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SOUND-BASED METHOD OF MEASUREMENT FOR THICKNESS OF FILM

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ABSTRACT
The purpose of this research work is to develop a new method of measuring film thickness or density by using the sound frequency. A sheet of thin film or membrane is spread on a case of which the top upside is opened. An air layer of appropriate thickness exists between the film and bottom of the case. Acoustic signals from a speaker connected with a sound generator are emitted toward the film surface. The sound pressure in the case takes a large value at the resonance frequency. When the thickness of the air layer is constant, the resonance frequency of this oscillating system varies with the thickness or density of the film. From the experimental analysis, it was made clear that the measurement for the thickness or density of thin film by measuring the movement of the resonance frequency was possible.

1 - INTRODUCTION
In order to measure the thickness of a thin film or membrane, the mechanical measuring instrument for the displacement, such as a thickness gauge or a micrometer, and the measuring instrument employing the resonance phenomenon, such as an ultrasonic oscillator, have been used in industry. The contact styli with the object are adopted in these methods. These contact methods to measure the thickness of the thin film have some disadvantages of low measuring accuracy and give injury on the surface of the film by supplying the contact pressure. In order to exclude these disadvantages, a new non-contact method of the measurement for the thickness of thin film employing the sound frequency has been originated.
The purpose of this research work is to clarify a new non-contact method measuring the thickness of a thin film with simple equipments employing the resonance sound frequency. The film is stretched with a constant load on the test equipment which suitable thickness of an air layer exists between the film and rigid plate. The film and air layer are resonated by the sound energy radiated from the sound source.
The resonance sound frequency in the air layer is mainly depending on the thickness (density) of the film and the thickness of the air layer. So the thickness of the film can be obtained by measuring the resonance frequency. This report includes the experimental results on the non-contact method of the measurement for the thickness of the film conducted under various experimental conditions and the possibility of practical development of this method.

2 - MEASURING PRINCIPLE OF THE THICKNESS OF THE FILM
As shown in Fig. 1, a sheet of thin film is stretched on the air layer surrounded by the solid wall and bottom plate. A speaker is fixed over the film with a constant distance from the film. The speaker has a flat vibrating membrane and radiates the plane sound waves toward the film. The sound energy oscillates the film and air layer. The resonance appeared in a certain frequency which depends on the distance between the speaker and film, the thickness of the film and thickness of the air layer. When the working conditions except the thickness of the film are kept constant, the resonance sound frequency varies with the increase of the thickness of the film. Accordance with the relationship between the resonance frequency and the thickness of the film, the thickness of the film can be obtained by measuring the resonance frequency.

This method applying the sound signal has some advantages of non-contact measuring. The thickness of the soft film can be accurately measured because of non-contact. The injury on the surface of the soft film is not observed after the measurement. Thin film is also accurately measured with the simple equipment.

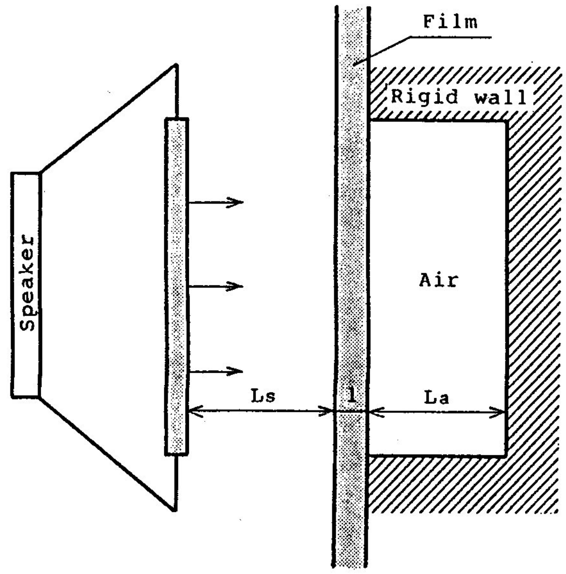

Figure 1: Sketch for principles of measuring.

