Turbocharger noise reduction by multilobe floating ring bearings

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Abstract
Floating ring bearings are commonly applied in automotive turbocharger machinery because they are inexpensive and are able to reduce unbalance induced vibrations. This type of bearings, however, can become a source of noise due to oil whirl-induced sub-synchronous vibrations. This study examined whether the concept of a floating ring bearing with a lobed clearance might be a solution to diminish oil whirl induced vibrations. A numerical model is developed to evaluate the dynamic behavior of the coupled rotor-bearing system. The resulting run-up simulations have been validated with experimental results of turbocharger run-up measurements. The results of the plain floating ring design and the multilobe floating ring design are compared, showing that the multilobe floating ring bearing design is superior in suppressing both synchronous and sub-synchronous vibrations at the cost of a slight increase in friction losses. Hence, multilobe floating ring bearings are an attractive alternative to plain floating ring bearings for automotive turbocharger applications.

Keywords: turbocharger NVH · whirling · floating ring bearing · subsynchronous noise · multilobe bearing

Introduction

Turbochargers help to make combustion engines more powerful and more efficient. Even when it operates at rotation speeds over 200.000rpm, the turbocharger should fulfill its task as quiet as possible. Turbocharger noise can be very unpleasant, so turbocharger manufacturers put considerable effort in creating turbocharger rotor-bearing designs which run as smooth as possible. In this paper, we will first introduce the categories of turbocharger noise and explain their origin. Then, as a solution for reducing the noise particularly originating from the bearing system, the concept of the *multilobe floating ring bearing* will be presented as a novelty introduced by Mitsubishi Turbocharger.

Types of turbocharger noise

Turbocharger whining noise can originate from 3 different sources: rotor unbalance, blade generated pulsations or self-excited vibrations in the bearing system [1].

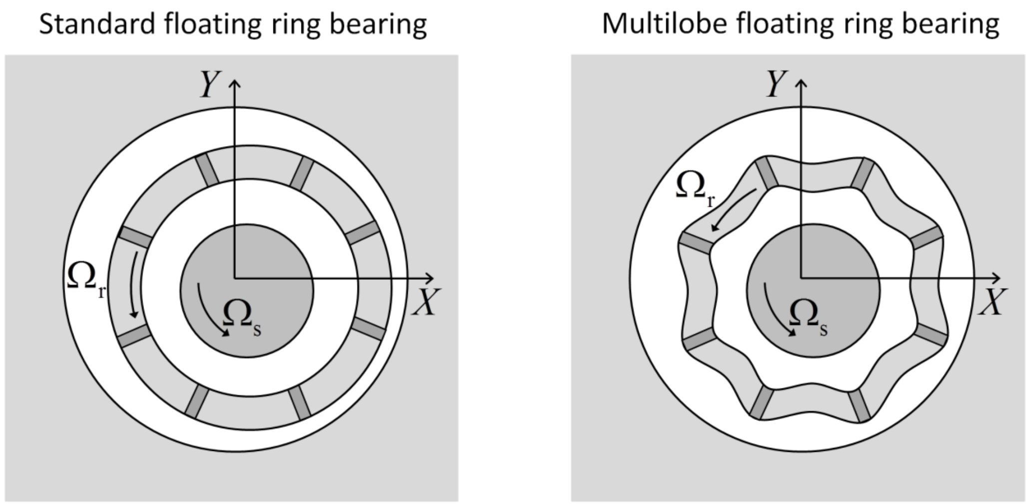
Rotor unbalance causes a first order vibration (synchronous vibration), which is commonly perceived as *turbo whistle*. The frequency of the noise follows the rotation speed of the turbocharger. In order to minimize the noise generated by the turbocharger, the rotor-bearing system is balanced during production. This is done by balancing the individual rotor components and by balancing the entire assembled rotor in operating state. Especially in case of ball bearing type turbochargers, unbalance induced vibrations can lead to noisy turbochargers [2]. The allowed amount of unbalance is usually indicated by the vehicle manufacturer, following the methods described by Calvo [3].

Blade generated pulsations can be caused by blades traversing a local pressure gradient, such as traversing the tongue area in the compressor housing. Typically, this type of noise is extremely high frequency: it follows the rotation speed multiplied by the number of blades (super synchronous), typically resulting in frequencies above 5kHz. The designs of the compressor wheel and the turbine wheel are evaluated by measurements to see if the amount of pulsation is low enough in order not to cause any audible noise. This is done in a turbocharger test facility where the turbocharger can be tested over its full operating range, separately from the combustion engine. The acoustic output from these tests can be plotted in acoustic operating maps [4].

Self-excited vibrations in the bearing system can occur in case the turbocharger uses conventional (semi-) floating ring bearings. A tonal type of noise, typically referred to as *constant tone* noise can be heard when the turbocharger is rotating. The frequency of this type of noise does not vary strictly with the rotation speed, and typically has a frequency of 400Hz-900Hz (sub-synchronous). By carefully selecting the clearances of the bearings, this type of noise can be minimized. However, especially under varying oil temperatures, the bearing system can still become unstable and cause constant tone noise. Therefore, the multilobe floating ring bearing has been developed to suppress these self-excited vibrations under all circumstances, as will be explained in the next Section.

