A NOVEL COST-EFFECTIVE SCHEME OF POWER AMPLIFIER FOR AMB USING SPACE VECTOR TECHNOLOGY

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ABSTRACT

This paper discussed new PWM schemes for AMB (active magnetic bearing) using the space vector PWM technology. A novel cost-effective three-level PWM scheme of AMB power amplifier using IGBT power module for AC motor is proposed. The feasibility of the scheme is proven through several simulations. Experiments with 1 DOF AMB system has been performed to show the effectiveness of the proposed scheme. Although this scheme needs the current feedback loop as well as position control loop in the main processor, the evolutionary improvement of processor capability would make this scheme be implemented successfully

INTRODUCTION

Pulse Width Modulation (PWM) techniques have been the subject of interesting research during the last few decades. A large variety of methods, different in concept and performance, have been newly developed and described [1, 2]. However, few techniques are used in AMB (Active Magnetic Bearing) industry such as three-level PWM, bearingless induction motor drive. Therefore, it is necessary to apply the proven good technologies of AC drive industry to AMB field.

The use of inverters with small AC motors in appliances and low power industrial applications is increasing rapidly. The power stage of these inverters is required to meet the efficiency, reliability, size, and cost constraints of the end products. The various IGBT power modules are designed to provide a cost-effective solution to these needs by combining optimized drive ICs and power devices into a single package[3, 4]. Therefore, these power modlues are expected to play a great role in AMB industry as well as the AC drive industry.

The most cost effective scheme of AMB power amplifier using IGBT power module for AC motor is the half bridge type amplifier. The two DC sources are built up by splitting the DC link voltage with two capacitors. The drawback of this scheme is that the balance of the two split DC sources must be carefully maintained [5]. For the system of AMB with five axes, the 4 IGBT power modules (while 7 power modules for the full bridge) are enough and the remaining two half bridge can be used to balance the two halves of the circuits. However, another control loop is necessary to maintain the balance of two split DC sources and moreover severe current ripples would be occur due to the two levels of output voltage (while 3 output levels of output voltage for the full bridge).

Authors propose a novel cost-effective three-level PWM scheme of AMB power amplifier based on the space vector PWM technique. One IGBT power module is used to drive one axis of AMB, i.e. two coils. The proposed scheme has following features:

-The higher voltage can be supplied to the coils compared to the half bridge case.

-The voltage and current of two coils can be controlled independently through the space vector PWM technique.

-Much less output current ripples due to three levels of output voltage just like full bridge inverters.

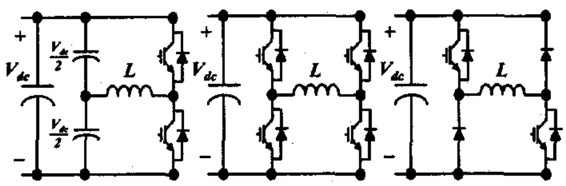
- Only 5 power modules against 7 power modules in case of full bridge scheme for 5 axis AMB application.

At first, authors introduce and compare several new PWM schemes using the space vector PWM technology. Then, the feasibility of this scheme is proven through several simulations. Experiments with 1 DOF AMB system has been performed to show the effectiveness of the proposed scheme. Although this scheme needs the current feedback loop as well as position control loop in the main processor, the evolutionary improvement of processor capability would make this scheme be implemented successfully.

POWER AMPLIFIER FOR AMB

AMB needs power amplifier to convert the control command into current, voltage or flux. The performance of power amplifier for AMB is divided into steady state and dynamic performances. The steady state performances are related to current-force, voltage-force slew rate, current harmonics and efficiency. The dynamic performance is related to the bandwidth or phase delay of power amplifier.

Figure 1 shows three switching power amplifier schemes. The full bridge has small current ripple than the half bridge although the full bridge is more expensive that half bridge. The modified half bridge was developed considering the one-directional current flow.



(a) Half bridge (b) Full bridge (c) Modified half bridge

FIGURE 1: Three switching power amplifier schemes

Most PWM schemes are based on two-level modulation, in which the output voltage of a amplifier is either positive dc-link voltage or negative one. The common drawback is that the current harmonic distortions are related with dc link voltage. It is shown that the standard power amplifiers with two switches are enough for AMB applications as shown in Figure 1 (c). With these two switches there are four operation modes, in which not only positive and negative output voltage can be generated but also zero voltage. Corresponding to these four operation modes, a three-level PWM-scheme is adopted for the control of output voltage or current [5]. The three-level PWM-scheme has several advantages: large bandwidth and reduction of current ripple and small current harmonic distortion.