3 - EXPERIMENTAL EQUIPMENT AND EXPERIMENTAL METHOD

Figure 2 shows a diagrammatic sketch of the experimental equipment. A random noise generator is employed as a sound generator which is connected to the speaker. The air layer and film to be measured are resonated by the sound waves from the speaker which are introduced to the FFT analyzer through a condenser microphone mounted on the rigid bottom plate. The resonance frequency can be obtained from the FFT analyzer which averages the signals from the microphone.

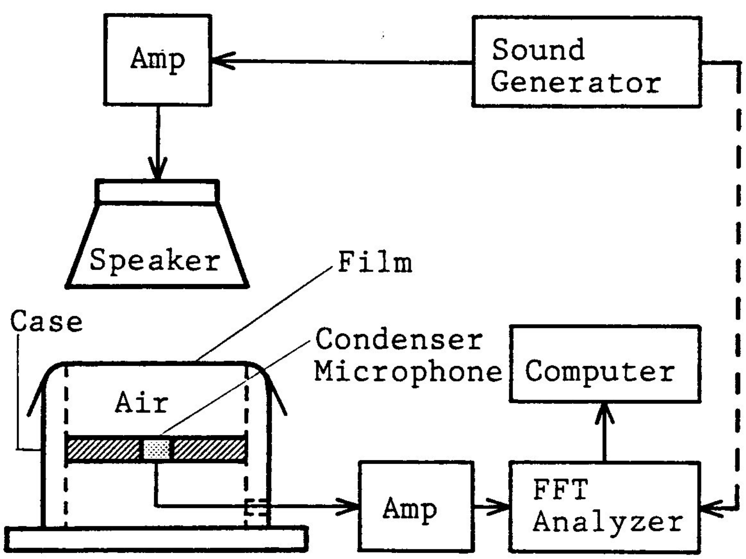

Figure 2: Diagrammatic sketch of experimental equipment.

Figure 3 shows an experimental model of the apparatus. The film is placed on the apparatus and is stretched with a constant tensile force. L_a is the thickness of the air layer which shows the distance between the film and bottom plate. L_a is varied by changing the length of the block placed under the bottom plate. The thickness of the rigid wall is 20 mm and the contact face with the film is precisely grinded to the curved faces which protect air leak. The apparatus is placed on a rubber plate to isolate the vibration from surrounding equipments. The effect of the position of the microphone (positions (a), (b) and (c)) on the frequency analyses is also examined in order to decide the optimum position of the microphone. The diameter of the speaker is 200 mm and maximum output power is 25 W. The range of the film density per unit area (corresponding to the thickness of the film) distributes from 0.0014 to 0.0217 g/cm^2. These were obtained from the surface area and weight measured by a precise physical balance. The tensile load to the film was changed for each film density to keep the constant tensile pressure. The material of the film is polyethylene. The relationship between the thickness and density of the film is experimentally obtained and is shown in Fig. 4. All experiments were conducted in a thermostatically controlled room at a constant temperature of 20 degree.

