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Some phenomena of cylindrical storage tanks during dynamical experiments

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ABSTRACT: Some new ideas obtained from a set of photographs which are enlarged from the cine-film taken by a high-speed camera during the vibrational experiments of models of cylindrical storage tanks. Such as, the vibrational mode of the shell is not like that of a cantilever beam; the response frequency of the shell is not the same frequency of shaking table; the liquid in the storage tank does not obey Laplace equation and the wave form of the liquid surface does not like the assumptions used in other papers.

1 INTRODUCTION

The dynamical characteristics of a structure should be known before designing. But in designing a storage tank, these characteristics are usually not considered(1)(2). Perhaps it may be the only one exception in aseismic designing works. Till now, there is not a designing method which is a practical one and will be accepted by engineers. In experimental studies, there is not a definite results of the behavior of the dynamical characteristics of storage tanks. Now some new conceptions are much different from usual ideas, such as:

1. The vibrational mode of shell coupled with liquid in it;
2. The mass of liquid which will be vibrated with the shell.

These are two difficult problems, and the opinions are widely divided(3)(4)(5)(6). Some popular methods of resonance, microtremor, white-noise excitation, impact and explosion etc. were used to measure the dynamical characteristics of storage tanks.

However, many results have been gotten, but the suspicious does not cleared. It seems:

1. There are many natural frequencies of a storage tank, and they are closely distributed. The energy conserved in this structure are almost in same amount for each natural frequency.
2. It is difficulty in spectrum analysis caused by additional damping force of coupled structure, and the resonance peak is undistinguished. While it is combined with the above problem, the resonance curve is a very plain curve.
3. The vibrational modes are complex, and the fundamental natural frequency does not correspond to the simplest mode of the shell-fluid structure. This is an exception in structural dynamics.
4. On the other hand, experiments are not directly through the sense. Sometimes it can not get a unique result when the same experiment repeated. So, for the sake of getting a persuadable experiments the high-speed camera was used for study the dynamical characteristics of storage tanks.

2. DESCRIPTIONS OF EXPERIMENTS

Beside some electronic instruments, a high-speed camera was used to record the vibrational mode of the model of storage tank.

Bearing capacity of shaking table: 5 ton
High-speed camera: Type SJC-16K.
Speed: 144 frames/sec.
120 ''
96 ''

A sketch of experiments for taking the high-speed cine-film is shown in Fig.1.

Uppon the opening of the model of storage tank, there is a steel ring painted by black-white colors and right coincide to the opening of the shell in sight of camera, that is to say the trace of the ring in the photographs is just on the trace of undeformed opening of the tank

