The Dynamic Behavior of Liquid Droplets on Vibrating Plate

Seiichi SUDO\textsuperscript{1}, Ayaka GOTO\textsuperscript{1}, Hiroki KUWANO\textsuperscript{2}, Yuichiro HAMATE\textsuperscript{2}, Tetsuya YANO\textsuperscript{1} and Kyohei HOSHIKA\textsuperscript{1}

\textsuperscript{1}Faculty of Systems Science and Technology, Akita Prefectural University, Yurihonjo 015-0055, Japan
\textsuperscript{2}School of Engineering, Tohoku University, Aoba-ku, Sendai 980-8579, Japan

(Received 3 January 2010; received in revised form 4 May 2010; accepted 12 June 2010)

Abstract
The dynamic behavior of water droplets on a vibrating solid surface was investigated experimentally. The liquid drop responses were examined by two vibrating methods. At first, the dynamic behavior of a water droplet on the solid plate subject to vertical vibration was investigated. In this experiment, an electrodynamic shaker was operated to generate the vertical vibration. Secondarily, the dynamic behavior of the magnet-magnetic fluid element on the plate subject to the vertical vibration was investigated because of the comparison with the behavior of water droplet. Thirdly, liquid atomization by ultrasonic vibration was investigated with a surface acoustic wave device. The dynamic behavior of water droplets on the vibrating plate was analyzed by a high speed video camera system. It was found that the water droplet responds to the excitation in elongation and contraction (axisymmetric modes) at lower excitation accelerations. With increase of excitation acceleration, the water droplet showed the polygonal oscillations (polygonal modes). The water droplet was completely atomized by the ultrasonic vibration using the surface acoustic wave device.

Key words
Water Droplets, Liquid Sloshing, Drop Oscillations, Surface Phenomena, Atomization, Magnetic Fluids

1. Introduction
With the development of space technology and seismology, the dynamic behavior of liquid in a moving container has stimulated our interest. When a container partially filled with a liquid is vibrated, the liquid presents the dynamic behavior responding to the vibrating external force. It is called “liquid sloshing phenomena”. Such phenomena come up as an important problem in various fields of space technology, seismic technology, and chemical engineering. Many extensive investigations have been conducted by authors [1-4]. In our previous paper, the surface disintegration phenomena of liquid in the vibrating containers were reported. When the container holding water was vibrated at higher accelerations above a specific acceleration, the free surface was disintegrated, and spray particles were ejected from the surface. Such spray particles fell to the vibrating plate ejecting over the container. The liquid droplets on the plate are subjected to vibration again. A lot of extensive investigations of the response of a sessile drop on a solid plate subject to vibration have been conducted and reported. For example, Noblin et al. discussed the application to contact angle measurements and the surface modes of sessile drops on hydrophobic substrates [5]. Brunet et al. reported an experimental study of liquid drops moving against gravity, when placed on a vertically vibrating inclined plate, which is partially wetted by the drop [6]. Dong et al. investigated the resonant modes of sessile water drops on a hydrophobic substrate subjected to a small-amplitude lateral vibration using computational fluid dynamic modeling [7]. Sudo et al. studied the surface responses of a single magnetic fluid droplet on a horizontal solid nonmagnetic base subject to magnetic field and vertical vibration [8]. Tan et al. observed an extraordinary fluid jetting phenomena of a drop by large accelerations associated with surface acoustic waves (SAW) and derived a simple equation based on a momentum balance to predict the jet velocity [9]. These reports, however, show the results obtained experimentally under the limited exciting condition. The research data on the surface responses of a sessile drop subject to vibration are insufficient, and there still remains a wide unexplored domain. In order to clarify the fluid phenomenon in the nonlinear and nonequilibrium systems, it is necessary to investigate the chaotic responses of liquid drops on the vibrating plate from a global viewpoint.

In this paper, the dynamic behavior of a water droplet on a solid plate subject to vertical vibration, liquid atomization by surface acoustic waves (ultrasonic vibration), and the surface responses of magnetic fluid adsorbed to a ferrite permanent magnet subject to vertical vibration were studied with a high-speed video camera system. The resonant modes of sessile liquid drops on a vibrating plate were observed. The jet formation and liquid atomization at the certain excitation conditions were revealed.