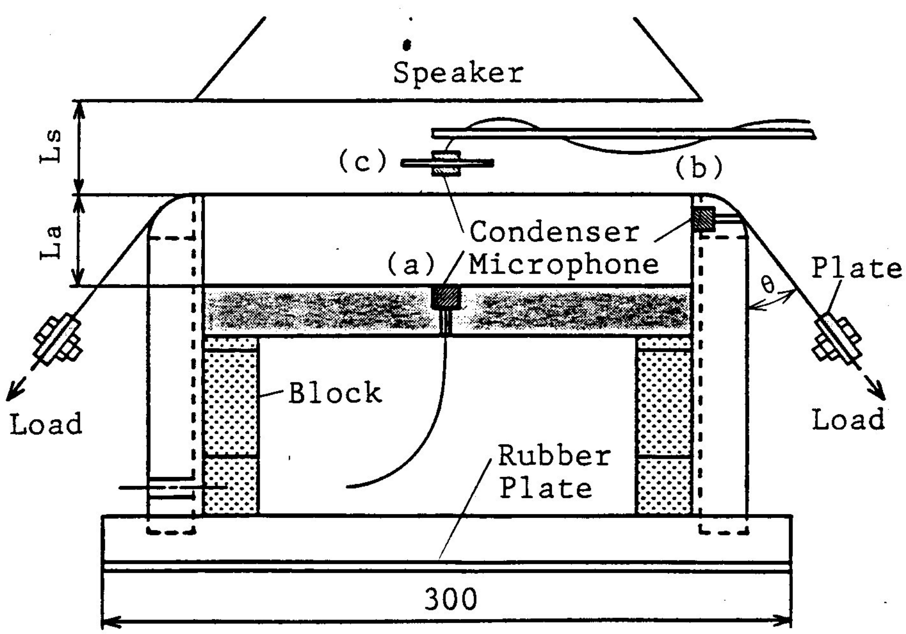

Figure 3: Experimental model of apparatus.

4 - EXPERIMENTAL RESULTS

4.1 - Position of the microphone

Figure 5 shows the frequency analyses for three positions of the microphone (a), (b) and (c) which are shown in Fig. 3. The density of the film 0.0059 g/cm^2, the length L_s=76 mm and length L_a =11.1 mm were kept constant during the analyses. The three figures of the frequency analyses shown in Fig. 5 are very similar and the resonance frequencies shown by an arrow are same. The position (a) of the microphone is easy to fix the microphone and gives nothing an obstacle in the experiment. So, the position (a) was adopted through all experiments.

4.2 - Frequency spectrum

Figure 6 shows the frequency spectra for seven films of the density 0.0014 to 0.0080 g/cm^2. The experimental conditions are shown in Fig. 6. The lengths L_a and L_s are kept constant during the test. The resonance of each film appeared at the frequency shown by an arrow. It is apparent from Fig. 6 that the resonance frequency increases with the decrease of the density (thickness) of the film. The form of the frequency spectrum is not affected by the thickness of the film except the resonance frequency.

Figure 7 shows the frequency spectra for various distances of L_a=15.6 to 41.0 mm. Thickness of the film is kept constant 0.0042 g/cm^2. The resonance frequency is apparently affected by the distance (L_a) between the film and bottom plate. The resonance frequency increases with the decrease of the distance L_a. Also, experiments for the density of the film lower than 0.022 g/cm^2 were conducted and similar tendency with 0.0042 g/cm^2 was obtained. Higher acoustic power from the speaker is required to be appeared the peak of the resonance frequency when the density of the film is larger than 0.03 g/cm^2.