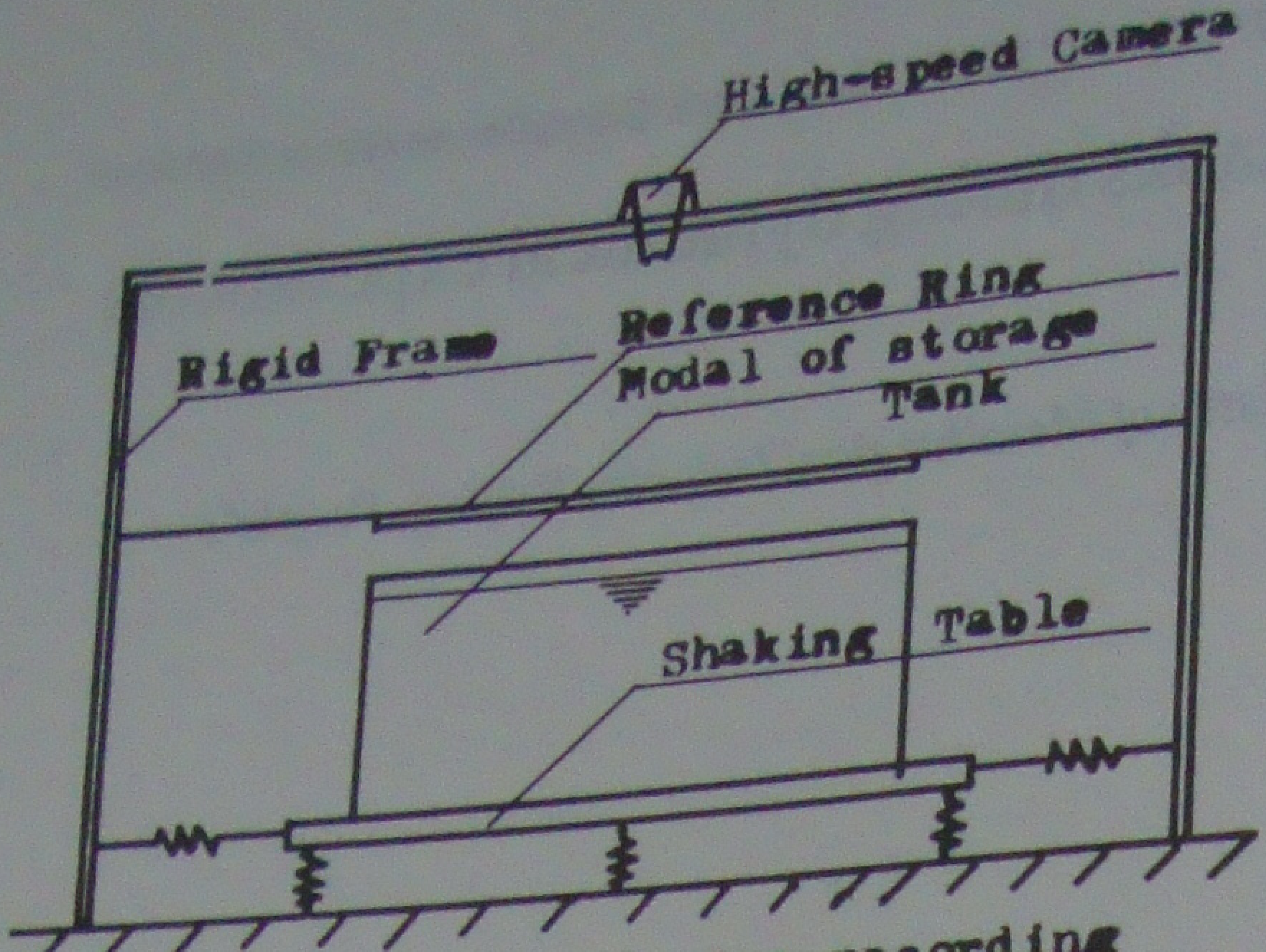
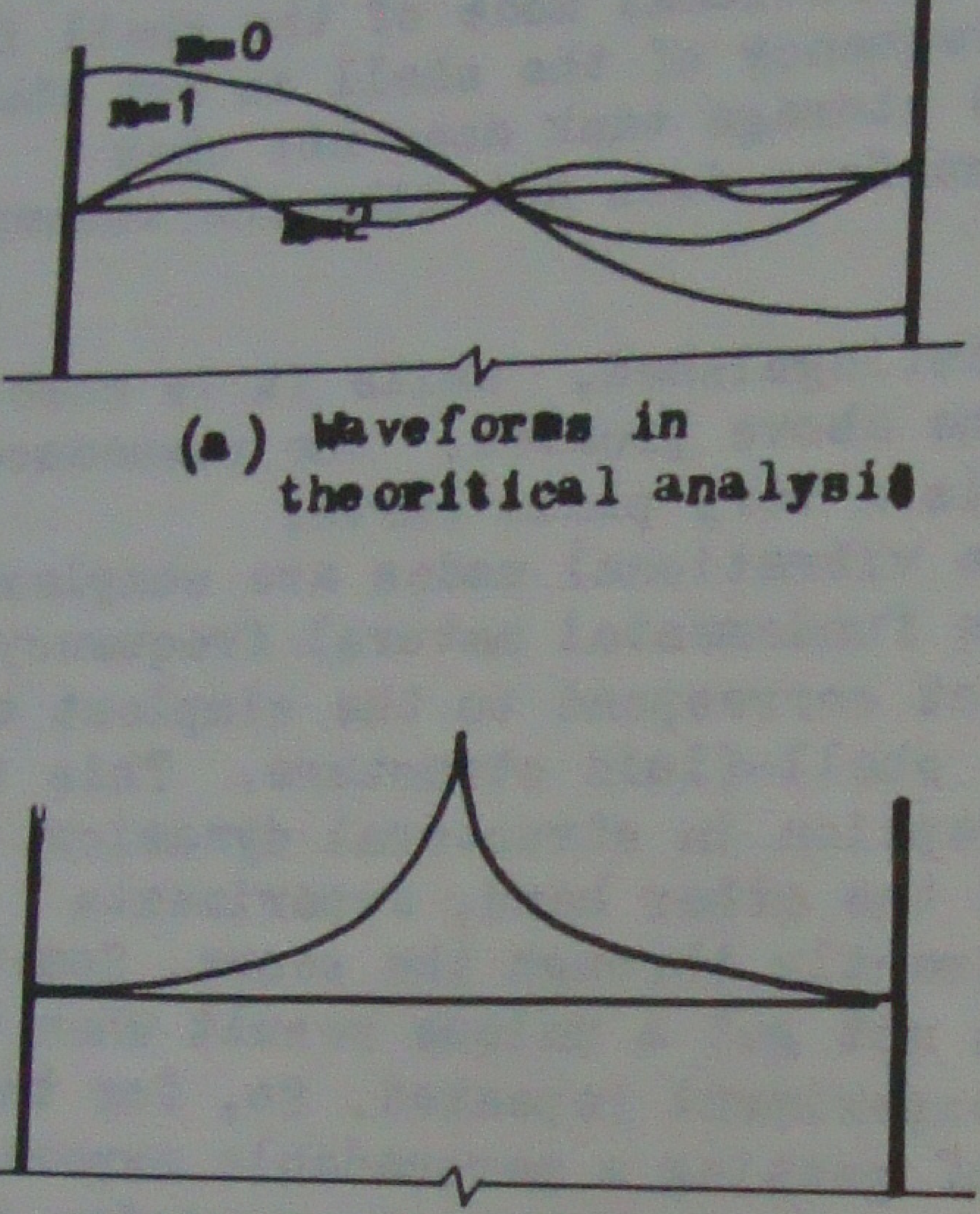


Fig.1 Sketch of cine-recording



(a) Waveforms in theoritical analysis

(b) Waveform in photographs

Fig.2 Waveform

model. On the fluid surface, some signals in triangular, circular and square shape are floated as references to indicate the flow direction of fluid.(Fig.4,5,6). On the other hand, the wave form, wave height and up-lift of shell bottom are recorded by high-speed camera.

