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EXPERIMENTAL VERIFICATION OF VELOCITY MODULATION BY STRONG ELECTROMAGNETIC FIELD

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Summary: *Theoretical derivations and analyses of modulation of the liquid flow through the inverse magnetohydrodynamic phenomenon have been implemented by experimental data. Two different series of measurements were realized, both at low-pressures of flowing water: The presence of the phenomenon was tested in the simple plexiglass chamber with rectangular cross section, the fluctuations induced in water flow by inverse magnetohydrodynamic phenomenon should be detected in special excitation-measuring double-chamber. The results of measurements of the voltage generated by steady state flow of water through the chambers are presented in the form of graphs and table. The results of tests in double chamber are summarized and evaluated verbally.*

1. Introduction

In 1999 the new method for generation of modulated or pulsing jets was proposed based on magnetohydrodynamic phenomenon (Hlaváčová & Hlaváč, 1999). The basic theoretical analysis was presented and then implemented in 2001 (Hlaváčová & Mádr, 2001). The basic idea can be summarized as follows: The liquid containing charged particles when flowing across the strong magnetic field displays behavior similar to the Hall effect in semiconductors – induced voltage appears perpendicularly to the magnetic field lines and the flow direction. This "magnetohydrodynamic" effect is well described and also used in the case of highly conductive liquids (liquid metals, plasma) but it occurs in the less conductive liquids as well. On the other hand application of the strong electric field perpendicular to the magnetic induction should result in the flow rate changes. If the harmonic voltage is used together with constant magnetic field the resulting flow rate should be harmonic as well.

The mathematical description of the magnetohydrodynamic phenomenon enabled Hlaváčová & Mádr (2001) to express the longitudinal component of the liquid rate in the form of the Fourier series

$$u_P(y,t)=\frac{4}{\pi\rho}\sum_{k=1}^{\infty}\frac{(-1)^{k-1}}{2k-1}\cdot\cos\frac{(2k-1)\pi y}{2y_0}\cdot\left(\frac{\sigma E_0 B_0\cos(\omega t-\varphi_k)}{\sqrt{\omega^2+\lambda_k^2}}+\frac{1}{\lambda_k}\frac{\partial p}{\partial x}-\mathrm{e}^{-\lambda_k t}\left(\frac{\lambda_k\sigma E_0 B_0}{\omega^2+\lambda_k^2}+\frac{1}{\lambda_k}\frac{\partial p}{\partial x}\right)\right) \quad (1)$$

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Steady Hartmann problem analyzed by Hlaváčová & Hlaváč (1999) leads to the equation

$$u = \left(\frac{1}{\sigma B_0^{\,2}} \frac{\partial p}{\partial x} + \frac{E_z}{B_0} \right) \left(\frac{1}{\cosh H_a} - 1 \right) \tag{2}$$

This equation defines the flow profile in terms of pressure gradient $\partial p/\partial x$, magnetic induction B_0 and electric field intensity E_z. This equation, on the other hand, should make possible to calculate the pressure gradient from the measured transversal voltage on the fluid flowing with known velocity across the known magnetic field.

Verification of the theory has to be realized in several steps. The first one is measurement of the magnetohydrodynamic effect on the low-pressure liquids. The experimental channel simulating the "Hartmann" problem was designed and the set of experiments was realized aimed at determination of the magnetohydrodynamic effects in various liquids under several conditions. The conductivity, liquid velocity and magnetic field were changed and resulting electric voltage was measured. The results are discussed in this paper with regard to their application for liquid jet modulation.

2. Hartmann-like channel

The Hartmann problem describes a steady flow of the conductive liquid through a gap formed by two large perfectly insulating plates placed in a strong magnetic field with constant magnetic induction. Supposing that the width of the channel exceeds its thickness several times, the gap formed by unlimited plates, from the technical point of view, should be substituted by a long flat channel. The sidewalls of the channel are formed by perfectly conducting electrodes so that the induced voltage can be measured.

Two different chambers were used for the measurement. They were made of plastic plates with the thickness of 4, 6 and 10 mm. Their inner dimensions were 15x52x120 mm and 15x56x120 mm. Their endings were provided with the cylindrical inlets with the diameter of 9 mm enabling the connection of hosepipes for an input and an output of the liquid. There were two electrodes placed at the smaller sidewalls of the chambers. One of the chambers has got the electrodes at the inner side of the walls, so that there was not necessary to include the influence of another material into calculations. As far as the electrodes are hence in the direct contact with the measured liquid, the originally designed copper electrodes were replaced by titanium ones, in order to prevent rising of electrochemical potentials and transient effects. It came out, however, that neither this arrangement solved the problem. Therefore, the second chamber was provided with the electrodes on its outer walls and a voltage transformer was connected to them on account of the planned generation of the inverse magnetohydrodynamic phenomenon.

