The Actuators Control by Probabilistic Mathematical Modelling

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Abstract. The paper presents a new real time control method in actuators continuous flux and their implementation using complex automations, aimed at determining the behaviour, functional parameters and performances. The mathematical model is presented for the real-time control problem of continuous flow actuators and there are indicated two probabilistic modalities which have been approached: a probabilistic evaluation and a linear prediction based procedure. The experimental results are in good agreement with the theoretically predicted results for mathematical modelling of the correlation between actuators. Finally, we obtain real-time control of actuators without the entry signals to be generated by the trial actuator by means of direct measurement. Theoretic and experimental results have shown that the behaviour errors of the actuators that have been tested through the proposed method are less than 1% while the testing duration is over 30 times less.

Key-Words: actuator control, real time control,complex automations, mathematic modelling, PLCs, probabilistic evaluation, linear prediction

1. Introduction.

The new tendencies in complex automations are using PLC in decentralized and distributed structures, conferring a lot of capacities and facilities to both equipment, installation, engineering plant producers and users. Hence we can envision, design and build pyramidal structures with PLCs and PCs for automatic control of complex processes, for monitoring and management of process parameters, as well as constructing redundancy structures which endow the systems with maximal safety during functioning and, first of all, high reliability [1,2,3]. These structures allow the interconnection of several automation systems for controlling, monitoring and centralized dispatching of processes within complex mechanisms.

The decentralized and distributed structure with PLCs systems must be understood as an intelligent interface between the process and the central control system within the pyramidal structures of controlling, monitoring and dispatching processes. The same structure could be perceived as an intelligent system that, during the control of some unique processes, equipments, engineering lines, is distributed on a large working area. In both cases the human factor is only supervising the processes' progress. The philosophy of decentralized and distributed structures is based upon the creation of some intelligent islands wherein the execution elements connected through the specific communication network of the PLCs are concentrated [1, 4, 5]. The main advantage of using systems in decentralized and distributed structures is that they may lead to controlling, monitoring and supervising several processes which are meant to create a unique final process. Thus a lot of interconnected processes, that are all part of the final process, are created.

The paper presented offers a new actuator control solution for continuous flux trials, based on the concept of open architecture systems.

For real time control of the actuators in order to determining the characteristics, functional parameters and performance several technical solutions are known which consist of measuring directly from the transducers mounted onto the actuator the input signals (accelerations, currents, power, torque, etc.). To this end, the tried actuator is connected to a charge, usually passive, integrated into the control system and the actuator's control signals are measured. The disadvantage is mainly that, in order to determine the characteristics, the functional parameters and the actuator performances in continuous flux testing, it is necessary to move the measurement transducers and the command elements from the tested actuator to another actuator, which leads to longer periods needed for the operation, less reliable measurements done with human intervention, the possibility of bad couplings between the measurement transducers and the actuator which can lead to measurement errors, etc.

2. The Control Method.

The control method allows real-time control for determining characteristics, functional parameters and performances of progressive actuators without the entry signals to be generated by the tested actuator which leads to a reduction in trial duration, higher measurement precision and performing complex trial regimes. In conformance with the method presented herein, in order to control actuators in real time a high performance measurement of the characteristics for functional parameters of a reference servo-actuator is performed. Its role is that of reference point for measurements and represents the charge of the trial actuator, coupled with the reference actuator by means of a coupling transducer and connected to a control system with open architecture, which together with a process computer PC-SERVER, with high speed and high computation power, generate the mathematical model of the servo-actuator in off-line mode and the mathematical model of the tested actuator in on-line mode, allowing a correlation between them by means of mathematical modelling and teach-in functions in off-line mode of the servo-actuator. It also generates complex trial regimes of the tested actuator, like characterization on starting signal type Dirac, right signal, movement laws with predefined functions as regards speed/acceleration: trapezoidal, sinusoidal, etc. Finally, according to the presented method, we obtain real-time control of actuators without the entry signals to be generated by the trial actuator by means of direct measurement.