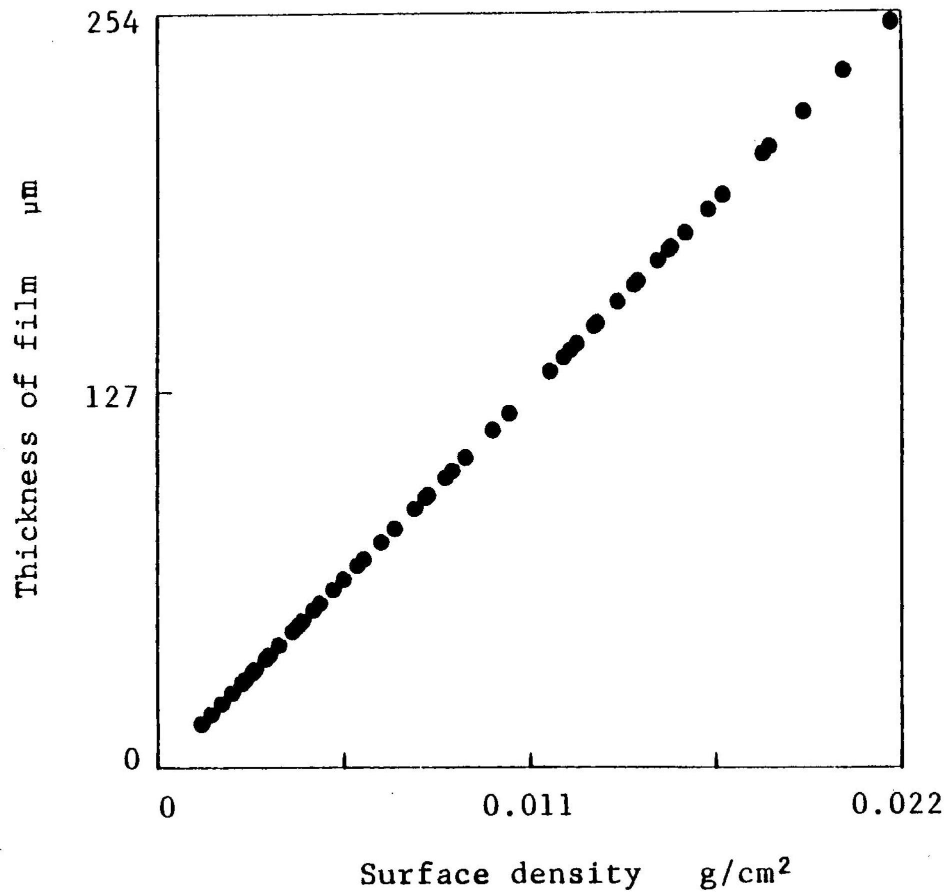

Figure 4: Relationship between density and thickness of film.

4.3 - Effect of the thickness of air layer and the density of the film on the resonance frequency

Experimental results for the thickness of the air layer are shown in Fig. 8. Three different thicknesses of the film were tested. As shown in Fig. 8, the decreasing rate of the resonance frequency at small thickness of the air layer is higher than that of the larger thickness of the air layer. It is necessary to choose the optimum range of the thickness of the air layer in practical application that the frequency variation against the thickness of the film is large and the scatter of the experimental data is small.
Figure 9 shows the relationship between the density of the film and the resonance frequency for constant conditions L_s=71 mm and L_a=8.7 mm. Similar relationship for L_s=37 and L_a=8.7 mm is also shown in Fig. 10. As shown in Figs. 9 and 10, the resonance frequency decreases with the increase of the density of the film. In order to measure precisely the thickness of the film from the resonance frequency, the distances L_s and L_a must be kept constant through the tests.

5 - CONCLUSIONS

A new method of the measurement for the thickness of the film applying the sound frequency is presented. Some tests were performed for various thickness of the polyethylene film. It was made clear from the experiments that the resonance sound frequency decreases with the increase of the thickness of the film. Under constant measuring conditions of various factors affecting on the sound frequency, it was confirmed that the thickness of the film is possible to measure by means of the resonance sound frequency. The apparatus of this measuring method is very simple and soft film can be precisely measured without injury on the surface. This method can be applicable not only to the thin films of nylon, vinyl, etc. but also thin paper sheet and plastic thin plate.

