Computer measurement system for determination of static and dynamic characteristics of electromagnetic actuator with ferrofluid

Aneliya Terzova[1], Valentin Mateev[1] and Iliana Marinova[1]
[1] Technical University of Sofia, Department of Electrical Apparatus,
e-mail: aterzova@tu-sofia.bg, vmateev@tu-sofia.bg, iliana@tu-sofia.bg

Abstract: In this work we propose a method and measurement system for determination of static and dynamic characteristics of electromagnetic actuator with ferrofluid. The measurement method uses a setup with force sensor for determination of static electromagnetic characteristics of the actuator. Measurement process for determination of dynamic characteristics is automated using LabVIEW environment. Operational characteristics of electromagnetic actuator are obtained with ferrofluid in the working gap and without ferrofluid. Measured results are presented and analyzed.

Key-Words: - Computer measurement system, electromagnetic actuator, ferrofluid, static characteristic, dynamic characteristic, LabVIEW.

1. Introduction

The electromagnetic actuators are widely used in industry [1-3]. They are part of various electromechanical devices, controlling mechanisms or systems. An electromagnetic actuator with solenoid type electromagnet are used in electromagnetic valve actuation systems, fuel injection actuation, exhaust gas recirculation systems, refrigerators, washing machines and etc.[1-3]. Such actuator is a simple linear actuator that uses a principle of position-dependent reluctance to convert electrical energy into mechanical energy of the plunger movement which is then used to apply force.

Electromagnetic actuators with ferrofluid material in working gap have many advantages. These actuators characterize with better operational characteristics compared with those with air gaps, reduced energy consumption, compact in size and etc.

Nowadays the ferrofluid liquids could be found in many industrial and laboratory applications. Ferrofluid is a stable colloidal suspension of ferrite nanoparticles in liquid and surfactant. The surfactant molecules covered the solid particles and the fluid behaves as a homogeneous system even in the presence of external forces or magnetic fields. The nanoparticles are usually iron oxides or different compounds of ferrofluid oxides. The sizes of nanoparticles can vary from 1 nm to 100 nm and determine the properties of ferrofluid. The ferrofluids are specified by key parameters such as magnetization saturation and fluid viscosity [3, 4].

Static and dynamic characteristics of the electromagnetic actuators are extremely important for their proper and energy safe operation. Accurate measurement of the electromagnetic force of actuators is an important issue.

In this paper, an electromagnetic actuator with a plunger moving in ferrofluidic liquid is considered. We developed a method and measurement system for accurate determination of the static and dynamic characteristics of electromagnetic actuator with ferrofluid. Electromagnetic force of solenoid type actuator is measured by laboratory test setup. Dynamic characteristics are determined using LabVIEW - graphical programming environment. Operational electromagnetic characteristics are determined for plunger moving in ferrofluid in the working gap and compared with characteristics for plunger moving in air gap.

2. Measurement system

Computer measurement laboratory test system is developed for determination of static electromagnetic and dynamic characteristics of electromagnetic actuator with solenoid type electromagnet. In Fig. 1 is shown block diagram with main elements of the developed measurement system.

Computer measurement system is composed of test bench/fixture, measurement sensors and transducers, controllable power supply, data acquisition measurement module and computer unit with LabVIEW software, shown in Fig.2.

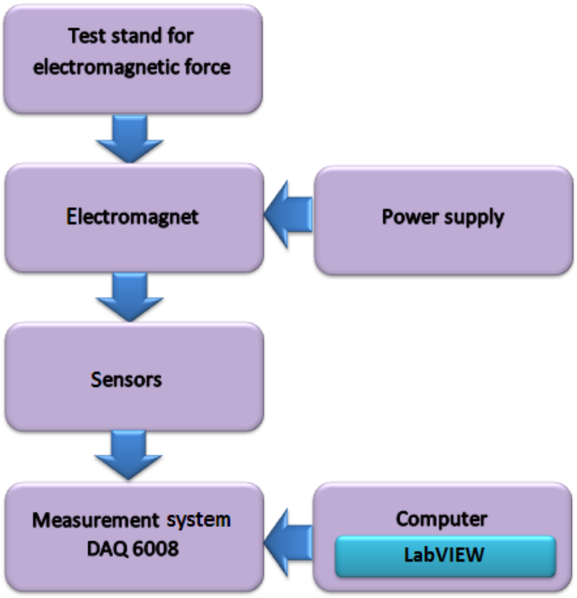


Fig. 1 Block diagram of the experimental computer measurement system.