A number of 6 phases has been identified for the method, with reference to fig.1. A first phase (A) which consists of choosing a SVA servo actuator with high performance, as reference for measurements, and which becomes the charge for the ATs testing actuator. **In the next phase (B),** a mathematical model is generated off-line of the SVA servo actuator, as reference for measurements, and which will represent the charge of the tested actuator, coupled through a coupling transducer by an actuator of the same class with the tested actuator, using a control system with an open CADA architecture and a PCS PC-server process system with high speed and large calculation capability. The generation of the signals necessary to obtain the motion laws, for the mathematical modelling without coupling to the test actuator, but coupled with an actuator from the same class as the test actuator is done by the TIN (teach-in) instruction module. **In phase (C**) previous to the measuring procedure in continuous flow, the ATs tested actuator is coupled with the SVA servo actuator through a MC coupling module. **In phase (D)** we generate the complex trials systems of the ATs tested actuator, motion laws with predefined functions for speed and/or accelerations of trapezoid, sinusoidal type, etc. **In the following phase (E)** we generate on-line the mathematical model of the ATs tested actuator performed by the mathematical modelling module of the (MMA) tested actuator through modelling with the same modelling method considered to be the best in the (B) off line phase, using the SCAD control system with open architecture and the PC-server process server system. **In phase (F)** we achieve, through mathematical modelling, a correlation between the SVA servo actuator, which matters as reference, and the ATs actuator.

Phase (B), which allows the determination of the mathematical model of the servo-actuator (SVA) is the most complex and has the longest necessary timespan, but has the advantage of being done off-line and only in the conception phase of the software. It contains a number of 9 sequences undertaking complex mathematical calculus through mathematical modelling, a part of which will be presented in this paper. So, **in sequence (B1)** we determine the feature of one of the “p” parameters of the SVA reference actuator coupled with an actuator from the same class as the test actuator, through direct measurements (transducers mounted on the reference actuator), generating one of the “q” motion law. The number of “p” parameters is minimum 1 and it can be high enough for a good characterization of the mathematical model of the SVA servo actuator. Examples for the actuators’ parameters: power, energy consumed from CSV power controller, dephasing, distortions introduced to the CSV power controller, actuator capacity, actuator’s couple, etc. The “q” number of the motion laws is minimum 1 and it can be chosen as high as possible for a good characterization of the mathematical model of the SVA servo actuator. Examples of entry signals to generate complex motions systems: Dirac signal, step signal, trapezoid signal, sinusoid signal and other signals with predefined motion laws. **In sequence (B2)** sequence (B1) is repeated to determine the characteristic of the same "p" parameter in the same "q" motion law of the actuator from the same class with the test actuator coupled with the SVA reference actuator. **In the following sequence (B3),** sequences (B1) and (B2) are repeated to determine all the "p" parameters at the same "q" motion law, for both the SVA reference actuator and the actuator from the same class as the test actuator. In sequence (B4) sequences (B1)-(B3) are repeated to determine the same "p" parameter by applying another law of the "q" motion laws for both the SVA reference actuator and the actuator from the same class with the test actuator. **The sequence (B4)** continues until it gets to the maximum number of "q" motion laws for the "p" parameters (pxq characteristics). **In the following sequence (B5**) the mathematical modelling is done for one of the "p" at the application of another law of the "q" motion laws through one of the "d" methods, for example through determining the transfer function between the "p" characteristic at a "q" motion law of the SVA servo actuator, according to the (B1) sequence and the characteristic of the same "p" parameter at the same "q" motion law of the actuator from the same class as the test actuator, according to the (B2) sequence. Other examples of modelling methods [6, 7, 8]: backward or forward linear prediction, Matlab, Simulink mathematical modelling, statistic prediction methods, fuzzy method modelling, etc. **In sequence (B6)**, measurements are repeated according to sequences (B1)-(B5) for the modelling, through "d" methods of all "p" parameters at the application of "q" motion laws, of the SVA servo actuator, with the charge of an actuator from the same class as the tested one. In the end of the (B) phase we obtain the modelling of all the "p" parameters , at the application of "q" motion laws and "d" modelling methods (pxqxd characteristics of the modelling of the SVA servo actuator). **In sequence (B7)** the measurements are repeated according to sequences (B1)-(B6) for the modelling, through "d" methods of all "p" parameters at the application of "q" motion laws, of the SVA servo actuator, with the charge of another actuator, of the "t" actuators from the same class as the tested actuator. The "t" number of the actuators from the same class as the test actuator is minimum 1 and it can be high enough for a good characterization of the mathematical model of the SVA servo actuator. Finally we obtain (pxqxdxt characteristics of the SVA servo actuator modelling **In sequence (B8)** we choose the mathematical model which best reflects the difference between the actuator with very high performance and the actuator with performance at the very limits of the accessibility field, determined through direct measurement. **In sequence (B9)** the mathematical model thus determined is introduced in the module of mathematical model of the (MMSV) servo actuator, as a reference function.