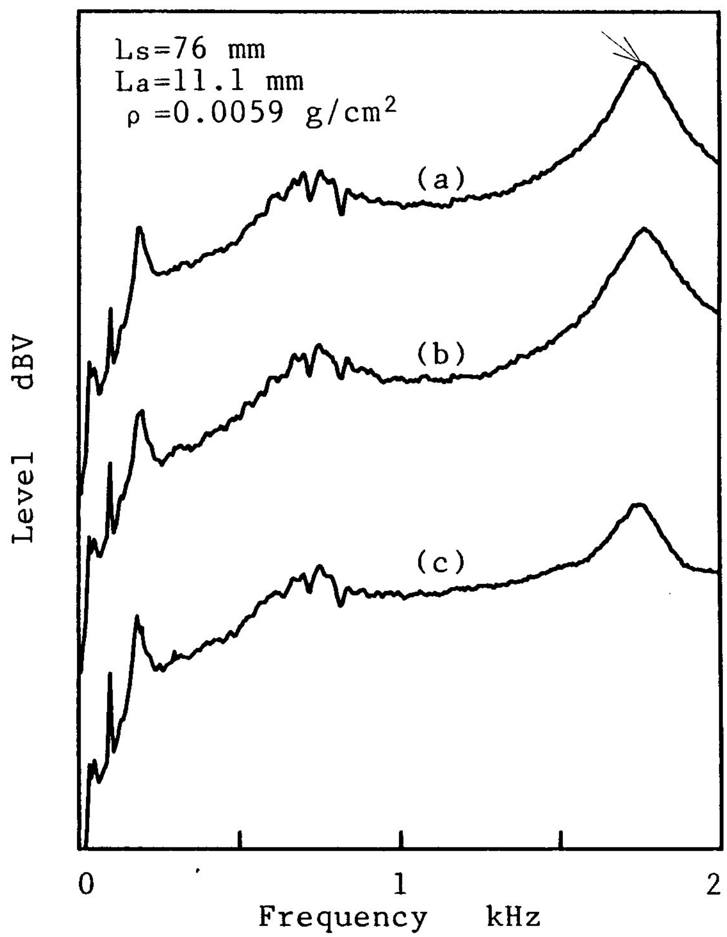

Figure 5: Frequency spectra for various positions of microphone.

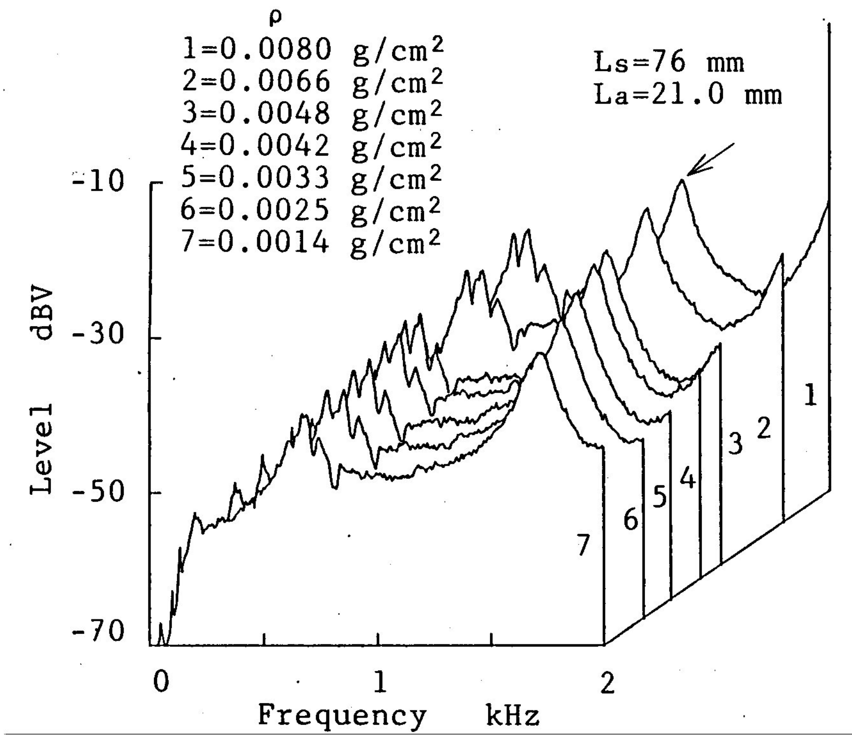

Figure 6: Frequency spectra for various densities (thickness) of film.

