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Restriction of Helmholtz Model

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The results of the experimental studies of physical mechanisms of energy dissipation in the oscillating system in which air cavity held by the forces of magnetic levitation is used as the elastic element, and magnetic fluid prepared on the basis of dispersing media with different viscosity level is used as the inertial element are considered in the article. Based on the obtained results the conclusion on the restriction of the applicability of Helmholtz equation, caused by boundary effects is made.

Keywords: Magnetic fluid, Magnetic levitation, Nanodisperse magnetic fluid, Inertial element.

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The magnetic fluid (MF) column which is in resting contact upon air cavity in the tube represents an oscillating system [1]. In this study, an air cavity is held by forces of magnetic levitation [2-4]. Levitation effects on the basis of magnetorheological suspensions are widely used in modern technologies [5-11]. Under the influence of the magnetic field the dispersed particles of magnetorheological fluid form stable chain-like clusters and give the system the effect of the controlled fluidity and form. On this basis, using a magnetic placed into the magnetorheological fluid, it is possible to carry out its directive migration [10]. Magnetic field and its gradient levitate objects, arrange their 3D-self-assembly on the substrate and affect the shape of the cluster being assembled [11]. The structure of the assembled 3D-objects can be further completed using hard mechanical substrates: either the walls of the package, or co-levitating components which are spatially superimposed by the magnetic field gradient.

The main objective of this research is to get information about the energy dissipation in the oscillating system, using MF as the inertial-viscous element prepared on the basis of dispersing media with different viscosity level. The block diagram of the experimental research facility is given and described in detail in the articles [2, 3]. A technique of capturing and transporting the air cavity using the controlled MF flow is also described in the mentioned articles.

The experimental results presented in this paper using all the MF samples under study include: the oscillograms of the damping oscillations of the system 'MF column – air cavity, held by the forces of magnetic levitation'; the tables with the parameters of the oscillating process (the oscillation frequency – ν, the damping coefficient – β, the height of the MF column – h, the tube diameter – d, calculated according to Helmholtz formula coefficients of damping – β_η and of 'inviscid damping' – ψ.

The coefficient of 'inviscid damping' – ψ is numerically equal to the difference between the experimentally determined damping coefficient β and calculated according to Helmholtz formula β_η:

$$\Psi = \beta - \beta_\eta,$$

The coefficient $\Psi = \beta - \beta_\eta$ characterizing the contribution to the coefficient of damping of 'inviscid' mechanisms (interphase heat exchange and acoustic radiation) and boundary effect on the height of the MF column h.

PHYSICAL CHARACTERISTICS OF THE SAMPLES UNDER STUDY

The physicochemical parameters characterizing the MFs samples under study are given in Table 1.

MF-2, MF-3 and MF-4 samples are synthesized in the scientific research laboratory of Applied ferrohydrodynamics of Ivanovo State Power Engineering University (Ivanovo, Russia). These samples are characterized by different dispersive medium and, what is important in our case, by different viscosity levels.

RESEARCH EXPERIMENT FACILITY AND MEASUREMENT TECHNIQUE

The block diagram of the research experiment facility designed to measure the oscillation parameters of the oscillating system, the inertial element of which is a magnetic fluid column located above the gas cavity is shown in Figure 1.

Table 1 – The physicochemical parameters MFs samples

MF sample	Density, ρ (kg/m³)	Carrier liquid	Saturation magnetization, Ms (kA/m)	MF viscosity, η (Pa·sec)
MF-2	1385	Polyethylsiloxane ПЭС-2	34	0,125
MF-3	1282	Mineral hydrocarbon oil	34	0,368
MF-4	1405	Polyethylsiloxane ПЭС-4	34	0,630

