Ten-Phase-Nine-Leg Topology for Five-Axis Active Magnetic Bearing Drive

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Abstract

Active magnetic bearing plays an essential role in high-speed rotational machine. Due to the need for multiple coils, optimal control performance necessitates power amplifier with numerous power electronics switches. However, a significant amount of power electronics switches greatly increases cost, volume and risk of switch failure. Therefore, this paper proposes a novel topology for optimizing the number of switches without affecting control performance. The basic properties and control strategies of the Ten-Phase-Nine-Leg topology are analyzed in Section 2. In simulation, results proved the feasibility of this topology, shown in Section 3. Finally, Section 4 concludes this article.

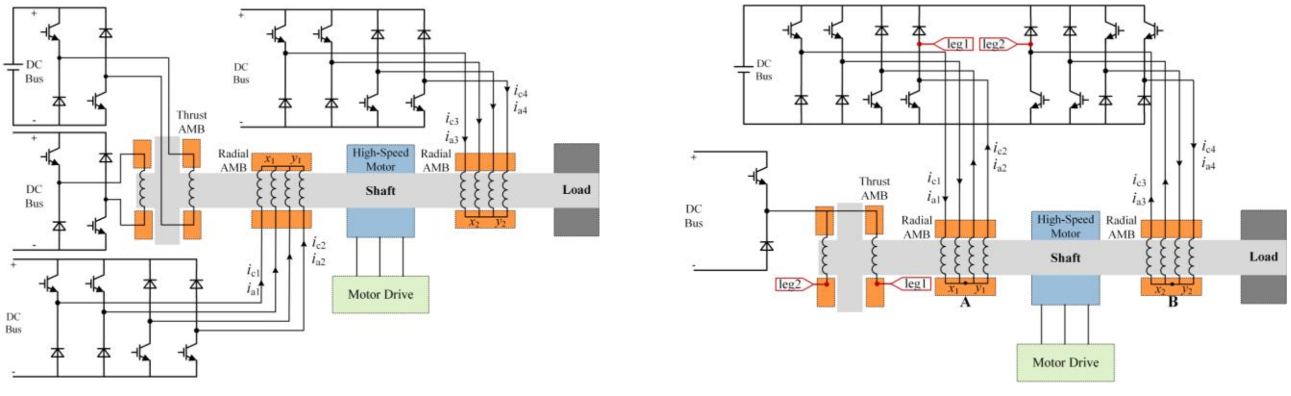
Keywords: *power amplifier, power electronics switches, Ten-Phase-Nine-Leg topology.*

1. Introduction

With the merit of no mechanical contact, no lubrication requirement, active magnetic bearing (AMB) has become the best solution to replace traditional mechanical bearings in high-speed rotating machinery [1]. As the core of AMB, power amplifier has more than ten switches to achieve AMB drive.

Half-H topology is the first type which uses independent H-bridge to control each winding. It requires a large number of power devices, leading to large controller, more loss and greater risk of switch failure [2]. Therefore, many experts have studied the topology based on switch multiplexing, like three-half-phases-legs, shared-bridge, reversed shared-bridge, series-end winding [3-5]. The above topologies at least need 11 legs to drive 5-axis AMB, which is still quite a lot. There is a basic requirement for topology design, that is, bias current of all magnetic bearing windings that control the radial are equal. Based on the above characteristic, four-phase-four-leg topology, shown in Figure 1(a), was introduced to drive four-axis AMB, which achieves the least switches usage [6]. However, this topology is limited by radial windings drive. For this reason, the most common type, five-axis AMB could not utilize such an imperfect scheme.

Therefore, also taking advantage of radial windings bias current equality, this article presents a ten-phase-nine-leg topology, shown in Figure 1(b). This topology achieves the minimum switches to drive five-axis AMB. Section 2 analyzes the principles of the proposed topology. The simulation results are displayed in Section 3. Finally, Section 4 concludes this article.



(a) (b)

Figure 1 Comparison of four-phase-four-leg topology(a) and ten-phase-nine-leg topology(b).

2. Principles of Ten-Phase Nine-Leg Topology

As shown is Figure 1, it is not difficult to see ten-phase-nine-leg topology also using feature of radial windings bias current. The point A and B have the KCL equations, expressed as:

$$\begin{cases} i_{a1}+i_{c1}=i_{a2}+i_{c2}=2I_{bia} \\ i_{a3}+i_{c3}=i_{a4}+i_{c4}=2I_{bia} \end{cases} \tag{1}$$

The overall diagram is shown in Figure 2.