Some data of the galvanized steel sheet models of storage tank are listed below:

Table 1

No. of tank	Diam. (mm)	Height (mm)	Wall thickness (mm)	Fluid depth (mm)
5	1200	1000	0.5	900
6	1200	1000	0.5	900 *
7	1200	650	0.5	550
8	1200	650	0.5	550 *

* Floating roof tank

3. RESULTS AND OPINIONS

A series of photographs(Fig.3) are enlarged from a section of cine-film of radial vibrational mode of the tank model which is vibrated on a shaking table in 7 Hz sine wave(while the maximum response of the shell occurs). In Fig.4 & 5, there are some distinct drawings of several photographs from Fig.3 for easy seeing of the radial deformations. In these figures the dotted circles are the reference circle(does not move during experiment), and the white circle are the deformed upper rim of the tank model. In comparing of these two circles, the radial vibrational mode will be seen obviously.

There are many interesting results observed, and only some distinctive results are discussed in this paper.

3.1 The vibrational mode of a shell-fluid storage tank is a very complex shape, it does not like the vibrational mode of a cantilever beam as reported in the paper (9). The radial mode corresponds to the fundamental frequency of our test models(H/D=1.5) is $\cos 3\theta$ or $\cos 4\theta$ (Fig. 4 &5). Even the wave form of the shell may be varies with H/D ratio and its wall thickness, but the maximum response will corresponds to $\cos 3\theta$ or $\cos 4\theta$.

From a lot of film analysis and measurements by electronic instruments in storage tank model tests (field tests and laboratory tests), a conclusion has been obtained that the multi-wave circular vibrational mode of storage tanks is a natural characteristics, it does not caused by the poor manufecture of the nonround shape of shell.(3)(5)(6)(10)

3.2 There is a fact should be noticed. In Fig.3, it is seen that the half period of the tank model is presented between 17-18 frames of cine-film(i.e. every 17-18 frames repeated the null positions of white circle coincides to the dotted circle), while the film speed is 120 frames/sec. the period of the tank model is about 0.3 second(this period corresponds to the mode of $\cos 3\theta$). But at that time, the frequency of shaking table is 7 Hz, this fact is much different from the ordinary theory that the steady state response of an alastic system will be vibrated in the same frequency of the external exciting force.

Does the exciting force may be in two parts: one is the shaking motion of the shaking table, and another one is due to the fluid pressures when the tank is vibrating in its fundamental mode (Cos3θ) ?

3.3 An ideal fluid assumption(non-source and irrotational) is used in theoritical analysis of the fluid in storage tanks. So that the partial differential equation may be a very simple equation. But in the view of photographs taken by high-speed camera(Fig.7 & 8) water drops sometimes sprayed up from the container and sometimes fall down into the container. That is to say, the fluid does not obey the non-source assumption.

On the other hand, if a floating roof covered the fluid in the tank (tank No. 6 & 8), its wave height is limited and no water springs, so it may be satisfy the non-source assumption, but its dynamical characteristics of storage tank are rather different from that of open tank.

The damping factor of a cylindrical storage tank fulfilled with liquid is very large and its value may be greater than 10%. But the damping factor is small when the liquid is considered only and the damping factor of empty shell is small also. These are results measured by using electronic instruments. Then an idea is risen that the dynamical characteristics (natural frequency, damping force and stiffness) are variables. That is to say, the storage tank is a complex structure with variable mass (participating liquid mass), variable damping force and variable stiffness. The natural frequency may be a function of time. Then the theoritical analysis of dynamical characteristics and its responses may be very complex.

3.4 On the wave form of the liquid in the tank, Fig.(2a) shows the results obtained from theoritical analysis and the wave height measurements by instruments. In this figure, the summit of waves are always at the periphery, and there is no wave at the center of liquid surface. When the tank is excited horizontally, the wave number n=0 or n=1 of the liquid be considered only. A lot of research works of theoritical analysis have got this conclusion(3). But in our experiments (Fig.7 & 8), the wave form is presented in Fig.2b. The spray drops are always in the center area of the liquid surface while it is excited horizontally, and its wave form is not a smooth sine curve.

At present time, this phenomenon can not be interpreted by theoritical analysis, and it may change the analytical equations, boundary conditions, participating mass, damping force and so on.

3.5 Uplift of the bottom of tank model and its fall down on foundation makes an impact action. It has been taken by a camera (Fig.9). The bottom is lifted about 1 cm from its foundation. There are some tanks collapsed near their bottom and is called as 'elephant foot' which is not interpreted. Till now, it is seldom to make an experiment to study the occurance of 'elephant foot'. Some analysis of uplift phenomenon will be discussed with theelectronic instrument measurements on accelerations, dynamical stresses and liquid pressures in another paper.

4. CONCLUSIONS

These are some descriptions of the direct sense experiment only. Comparing these results to the measurements by using electronic instruments,or the results of theoritical analysis will be discussed later. The moving traces of the floating signals on the fluid surface are shown clearly in Fig.5. But its moving rules have not been discovered.

Nevertheless, making these records of vibrational mode of storage tank by using high-speed camera is a very good and direct-sense method. Its results are indisputable than other analysis. It gives us some new ideas for developing the research works of cylindrical shell storage tank.

Thanks to Dr. Lee Li who suggested and directed this work.