2. Experimental Apparatus and Procedures

2.1 Vertical vibrations
A schematic diagram of a vibration exciter and a measuring system is shown in Fig. 1. An electrodynamic shaker (IMV Vibration Simulation System: VE-Series Multi Purpose Air Cooled Type VE-3201) was operated at a given frequency, displacement, and acceleration within the range of maximum exciting force 4.1 kN, maximum exciting acceleration 784 m/s\(^2\), maximum exciting amplitude 25 mm, and maximum exciting frequency 3000 Hz [10]. A transparent circular plate of diameter 110 mm and thickness 10 mm was mounted on the vibrating table of the electrodynamic shaker. Tap water at approximate 17 °C was used as the test liquid. A water droplet was located on the horizontal solid base by a micropipette. The vibration frequency was set as desired, and the vibration table connecting to the exciter was vibrated vertically at an arbitrary level of input vibration acceleration. The dynamic behavior of the water droplet on the vibrating base was recorded by a high-speed video camera system, Photron FASTCAM-Ultima SE. The Photron Ultima SE is an ultra high-speed video recording system with the ability to record up to 4,500 full frames per second (or up to 40,500}
partial frames per second) for immediate playback. The Imager is equipped with a C-mount lens adapter. In this experiment, a lens Micro-Nikkor 55mm f/2.8 was attached to the C-mount lens adapter of the Imager. A series of frames of the free surface behavior of the droplet on the vibrating plate was analyzed by the personal computer.

2.2 Ultrasonic vibrations
The dynamic behavior of the water droplet subject to ultrasonic vibration was also observed by the high-speed video camera. The ultrasonic vibration was generated by a fabricated surface acoustic wave (SAW) device. The fabricated surface acoustic wave device consists of a glass plate and an interdigital transducer arranged on the piezoelectric substrate (LiNbO₃). The alternating current signal was supplied from the frequency synthesizer, and was amplified by the bipolar power supply. In the experiment, a single water droplet was located on the fabricated surface acoustic wave device by the micropipette, and the droplet was vibrated at 3.17 MHz. Figure 2 shows the outline of the water droplet on the fabricated surface acoustic wave device.

2.3 Magnetic fluid
The dynamic behavior of the water droplet was compared with the behavior of the magnetic fluid bulk under the magnetic field. The magnetic fluid adsorbed to the small permanent ferrite magnet was put on the vibration table as shown in Fig. 1. The magnet-magnetic fluid element is shown in Fig. 3. The iron plate with 1 mm thickness was laid under the acrylic plastic base for the weak attraction of magnet-magnetic fluid element. The weak magnetic attraction maintains the magnet-magnetic fluid element at a fixed place against the base incline. In this experiment, the sample magnetic fluid is kerosene-based ferricollid HC-50 (the saturation magnetization $M_s = 33.42$ kA/m). The surface tension of the magnetic fluid is 0.0277 N/m (magnetic fluid/air at a temperature of 19 ºC).

3. Experimental Results and Discussion
3.1 Axisymmetric responses
The dynamic behavior of water droplets on the acrylic plastic plate subject to vertical vibration was investigated in the beginning. The sessile water drops were vibrated vertically at the following displacement:

$$x = x_0 (\cos \omega t)$$  \(1\)

where $x_0$ is the excitation amplitude, $\omega$ is the excitation angular frequency ($\omega = 2\pi f_0$, $f_0$ is the excitation frequency),
and \( t \) is the time. When the drops were vibrated at lower amplitudes, the drop showed the harmonic response. Figure 4 shows a sequence of two water drops on the plate subject to vertical vibration. In Fig. 4, \( V_0 \) is the volume of drop, and \( G_0 \) is the input dimensionless acceleration, which was defined as follows:

\[
G_0 = \frac{\omega^2 x_0}{g} = \frac{(2\pi f_0)^2 x_0}{g}
\]

where \( g \) is the gravitational acceleration. Two water drops show the elongation and contraction response on their center axes. It can be seen from Fig. 4 that a larger water drop shows a larger response amplitude. The water drops show axisymmetric responses at lower excitation accelerations. Figure 5 shows a sample plot of the measured drop height and diameter at the surface of base plate against elapsed time in frames. In this Fig. 5, \( h' \) is the dimensionless drop height \( (h' = (h-h_0)/h_0 : h_0 \) is the equilibrium drop height), and \( d' \) is the dimensionless drop diameter \( (d' = (d-d_0)/d_0 : d_0 \) is the equilibrium drop diameter). It can be seen from Fig. 5 that the water drop responds to the excitation in the elongation and contraction of its height. The frequency of the drop pulsation for vertical excitation corresponds precisely to the forcing frequency. The drop diameter at the surface of plate is completely contrary to the drop height in the response phase. It can be seen also that there is a phase lag between the vibration table and drop response. The resonant frequencies of oscillation of free liquid drops have been studied by Lamb [11]. Ignoring the viscous damping in the drop, a general expression for the different oscillation modes of a free liquid drop, and a circular liquid column are described as follows:

