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# Mathematical Model of Complete Electromagnetic Rotor Suspension

N.D. Polyakhov, A.D. Stotckaia*, T.O. Kuzmina

*Saint-Petersburg state electrotechnical university LETI, ul. Prof. Popova 5, Saint-Petersburg, 197376, Russia*

**Abstract**

A mathematical description of complete (non-contact) electromagnetic suspension of the rotor representing an alternative approach to the bearing construction of high-speed electrical machine is discussed. This approach provides an accurate positioning of the rotor in the air gap, increasing system uptime compared with conventional bearing assemblies. Synthesized selective control law of rotor position in complete electromagnetic suspension is considered.



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*Keywords:* active magnetic bearing; complete electromagnetic suspension; selective control.

## 1. Introduction

In modern engineering are increasingly put the task of designing electromechanical systems with ultra-high speed of the rotor to create a high-tech installations (compressors, air-purge, turbo generators, refrigeration units, etc.). To solve the problem of achieving ultra-high speeds (150 000 - 200 000 rpm) it is necessary to use a special bearing supports capable of operating in a given speed range. Hydrodynamic, gas-dynamic or hydrostatic bearings are most commonly used at the present time. These bearings have very low friction coefficients - is much lower than the mechanical bearings. The main source of friction is the viscosity of the liquid or gas. However, the main disadvantage of the use of such supports is complex power system and limit rapidity due to friction. As an alternative approach of systems construction of high-speed electrical machine bearing supports, completely

* Corresponding author : Tel.: +7–960–242–01–23; fax: +7–812–346–33–07.
*E-mail address:* inferum@mail.ru



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eliminates friction, is the application of active magnetic bearings (AMB). The use of these bearings allows not only to achieve the rotor speed, but also to implement a system that does not require lubrication.

**Nomenclature**

| | |
|---|---|
| $F$ | tractive force of the electromagnet |
| $F_m$ | maximum tractive effort |
| $I$ | coil current |
| $I_2$ | current, taking into account the effect of the eddy currents |
| $I_{m0}$ | maximum current in the coil at the central rotor position (z = 0) |
| $I\mu$ | magnetizing current |
| $I_\sigma$ | current, taking into account the effect of the eddy currents of leakage flux. |
| $L$ | inductance corresponding to the magnetic flux in the air gap |
| $L0$ | inductance in the air gap corresponding to the magnetic flux at the rotor central position |
| $L1$ | inductance corresponding to leakage flux |
| $Q$ | external component of the force acting on the rotor from the electromagnet |
| $R$ | active resistance of winding |
| $R_1$ | the active component of the eddy current loss of leakage flux. |
| $U$ | voltage applied to the electromagnet coil |
| $U_{m0}$ | voltage in the coil at the central rotor position (z = 0) |
| $z$ | deviation from the central rotor position |
| $\delta$ | air gap between the rotor and the stator at the central rotor position |
| $\psi$ | linkage flux |
| $\psi_m$ | maximum linkage flux |

## 2. Active magnetic bearing

Active magnetic bearing is a complex electronic device that allows to carry out contactless suspension of the rotor of electrical machine. The main feature of such a systems is that the design and operating principle of the AMB, realizing complete electromagnetic rotor suspension ensures operation electrical machine without friction over a wide speed range. The introduction the AMB technology in high-speed electrical machines leads to a reduction the costs of aggregates technology services and also improves lifetime of the device as a whole.

Further advantages of the AMB are relatively high load capacity, high mechanical strength, the ability of the non-contact rotor stable suspension, the possibility of changing the stiffness and damping in a wide range, with the possibility of using high rotational speeds, in vacuum, high and low temperatures, sterile technologies [1].

## 3. Description of the developed system

Significant complexity of the existing electromagnetic suspension (EMS) control system limits the potential scope of its application. The characteristic feature of EMS is that the designed system plant is a composite object "magnet rotor" having a complicated nonlinear mathematical description.

The principle of operation of EMF is that the rotor is held in a predetermined position, radial or axial, through the action of magnetic fields generated by electromagnets.

The electromagnets are located inside the stator of the electric machine and currents supplied to the windings are changed depending on the rotor position, measured by position sensors by a particular control law.

For the synthesis of the position control law a mathematical model of the magneto-mechanical system (complete electromagnetic suspension) consisting the following elements are developed:

- model of flexible horizontally oriented rotor
- model of radial active magnetic bearing (RAMB)
- model of axial (thrust) active magnetic bearing (AAMB)