The Control of Electromagnetic Filter by Using FPGA Based PI Type Fuzzy Controller

Ilker Ali OZKAN[a], Ismail SARITAS[b], Saadetdin HERDEM[b]
[a]Department of Computer Engineering, [b]Department of Electrical and Electronics Engineering
Selcuk University
AlaaddinKeykubad Campus, Selculku, Konya
TURKEY
ilkerozkan@selcuk.edu.tr, isaritas@selcuk.edu.tr, sherdem@selcuk.edu.tr

Abstract: - There are a lot of factors like particle size, concentration and flow rate which affect the performance of the Electromagnetic Filter (EMF) used for cleaning of industrial filters. In this study, an FPGA based PI type fuzzy control system is designed and realized considering the all parameters affecting the EMF performance. Realized controller has been integrated in EMF kit and used for cleaning of industrial liquids. Results of the performed experiments and previous literature results are given with their differences in EMF structures.

Key-Words: Electromagnetic filter, PI type fuzzy controller, FPGA based controller, Fuzzy controller

1 Introduction

The high quality of industrial liquids and gases is first determined by the cleanness of content after they have used in technological processes, and secondly, invariability of physical and chemical characteristics during their usage in the course of production [1]. After performing many experiments, it is reported that industrial liquids and gases mostly contains iron compound contaminants [2, 3] Because the contaminants have granular structure and basically shows magnetic properties, it is advantageous to use electromagnetic methods. Filters utilizing the particles magnetic properties and using different types and structures of filter matrices and performing cleaning process are called EMF [1]. Cleaning with EMF can be performed either in the beginning phase, during or at the end of the technologic process [4].

The difference of EMFs from classic filters is that their filter elements consist of ferromagnetic materials. A basic EMF principal schema is given in Fig. 1 [5]. The industrial liquid which is supposed to be filtered by the EMF is first pass through the input pipe (4) and then filtering process is performed. The liquid consequently returned to the system through the output pipe (5). To create magnetic field around the filter matrix (3) elements external system (1) consists of magnets and electromagnets. EMF body (2) is non-magnetic stainless material.

Filter matrix elements can easily be magnetized by an applied external homogeneous magnetic field density of approximately B=0.05 to 1.5 T and create high gradient multi-field around themselves. The magnetic field density of the locale becomes much greater than the applied external magnetic field density. The regions of the created fields are called "active region" or "holding region" [4, 6].

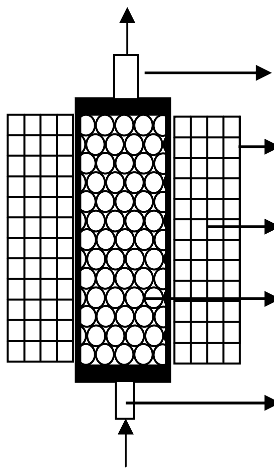

Fig. 1. EMF principle schema

The performance of the magnetic filters decrease as they operate, the performance may degrade to nothing for long duration of filter operation. The situation changes depending on many parameters and these parameters can be defined as technological parameters. Parameters may be determined by filter length, the size and type of the filter elements, flow rate of the liquid, applied magnetic flux density etc. The control systems design which considers all the parameters changes are required to hold the performance of the filter high [1]. A performance of the EMF (ψ) is determined by using the equation (1).

$$\psi = 1 - \frac{OPC}{IPC} \qquad (1)$$

In literature, input particle concentration (IPC) and flow rate (FR) of cleaned liquid are reported to affect the EMF performance [7]. In the studies to control the EMF, there are reports about fuzzy controllers adjusting the PWM reference voltage which determines the magnetic flux of the EMF depending on IPC and FR changes [5, 7, 8]. In this study, the output particle concentration (OPC) is also given and the effect of OPC on the EMF performance are examined. Studies in the literature, it is reported that fuzzy controller regulates the EMF performance successfully for the cases of changing IPC and FR. Additionally, EMF controller design which considers EMF performance is reported but there is no reported experimental study to clean the industrial liquids by using mentioned design [9].

In this study, a PI type fuzzy controller which considers all the factors affecting the EMF performance has been designed and an FPGA on the controller kit has been programmed accordingly. An experiment has been performed to clean the industrial liquids with the developed controller on EMF kit and results have been reported.

2 EMF Experiment Kit

In this study, EMF kit realized by the project "Adaptive Control of Electromagnetic Filters Used in Cleaning of Industrial Liquids by Using Artificial Intelligence and Kit Design (109E037)" which is supported by "The Scientific and Technological Research Projects Support Program" of The Scientific and Technological Research Council of Turkey (TUBITAK) [10]. This EMF kit used for cleaning industrial liquids houses waste depot, power unit, EMF coil and matrices, particle sensors and control units. The EMF kit's units which are used in this study and control system's working principles are given in Figure 2.