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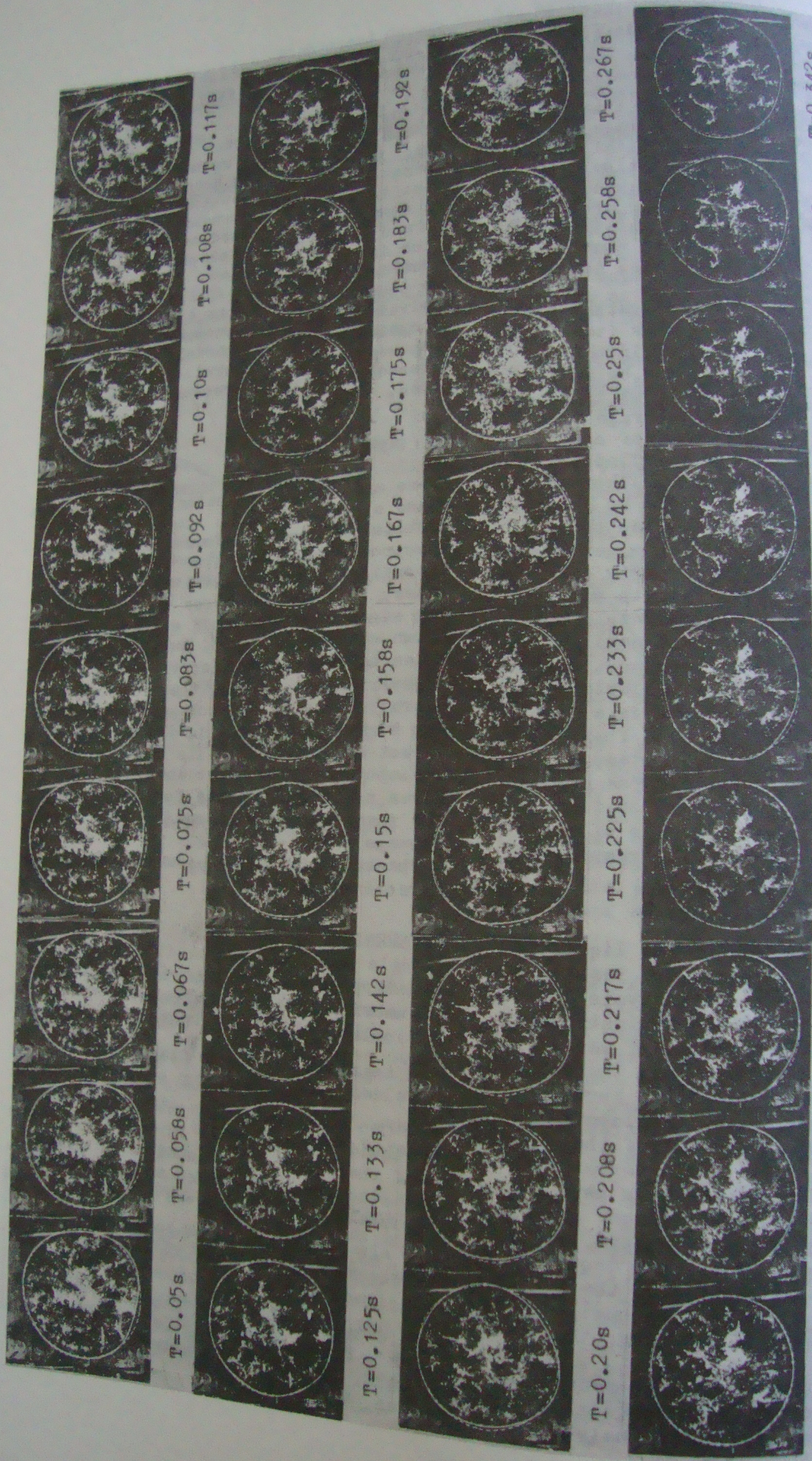
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Fig. 3