It is worth mentioning that modulation of the topology is the key to drive. The procedure of multi-leg modulation is:

1) According to the output of the current loop and the shape of this topology, list the KVL equations, expressed as:

$$\begin{cases} u_1-u_2=u_{a1}-u_{c1} \quad u_2-u_3=u_{c1}+u_{a2} \quad u_3-u_4=-u_{a2}+u_{c2} \\ u_4-u_5=-u_{a5} \qquad u_5-u_6=u_{c5} \\ u_6-u_7=-u_{a3}+u_{c3} \quad u_7-u_8=-u_{c3}-u_{a4} \quad u_8-u_9=u_{a4}-u_{c4} \end{cases} \tag{2}$$

2) With special modulation limit, like maximum DC voltage utilization or minimum switch loss, duty ratio of each leg can be obtained.

3) Through carrier-based PWM, PWM generated to control the switches.

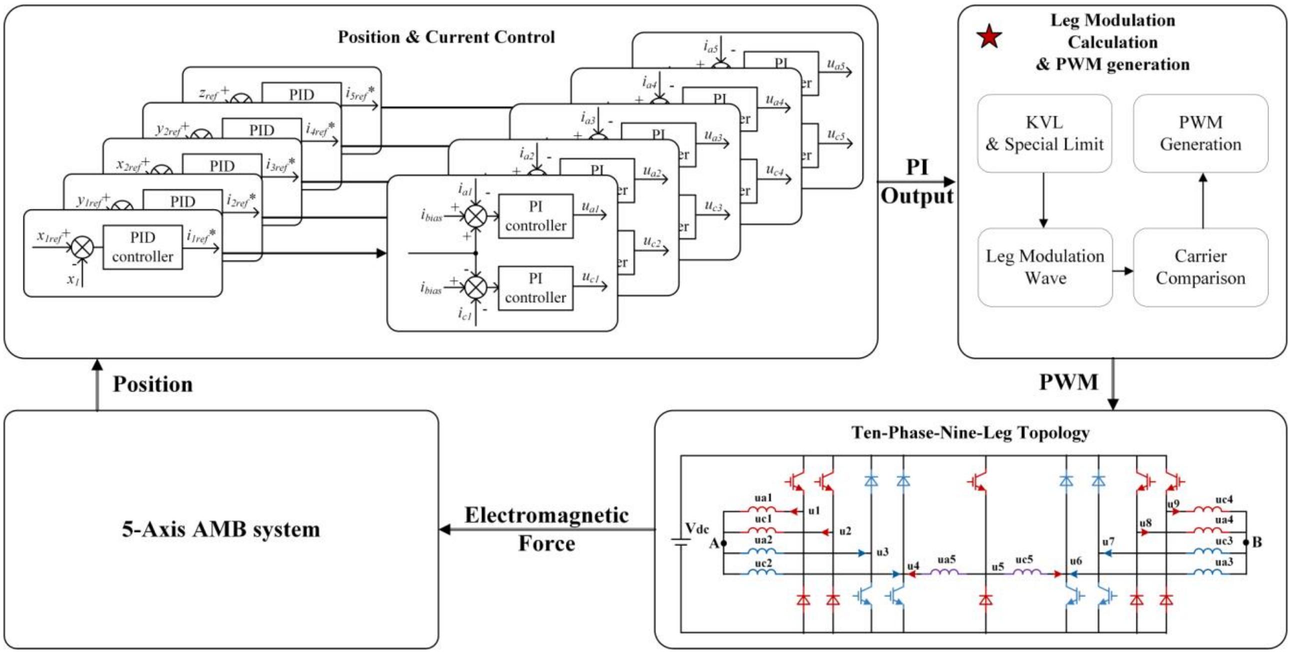


Figure 2 Overall diagram of ten-phase-nine-leg topology drive.

