A Novel Sinusoidal Pressure Generator Based on Magnetic Liquid

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Abstract —A novel sinusoidal pressure generator with low frequency (0.1Hz~100Hz) based on magnetic liquid is proposed in this paper. The relation between input electrical signal and output pressure signal was analyzed. Meanwhile, the experimental platform was built for testing the performance of the pressure generator. Finally, the time-domain waveform and frequency-domain response of the pressure generator is measured. The relation curve between the pressure and the amplitude of current is test by experiment. The result of the experiment is accord with the simulation analysis.

I. INTRODUCTION

Magnetic liquid, a new function material, is a stable colloidal solution constituted of carrier liquid, strong magnetic particles and surfactant. Because magnetic liquid has the advantages both magnetism characteristic of solid magnetic material and fluidity of the liquid, therefore it has been applied to develop innovative instruments and sensors without moving mechanical part[1-2]. However, it is a new application to put the magnetic liquid in the field of dynamic calibration. The topic of this article is to demonstrate a new method of making sinusoidal pressure generator by use of magnetic liquid.

II. MODEL OF THE PRESSURE GENERATOR

Magnetic liquid sinusoidal pressure generator consists of permanent magnet, coil, magnetic liquid and U-tube, shown in Fig.1. When the magnetic liquid is located in a magnetic field, magnetic force along the direction of the magnetic field will be exerted on magnetic liquid [3].

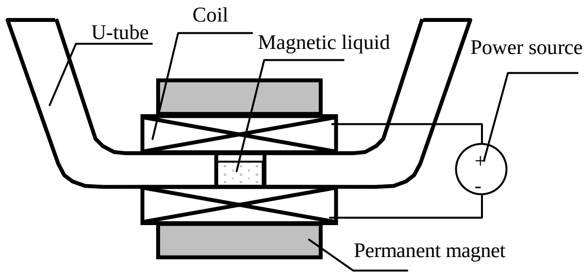

Fig. 1 Model of the pressure generator

III. PRINCIPLE ANALYSIS ON THE SINUSOIDAL PRESSURE GENERATION

The analysis of the ferrofluid dynamics in an alternating magnetic field is quite complicated. So, it is essential for us to make some assumptions that the magnetic liquid is incompressible and the viscidity is low to simplify the analysis.

According to the theory of molecular current model, the magnetic force $\boldsymbol{f}_{\mathrm{m}}$ acting per volume of magnetic liquid can be expressed as following[4]:

$$\boldsymbol{f}_{\mathrm{m}} = \mu_0 \chi_{\mathrm{m}} H \nabla H \tag{1}$$

Where μ_0 the permeability of free space is, χ_{m} is the magnetic susceptibility of magnetic liquid. H is the magnetic field intensity.

The expression of the total magnetic force is

$$\boldsymbol{F}_{\mathrm{m}} = 2\pi R_1^2 \int_0^L \mu_0 \chi_{\mathrm{m}} H \nabla H \mathrm{d}x \tag{2}$$

In fact, the mechanical model of the magnetic liquid sinusoidal pressure generator is a single degree of freedom system, which consists of a mass, a spring, and a damper[5]. If there is driving force $f(t)$ acting on the mass, the system vibrates under the driving force, which is called forced vibration. The whole process of the motion can be analyzed by Newton's second law of motion and the differential equation of motion is expressed as following:

$$m\ddot{y}(t) + c\dot{y}(t) + ky(t) = f(t) \tag{3}$$

Where m is the mass, c is the viscous damping coefficient, k is the equivalent stiffness, $y(t)$ is the displacement of the mass. In this system, the magnetic liquid column is equivalent to the mass and the magnetic force acts as the role of the driving force,

$$f(t) = F_m = F_0 \sin\omega t \tag{4}$$

When the initial conditions is $y(0) = 0$, $\dot{y}(0) = 0$, the solution of the equation (3) is:

$$y(t) = A\sin(\omega t - \phi) = \frac{F_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + 4\delta^2\omega^2}} \sin(\omega t - \phi) \tag{5}$$

Where $\omega_0 = \sqrt{k/m}$ is the circular natural frequency of the system, $\delta = c/2m$, and ϕ is the phase angle. According to equation (5), we can draw the conclusion that the displacement of the magnetic liquid column $y(t)$ varies sinusoidally with the frequency ω .