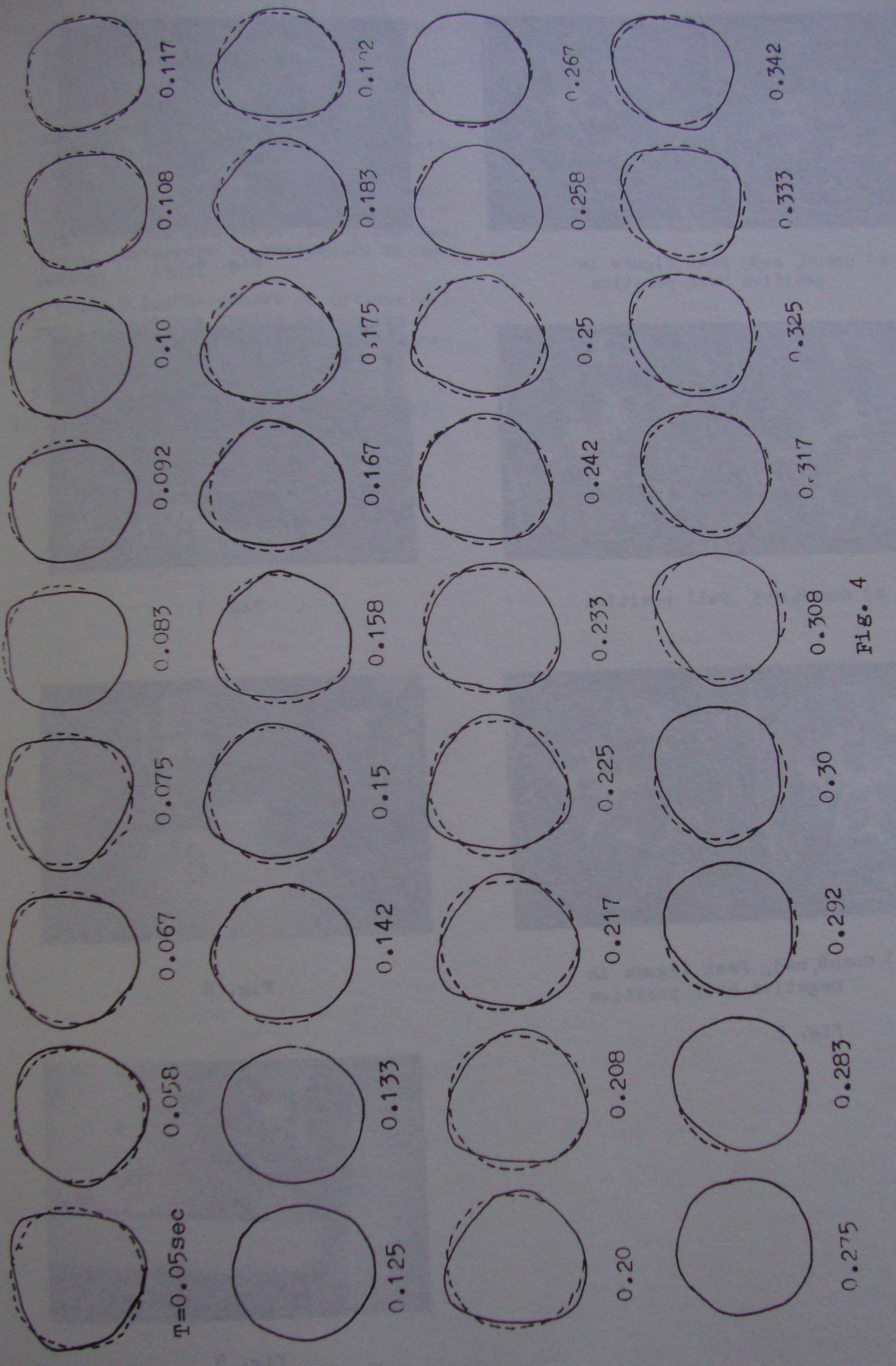
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