Constructed test bench/fixture is shown in Fig.3.

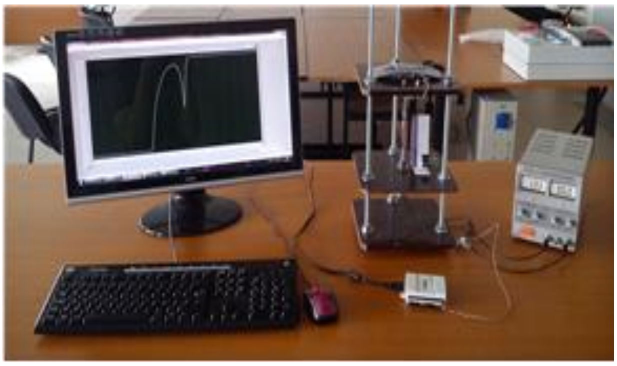


Fig. 2 Computer measurement system.

The main elements of the test bench are force/strain gauge, holder for fixing armature, injector for ferrofluid.

A force/strain gauge for measuring the strength/pressure at range ± 30N with accuracy of 0,001 N is used.

The computer measurement system is supplied by DC electric power supply HY3005D [4].

Fig. 3 Test bench
1 - digital display; 2 - weight sensors 3 –spring; 4 – solenoid type electromagnet.

Automation of the measurement process is done by using the program LabVIEW. LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments. LabVIEW programs are called virtual instruments. Each virtual instrument has three components: a block diagram, a front panel and a connector panel. The main advantage of LabVIEW environments is the extensive support for measuring instruments [5].

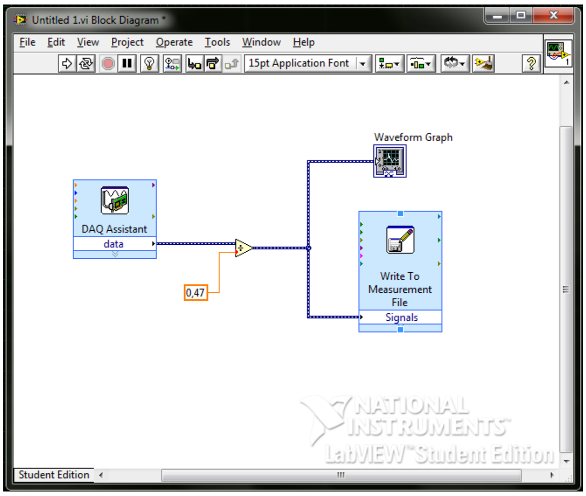


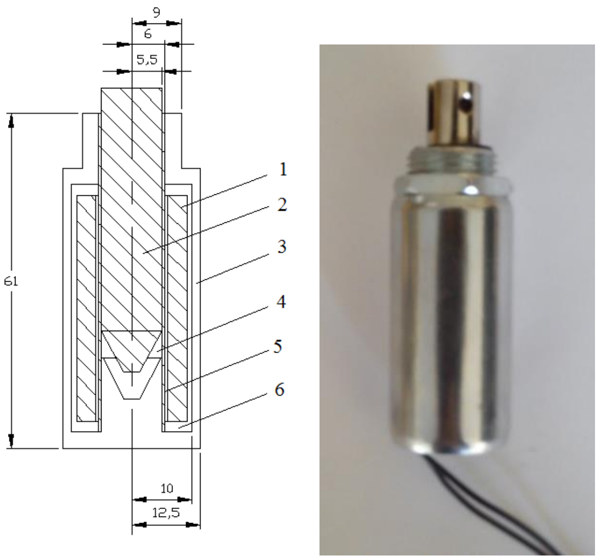
Fig. 4 LabVIEW virtual instrument for measuring the dynamic characteristics of the electromagnetic actuator.

In Fig. 4 is shown the developed virtual instrument for measuring the dynamic characteristics of the electromagnet in LabVIEW environment. It is visualizing and storing the data during experimental process.

The investigated electromagnetic actuator is attached to test bench/fixture. It is connected to the power supply and force measuring sensors. The current is measured by a shunt resistor R=0,5Ω, which connected in series in the circuit. DAQ device measures the voltage drop on the shunt resistor and convert it to the LabVIEW program for process, storage and visualization of results. A device DAQ USB 6009 with a measurement accuracy of 1.47 mV and LabVIEW 8.6 are used [5,6].