Examples of the correlation between the SVA servo actuator and the ATs actuator through mathematical modelling are: backward or forward linear prediction, Matlab, Simulink mathematical modelling, statistic prediction methods, fuzzy method modelling, the determination of the transfer function respectively of the correlation function between the SVA actuator and the ATs actuator, etc. This function is processed in the calculation module of the (FCO) mathematical model of correlations, between ***v*** signals from the (SVA) servo actuator module with off-line functioning, which matters as reference, and ***v*** on-line functioning signals of the ATs testing actuator, obtained through on-line generation by the (CSV) power controller in a complex trial system of the instruction functions. Thus, in the end we obtain the real time control of the ATs testing actuator functioning, without generating entry signals from the ATs tested actuator through direct measurement.

Chapter 4 presents two possibilities for mathematical modelling with the aim of determining the correlation between the reference actuator and the test actuator.

3. The System Architecture

The system architecture consists of a high performance servo-actuator module, which mechanically engages the test actuator through a couple, in conformance to certain complex trial regimes and sends to the open architecture control system ***n*** measurement signals.

Based on these signals, which are processes by a powerful high speed PC – Server process computer, the mathematical model of the servo-actuator is generated off-line and that of the tested actuator is generated on-line The correlation functions between the two are also generated. The resulting information allows statistical characterization, diagnosis and determination of characteristics, functional parameters and the tested actuator's performances. This way the method leads to real time control for actuators, without the input signals being generated by the tested actuator through direct measurement.

A real time open architecture control system has been developed for determining the characteristics, parameters and performance of high performance servo-actuators, which represents the charge of the tested actuator and serves as a reference for measurements. The two actuators are coupled rigidly through a mechanical system, on which there is a torque transducer.

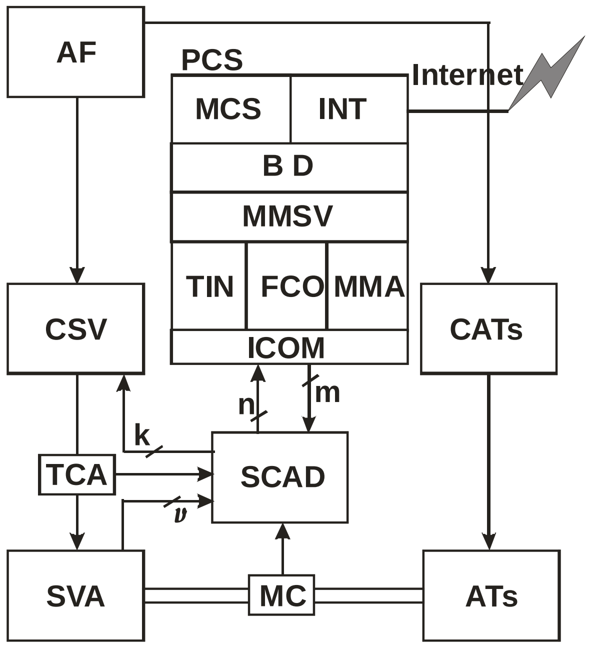

Fig 1 Method for real time control of the actuators

The open architecture control system together with a PC-SERVER process computer generate the mathematical model of the servo-actuator in off-line and the mathematical model of the tested actuator in on-line In the off-line state by using the training functions (teach-in), the mathematical model of reference is determined on groups of test actuators by generating complex trial regimes. Regimes have been chosen which can define the actuators' transfer function, such as characterization on a entry signals such as Dirac type, stair type, movements laws with predefined functions for speeds/accelerations: trapezoidal, sinusoidal, etc. the system enters a state where it is necessary to introduce new actuator groups, which can be tested in order to "learn" the control system for "working" with the new actuator group which has to be tried. On-line the actuator tested through signals generated by open architecture system is subjected to the same complex trial regimes in order to determine the mathematical model. The resulting data is processed by the process computer which generates the correlation function between the actuator group's reference mathematical model and that of the tested actuator.

Using this and other prediction methods a data base is generated containing the reference performances of the tested actuators' groups, which in comparison with the data processed on-line will allow monitoring of the actuator's performances. Moreover, the stored information ensures the diagnosis of tested actuators and sending it through the internet allows remote monitoring and dispatch. Finally, the gain is obtaining real time control of the actuators without the input signals being generated by the tested actuator through direct measurements. Studies have lead to a control system whose architecture is presented in fig.1.