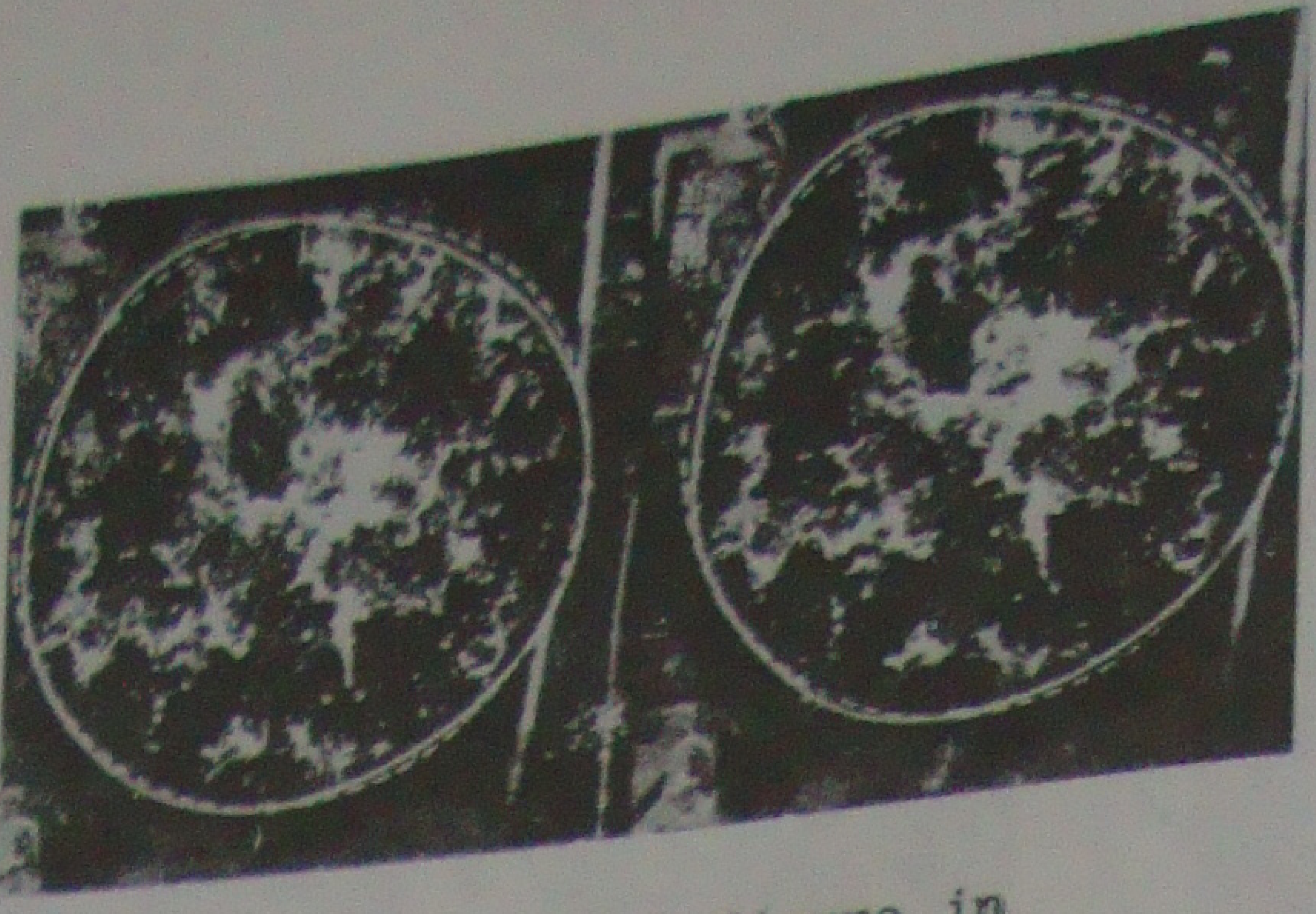
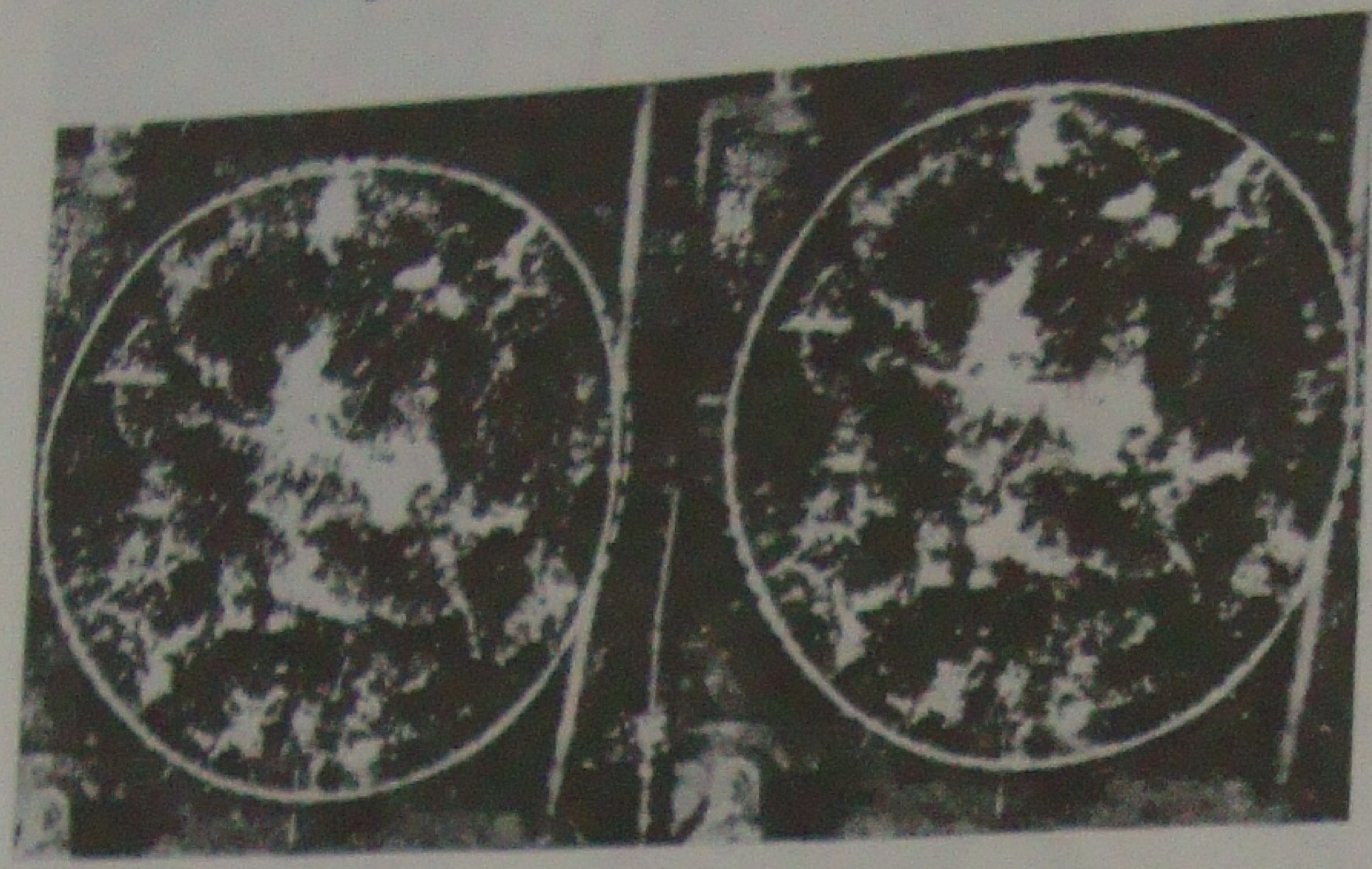
Fig. 4