3. Investigation

The electromagnetic actuator with solenoid type electromagnet is shown in Fig.5. It consists of stationary ferromagnetic core, a movable ferromagnetic plunger with cone end and air gap. The electromagnet coil has 750 turns of copper wire with diameter 0.5 mm. Average current density at coil region is $J = 7\times10^6$ A/m^2.



a) Cross-section b) Outlook

Fig. 5 Electromagnetic actuator
1 – coil; 2 - ferromagnetic plunger;
3 - ferromagnetic core; 4 – magnetic gap;
5 - brass tube; 6 - insulation of the coil.

Ferrofluid, used in experiment, has a relative magnetic permeability μ = 1,21; saturation magnetization B_s = 44 mT (± 10%), viscosity < 6 mPa.s; density 1,1 g/cm^3; boiling point 230 °C (± 10 %) [7].

4. Results

Static electromagnetic characteristics

The static electromagnetic characteristics are determined using computer measurement system for electromagnetic force.

At first, the static electromagnetic characteristics of the actuator are measured when the plunger moves in working air gap. Second, the working gap is filled with ferrofluid and the static characteristics are measured when the plunger moves in ferrofluid (Fig. 6).

The value of the electromagnetic force obtained at air gap δ=1 mm is F=21.88 N, at air gap δ=18 mm the force is F=0.79 N. In catalogue the maximum electromagnetic force is at air gap δ=1 mm and its value is F=22 N. The minimum of electromagnetic force is at air gap δ=18 mm and its value is F=0.78 N.

The maximum value of electromagnetic force obtained with working gap filled with ferrofluid is F= 18.6298 N, electromagnetic force obtained at working gap δ=18mm is F= 1.127 N.

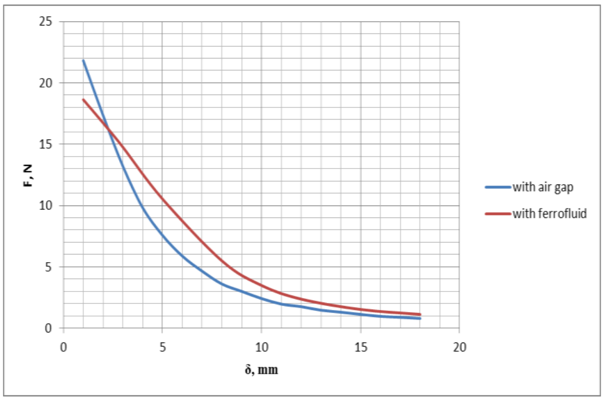


Fig. 6 Static electromagnetic characteristics

Comparison of the two static electromagnetic characteristics shows that at air gaps 1 mm and 2 mm, the force obtained when the plunger moves in ferrofluid is less than when the plunger moves in air gap.

When working gaps are larger than 2 mm, electromagnetic force is with higher values when the ferrofluid fills the working gap.

Dynamic characteristics

Dynamic characteristics of the electromagnetic actuator are measured by the developed computer measurement system. These characteristics are determined in switching - transient mode for electromagnet armature. For this purpose the holder device for fixing actuator armature in the stationary position has been replaced by spring mechanism.

In Fig. 7 are given the dynamic characteristics of the current changing with time in switching mode of the electromagnet. Rated current of the solenoid type electromagnet is 1.66 A.

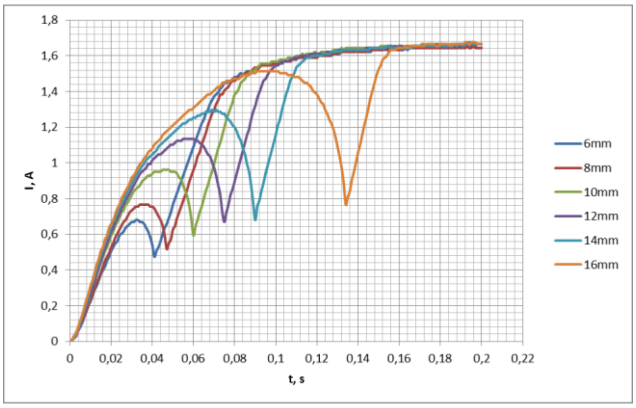


Fig. 7 Dynamic characteristics of the actuator at various gaps at supply current of I =1.66A

The dynamic characteristics of the electromagnet is determined also at current 25% higher than rated one (I = 2.075 A). The results obtained for transient process are shown in Fig.8.