The initial pressure and volume in both pressure chambers of the U-tube, whose inner space is separated into two chambers by the magnetic liquid column, the left chamber and the right one, shown as Fig.1, are equal when the magnetic liquid column is in equilibrium position. And we suppose that the initial pressure is P_0 and volume is V. According to the ideal gas equation of state, the volume of a gas varies inversely as the pressure when the temperature is constant. So, we get the following equation,

$$p_L V_L = P_0 V \quad (6)$$

$$p_R V_R = P_0 V \quad (7)$$

Where p_L and p_R represent the pressure of left chamber and right chamber respectively. V_L and V_R are the volume of left chamber and right chamber when the magnetic liquid column moves in the U-tube.

$$\Delta p(t) = p_L(t) - p_R(t) = \frac{-2y(t)L_0}{L_0^2 - y(t)^2} P_0$$

$$= \frac{-2F_0/m}{L_0\sqrt{(\omega_0^2-\omega^2)^2 + 4\delta^2\omega^2}} P_0 \sin(\omega t - \phi) \quad (8)$$

Equation (8) shows that Δp varies sinusoidally and it has the same frequency with the exciting current ω. So, if there is a sinusoidal current through the coil, correspondingly, there will be a sinusoidal pressure produced.

IV. EXPERIMENT AND RESULTS

The magnetic liquid used in the experiment is kerosene base magnetic liquid. The saturate magnetization is 0.04T, viscosity is 2.9×10^{-3} Pa · s and the density is 1.1×10^3kg/m^3. The dosage used in the setup is 0.4ml. The inside radius of coil is 4×10^{-3}m, external radius is 1×10^{-2}m. The turn of the coil is 2000.

The DDS functional signal source provides AC current for magnetic liquid sinusoidal pressure generator. The frequency range is 0.04Hz~6MHz. The generator is connected to a micro differential pressure transformer, whose measuring range is from -1.5kPa to 1.5kPa. Precision is 0.2%FS. The electrical signal, coming from the output of the micro differential pressure transformer, whose characteristic reflects the information of the pressure signal, is processed by the signal modulate circuit and A/D convert circuit. Finally, we get the time-domain and frequency-domain response of the magnetic liquid sinusoidal pressure generator as shown in Fig.2. The pressure waveforms are produced by the currents with the peak value of 60mA, frequencies of 35Hz. The top part is the time-domain waveform and the bottom part is the frequency-domain waveform.

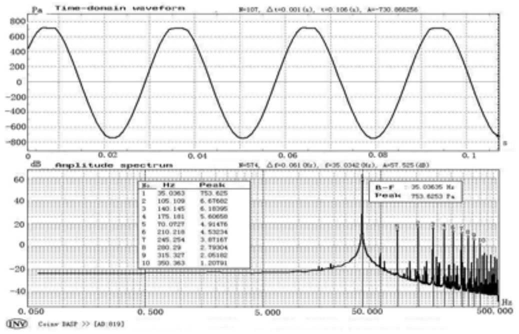

Fig. 2 Pressure waveform and spectrum, f=35Hz

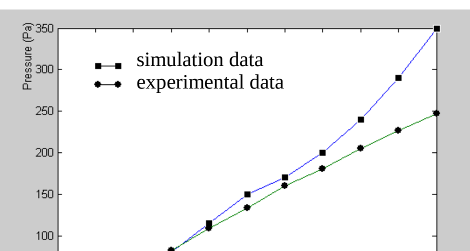

Fig. 3 Results comparison between simulation and experiment

The relation curve between pressure and excitation frequency is measured. And this result was got when the amplitude of the current is 60mA. The maximal output pressure is 750Pa when the frequency is 35Hz. And it can be deduced from equation (8).

For the purpose of getting the relation curve between the amplitude of current and the pressure, the experiment was done when the frequency was 50Hz. And the result is shown in Fig. 3.

V. CONCLUSIONS

A novel sinusoidal pressure generator based on magnetic liquid has been discussed in this paper. The experimental result shows that the pressure generator is able to produce sinusoidal pressure with frequency range (0.1Hz~100Hz) and pressure range (23Pa~750Pa).

VI. ACKNOWLEDGMENT

This work was supported by National Natural Science Foundation of China under Grant No.51077037, and Natural Science Foundation of Hebei province, CHINA under Grant No.E2008000050.

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