The Comparison of excitation source for sensors of the AMB system in HTGR

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***Abstract*—Nowadays the High Temperature Gas-Cooled Reactor (HTGR) is developed widely over the world. A helium turbine of a 10 MW HTGR test module reactor with the core made of spherical fuel elements is under research at the Institute of Nuclear and New Energy Technology of Tsinghua University in China. In HTGR, the magnetic bearings are widely applied, where the rotating machineries are running under highly pure helium environment. Compared with conventional bearings, Active Magnetic Bearings (AMBs) possess several attractive advantages, such as contact-free, no-lubricating and active damping vibration. The sensors are the key components of the AMBs system and are responsible for measuring the position and movement of the rotor, the operating temperature and so on. In order to operate the sensors successfully, a stable and efficient excitation source is needed. The paper will present the design, simulation and test of Class AB and Class D type power amplifier excitation sources for the sensors of the AMBs system.**

I. BACKGROUND

A. *High Power Sinewave Signal Excitation Source*

A high power sinewave signal excitation source [1] is always used to drive the sensor in the AMBs system [2-6], which can be obtained by a basic sinewave signal after amplification by a power amplifier device or circuit. Several methods could be used to generate the basic sinewave signal, such as Wien-bridge circuit [7] and direct digital frequency synthesizer (DDFS) [8]. The Wien-bridge circuit is analog circuit and the DDFS is digital circuit that often needs a CPU. Power amplifier (PA) circuits are often classified as Class A, B, AB, D and so on. Class A designs are the simplest but with the lowest efficiency. Class B amplifiers can achieve 78.5% efficiency theoretically but introducing crossover distortion. Class AB is a good compromise with a higher efficiency than Class A and a lower distortion than Class B, so it is widely used for audio power amplifiers. Currently both Class AB and Class D type PAs for the excitation source of sensors are developed. The power of Class AB type is about 100~500W and could not reach a high value because its power dissipation results in a high temperature condition that will introduce much more noise and distortion. A cooling fan helps to improve the condition but contributes to a more complex circuit. However, the class D type can achieve up to 90~95% efficiency and therefore reduces the power cost, temperature, and noise so that the power could be in the range of 100~1000W even without the cooling fan. Though there are many Class AB and Class D high power PA products for concert audio speakers and other audio field, the frequency of excitation source, in the range of 10kHz ~ 22 kHz, is much higher than that of audio speakers within 0 ~ 4 kHz and that makes the designs are different.

II. CLASS AB POWER AMPLIFIER

A. *Basic Class AB Topology*

Fig. 1 shows a simplified Class AB amplifier structure. The upper transistor is NPN or NMOS and the lower one is PNP or PMOS. In this operation, each transistor amplifies half of the input waveform, but also conducts a small amount on the other half. As a result the region where both transistors simultaneously are nearly off is reduced. The output waveform is combined by two amplified half and the crossover is minimized greatly.

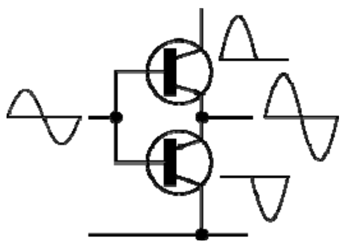

Figure 1. A basic Class AB amplifier.

The Class AB integrated circuit, TDA8547, is used to implement the amplified part for the excitation source of the sensors, as the Fig. 2 illustrated. The frequency of this IC is limited to 20 kHz because it is designed for audio field originally and then the amplitude attenuation would exist so that an extra amplitude tuner is needed.

B. *Basic Sinewave Signal Generator*

To simplify the sinewave generation, an integrated circuit, MAX038, is utilized instead of discrete component. The

MAX038 is a high-frequency function generator that

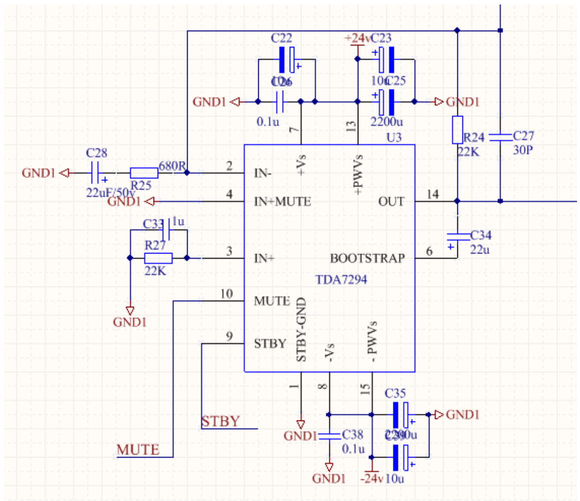

Figure 2. Class AB part: TDA8547 IC.