3. Experimental procedure

The measurements were realized in Ostrava and in the laboratory of the Department of the physical and physicochemical mineral processing methods of the Institute of Geotechnics in Košice. The magnetic field in Ostrava laboratory was generated by an electromagnet Phylatex (see Fig. 1.). The electromagnet consisted of two great coils with a variable gap between them. It was fed from the external source by streams up to 12 A, the change of the feeding voltage made it possible to preset several values of the magnetic field induction. This configuration provided a relatively homogenous (deviation not exceeding 1 per cent) magnetic field (with the induction ranging from 0.20 to 0.98 T) large enough to cover the whole volume of the measuring chamber. The gap between the cores of the electromagnet was set to be as small as possible, i.e. the measuring chamber was fixed by the cores and simultaneously they also fixed the measuring probe of the Gauss-meter used for measuring the magnetic field induction. This configuration remained stable during all the experiments.

a) b)

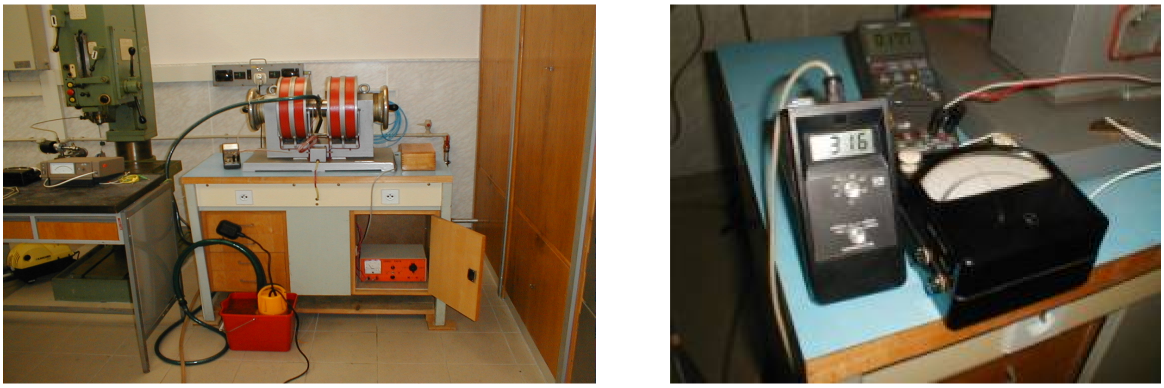

Fig.1. Measurement of the magnetohydrodynamic effects on the liquids on VŠB-TU Ostrava: (a) arrangement; (b) measurement

The starting point of the measurement was zero voltage, after switching on the movement of the liquid, however a voltage of about 20 till 40 mV appeared on the electrodes. This value usually varied throughout the measurement (most often gradually increased). It was also different in various experimental days.

The liquid was driven either by the sludge pump Royal Einhell SP760 (drained from the vessel) or by the pressure of the water main. Using the closed looping (sludge pump measurement), results may be rather distorted by the fact that the temperature of the liquid gradually grew up. The volume of the liquid in the looping was too small to be cooled down when running through the looping. The growth in temperature should be accompanied by a change in conductivity as well as viscosity. There was no direct influence of these changes observed in our measurement, however. When the water was taken from the water main and then driven away to the drainage, the whole system appeared to be more stable.

The flow rate of the sludge pump was unchangeable whilst the flow rate from the water main was controllable by the tap. The experiments were carried out with five different flow rates set by the tap (namely 0.03 $l.s^{-1}$, 0.10 $l.s^{-1}$, 0.15 $l.s^{-1}$, 0.24 $l.s^{-1}$ and 0.40 $l.s^{-1}$); the flow rate of the sludge pump was 0.42 $l.s^{-1}$. The velocity of the flow inside the chamber was calculated from the cross-section of the chamber and the measured flow rate; it varied from 0.04 $m.s^{-1}$ to 0.53 $m.s^{-1}$. A Gauss-meter Tesla was used for the determination and measurement of magnetic field induction. The laboratory digital multi-meter M3850 Voltcraft was used for measurement of the voltage induced in the chamber.

Several series of measurement were performed being focused on various parameters of the magnetohydrodynamic phenomenon. Water as well as sodium chloride water solution with the mass concentration of about 0.28 % driven by the sludge pump was investigated. Conductivities of the liquids measured by Behrotest LF86 were approximately 0,02 and 0.41 $S.m^{-1}$, respectively.