NOVEL POWER AMPLIFIER SCHEME

IGBT Power Module

IGBT power module for AC motor consisting of high performance IGBT power devices with integrated gate drive and protection circuits have been widely accepted for motor control applications [3, 4]. The expanding use of IGBT power module in motor controls is primarily the result of the many advantages that have been realized by the technology. Some of these advantages include:

Reduced design time Gate drive and protection circuits are built-in eliminating the need to design them from scratch.

Improved reliability Protection circuits are matched to ower device capability and factory tested.

Improved performance Simultaneous optimization of power chips, gate drive and protection circuit results in improved efficiency.

Smaller size Use of bare power chips and application specific gate control ICs allows a substantial space savings over discrete approaches.

Improved manufacturability Reduced external component counts and convenient isolated base module designs simplify motor drive assembly.

Half bridge type power amplifier using IGBT power module

The two DC sources are built up by splitting the DC link voltage with two capacitors as shown in Figure 2. The magnet coils are divided into two groups corresponding to the two DC sources. The drawback is that the balance of the two halves of the circuit must be carefully maintained. The balance condition is the total currents of the two halves circuits must be kept equal. For the system of AMB with five axes, the 4 IGBT power modules (7 power modules for the full bridge) are enough and the remaining two half bridge can be used to balance the two halves of the circuits. Since two state PWM will be used due to the needs of two many PWM gates in case of three state PWM, the current harmonics is very large.

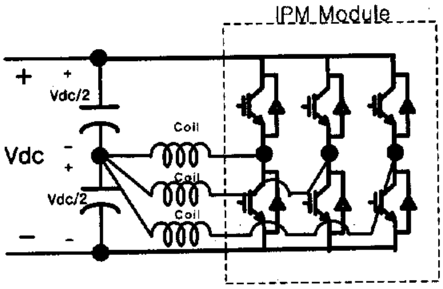
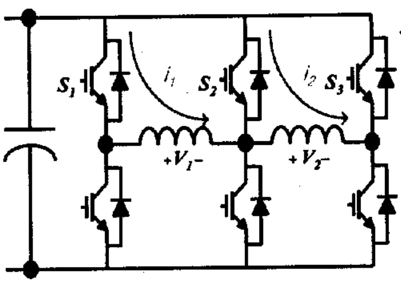


FIGURE 2: Halfbridge type power amplifier using IGBT power module

Novel power amplifier using IGBT power module

Figure 3 shows the novel power amplifier scheme and the relationship between switching and induced voltages. This scheme use three arms to drive two coils and 5 IGBT power modules are needs for general 5 axis AMB rotating system.



S_a	S_b	S_c	V_1	V_2
0	0	0	0	0
0	0	1	0	$-V_{dc}$
0	1	0	$-V_{dc}$	V_{dc}
0	1	1	$-V_{dc}$	0
1	0	0	V_{dc}	0
1	0	1	V_{dc}	$-V_{dc}$
1	1	0	0	V_{dc}
1	1	1	0	0

(a) Power amplifier scheme (b) Voltage in two coils

FIGURE 3: Novel power amplifier using IGBT power module

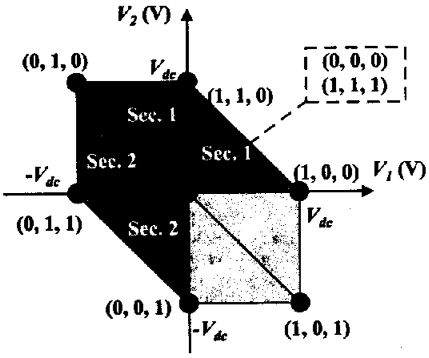
TABLE 1: The comparison among PWM scheme

	# of arms per coil	# of PM per 5 axis	Voltages in coil
Half bridge	1	4	$-V_{dc}/2$, $V_{dc}/2$
Full bridge	2	7	$-V_{dc}$, 0, V_{dc}
Proposed scheme	1.5	5	$-V_{dc}$, 0, V_{dc}

Table 1 shows the comparison among the half bridge, full bridge and proposed scheme. The proposed scheme is better than the full bridge in the point of cost and is better than the half bridge in the points of current ripple and achievable voltage in coil. However, the voltage region is restricted compared to the full bridge since (V_{dc}, V_{dc}) and ($-V_{dc}$, $-V_{dc}$) are not. If the two coils are used a pair of one AMB axis, the restriction of voltage region is not important since the quadrants of ($-V_{dc}$, V_{dc}) and (V_{dc}, $-V_{dc}$) are dominant mode after levitation.

Switching strategies

No offset voltage with 7 operating point All 7 operating points are shown in Figure 4 (a). The a is V_1/V_{dc} and b is V_2/V_{dc}. Without offsets voltage in switching command, the operating points are divided into 3 sectors and the 3 conditions are needed to implement the scheme as shown in Figure 4 (b). V_{an}, V_{bn} and V_{cn} are the voltage reference for PWM.