\[
\omega_n = \sqrt{\frac{\sigma(l-1)(l+2)}{\rho R^3}} \quad \text{(for a spherical drop)} (3)
\]

\[
\omega_c = \sqrt{\frac{\sigma(l-1)(l+1)}{\rho R^3}} \quad \text{(for a circular column)} (4)
\]

where \( \omega_n \) and \( \omega_c \) are the resonant angular frequencies, \( l \) is the oscillation mode, \( \sigma/\rho \) and \( R \) are the kinematic surface tension and the radius of the drop or column, respectively. Later study by Dong et al. [7] showed that a drop in partial contact with a surface has an extra low-frequency mode related to the center-of-mass oscillation. In this experiment, various surface mods of sessile water drops on the plate subjected to vertical vibration were observed. Figure 6 shows the multiple exposure photographs of the first mode and the second mode for the drop oscillations. Figure 6(a) shows the first mode and Fig. 6(b) shows the second mode of sessile drop oscillations. In Fig. 6, the gray shadow parts

![Fig. 5 Relation between drop response and table oscillation](image)

![Fig. 6 Multiple exposure photographs of sessile drops on the horizontal plate subject to vertical vibration](image)

![Fig. 7 A sequence of photographs of the drop ejection process at the experimental condition of \( f_0=37.0 \) Hz and \( G_0=2.32 \)](image)
Fig. 7 shows two states of maximum and minimum heights in the drop response. The frequency of the water surface motion usually corresponds to the excitation frequency at the lower excitation amplitude or acceleration. It can be seen from Fig. 7 that harmonic water surface motions are concentric waves.

3.2 Drop ejection by ligament breakup

In general, large-amplitude waves of liquid in a container can be produced by exciting the container in the direction normal to the liquid surface. Such waves, known as Faraday waves (that the wave frequency equal to half of the excitation frequency), have been extensively studied by many researchers [1-4, 12, 13]. In such waves, the dispersion relation is described as follows:

\[ \omega_t = \left( \frac{gk + \frac{\sigma}{\rho}k^3}{\tanh(kH)} \right)^{1/4} \]  

where \( k \) is the wavenumber, \( H \) is the fluid depth, and \( \omega_t \) is the angular wave frequency. According to Eq. (5), the crossover wave frequency from gravity waves to capillary waves is given as follows:

\[ \omega_c = \left( \frac{4g^3 \rho / \sigma}{\nu} \right)^{1/3} \]  

The excitation threshold acceleration for parametric instability in the capillary, unbounded and infinite fluid depth limits, is described as follows:

\[ a_t = \frac{8(\rho / \sigma)^{1/3}}{\nu_0^{3/3}} \]  

where the angular excitation frequency \( \omega = 2\omega_n \), and \( \nu \) is the kinematic viscosity.

In this experiment, the one-half subharmonic response of water droplet was observed as well as liquid wave motion in the container. In addition, the minute droplet ejection from the wave crest of drop surface was observed as well as the surface disintegration of liquid in longitudinally excited containers [1-4]. In our previous paper, the drop formation mechanism and the droplet size distribution have been examined, both theoretically and experimentally [3]. The growth rate of the top part of the liquid column was very large compared to the horizontal width of the column; that is, cylindrical jet columns were formed on the liquid surface. A swell appeared immediately at the top of the liquid jet. Subsequently, a neck appeared just below the swell, and the swell grew rapidly. Finally, the liquid column disintegrated into a liquid droplet at the neck point. Figure 7 shows a sequence of photographs showing the droplet ejection by ligament breakup generated by the growth of the wave crest. In this experimental condition \((f_0 = 37.0 \text{ Hz and } G_0 = 2.32)\), the behavior of water drop shows the one-half subharmonic response because the excitation acceleration exceeds the value of Eq. (7). Furthermore, the excitation acceleration in Fig. 7 exceeds the following value [14]:

\[ a_0 \approx 0.26(\rho / \sigma)^{1/3} \omega^{4/3} \]  

where \( a_0 \) is the critical excitation acceleration for the onset of drop ejection. The dynamics of the droplet ejection process by the vertical vibration was investigated numerically by the axisymmetric, incompressible, Navier-Stokes solver, which was developed by James et al. [15]. The droplet ejection process observed in this experiment was qualitatively corresponding to their numerical simulation.