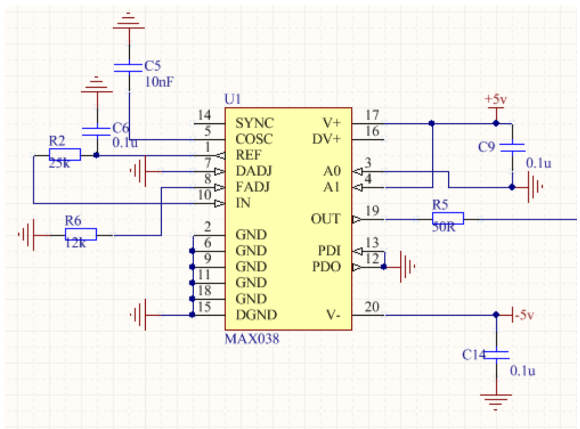

Figure 3. sinewave generator: MAX038 IC.

produces low-distortion sine, triangle, sawtooth, or square waveforms at frequencies from less than 1Hz to 20MHz or more, using a minimum of external components. Fig. 3 shows the implementation of this IC. The frequency of sinewave is calculated by Eq. 1.

$$f = 2 \times 2.5/(R_2 C_5) \quad (1)$$

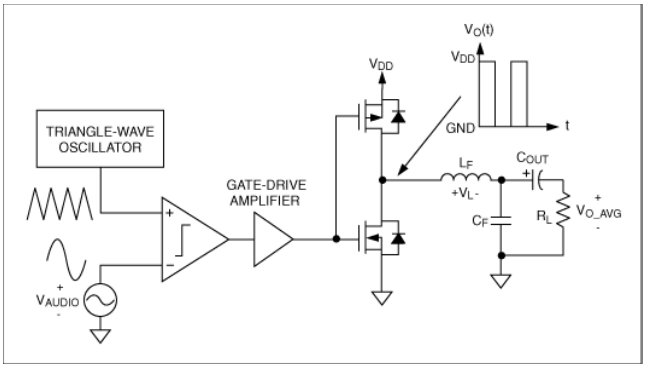

Figure 4. A basic class D amplifier.

III. CLASS D POWER AMPLIFIER

A. Basic Class D Topology

Fig. 4 shows a simplified functional block diagram illustrating a basic half-bridge class D amplifier. It consists of four parts: pulse width modulation (PWM) wave generator, gate driver, half-bridge or full-bridge power MOSFET and LC low-pass filter. The PWM wave is generated by using a sinewave sampled by a triangle-wave with a dozens of sample rates. A higher rate helps to achieve a less distorted final amplified sinewave but requires a gate-driver with a higher switching frequency. The gate driver produces a couple of switching signals for a half bridge or a full bridge with double amplitude using inverted input. Note that a full bridge consists of two half bridges. All NMOS devices are always preferred because NMOS has several advantages over PMOS, such as smaller on-resistance, higher efficiency, and lower temperature. A bootstrap circuit is needed for the bridge driver to drive the upper NMOS in the bridge circuit. The LC filter is for reducing the harmonics of the original sinewave and the sampling triangle wave.

B. PWM Wave Generator

The PWM wave generator consists of three parts: the original sinewave, the sampling triangle wave and the comparator. Many methods can be used to generate the sinewave using analog circuits such as the Wien-bridge but with poor ability to tune the frequency. A simple STM32F108 MCU using the SPI port can help to produce an easily tunable PWM wave with a high sample frequency. Fig. 5 shows a 20 kHz sinewave and a 450 kHz triangle wave and the generated PWM wave using a 9 MHz SPI clock.