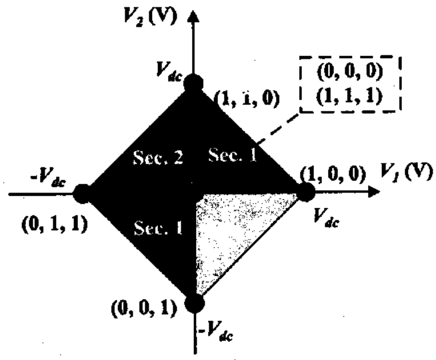
(a) Voltage region

	$a+b>0$	$a>0$	$b>0$	V_{an}/V_{dc}	V_{bn}/V_{dc}	V_{cn}/V_{dc}
Sec.1	1	x	1	$\|a+b\|$	$\|b\|$	0
Sec.2	0	0	x	0	$\|a\|$	$\|a+b\|$
Sec.3	x	1	0	$\|a\|$	0	$\|b\|$

(b) Switching command according to sectors

FIGURE 4: No offset voltage with 7 operating points

5 operating points Although the scheme of 5 operating points as whon in Figure 5 (a) loses some voltage region, all quadrants have same characteristics and clear physical meanings. Sector 1 means the initial levitation and sector 2 and 3 do the operation after levitation. Also, the number of conditions to implement the scheme is two as shown in Figure 5 (b).



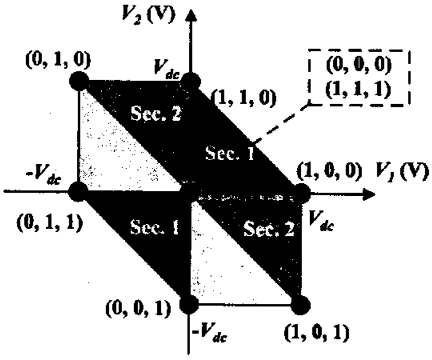
(a) Voltage region

	$ab>0$	$a>0$	V_{an}/V_{dc}	V_{bn}/V_{dc}	V_{cn}/V_{dc}
Sec.1	1	x	$(a+b)/2$	$(b-a)/2$	$-(a+b)/2$
Sec.2	0	0	$a+1/2$	$1/2$	$-b+1/2$
Sec.3	0	1	$a-1/2$	$-1/2$	$-b+1/2$

(b) Switching command according to sectors

FIGURE 5: 5 operating points

Offset voltage with 7 operating points Offset voltage makes one switching between on and off sequences to reduce the current ripple. The resulting voltage region and sectors are shown in Figure 6 (a). The sectors have clear physical meanings like 5 operating points and the number of conditions is two as shown in Figure 6 (b). That is, this scheme requires only two conditions without loss of physical meaning and the voltage region.



(a) Voltage region

	$a+b>0$	$ab>0$	V_{an}/V_{dc}	V_{bn}/V_{dc}	V_{cn}/V_{dc}
Sec.1	x	1	$(a+b)/2$	$(b-a)/2$	$-(a+b)/2$
Sec.2	1	0	$b/2+a$	$b/2$	$-b/2$
Sec.3	0	0	$a/2$	$-a/2$	$-a/2-b$

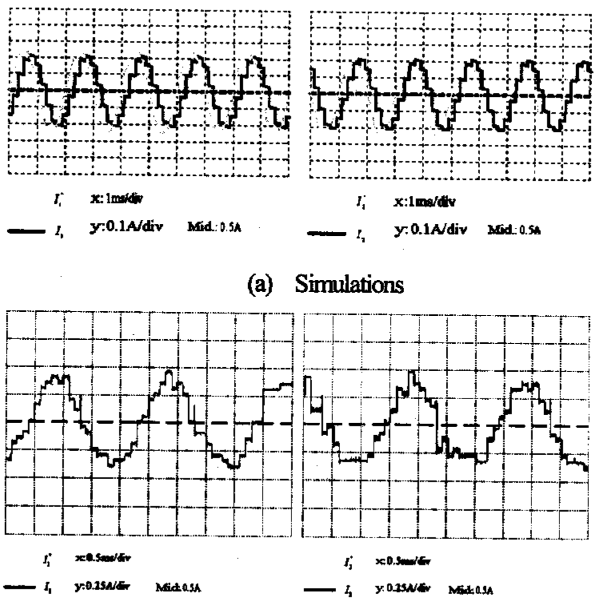
(b) Switching command according to sectors