The multilobe floating ring bearing

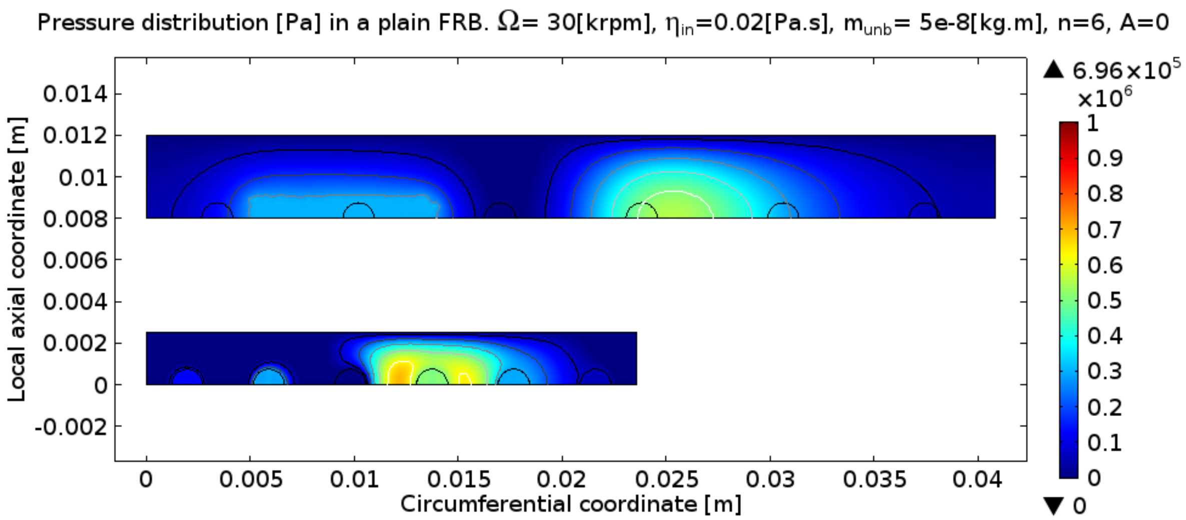
Floating ring bearings are commonly used in automotive turbochargers because of their low cost and their ability to operate under extreme rotation speeds [2]. The floating ring bearing has a freely rotating bush between the shaft and the bearing housing so that two hydrodynamic oil films in series are formed, as can be seen in the Figure below. These two oil films generate the carrying capacity to separate the rotor shaft from the bearing housing and provide damping to unbalance induced vibrations of the rotor.

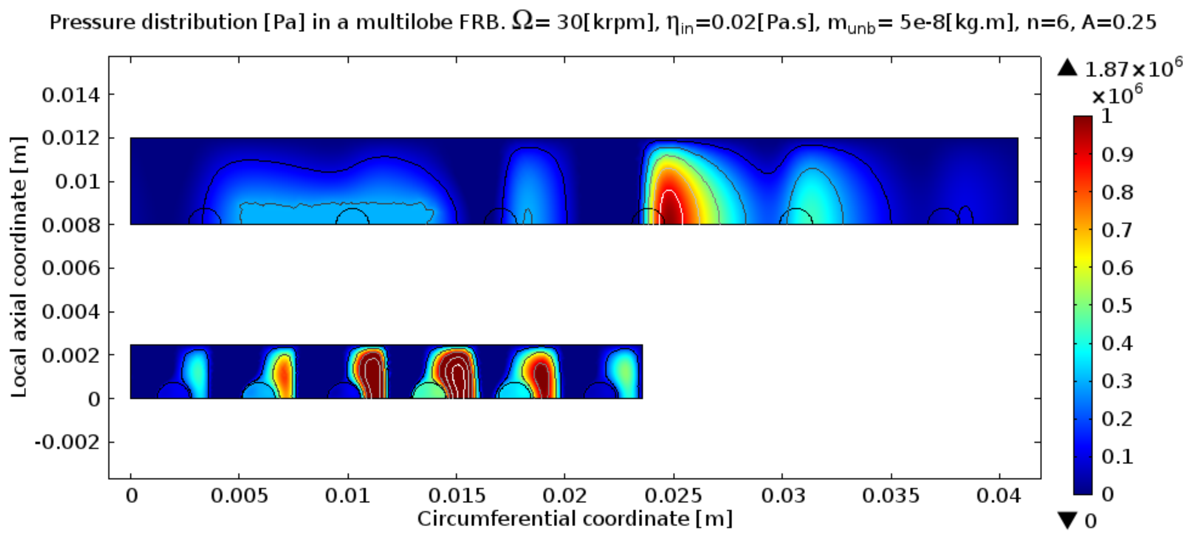


A cross-section of the bearing housing showing the shaft rotating in a conventional floating ring bearing (left) and in a multilobe floating ring bearing (right). The lobe shapes of the multilobe floating ring bearing create hydrodynamic pressure peaks distributed over 360 degrees of the ring, whereas conventional floating ring bearings only creates a hydrodynamic pressure peak when the shaft operates in an eccentric position. Therefore, the multilobe floating ring bearing pre-stresses the position of the rotor and the floating ring so it becomes more stable, even in the centered position.