The physical structure seen in the figure can be summarized as the passing the liquid which is supposed to be cleaned to exit after cleaned by the EMF. Signals gathered from IPC sensor (S1) and OPC sensor (S2) are passed to sensor circuits which then can be applied to instrumentation amplifiers. Analog data gathered from the sensor circuits is sent to FPGA through a parallel output ADC interface card. The control of the magnetic flux is done by the output of the control system running on FPGA. Analog PWM reference voltage which is an output of the controller programmed on FPGA is passed to PWM by using a DAC card. Voltage applied to EMF coil is controlled by the PWM which is controlled by the reference voltage. By changing the coil voltage, magnetic flux is controlled [10].

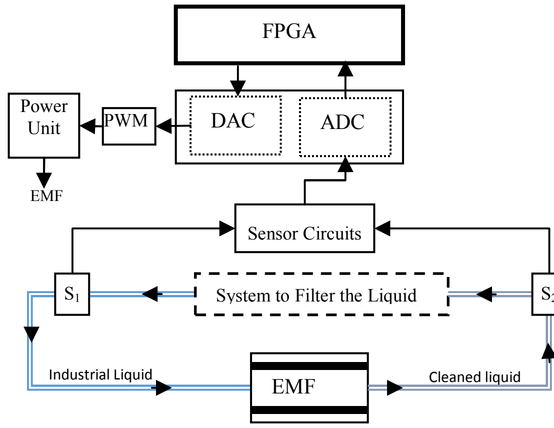

Fig. 2. Structure of Magnetic Filter Control System.

3 PI Type Fuzzy Controller

A fuzzy controller consists of fuzzifier, extraction mechanism and defuzzifier phases. Control input values gathered from the system are converted into symbolic values which are linguistic expressions in fuzzification phase. Inference mechanism produces linguistic expressions of control progresses as expected from an expert on subject according to state of input variables by using rules and concepts defined in the rules base. At the output, fuzzy numbers specified by linguistic variables and membership function are obtained. Crisp control values are acquired from fuzzy numbers belonging to output values produced by inference mechanism in defuzzification phase [7, 8]. A PI type fuzzy controller (PI Type FC) structure designed to apply the EMF is given in the Figure 3.

As seen in the Figure 3 EMF performance error and error change are the input variables of the fuzzy controller. Error and error change expressions are given in equation (1) and (2) respectively.

$$e(k) = P_{ref}(k) - P(k) \qquad (1)$$

$$\Delta e(k) = e(k) - e(k-1) \qquad (2)$$

Here k is sampling time, P_{ref} is reference performance value, P is EMF's performance. The output of the controller is given as the equation (3).

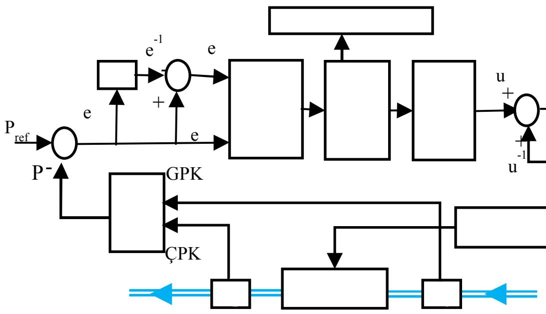

Fig. 3. Blok Diagram of Control System.

(3)

Here Δu(k) is the output of the PI type FC and shows the change in control value.

Membership functions used in fuzzification of input and output variables are given in the Figure 4. Used membership function are NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big).

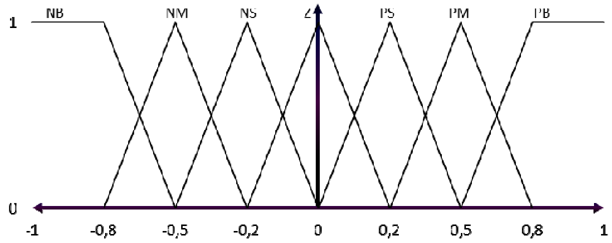

Fig. 4. Membership functions for *e*, , Δ*u*.

Membership function values are defined in the range of [-1,1] and scaling coefficients are used for input and output values. Suitable selection of scaling coefficients values are made based on proficient opinion of the field experts of EMF control and trial and error methods.

Fuzzy rule base used for type-PI fuzzy controller is given in Table 1.

Table 1. Fuzzy rule base for Δu

\ *e*	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NS	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	K	PS	PM	PB
PS	NM	NS	K	PS	PS	PM	PB
PM	NS	K	PS	PM	PM	PM	PB
PB	K	PS	PS	PM	PB	PB	PB

In this study, we have chosen MAX-MIN inference method and weighted average defuzzification method because of its requirement of less calculation power and being a more FPGA friendly method considering the "empty areas".