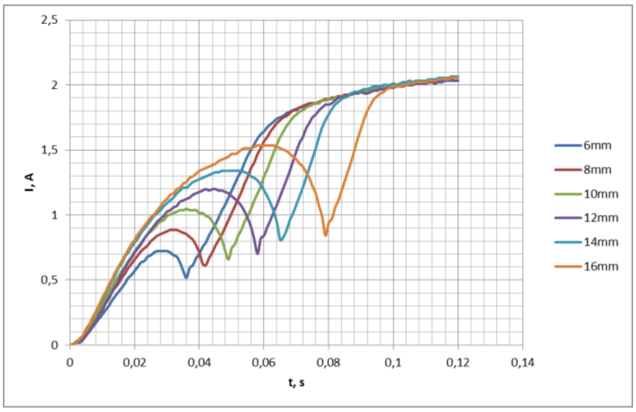


Fig. 8 Actuator dynamic characteristics of current changing with time for various working gaps at supply current I = 2.075A.

The response time of the electromagnet for air gap δ = 6 mm with current I = 1.66A is t = 0.041s and with current I = 2.075A, t = 0.036s. For air gap δ = 16 mm and I=1.66 A the response time is t = 0.134 s and for I = 2.075A, t=0.079 s.

It is seen that for larger air gaps with increasing current by 25%, the response time of the electromagnet decreases almost by half.

5. Conclusion

The paper describes computer measurement system for investigation of electromagnetic actuators. The system is applied for determination of static and dynamic characteristics of electromagnetic actuator with solenoid type electromagnet and plunger moving in ferrofluid.

The developed and implemented computer measurement system is characterized with simplicity, with easy operation and with high accuracy according to force measurements (0.001 N), distance measurements (0.1 mm) and electric voltage measurement (1.47 mV).

Measurement process could be further improved by applying more sophisticated virtual instrument and accurate sensors.

Developed computer measurement system is suitable for investigation of electromagnetic actuators as well as for scientific and educational research.

6. Acknowledgements

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6. References

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Authors:

Aneliya Terzova. MSc in Electrical Engineering (2012). Assistant Professor and Ph.D. student at Department of Electrical Apparatus, Faculty of Electrical Engineering, Technical University of Sofia, Bulgaria. Research interests: computational electro-magnetism, finite element method, computer-aided design, optimization methods, computer aided testing.

Valentin Mateev. MSc in Electrical Engineering (2004). Assistant Professor at Department of Electrical Apparatus, Technical University of Sofia, Bulgaria. Research interests: computational electromagnetism, electro-magnetic fields, computer-aided design.

Iliana Marinova. D.Sc. (2010), PhD in Electrical Engineering (1989). Professor at Department of Electrical Apparatus, Faculty of Electrical Engineering, Technical University of Sofia, Bulgaria. Research interests: inverse problems in electromagnetics and biomagnetics, electromagnetic fields, numerical methods, finite element method, boundary integral equation method, computer aided design, optimization, image processing, and visualization.

Компютърна измервателна система за определяне на статични и динамични характеристики на електромагнит за задвижване с ферофлуид

Анелия Терзова [1], Валентин Матеев [1] и Илиана Маринова[1]

Технически университет - София, катедра “Електрически апарати”,

email: aterzova@tu-sofia.bg, vmateev@tu-sofia.bg, iliana@tu-sofia.bg

Резюме: - В този доклад са представени метод и компютърна измервателна система за определяне на статичните и динамични характеристики на соленоиден електромагнит с ферофлуид. Методът използва тензометричен сензор за определяне на статичните електромагнитни характеристики на електромагнита. Направен е стенд за изпитване, чрез който е определена електромагнитната сила на соленоидния електромагнит. Експерименталното определяне на динамичните характеристики е автоматизирано с помощта на програмата LabVIEW. Електромагнитните характеристики на соленоидния електромагнит са получени с и без използването на ферофлуид в работната междина. Получените резултати са представени и анализирани.

Ключови думи: - Компютърна измервателна система, електромагнити, ферофлуид, статични характеристики , динамични характеристики, LabVIEW.