3.3 Polygonal oscillation of sessile drop

The external vibration to the liquid drop leads to the formation of waves on the free surface. As the above-mentioned, the surface modes of the drop were axisymmetric at the lower excitation amplitudes. In this experiment, however, some polygonal modes were observed when the excitation amplitude was higher above a threshold. As one example, the droplet oscillation of a quadrangle mode in over view is shown in Fig. 8. The polygonal modes of the droplet oscillations showed the one-half subharmonic responses. It can be seen from Fig. 8 that the capillary waves are also generated on the surface of the water droplet. The polygonal mode of the water drop changed with the increase in the excitation acceleration. In Fig. 8, standing waves are created by vertical vibration of the plate. Figure 9 shows the wave motions of the surface of water drop on the plate subject to vertical vibration. The dominant wave is up-and-down motion at the drop center in Fig. 9. Such a response occurs when the liquid responds as a one-half subharmonic of the excitation. In addition, the waves with the shorter wavelength are observed in Fig. 9. Figure 10 shows the change of the mode of the water drop with the acceleration.
increase. It can be seen from Fig. 10 that the number of waves for the polygonal mode increases with the excitation acceleration. Such pattern evolution in the water drop surface was observed also in the water surface in a vertically vibrated cylindrical container [13].

### 3.4 Chaotic shape oscillation

As stated above, when a water droplet on the acrylic plastic plate is vibrated vertically, the droplet presents a pulsating motion corresponding to the vibration of the plate. When the excitation acceleration $G_0$ increases slowly from zero at a given frequency $f_0$, a stable elongation and contraction oscillation with smaller amplitude can be observed. These motions show harmonic response with the same frequency as the excitation frequency. Further to this, the increase of excitation acceleration $G_0$ more than the value required for the harmonic motion causes polygonal oscillation of the water drop as the above-mentioned. Furthermore, the increase of excitation acceleration $G_0$ led to the chaotic shape oscillation of droplet. Figure 11 shows a sequence of selected frames from high-speed movie. In this experiment, the amplitude or acceleration of the vertical vibration is uniform everywhere on the plate. Pictures in Fig. 11 reveal the process of complicated shape variation in the droplet oscillation. The oscillating behavior of the water droplet was like the amoeba motions as shown in Fig.11.

Figure 12 shows the above-mentioned drop oscillations depending on the excitation acceleration. In Fig. 12, $\eta$ is the maximum response height of the water drop. The maximum response height $\eta$ was measured as the peak height of drop from the horizontal acrylic plastic plate. It can be seen from Fig. 12 that the response height $\eta$ increases with the excitation acceleration. We can explain that the transition of the liquid surface pattern of the water drop responds as follows. When the external energy is supplied into the water drop by the external vibration, the energy is absorbed to form the harmonic concentric waves if $G_0$ is relatively small. With further increases of $G_0$, the energy is absorbed to grow the wave amplitude. However, the wave height is limited, and the maximum wave height depends on the wavelength. Therefore, the energy is absorbed to form a new wave which has a different mode. Then the energy is absorbed to grow the new wave amplitude for the increase of $G_0$. There is also a limit to the increase of the amplitude. When the wave amplitude of the specified mode grows fully, it seems that the wave response becomes unstable and presents the chaotic state, if the wave mode does not change into different modes. Finally, when the energy is supplied continuously to the drop-plate system over the absorption limit of the periodic liquid motion, the transition from periodic to chaotic oscillation occurs on the liquid surface of a droplet.