The high performance **servo-actuator module** (SVA) set on the test actuator (ATs) through a coupling module (MC), conformant to complex trial regimes generated by the servo-actuator force controller (CSV) and sends ***v*** measurement signals to the open architecture control system (SCAD) in order to determine the correlation functions and the mathematical modelling of the tested actuator. Conversion of energy from the force charge module (AF) to the servo-actuator module (SVA), depending on the control signals generated by the open architecture system (SCAD), is done by a servo-actuator force controller (CSV). In parallel, a test actuator controller (CATs) ensures conversion of energy from the force charge module (AF) to the tested actuator (ATs) after a normal regime without parameters variation.

The two SVA and ATs actuators are mechanically coupled through a coupling module (MC) which sends to the open architecture control system (SCAD) the measurement signal of the couple between the two actuators. Because the SCAD system is open architecture the ***v*** measurement signals from transducers mounted directly on the reference servo-actuator module (SVA), which represent phase or line tensions and currents, real, active, reactive powers, distortions, rotation velocity, etc. can be supplemented with measurement signal from transducers of vibrations, motor axle velocity, temperatures, electro-magnetic flux, etc. aimed at improving system performance in determining static and dynamic parameters. In order to determine the actuator behaviour in the charge regime, the SCAD receives from the coupling module (MC) the measured values for the couple resulting from the rigid connection of the axis of the two motors. Important information is also obtained from the supply control transducers (TCA) in order to characterize the force supply of the servo-actuator module (SVA). All these signals are acquired by the SCDA, digitally processed and sent as ***n*** measurement signals to the PC-Server module (PCS). In order to generate the soft implemented movement laws for the reference actuator in off-line state, such as Dirac impulse, stair signal, movement laws with pre-set functions for speeds/accelerations: trapezoidal, sinusoidal, etc., the PC-Server module (PCS) sends ***m*** control signals to the SCDA and by processing these ***k*** regime control signals are obtained at the servo-actuator force controller (CSV). A communication interface (ICOM) receives ***n*** measurement signals from the open architecture system (SCAD) and sends ***m*** processed signals from the PC-Server (PCS).

The open architecture structure of the real time control system is ensured by a PC-Server (PCS) module which receives ***n*** measurement signals from the open architecture control system (SCAD) and is processed it by the following software modules:

The training module (TIN, teach-in) in off-line, through which the necessary signals are generated for mathematical modelling of the servo-actuator without coupling the servo-actuator to the test actuator

The mathematical modelling module of the servo-actuator (MMSV) which generates the mathematical model of the servo-actuator based on the ***n*** measurement signals received from the open architecture control system (SCAD) during teach-in and which represent input data in the mathematical modelling module of the tested actuator (MMA) and the module calculating the correlation function (FCO)

The mathematical modelling module of the tested actuator (MMA) which achieves, on-line in real time during the tests, the mathematical modelling of the tested actuator (ATs) through modifications which appear in the ***v*** measured signals from the servo-actuator module (SVA) as a result of coupling the test actuator (ATs) and by processing the data resulting from the correlation function.

The correlation function calculus module realizes the correlation function between the ***v*** signals from the servo-actuator module (SVA) functioning off-line and the ***v*** signals functioning on-line

The data base module (BD) which memorizes through indexing the result data of each tested actuator

The statistical characterization module (MCS) which processes data from the data base (BD) and generates information for statistical characterization, diagnosis and determination of characteristics, functional parameters and performance of the tested actuator

The internet communication module (INT) which allows data conversion in order for it to be sent over the internet

4. The mathematical modeling of the correlation between actuators

Within this section we shall mathematically model the real-time control problem of continuous flow actuators and we shall indicate two probabilistic modalities which have been approached.

Input-output system based problem abstractization. Let S be a dynamic system built of a reference actuator and an installation that allows us couple the test actuator with the reference actuator. Within an interactive presentation the test actuators will represent the new system inputs, while the inferences these inputs exert upon the running characteristics of the reference actuator will represent the system outputs. Within this system, let us consider that the test actuators are submitted to some pre-established technical verifications. Namely, let us presume that at the beginning of the experiment an observation list (the same for all actuators) has been made, containing the technical parameters that need to be checked.