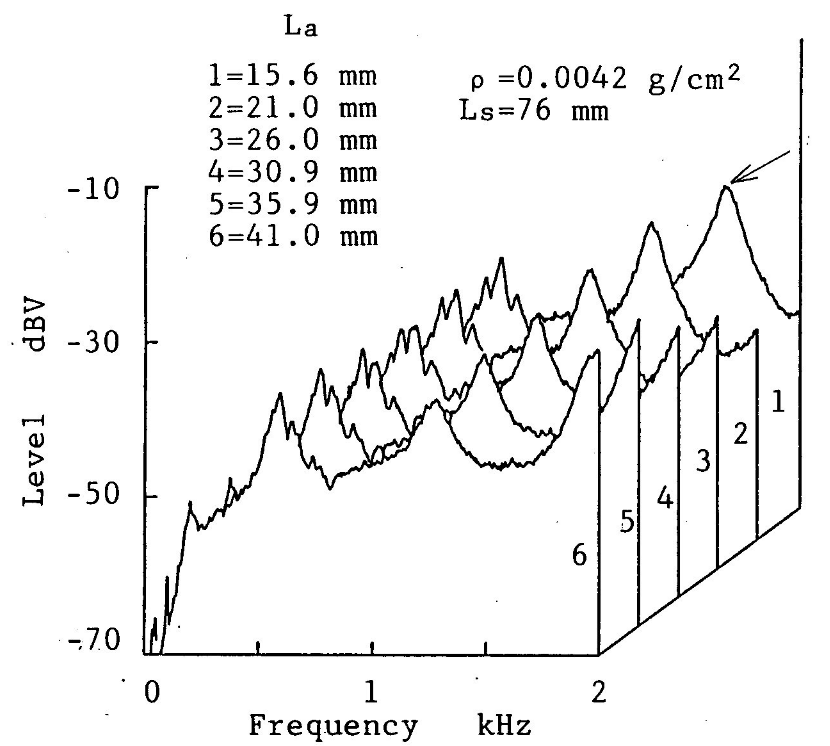

Figure 7: Frequency spectra for various thicknesses of air layer.

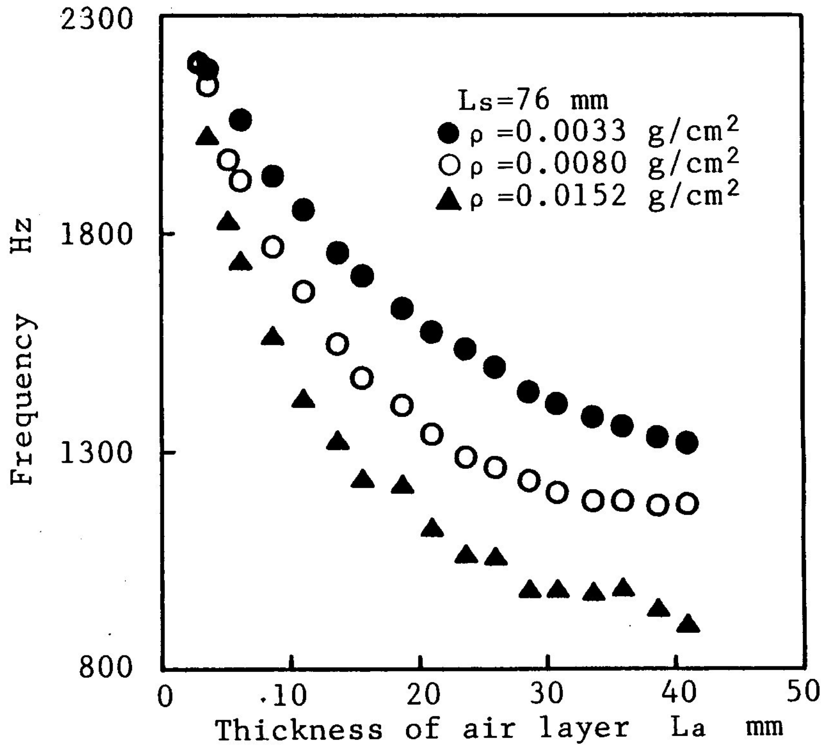

Figure 8: Effect of thickness of air layer on resonance frequency.