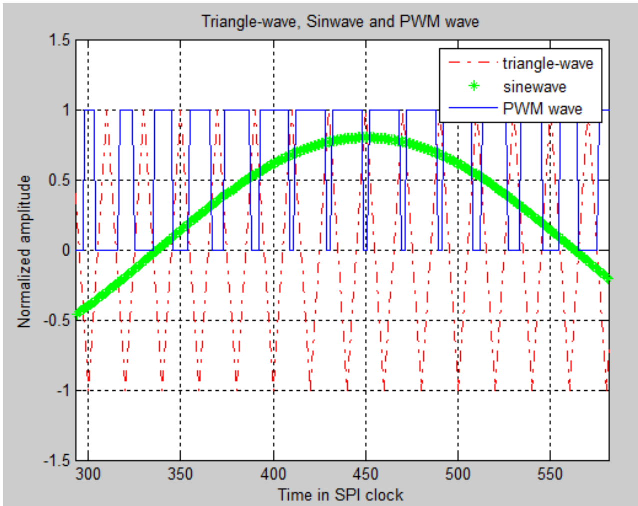

Figure 5. The PWM wave generated by a triangle-wave and a sinewave comparation.

C. Half-bridge Gate Driver

The main difference between the high power concert audio power amplifier and this excitation source is that the audio frequency range is normally about 0~4 kHz while the excitation source is in 10 kHz~22 kHz range. The much higher sample rate requires a higher switching frequency gate driver. Because the gate driver needs a dead time to control the half bridge to reduce distortion and power dissipation, the swing rate of the half bridge should be high and the dead time should be small. For example, an IRS2104S half-bridge driver with about 500 ns dead time at either the rising and falling edges will occupy about 50% of the duty cycle at the peak and trough of the sinewave in Fig. 2. This increases the distortion and improvement is required.

D. *Half-bridge and Full-bridge Comparison*

Class D amplifiers can be categorized into the half-bridge and full-bridge configurations. A half bridge using two MOSFETs is simpler while a full bridge using four MOSFETs is better in performance because the differential output structures of the two half bridges cancels the even-order harmonic distortions and DC offsets and generates two times the output swing. Table I shows a simple comparison. The excitation source for the sensor needs 40-100 V output swing and a full-bridge circuit has more choices in power devices and is easier to design.

TABLE I. A COMPARISON OF HALF-BRIDGE AND FULL-BRIDGE

	Half-bridge	Full-bridge
Output swing	1	2
MOSFET	2	4
Gate driver	1	2

E. *LC Low-pass Filter*

The amplitude-frequency response of the PWM wave is shown in Fig. 6. It is a 20 kHz sinewave modulated by a 450 kHz triangle wave. The signal above 20 kHz is of no use and should be removed by an LC low-pass filter (LPF) which behaves like a Butterworth LPF. The LC component value is determined by the LPF stop band frequency (f_{stop}) and the characteristic impedance of the load (Z_c), shown in Eq. 2. Setting f_{stop} to 50 kHz and for a load with a 2 Ω resistance in series with a 0.1 mH inductance, L is 10 μH and C is 3.3 μF approximately.

$$L = \sqrt{2} / f_{stop} \times Z_c$$
$$C = \sqrt{2} / f_{stop} / Z_c \qquad (2)$$

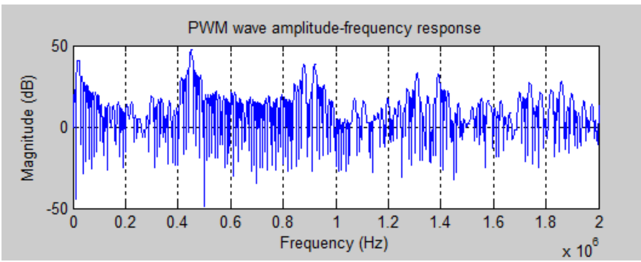

Figure 6. The amplitude-frequency response of PWM wave.

IV. SIMULATION AND TEST RESULT

A. *Circuit Schematic And Simulation Result*

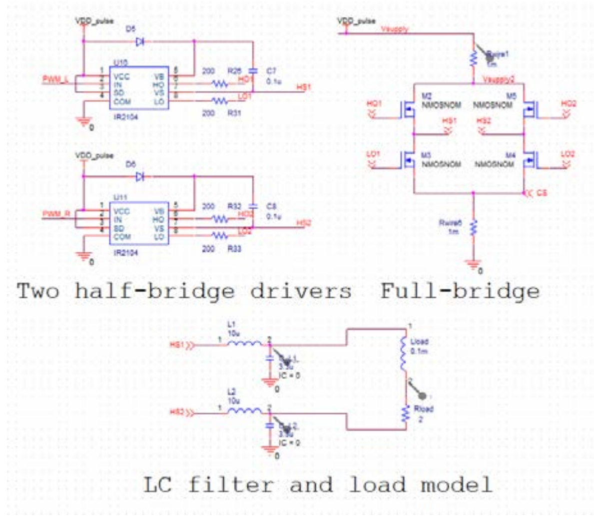

Figure 7. The main part of excitation source.