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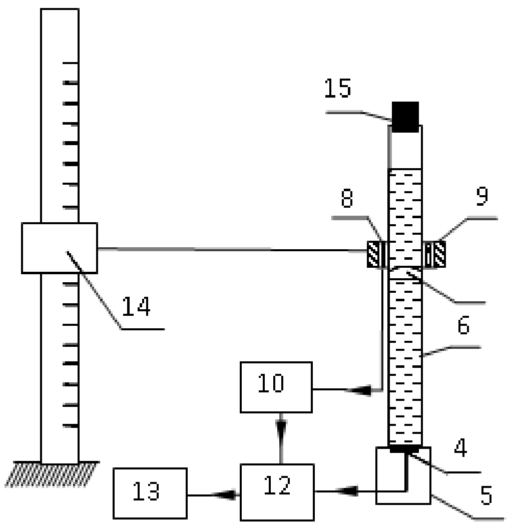

Fig. 1 – The block diagram of unit 2

To avoid repeating the description of Figure 1, in the description of the block diagram of this facility only the elements used for solving the set objectives will be mentioned. Piston 15 closing the upper end of the tube is used for excitation of oscillations of MF column which is in equilibrium condition. In the piston there is a through hole which allows introducing the piston into the tube without changing the pressure. Before pulling the piston out the hole is covered over by a finger. A signal received by the inductance coil 8 comes to the broadband amplifier 10, and then to the ADC 12 and the computer 13. ADC also receives a signal from the piezoelectric element 4. Receiving and initial processing of the signals from the piezoelectric and inductive sensors is provided by the program developed in NI LabView.

THE RESULTS OF THE EXPERIMENT

For conducting the experiment, the tube having a diameter of 1.3 cm is filled with MF to the height of 12.5 cm, and the height of levitating air cavity is ~ 1 cm. An oscillogram of free oscillations of the column of MF-2 is shown in Figure 2.

Table 2 shows the dependence of the frequency and the coefficient of oscillations damping of the column of MF-2 on the height of the column.

Here h is the height of MF column, ν is the frequency, β is the coefficient of oscillations damping, β_η is the damping coefficient according to Helmholtz model, Ψ is the difference $(\beta - \beta_\eta)$.

An oscillogram of free oscillations of the column of MF-3 is given in Figure 3.

The dependence of the frequency and the coefficient of oscillations damping on the height of the column is given in Table 3.

ANALYSIS OF THE OBTAINED RESULTS

The dependence of the coefficient of oscillation damping on the oscillation frequency in logarithmic coordinates / scale is shown in tables 5, 6, 7.

An oscillogram of free oscillations of the column of MF-4 is given in Figure 4.

The approximation of the dependence ln (β) [ln (ν)] of the experimental data for fluids under study and the experimental conditions represents a

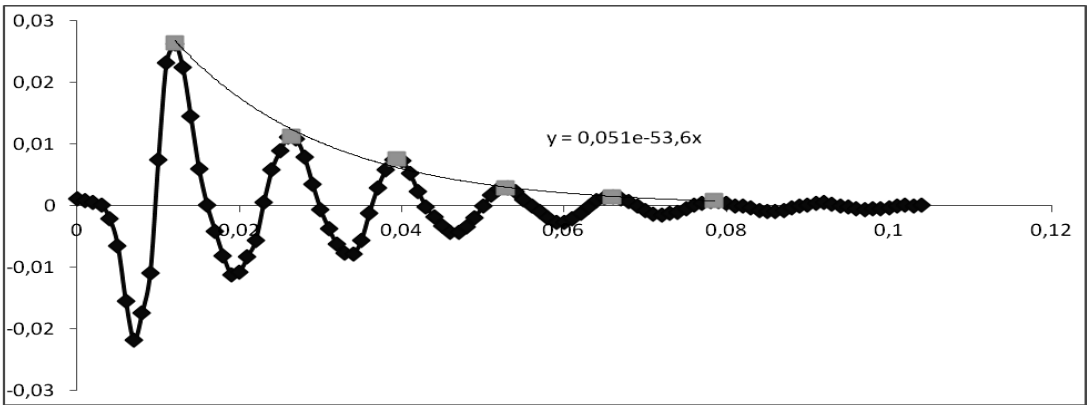

Fig. 2 – Oscillogram of free oscillations of the column of MF-2

Table 1 – The dependence of the frequency and the coefficient of oscillations damping of the column of MF-2 on the height of the column

