nonlinear rotordynamics is usually applied to the turbochargers to study and compute the nonlinear rotor responses of the harmonic, sub-, and supersynchronous vibrations.

Moreover, turbocharger engineers in the industry have to confront many problems at once, namely good quality, feasibility, form tolerances at the mass-production, time to market (TTM), highly innovative products, and product price. The last one is a very important issue for the company. No matter how good the products are, but nobody could afford them because they are very expensive. Then, the question is, how long the company could survive without selling any product or always selling products at a loss. Parallel to the product price, turbochargers must be qualitative and innovative in terms of high efficiency, best low-end-torque, working at high temperatures of the exhaust gas, less or no wear of the bearings, and as well as low airborne noises. They should come to the market as soon as possible since the first bird gets the worm; i.e., despite highly innovative products, the time to market (TTM) is always shorter because the competitors never sleep. Additionally, the turbochargers should work in all operating conditions while they are produced at a possibly wide range of the form tolerances in the mass-production; e.g., radial and thrust bearings with the large form tolerances since producing them with the narrow ones increases the production cost, leading to rise in the product price.

All these boundary conditions make the turbocharger development in the industry much more difficult, especially in the nonlinear rotordynamics of turbochargers. Therefore, development engineers of turbochargers need to have deeply understanding backgrounds of rotordynamics and bearing systems containing radial and thrust bearings applied to the automotive turbochargers. Furthermore, such issues of the rotor balancing and tribology in the bearings have to be coped with, so that the produced turbochargers work in any case at the given industrial development conditions. Customer requirements of the automotive turbochargers are very high, in terms of good rotordynamic stability, low airborne noises, less or no wear of the bearings at high oil temperatures, and as well as an acceptable product price.

Despite all careful efforts, there would be some unpredictable errors in this book. I would be very grateful to get your feedbacks and hints of errors. As a reason, readers of this book need to have a thorough analysis before applying it to their individual applications, and take their own responsibilities for possible damages.

I like to thank the board of directors of Bosch Mahle Turbo Systems (BMTS), Dr. M. Knopf, Dr. A. Prang, and Mr. J. Jennes for their supports and allowing me to use some pictures of BMTS in this book. Especially, I learned a great deal from working with Dr. B. Engels on turbocharging. Also, I am indebted to my colleagues at BMTS who supported me in technical discussions, and provided helps in this book: Dr. H. Haiser; Ch. Schnaithmann; Th. Ahrens, P. Kothe, and R. Kleinschmidt; R. Lemke and J. Kreth; G. Di Giandomenico (Bosch).

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About the Author

Dr. Hung Nguyen-Schäfer is a senior expert in rotordynamics and bearing designs of turbochargers at Bosch Mahle Turbo Systems (BMTS) in Germany. He received B.Sc. and M.Sc. in mechanical engineering with nonlinear vibrations in fluid mechanics from the University of Karlsruhe, Germany in 1985; his Ph.D. degree in nonlinear thermo- and fluid dynamics from the same university. In 1988, he joined Bosch Company and worked as technical manager on many development projects of anti-lock braking and traction systems, high-pressure fuel injection systems, combustion engine systems, fluid cavitation, and electric drive turbochargers for automotive fuel cell systems (PEMFC). Since 2007, Dr. Nguyen-Schaefer has been in charge of rotordynamics and bearing designs of automotive turbochargers at Bosch Mahle Turbo Systems (BMTS) located in Stuttgart, the joint venture of Bosch and Mahle.

He has extensive experience in the fuel injection systems of gasoline, diesel, compressed natural gas (CNG), anti-lock braking systems, and automotive turbochargers, especially in rotordynamics and bearing designs. Moreover, he has authored many technical papers and reports, and supervised two Ph.D. and numerous Master's candidates. He holds several international patents in automotive applications and turbochargers. He lives with his wife and one son near Stuttgart in Germany.

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