According to the framework created, following each technical examination a list of values representing the technical characteristics of the test actuator, denoted by l is obtained, as well as a list of values representing the way the test actuator influences the functioning parameters of the reference actuator, denoted by r. In order to maximize the abstractization degree, we shall identify the test actuators according to the corresponding technical characteristics lists. In this way, a class of actuators (referring to all actuators that verify the data in the list) corresponds to a list of technical characteristics. We emphasize the fact that for two different lists l_1 and l_2, the system output r can be the same.

A probabilistic evaluation based procedure. In the procedure we shall present, the events taking place within the series of tests will be perceived as random processes from a mathematic point of view.

Let us suppose that we have successively operated N inputs $l_n,\ 1 \le n \le N$ upon the system S. Let $P(r \mid l_n)$ be the probability that the output r of the reference actuator has been generated by the process l_n (by a reference actuator of class l_n). Presuming that one can not act upon the system S with more than a single input at a given time, by means of the total probability we can then express the probability that the system output is a specific one. More exactly, if the expected output is r, then

$$P(r) = \sum_{n=1}^{N} w_n P(r \mid l_n), \tag{1}$$

where w_n is the probability that the process is taking place:

$$l_n,\ n = 1, 2, .., N,\ \sum_{n=1}^{N} w_n = 1, \tag{2}$$

Under these circumstances, the probability that afterwards the output r of the system S is generated by the process $l_k, 1 \le k \le N,$ is given by Bayes' formula.

$$P(l_k \mid r) = \frac{w_k P(r \mid l_k)}{\sum_{n=1}^{N} w_n P(r \mid l_n)} \tag{3}$$

A linear prediction based procedure (method). Within the construction we shall consider in this section, we shall adopt the following conventions:

1) by $l(r)$ we shall understand a list of technical characteristics (or a class of test actuators) that generates the output r once it has been introduced in the system S;

2) by $l_n(r),\ n \ge 1$, we shall denote the list (technical sheet) $l(r)$ obtained within the experiment of degree n;

3) we assume that the chain (process) $l_n(r),\ n \ge 1$, is stationary.

In order to realize the real-time actuator control we need a simple modality to estimate the values of the process $l_n(r),$ (of the technical characteristics list) at a given time, on the basis of a finite number of consecutive anterior observations (samples) q. In this respect we shall try to determine the estimated values $\hat{l}_n(r)$ of the process $l_n(r),$ as an expression of the form:

$$\hat{l}_n(r) = -\sum_{k=1}^{q} a_k(q) l_{n-k}(r) \quad (4),$$

where $\{-a_k(q) \mid k = 1,...,q\}$ represent the coefficients (weights) of the proposed linear combination. In the literature, this drafted mathematical is called one-step forward predictor of degree q. This model will completely be functional only when we indicate a method to determine its coefficients. For example we can have:

$$-a_k(q),\ k = 1,2,..,q \quad (5)$$

To this purpose we shall further on describe the classical procedure used to determine the coefficients of a linear predictor.

Within this procedure the difference between the authentic vector $l_n(r)$ and the predicted one $\hat{l}_n(r)$, called "prediction error", is firstly being analyzed. We shall denote this difference by $\varepsilon_n(q)$. In the studied case:

$$\begin{aligned}\boldsymbol{\varepsilon}_n(\mathbf{q}) &= \mathbf{l}_n(\mathbf{r}) - \hat{\mathbf{l}}_n(\mathbf{r}) \\ &= \mathbf{l}_n(\mathbf{r}) + \sum_{k=1}^{q} \mathbf{a}_k(\mathbf{q}) \mathbf{l}_{n-k}(\mathbf{r})\end{aligned} \quad (6).$$

Considering that the fundamental (constituent) space of the process is the probability space (Ω, F, P) and that E is the mean associated to the probability P, by means of variable $\varepsilon_n(q)$ we can now evaluate the prediction standard deviation $\xi(q)$,

$$\begin{aligned}\xi_n(q) &= E\left(\varepsilon_n^2(q)\right) = E\left(\left(\sum_{i=0}^{q} a_i(q) l_{n-i}(q)\right) \cdot \left(\sum_{j=0}^{q} a_j(q) l_{n-j}(q)\right)\right) = \\ &= E\left[l_n^2(r) + 2\sum_{k=1}^{q} a_k(q) l_n(r) l_{n-k}(r) + \sum_{i=1}^{q}\sum_{j=1}^{q} a_i(q) a_j(q) l_{n-i}(r) l_{n-j}(r)\right] = \\ &= \gamma_{n\,n}(l) + 2\sum_{k=1}^{q} a_k(q) \gamma_{n\,n-k}(l) + \sum_{i=1}^{q}\sum_{j=1}^{q} a_i(q) a_j(q) \gamma_{n-i\,n-j}(l),\end{aligned} \quad (7)$$

where:

$\gamma_{n-i\ n-j}(l) = E\left(l_{n-i}(r) l_{n-j}(r)\right),\ i,\ j = 0, 1,.., q$,

and $a_0(q) = 1$.