№	h(cm)	ν (Hz)	β (s^{-1})	β_η (s^{-1})	$\Psi = \beta - \beta_\eta$ (s^{-1})
1	3,2	96,0	72,0	24,4	47,6
2	4,3	87,9	68,7	23,4	45,3
3	5,2	86,4	64,4	23,2	41,2
4	6,2	85,0	62,9	23,0	39,9
5	7,2	71,4	57,2	21,1	36,1
6	8,2	66,1	54,4	20,3	34,1
7	9,2	65,0	52,0	20,1	31,9
8	10,2	64,8	48,3	20,1	28,2

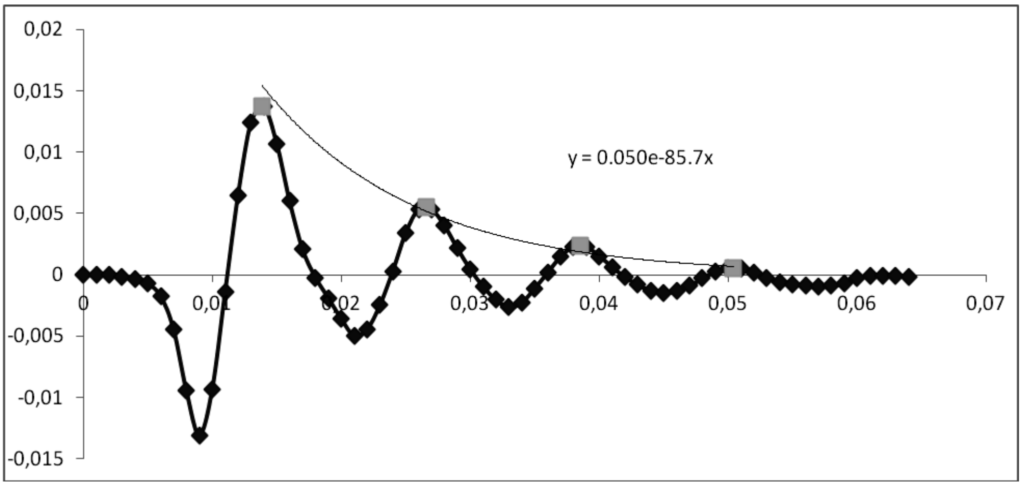

Fig. 3 – Oscillogram of free oscillations of the column of MF-3

Table 3 – The dependence of the frequency and the coefficient of oscillations damping on the height of the column of MF-3

№	h(cm)	ν (Hz)	β (s^{-1})	β_η (s^{-1})	$\Psi = \beta - \beta_\eta$ (s^{-1})
1	3,4	80,3	105,6	39,9	65,7
2	4,3	73,4	90,8	38,1	52,7
3	5,3	66,3	85,3	36,2	49,1
4	6,3	58,4	77,8	34,0	43,8
5	7,3	57,1	73,1	33,6	39,5
6	8,3	53,4	70,1	32,5	37,6
7	9,3	50,6	65,9	31,6	34,3
8	10,3	47,4	59,9	30,6	29,3

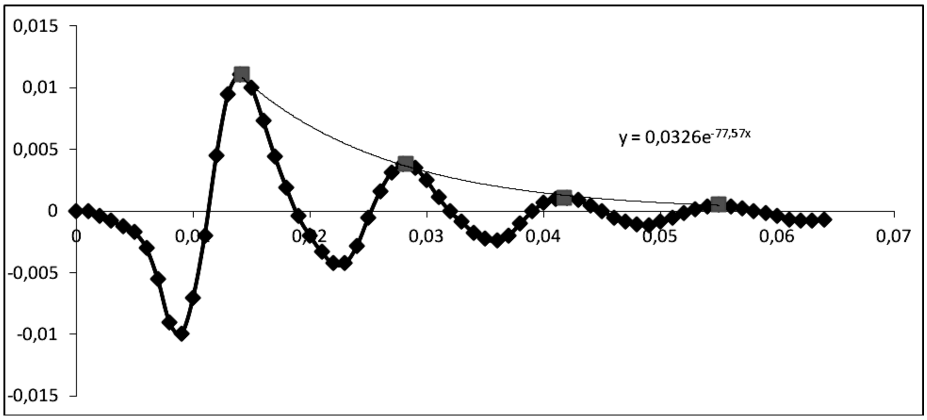

Fig. 4 – Oscillogram of free oscillations of the column of MF-4

Table 4 – The dependence of the frequency and the coefficient of oscillations damping on the height of the column of MF-4