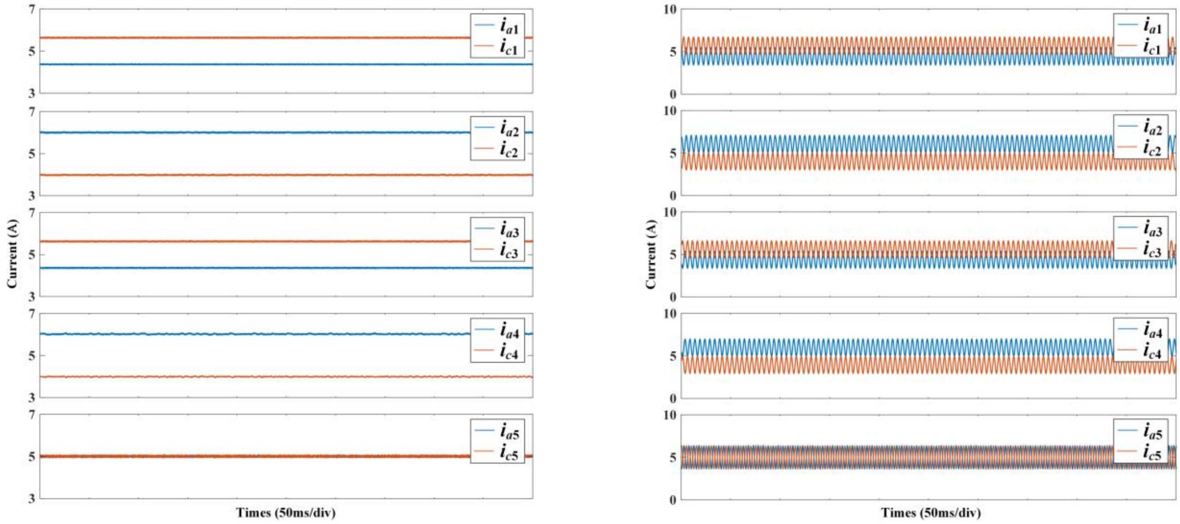
3. Simulation

To verify the proposed topology and performance of its drive, a simulation model was built, whose parameters are listed in Table 1. The following contains the waveforms of 5-axis currents and displacements under static suspension and high-speed rotation (12000 r/min) conditions.

Table 1 Simulation Parameters

	Parameter	*Value*
m	Rotor mass	10 kg
C_0	Airgap length	0.5 mm
I_0	Bias current	5 A
e	Eccentric distance	0.02 mm
f	Revolutions Per Minute	0~12000 r/min
L	Inductance	5 mH
R	Resistance	0.5 Ω
Vdc	DC-bus voltage	150 V

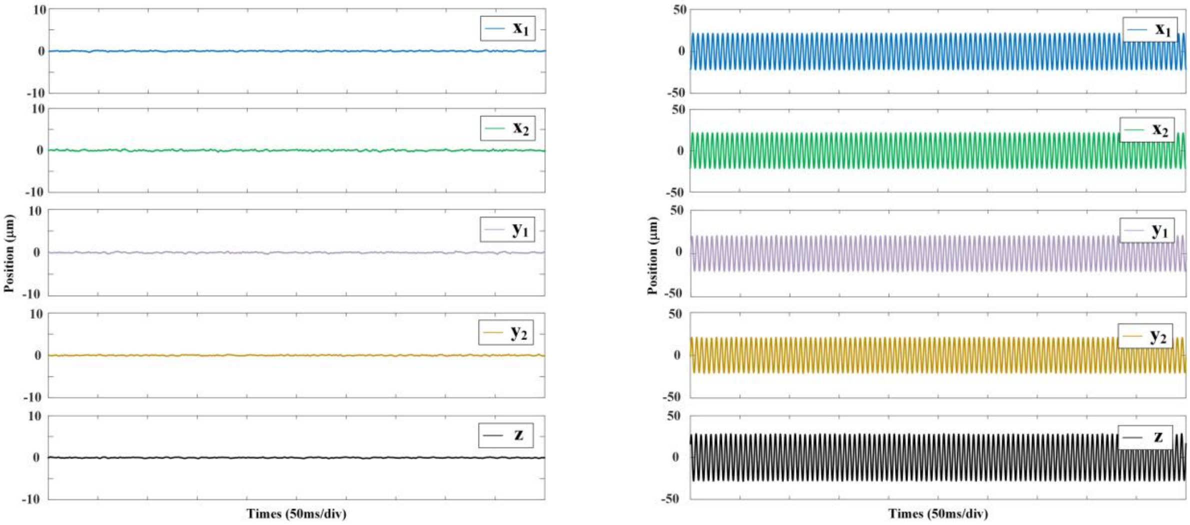
Figure 3(a) and Figure 3(b) respectively presented the currents under static and high-speed mode. In the figure, currents in all windings can be precisely controlled.



(a) (b)

Figure 3 Simulation results of currents in static and high-speed condition.

Figure 4(a) and Figure 4(b) respectively presented the positions under static and high-speed mode, which proved this topology has the ability to drive AMB in most applications.



(a) (b)

Figure 4 Simulation results of displacements in static and high-speed condition.

4. Conclusions

In this article, a novel ten-phase-nine-leg topology is proposed to drive five-axis AMB. With only 9 legs, this topology significantly decreases the switches and increases controller power density to some extent. Simulations and results are shown that this scheme has excellent performance with precise displacement control.

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