The solutions of blue vitriol and green vitriol were also measured; their mass concentrations being about 2.5 % and 5.2 % respectively. The estimated mass concentration was calculated from the measured conductivities of solutions that were 0.62 S.m^{-1} and 1.18 S.m^{-1}, respectively. Although the conductivity of the used liquid was rather high, there was nearly no change in the obtained data in comparison with the previous measurement. Nevertheless, the whole system was significantly less stable. Therefore, the vitriol measurements were taken only for the maximum magnetic field induction.

a) b)

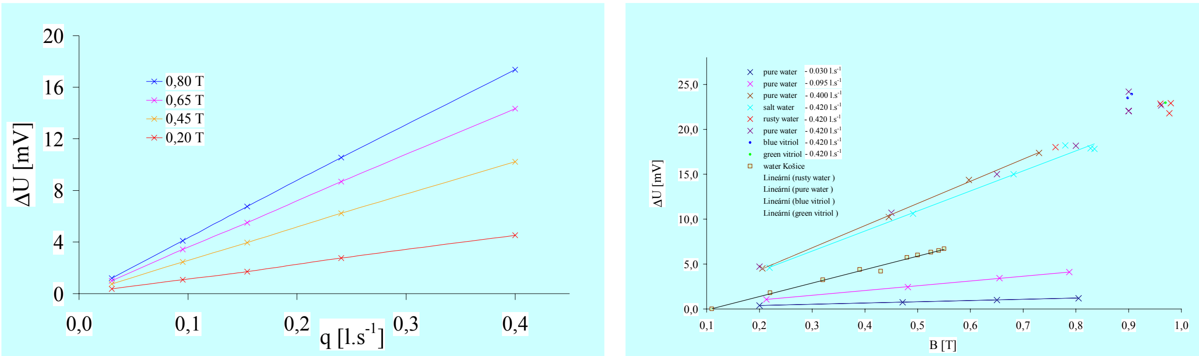

Fig.2 The growth of the induced voltage with the growing (a) flow q; (b) magnetic induction B

Another series of measurement was realized in the Institute of Geotechnics in Košice. The source of the magnetic field was an industrial electromagnet of Russian origin (see Fig. 2.). The experimental set up enabled to place the whole experimental double-chamber into a strong magnetic field with the induction ranging from 0.11 to 0.55 T. The magnetic field and therefore the whole measurement in Košice appeared to be more stable. Water was driven by local water main; the flow rate was 0.419 l.s^{-1}. The used water was rather dirty; the measured conductivity was 0.281 S.m^{-1}.

a) b)

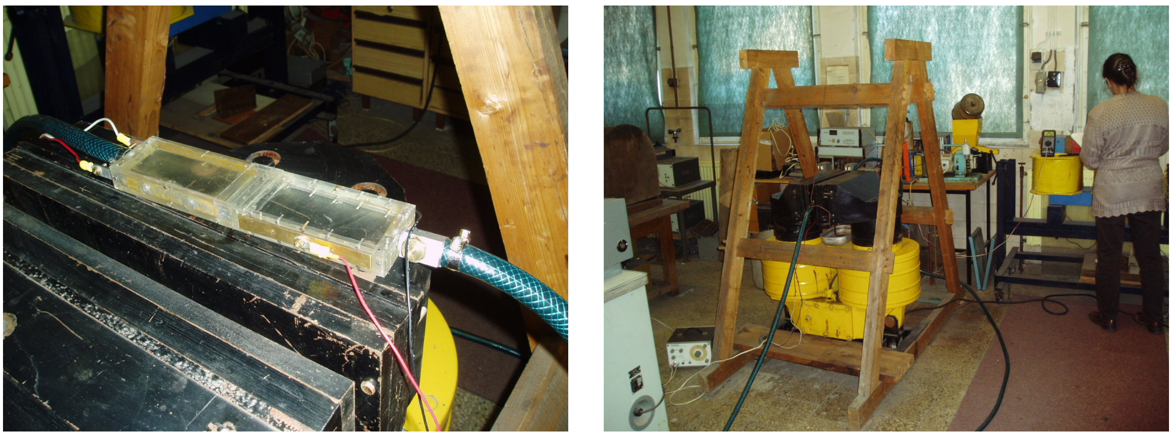

Fig.3 Measurement of the magnetohydrodynamic effects on the liquids in Košice:
(a) exciting-measuring double chamber; (b) measurement

The results of all verification measurements of the existence of the magnetohydrodynamic phenomenon are summarized in Tab. 1. The application of the measured data to the equation (2) made it possible to calculate the pressure gradient $\partial p/\partial x$. The calculated values of the Hartmann number H_a and the pressure gradient are also presented in Tab. 1. The results appear to be sufficiently consistent.

Tab.1. The results of pressure gradient ∂p/∂x measurement.