a) Cosnθ, n=3. Peak figure in positive half position



b) Cosnθ, n=3. Null position

c) Cosnθ, n=3. Peak figure in negative half position

Fig. 5

Fig. 6

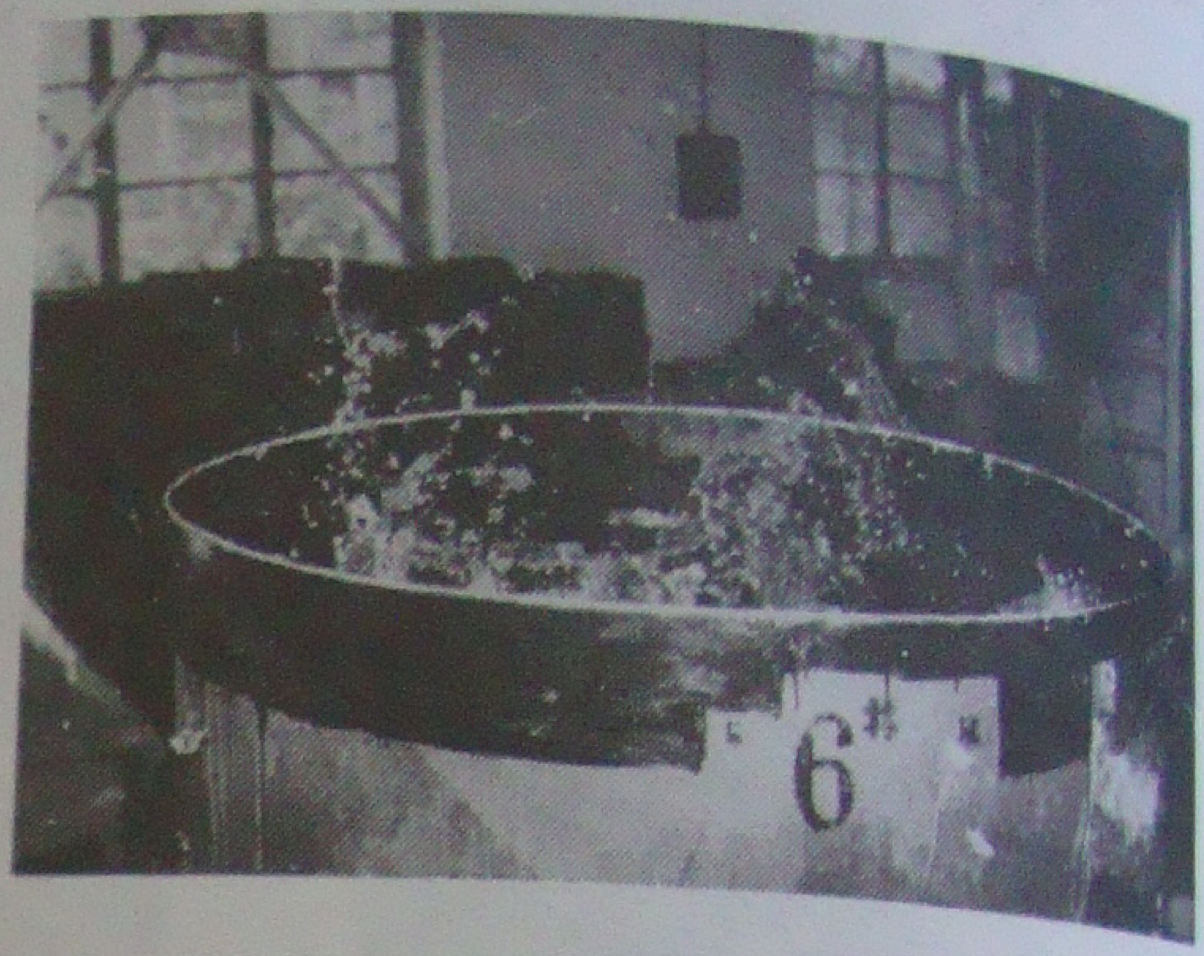