Conventional floating ring bearings are known to cause self-excited vibrations, which are an inherent feature of any circular hydrodynamic bearing under dynamic rotor load [2]. The multilobe floating ring bearing features a wavy pattern in the bearing clearance. This pattern generates a pressure buildup which has a tendency to be stable at the centered shaft position, as can be seen in the Figure above.

Using an advanced multiphysical rotor-bearing model, as described in reference [4], the pressure distribution in floating ring bearings can be predicted. The pressure distribution in the bearing provides a reaction force to the forces coming from the rotor so that the model can predict the movement of the rotor at each time step during a turbocharger run-up. These simulations form a cornerstone in developing rotor-bearing designs which optimally suit the various demands of the automotive industry, such as low friction losses, high durability and –of course- a minimum noise output.



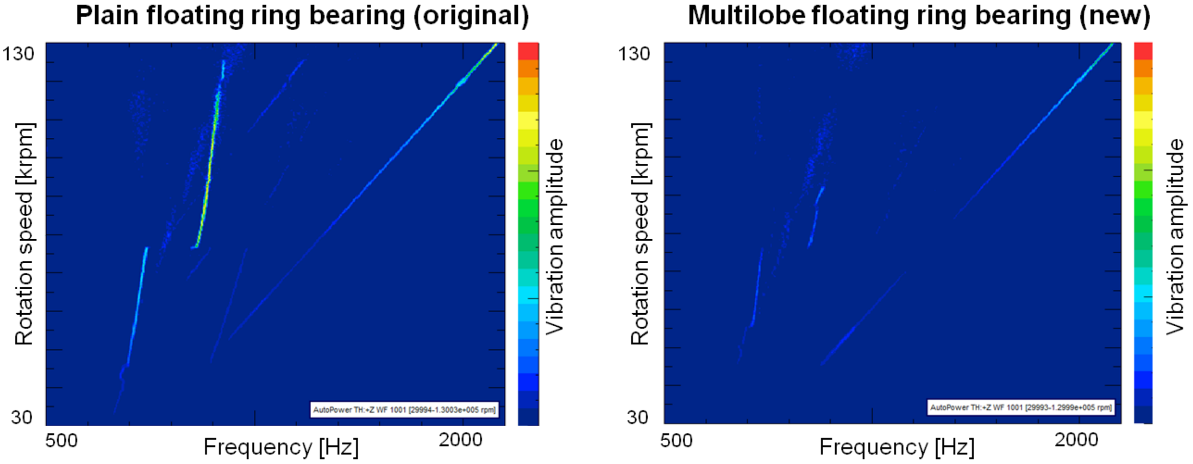


Pressure distribution in a conventional floating ring bearing (upper) and multilobe floating ring bearing (lower). The two rectangles in each plot represent the outer and the inner fluid film surface, respectively. As symmetry is used, only half of the axial length of the bearing is plotted. The semicircles in each fluid domain are the oil connecting channels which couple the inner and outer fluid film.

Results

The resulting dynamic behavior can be displayed in a waterfall plot. In such a plot, the frequency content of the measured vibrations of a turbocharger are plotted as a function of rotation speed. The vibration intensity determines if the turbocharger noise is audible in the vehicle. As can be seen in the comparison between conventional floating ring bearings and multilobe floating ring bearings, sub-synchronous vibrations can be decreased by the increased stability of the multilobe floating ring bearings.

Further details on the model and the measurements can be found in the publication presented at the 2014 Iftomm Conference on Rotordynamics [5].



Waterfall plot of a conventional (left) and a multilobe floating ring bearing (right). Clearly visible is the occurrence of sub-synchronous vibrations in the range 500Hz-1000Hz for the conventional floating ring bearing. The same turbocharger equipped with multilobe floating ring bearings shows sub-synchronous vibration values which are a factor of 5-10 lower than the conventional floating ring bearings.

Implementation

Following the development in 2014, over 1 million Mitsubishi turbochargers have been equipped with multilobe floating ring bearings. Since its implementation, multilobe floating ring bearings have been a reliable solution in preventing constant-tone noise. No cases of super-synchronous noise, excessive wear or other problems associated with these bearings have been reported. It is therefore considered to be a successful solution for constant tone noise.

Outlook: robust rotor-bearing designs ensuring silent turbochargers

A good rotor-bearing design is at the heart of every turbocharger and forms the basis for silent operation. Therefore, Mitsubishi Turbocharger performs research together with world leading universities. PhD research in cooperation with the Technical University of Delft, Technische Universität München and Imperial College leads to the development of new design and analysis tools. Using these tools, Mitsubishi Turbochargers aims for building the optimal turbocharger for every automotive application.

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