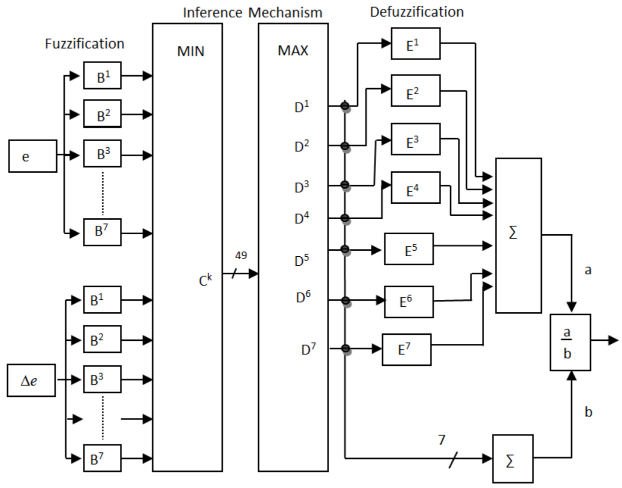

Fig. 5. General diagram of PI type FC.

Blok diagram of the all elements of the PI type FC system realized on an FPGA is given in Figure 5. Realized controller software is adapted to Cyclone II FPGA. According to synthesis results 20109 elements of the 68416 logic elements are used. For the processes required for the EMF control occupies the 29% of the used FPGA. Besides all collected data is transferred and saved to a computer via an RS-232 port during the experiment.

4 Control Experiment

An experiment has been performed by using designed PI type FC on EMF kit. Magnetic balls having 14mm radius have been used for the experiment. Industrial liquid used in the experiments has been prepared by adding 4-10x10^{-4} mm size iron powder to 200lt liquid depot. Experiments have been completed around 14 minutes.

The incoming values of IPC (S1), OPC (S2) and FR of industrial liquid to FPGA are transferred and saved to computer by using an RS-232 interface during the experiments. The current apply to EMF coil is determined by the FPGA based fuzzy controller by evaluating the values incoming from IPC and OPC sensors.

Experiment is realized when the EMF performance is not stable, in other words it is performed in the phase when the holding regions

ISBN: 978-960-474-336-0

cannot hold particles completely. P_{ref} value is defined as 95% during the experiment.

Change of IPC and OPC versus time during the experiment is given in Figure 6.

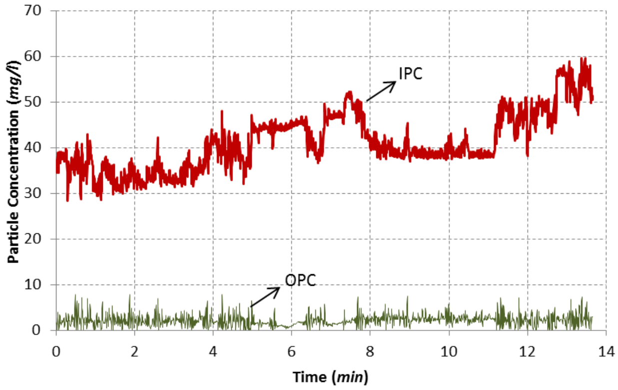

Fig. 6. IPC and OPC

The change in flow rate of industrial liquid is given in Figure 7.

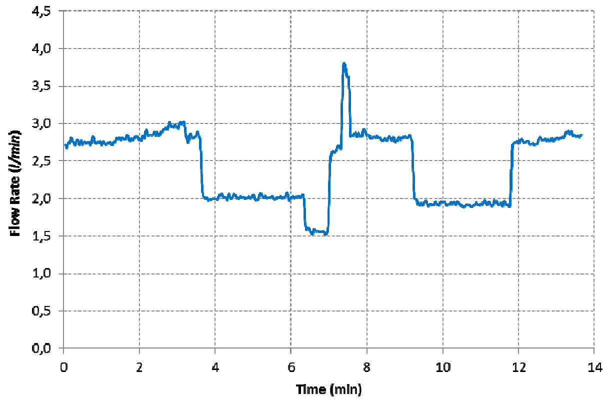

Fig. 7. Flow rate

Change in PWM reference voltage by using PI FC is given in Figure 8.