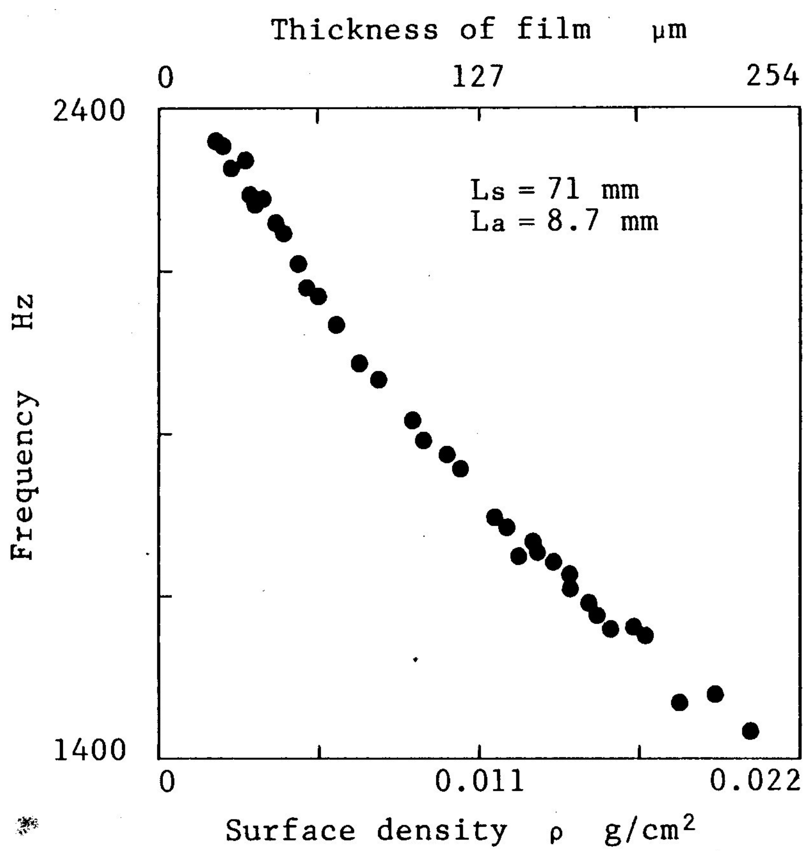

Figure 9: Relationship between thickness of film and resonance frequency for L_s=71 mm and L_a=8.7 mm.

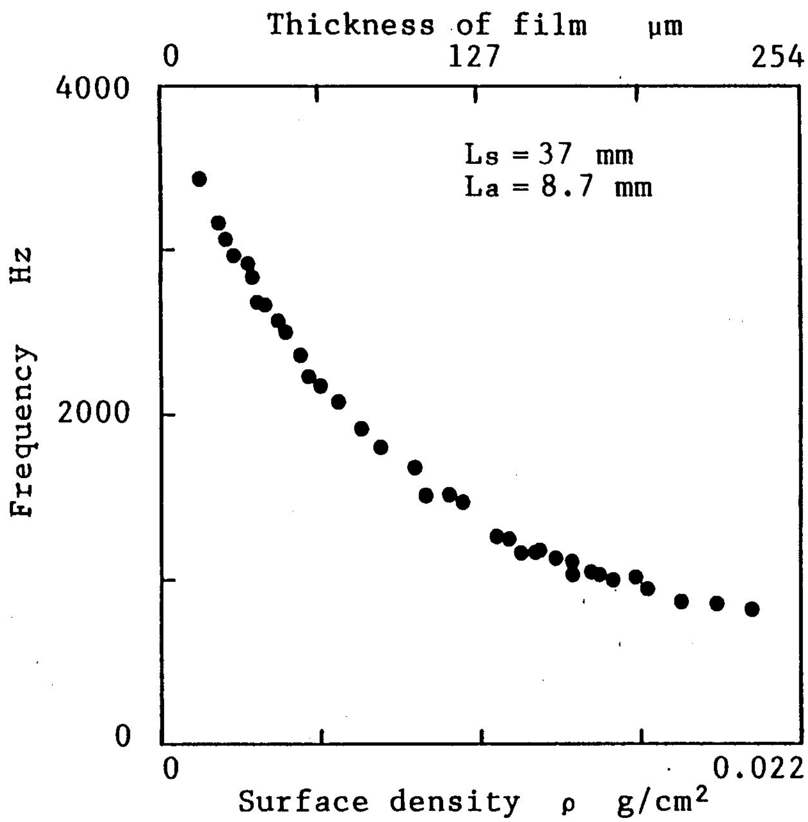

Figure 10: Relationship between thickness of film and resonance frequency for L_s=37 mm and L_a=8.7 mm.