### 3.5 Dynamic behavior of magnetic fluid bulk

The surface responses of a single magnetic fluid droplet on a horizontal solid nonmagnetic base subject to magnetic field and vertical vibration was studied by authors [8]. The dynamic behavior of the magnetic fluid droplet is determined by the Eq. (9) [8].

$$2\xi^9 + \xi^7 \left[ N \xi - E \sin(\alpha t + \varphi) \right] - \xi^6 - \frac{S}{4} \xi^5 - 1 = 0 \quad (9)$$

where $\xi$ is the dimensionless number $\xi=(h/R)^{1/2}$ (h is the instantaneous drop height), $\varphi$ is the phase difference, and
In Eq. (10), \( N_B \) is the Bond number, \( E \) is the vibration Bond number, and \( S \) is the magnetic Bond number, \( \mu_0 \) is the permeability of vacuum, and \( M \) is the magnetization. The shape of the magnetic fluid drop on the horizontal solid nonmagnetic plate subject to static magnetic field is determined by the magnitude of the dimensionless quantities in Eq. (10). In fact, Eq. (9) can explain qualitatively the drop response within the range of relatively small excitation acceleration [8]. The effect of the vibration on the magnetic fluid droplet depends primarily on its frequency and acceleration. The drop motion frequency for a response of this type corresponds to the excitation frequency. The vibration Bond number \( E \) is described as follows:

\[
E = N_B \cdot G_0
\]

When the excitation acceleration \( G_0 \) increases from zero at a given frequency \( f_0 \), a stable elongation and contraction oscillation with smaller amplitude can be observed. These motions show harmonic response with the same frequency as the excitation frequency. Further to this, the increase of excitation acceleration \( G_0 \) more than the value required for the above-mentioned harmonic motion at a given frequency causes chaotic oscillations. Therefore, the increase of the vibration Bond number leads the magnetic fluid droplet to the nonlinear responses (chaotic behavior). In this experiment, the dynamic responses of the magnet-magnetic fluid element on the horizontal plate subject to the vertical vibration were investigated because of the comparison with the behavior of water droplet. In general, a lot of spikes are observed on the surface of magnetic fluid adsorbed to a ferrite permanent magnet as shown in Fig. 3. The normal-field instability phenomenon (magnetic fluid spike phenomenon) was studied by Cowley and Rosensweig [16]. The condition for onset of the normal-field instability is described as follows:

\[
\frac{\Delta \rho \sigma}{\rho g R^2} = \frac{\rho_0 \sigma^2 R^2}{\Delta \rho \sigma} = \frac{2 \mu_0 M^2 R}{\sigma} \quad (10)
\]

In Eq. (10), \( N_B \) is the Bond number, \( E \) is the vibration Bond number, and \( S \) is the magnetic Bond number, \( \mu_0 \) is the permeability of vacuum, and \( M \) is the magnetization. The shape of the magnetic fluid drop on the horizontal solid nonmagnetic plate subject to static magnetic field is determined by the magnitude of the dimensionless quantities in Eq. (10). In fact, Eq. (9) can explain qualitatively the drop response within the range of relatively small excitation acceleration [8]. The effect of the vibration on the magnetic fluid droplet depends primarily on its frequency and acceleration. The drop motion frequency for a response of this type corresponds to the excitation frequency. The vibration Bond number \( E \) is described as follows:

\[
E = N_B \cdot G_0
\]

When the excitation acceleration \( G_0 \) increases slowly from zero at a given frequency \( f_0 \), a stable elongation and contraction oscillation with smaller amplitude can be observed. These motions show harmonic response with the same frequency as the excitation frequency. Further to this, the increase of excitation acceleration \( G_0 \) more than the value required for the above-mentioned harmonic motion at a given frequency causes chaotic oscillations. Therefore, the increase of the vibration Bond number leads the magnetic fluid droplet to the nonlinear responses (chaotic behavior). In this experiment, the dynamic responses of the magnet-magnetic fluid element on the horizontal plate subject to the vertical vibration were investigated because of the comparison with the behavior of water droplet. In general, a lot of spikes are observed on the surface of magnetic fluid adsorbed to a ferrite permanent magnet as shown in Fig. 3. The normal-field instability phenomenon (magnetic fluid spike phenomenon) was studied by Cowley and Rosensweig [16]. The condition for onset of the normal-field instability is described as follows:

\[
M^2 = \frac{2 \mu_0}{\mu_t} \left( \frac{1}{r_0} \right) g \Delta \rho \sigma \quad (12)
\]

where

\[
r_0 = \left( \frac{\mu_0}{\mu_t} \right)^{1/2} \quad (13)
\]