Fig. 7

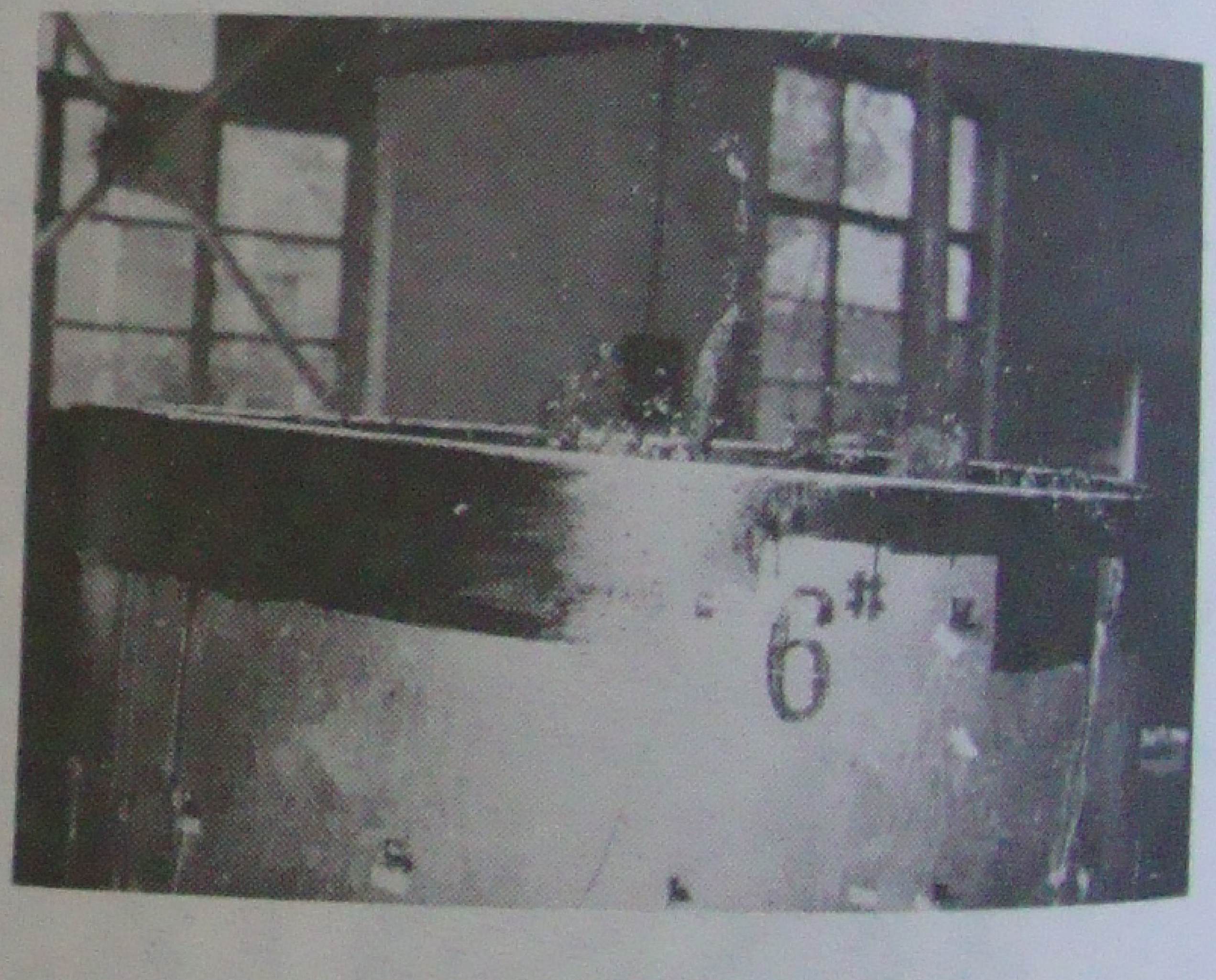


Fig. 8

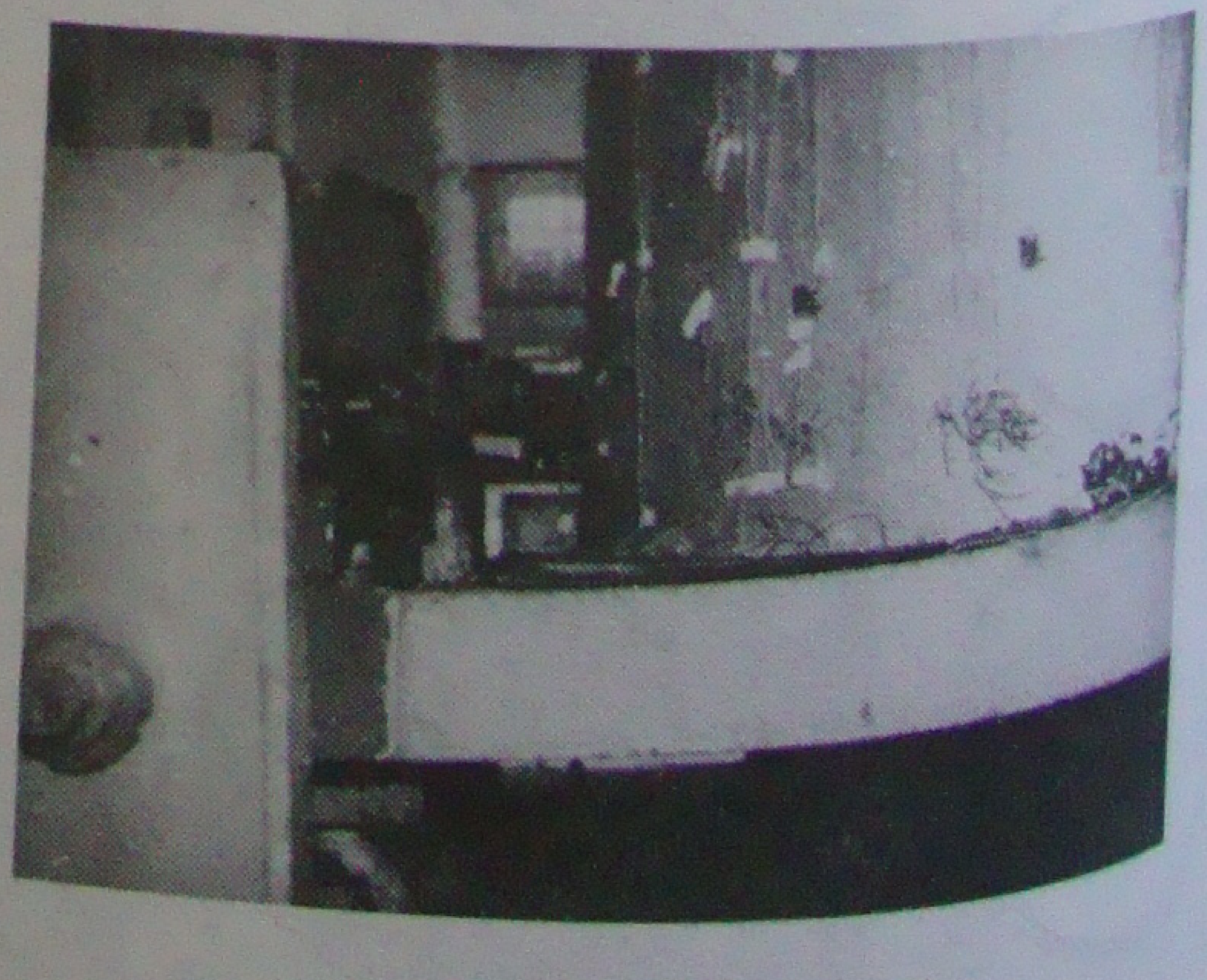


Fig. 9

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