№	h(cm)	ν (Hz)	β (s^{-1})	β_η (s^{-1})	$\Psi = \beta - \beta_\eta$ (s^{-1})
1	3,3	79,8	132,1	49,7	82,4
2	4,3	73,4	90,8	47,6	43,2
3	5,3	66,3	95,3	45,3	50,0
4	6,3	61,1	87,8	43,5	44,3
5	7,3	57,2	75,1	42,0	33,1
6	8,3	53,4	77,1	40,6	36,5
7	9,3	50,6	69,9	39,5	30,4
8	10,3	47,5	58	38,3	19,7

Table 5 – The dependence of the frequency coefficient of oscillation damping on the oscillation frequency in logarithmic coordinates / scale of MF-2

ln (ν)	4,56	4,48	4,46	4,44	4,27	4,19	4,17	4,17
ln (β)	4,28	4,23	4,17	4,14	4,05	4,00	3,95	3,88

Table 6 – The dependence of the frequency coefficient of oscillation damping on the oscillation frequency in logarithmic coordinates / scale of MF-3

ln (ν)	4,39	4,30	4,19	4,07	4,04	3,98	3,92	3,86
ln (β)	4,66	4,51	4,45	4,35	4,29	4,25	4,19	4,09

Table 7 – The dependence of the frequency coefficient of oscillation damping on the oscillation frequency in logarithmic coordinates / scale of MF-4

ln (ν)	4,38	4,30	4,19	4,11	4,05	3,98	3,92	3,86
ln (β)	4,88	4,51	4,56	4,48	4,32	4,35	4,25	4,06

straight line, which the tangent of the slope gives a value of the exponent of the frequency dependence of the damping coefficient ς [3]. *In* this case ς for samples of MF-2, MF-3 and MF-4 is 0.67, 0.75 and 0.76, respectively. It should be noted that in experiments with MF and kerosene as a basis, described in [3], $\varsigma = 0{,}64$. The mechanism of viscous flotation of the near-wall layers of the MF predicts the increase of the damping coefficient with the frequency in proportion $\beta(\nu) \sim \nu 0.5$. The fact is that two other mechanisms of energy dissipation noted above affect the numerical value of the exponent of this power function.

It is a distinctive feature that for all MFs when the height of the column of the fluid is ~ 9 cm, the value of $\psi = \psi_0 = 32 \pm 2$ s^{-1}. The magnitude ($\Psi - \Psi_0$) is damping related to the boundary effect. This implies that the applicability of Helmholtz formula is restricted due to the boundary effects, and the height of the column of fluid should exceed the tube diameter by more than 7 times. Thus, the energy losses associated with the interphase heat exchange and acoustic radiation remain constant within the order of magnitude in the experiments using one and the same experimental facility with the samples of MF which considerably differ from each other in viscosity.

The best agreement between theoretical ν_t and experimental ν_e values of oscillation frequency of MF column (Tables 2, 3, 4) is obtained taking into account the coefficient of ponderomotive elasticity.

CONCLUSIONS

It has been found that the coefficient of oscillations damping in the system far exceeds the value obtained on the basis of Helmholtz model.

The application of Helmholtz formula for assessing the contribution to the coefficient of oscillations damping of a viscous fluid in the tube is restricted by boundary effects.

For the model to be valid it is necessary to observe not only the condition of the ratio of the length of viscous wave and the diameter of the tube but also the condition under which the height of the column of fluid should exceed the tube diameter by more than 7 times.

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