Fig. 7 shows the main part of the Class D excitation source. It consists three parts: two half-bridge drivers, a full-bridge and an LC LPF with the load model. The PWM_L in Fig. 7 is the PWM wave as shown in Fig. 5 and the PWM_R is the inverted one. The half-bridge driver is an IRS2104S and the power MOSFET is an IRFH5053. Two inductances of 10 μH bearing up to 6-10A maximum current are needed for the LC filter with a 2Ω load in series of 0.1 mH inductance. The

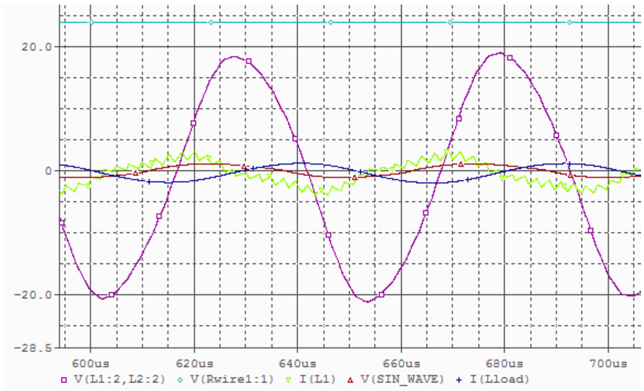

Figure 8. The simulation result using Cadence Pspice software.

simulation result using Cadence Pspice is shown in Fig. 8. The output waveform is indeed an enlarged sinewave and drives the load with less then 5A.

B. *Test Result*

The printed circuit boards (PCBs) are manufactured to verify the class AB and class D power amplifier excitation sources. The result of the PWM wave using an STM32F108 MCU with the algorithm of Fig. 5 is shown in Fig. 9. The output sinewave of the excitation source is shown in Fig. 10. These results illustrate that the PWM wave generator works well and the two half-bridge drivers, the full bridge and the LC filter are suitable for this source. The Class AB type also works well with a lower distortion but with a higher current and needs a cooling fan. The waveforms are the same and so here is not shown.

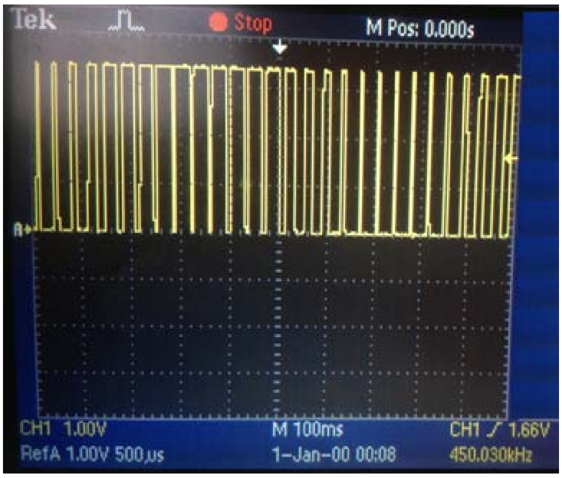

Figure 9. The PWM wave generated by an STM32F108 MCU.

V. CONCLUSION

A. Improvement and Future Work

Two types of excitation source for the sensor of the AMBs system have been verified and especially the proposed Class D power amplifier sinewave excitation source is shown to work by simulation and verified by experimental tests. It increases the efficiency and reduces an extra cooling fan versus the Class AB type source and this helps the sensor work stably. Future work will be carried out to reduce the distortion for the high frequency switch of the half-bridge driver.

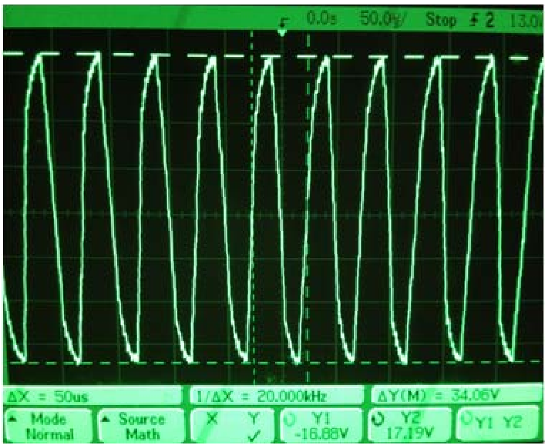

Figure 10. The output sinewave of the excitation source.

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