\( \Delta \rho \) is the density difference between magnetic fluid and air, \( \mu_0 \) is the chord permeability, and \( \mu_t \) is the tangent permeability. When the magnet-magnetic fluid element was vibrated vertically, the magnetic fluid spikes showed the elongation and contraction response. In the certain excitation frequency, however, the narrow vertical jet of magnetic fluid was generated on the center axis of the element. Figure 13 shows a sequence of photographs showing the jet formation and the drop ejection. It can be seen from Fig. 13 that the magnetic fluid jet is longer than the water jet in Fig. 7. The magnetic fluid jet is extended by the action of magnetic field generated by the permanent magnet. This phenomenon is generated by the resonance of a magnetic field and a surface wave of magnetic fluid. The

---

Fig. 13 A sequence of photographs of the magnetic fluid jet formation process at \( f_0 = 18.0 \) Hz and \( G_0 = 0.25 \)

Fig. 14 Photographs of polygonal modes of the magnet-magnetic fluid element: (a) \( f_0 = 35 \) Hz and \( G_0 = 0.67 \) (b) \( f_0 = 59 \) Hz and \( G_0 = 1.59 \)

Fig. 15 A sequence of photographs of the mist ejection from water surface of droplet
generation frequency of the magnetic fluid jet was corresponding to the excitation frequency (harmonic response). The polygonal modes in over view were also observed on the surface of magnetic fluid. Figure 14 shows the polygonal modes of the magnet-magnetic fluid element subject to vertical vibration. The jet formation, drop ejection, and polygonal modes were commonly generated in such liquid-vibration system.

3.6 Water atomization by surface acoustic wave
A new ultrasonic atomizer using surface acoustic waves was proposed by Kurosawa et al. [17]. A fine mist was obtained by the surface acoustic wave atomizing device. Tan et al. also reported the SAW device [9]. They used lateral focusing of the acoustic energy to a small region beneath a drop placed on the surface.

In this experiment, the droplet behavior produced by the SAW device as shown in Fig. 2 was observed with the high speed video camera system. Figure 15 shows the mist ejection from the oscillating droplet surface. The mist gushes out from the upper part of the minute liquid column in Fig. 15. The different droplet responses are based on the excitation acceleration. In this SAW experiment, the excitation acceleration is higher, because the excitation frequency is higher with the MHz order. The resonant frequency in the interdigital transducer (IDT) is described as follows:

\[ f_R = \frac{v_R}{\lambda_R} = \frac{v_R}{2l_p} \]  (14)

where \( v_R \) is the velocity of SAW, \( \lambda_R \) is the wavelength of SAW, and \( l_p \) is the pitch of IDT. In the experiment, the frequency of SAW device was fabricated at \( f_R = 3.17 \) MHz. Tan et al. [9] reported that the liquid drop responds as capillary wave vibration within the range of \( R < \lambda_R \) and \( Re_s < 1 \) (\( Re_s \) is the streaming Reynolds number \( Re_s = \rho U_c / \mu \), where \( \rho \) and \( \mu \) are the liquid density and viscosity, respectively, and \( U_c \) is the characteristic streaming velocity). The liquid drop responds as atomization within the range of \( R < \lambda_R \) and \( Re_s = 1 \sim 10^7 \). The liquid drop responds as jetting within the range of \( R >> \lambda_R \) and \( Re_s = 10^7 \) [9]. In our experiment, the water drop response showed the water atomization by the mist gush. It can be seen from Fig. 15 that the mist gush is generated intermittently. The mist gush occurs as a consequence of propagating SAW irradiation. The different droplet behaviors were observed as a function of surface acceleration magnitude and the droplet size.

4. Conclusions
The dynamic behavior of a liquid drop on a plate subject to vibration was studied with a high-speed video camera system. The results obtained are summarized as follows;

(1) The water drop on the acrylic plastic plate subject to vertical vibration shows axisymmetric response at lower excitation accelerations. The frequency of the liquid surface motion for the axisymmetric modes corresponds to the excitation frequency.

(2) When the excitation acceleration required for the axisymmetric mode is exceeded, the polygonal mode in over view is generated. The liquid responds as one-half subharmonic of the excitation.

(3) When the excitation acceleration required for the polygonal mode is exceeded, the liquid drop shows the chaotic behavior. The liquid drop shows the surface disintegration during chaotic motions.

(4) The magnet-magnetic fluid element on the horizontal plate subject to vertical vibration shows axisymmetric response at lower excitation accelerations. The frequency of the axisymmetric mode corresponds to the excitation frequency. At certain frequencies, the polygonal modes in over view are generated. The polygonal modes respond as the one-half subharmonic response.

(5) The water droplet on the SAW device shows the chaotic motions and the mist ejection. The mist gush is generated intermittently.

References