						$H_a = y_0 B_0 \sqrt{\frac{\sigma}{\eta}}$	$\left(\frac{u_0}{\frac{1}{\cosh H_a}-1} - \frac{\Delta U}{B_0}\right)\sigma B_0^2$
kapalina	konduktivita σ	průtok	mg. indukce B_0	průměrná změna napětí ΔU	rychlost kapaliny u_0	Hartmannovo číslo H_a	gradient tlaku $\frac{\partial p}{\partial x}$
	S/m	l/s	T	mV	m/s		Pa/m
voda z vodovodu	0,0204	**0,030**	0,81	1,20	0,0386	0,0273	**-1,4**
			0,65	1,00		0,0220	**-1,4**
			0,47	0,75		0,0160	**-1,4**
			0,20	0,37		0,0068	**-1,4**
	0,0204	**0,095**	0,79	4,10	0,1220	0,0267	**-4,3**
			0,66	3,43		0,0222	**-4,3**
			0,48	2,45		0,0163	**-4,3**
			0,21	1,07		0,0072	**-4,3**
	0,0201	**0,154**	0,76	6,75	0,1977	0,0258	**-7,0**
			0,64	5,50		0,0218	**-7,0**
			0,46	3,96		0,0156	**-7,0**
			0,21	1,71		0,0070	**-7,0**
	0,0203	**0,240**	0,77	10,55	0,3082	0,0260	**-11,0**
			0,63	8,68		0,0213	**-11,0**
			0,46	6,23		0,0155	**-11,0**
			0,20	2,75		0,0068	**-11,0**
	0,0202	**0,400**	0,21	4,53	0,5128	0,0069	**-18,2**
			0,45	10,23		0,0150	**-18,2**
			0,60	14,35		0,0201	**-18,2**
			0,73	17,36		0,0246	**-18,2**
	0,0209	**0,417**	0,96	22,64	0,5344	0,0330	**-19,0**
			0,90	24,20		0,0309	**-19,0**
			0,90	22,00		0,0309	**-19,0**
			0,90	22,05		0,0309	**-19,0**
voda Košice	0,2813	**0,419**	0,11	7,80	0,5372	0,0138	**-19,1**
			0,22	9,6		0,0277	**-19,1**
			0,32	11,05		0,0403	**-19,1**
			0,39	12,20		0,0491	**-19,1**
			0,43	12,00		0,0541	**-19,1**
			0,48	13,55		0,0604	**-19,1**
			0,5	13,80		0,0629	**-19,1**
			0,525	14,1		0,0660	**-19,1**
			0,54	14,30		0,0679	**-19,1**
			0,55	14,50		0,0692	**-19,1**
slaná voda	0,411	**0,417**	0,22	4,59	0,5344	0,0333	**-19,0**
			0,49	10,61		0,0747	**-19,0**
			0,68	15,01		0,1037	**-19,1**
			0,78	18,20		0,1185	**-19,1**
			0,83	17,86		0,1258	**-19,1**
			0,84	17,80		0,1269	**-19,1**
rezavá voda	0,0235	**0,417**	0,76	18,00	0,5344	0,0277	**-19,0**
	0,0235		0,96	22,83		0,0349	**-19,0**
	0,0215		0,98	22,91		0,0341	**-19,0**
	0,0219		0,98	21,78		0,0343	**-19,0**
skalice modrá	0,6393	**0,417**	0,91	23,91	0,5344	0,0318	**-19,0**
			0,90	23,48		0,0315	**-19,0**
skalice zelená	1,177	**0,417**	0,97	22,95	0,5344	0,2496	**-19,5**

The second part of our experiments was aimed at enforcing the flow modulation by electric and magnetic fields. We used both chambers. The one with outer electrodes was the first in the flow direction. The alternating voltage from the frequency generator was transformed to a higher level and connected to the electrodes producing so an alternating electric field inside the chamber. The magnetic field was constant. The second chamber with inner electrodes was used as a measuring device for proving the modulation. Both chambers were connected through a very short tube. Then they were partly taken to pieces and reassembled so that a special excitation-measuring double-chamber was created. Although a measurable response was observed, the experimental set up has to be improved so that the experimental results could be quantified more exactly. The modulating voltage was about 100 V (measured at the electrodes), the frequency was ranging from 100 Hz up to 20 kHz. The common water from water main was used for these experiments.

4. Conclusions

The most important results can be summarized:

- The effects of the magnetohydrodynamic phenomenon are measurable even for liquids with low conductivities.
- The amount of the magnetohydrodynamic effect is directly proportional to the flow rate of the liquid (i.e. to the flow velocity).
- The amount of the magnetohydrodynamic effect is directly proportional to the magnetic induction applied perpendicularly to the liquid flow velocity.
- The measurement of the voltage induced by the magnetohydrodynamic phenomenon can be used for the evaluation of the pressure gradient along the liquid flow inside the measuring chamber.

5. Acknowledgements

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6. References

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