FIGURE 6: Offset voltage with 7 operating points

SIMULATIONS AND EXPERIMENTS

Simulations and experiments with coils

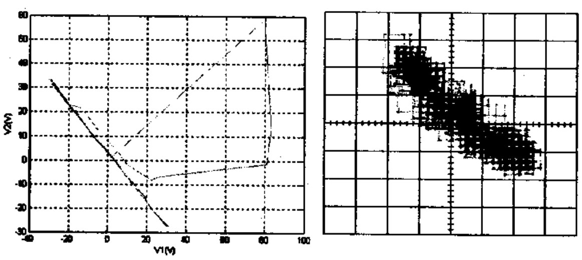
To verify the effectiveness of proposed switching scheme, the simulation and the experiments with two coils. The third PWM or offset voltage with 7 operating points scheme is used. The condition of simulation and experiment is as follows: 5kHz switching frequency, 10kHz sampling and 40mH coil inductance. The PI current controller is designed to have 500Hz bandwidth. 500Hz sinusoidal signal is injected as the sum of currents in two coils is maintained to 1A. Figure 7 (a) and (b) shows the simulation and experimental results, respectively. The Figure 7 shows that the current of two coils tracking the current commands and current control of each coil is possible independently. Also, the voltage command region is shown Figure 8. As mentioned before, the operating region is the quadrants of ($-V_{dc}$, V_{dc}) and (V_{dc}, $-V_{dc}$) after actual current reaches bias current.



(a) Simulations

(b) Experiments

FIGURE 7: Simulations and experiments with coils



(a) Simulation (b) Experiment (x : V_1, y: V_2-15V/div)

FIGURE 8: Operating region

Experiments with 1-DOF AMB system

Experimental set-up Experimental set-up of 1-DOF balance beam AMB system [6] is constructed and its schematics is shown in Figure 9. The balance of the beam is maintained with the control of coil currents in both sides. The specification of experimental set-up is as follows: 329mm length, 11.31kg mass, nominal gap 0.3mm and nominal coil inductance 25mH.

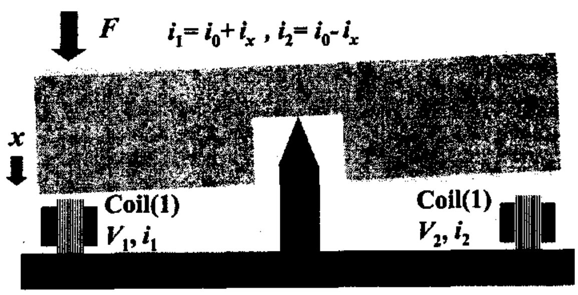


FIGURE 9: Experimental set-up

TMS320VC33 DSP, 12 bit AD and 14 bit PWM is used. The position sensor is KAMAN eddy current sensor. The used IGBT power module is ECN3067 (500V, 5A) that doesn't need any extra voltage source for gate drive.

The block diagram of overall experimental set-up is shown in Figure 10. The position controller is PD control with velocity estimator and the feed forward control is used to remove steady-state error. Current control is PI controller with 500Hz bandwidth.

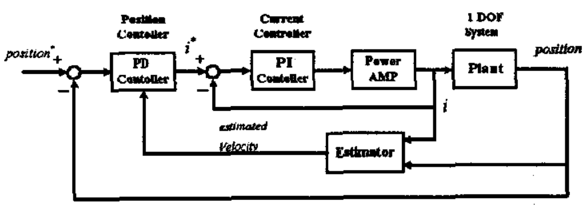


FIGURE 10: The block diagram of overall experimental set-up

The step command of displacement is injected to system and the current response is measured. The displacement and current responses are shown in Figure 11. The position is controlled well as well as current. Therefore, the proposed power amplifier scheme is possible to apply to current control for AMB system.

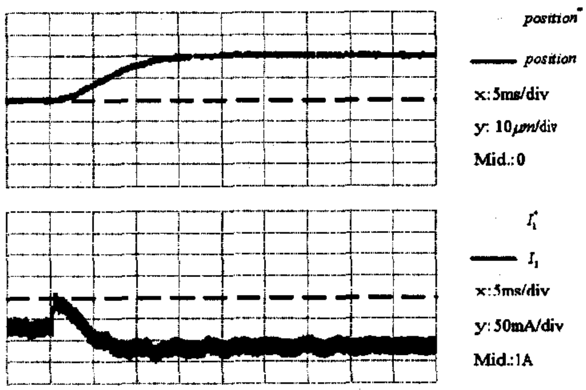


FIGURE 11: Displacement and current response for step command

CONSLUSION

At first, authors introduce and compare several new PWM schemes using the space vector PWM technology. Then, the feasibility of this scheme is proven through several simulations. Experiments with 1 DOF AMB system has been performed to show the effectiveness of the proposed scheme. Although this scheme needs the current feedback loop as well as position control loop in the main processor, the evolutionary improvement of processor capability would make this scheme be implemented successfully.

ACKNOLEDGEMENT

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