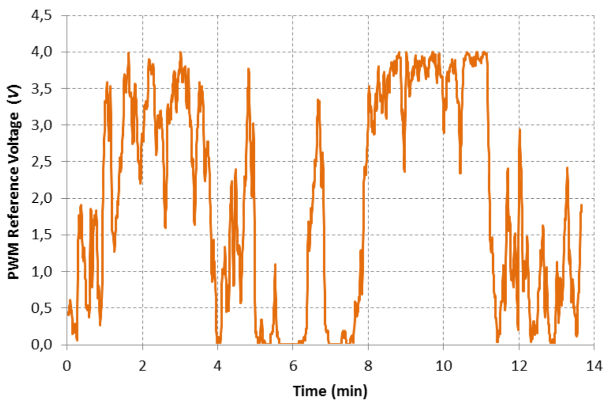

Fig. 8. PWM reference voltage

4 Results and Suggestions

Change in EMF performance along with the change in PWM reference voltage in the experiment using FPGA based PI type fuzzy controller versus time is given in the Figure 9.

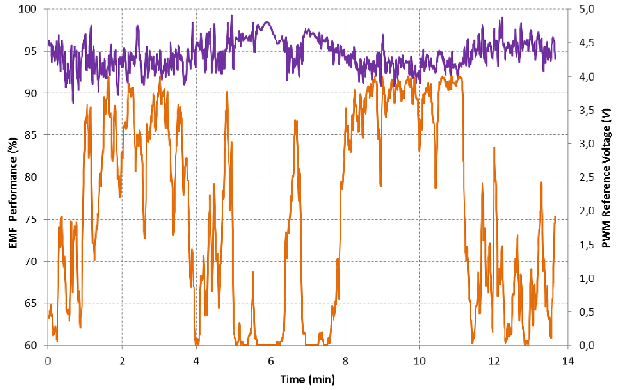

Fig. 9. PWM reference voltage and EMF performance with PI type FC.

When the EMF control experiment results are examined while the IPC and FR allowed to be variable, it is seen that applied current to filter coil is changed by FPGA based FC, consequently resulting a change in the magnetic flux.

If the Fig. 9 is investigated, it can be seen that in the regions EMF performance drops below 95% the applied current to filter coil is changed to force the increase in magnetic flux in the holding regions resulting a decreasing effect on OPC.

Moreover, because different from the literature studies, directly EMF performance value is accepted as the base value, PWM reference voltage does not change during the changes of FR as in the minutes 7 and 9.

It is known that factors affecting the EMF performance are not limited by IPC and FR, many technological factors can change the performance. Developed controller can produce response changes in all factors.

The investigated EMF kit controlled by the FPGA based FC can be developed further as an adaptive system changing itself according to different EMF parameters by utilizing the calculation power and parallel processing ability of FPGA.

Acknowledgements

This study is supported by Selcuk University Scientific Research Project Coordinate (BAP) and TUBITAK (Project 109E037).

References:

[1] T. Abbasov, Electromagnetic Filtration Process, *SeckinPress*, 2002 (in Turkish).

[2] J.H.P. Watson, Magnetic filtration, *J. Appl. Phys.*, 44(9), 1973, pp. 4209-4213.

[3] T. Abbasov, Magnetic filtration with magnetized granular beds: Basic principles and filter performance, *China Particuology*, 5, 2007, pp. 71–83.

[4] S. Herdem, T. Abbasov and M. Koksal, Modelling of Buildup Process of Particles in Pores of High Gradient Magnetic Filters by Using Fokker-Planck Equation, *J. Phys. D: Appl. Phys.*, 32(24), 1999, pp. 3146-3150.

[5] I. Sarıtas, I.A. Ozkan, S. Herdem, , The effects of fuzzy control of magnetic flux on magnetic filter performance and energy consumption, *Expert Systems with Applications*, Vol.37(12), 2010, pp. 7542-7551.

[6] P. Alizade, T. Abbasov, A. Nayie, AkışkanOrtamlarınElektromanyetikFiltrelerleTemizlenmesi, *Çev-Kor*, 7(25), 1997, pp. 17-18 (in Turkish).

[7] I. Saritas, ElektromanyetikFiltreTasarımıveYapayZekaYöntemleriyleAdaptifKontrolü,*Selcuk University Graduate School of Natural Sciences PhD Thesis*, 2008 (In Turkish).

[8] I.A. Ozkan, I. Saritas, S. Herdem, The control of magnetic filters by FPGA based fuzzy controller, *Energy Education Science and Technology Part A*, 29(2), 2012, pp. 1093-1102.

[9] I.A. Ozkanve S. Herdem, FPGA TabanlıKendiniAyarlayabilenBulanıkKontrolör ileManyetikFiltreninKontrolü, *OtomatikKontrolUlusalToplantısı TOK*, 2012 (in Turkish).

[10] S. Herdem, I. Sarıtaş, I.A. Ozkan, Endüstriyelsıvılarıntemizlenmesindekullanılanelektromanyetikfiltrelerinyapayzekayöntemleriyleadaptifkontrolüve kit tasarımı, *TUBITAK Project 109E037*, 2011 (in Turkish).