Due to the result obtained we can now regard the standard deviation error $\xi_n(q)$ as a function of

$$a_1(q),\ a_2(q),\ ..,\ a_q(q) \quad (8).$$

We shall further on demonstrate that the function:

$$\xi_n = \xi_n(a_1(q),\ a_2(q),\ ..,\ a_q(q)) \quad (9)$$

admits a minimum and we shall determine the values of the parameters $a_1(q),\ a_2(q),\ ..,\ a_q(q)$, that confirm this fact.

Because:

$$\frac{\partial^2 \boldsymbol{\xi}_n(\mathbf{a}_1(\mathbf{q}),\ \mathbf{a}_2(\mathbf{q}),\ ..,\ \mathbf{a}_q(\mathbf{q}))}{\partial \mathbf{a}_i(\mathbf{q}) \partial \mathbf{a}_j(\mathbf{q})} = \boldsymbol{\gamma}_{n-i\,n-i},\ \mathbf{i}, \mathbf{j} = 1, 2,.., \mathbf{q}, \quad (10)$$

square form defined by the matrix

$$\left(\frac{\partial^2 \xi_n(a_1(q),\ a_2(q),\ ..,\ a_q(q))}{\partial a_i(q) \partial a_j(q)}\right)_{i,\ j = \overline{1,q}} \quad (11)$$

is positively defined.

Indeed,

$$(x_1,..,x_q)\left(\gamma_{n-i\,n-i}\right)_{i,\,j=\overline{1,q}}\begin{pmatrix}x_1\\ \vdots\\ x_q\end{pmatrix}=\sum_{i=1}^{q}\sum_{j=1}^{q}\gamma_{n-i\,n-j}x_i x_j=$$

$$=E\left(\left(\sum_{i=1}^{q}l_{n-i}x_i\right)\left(\sum_{j=1}^{q}l_{n-j}x_j\right)\right)=E\left(\left(\sum_{i=1}^{q}l_{n-i}x_i\right)^2\right),\ \forall(x_1,..,x_q)\in R^q. \qquad (12)$$

It follows that function:

$$\xi_n=\xi_n(a_1(q),\ a_2(q),\ ..,\ a_q(q)) \qquad (13)$$

admits a minimum point. To find the minimum point we shall resolve the system:

$$\frac{\partial\xi_n(a_1(q),\ a_2(q),\ ..,\ a_q(q))}{\partial a_k(q)}=0, \qquad (14)$$

$k=1,2,..,q$, with the unknowns:

$$a_1(q),\ a_2(q),\ ..,\ a_q(q).$$

Since:

$$\frac{\partial\boldsymbol{\xi}_{\mathbf{n}}(\mathbf{a}_{1}(\mathbf{q}),..,\mathbf{a}_{\mathbf{q}}(\mathbf{q}))}{\partial\mathbf{a}_{\mathbf{k}}(\mathbf{q})}= \qquad (15)$$
$$2\boldsymbol{\gamma}_{\mathbf{nn-k}}(\mathbf{l})+2\sum_{\mathbf{i=1}}^{\mathbf{q}}\mathbf{a}_{\mathbf{i}}(\mathbf{q})\boldsymbol{\gamma}_{\mathbf{n-in-k}}(\mathbf{l}),\ \mathbf{k}=1,2,..,\mathbf{q},$$

The minimum condition of function $\xi_n(q)$ is given by the system solution:

$$\sum_{\mathbf{i=1}}^{\mathbf{q}}\mathbf{a}_{\mathbf{i}}(\mathbf{q})\boldsymbol{\gamma}_{\mathbf{n-in-h}}(\mathbf{q})$$
$$=-\boldsymbol{\gamma}_{\mathbf{nn-k}}(\mathbf{l}),\ \mathbf{k}=1,2,..,\mathbf{q}. \qquad (16)$$

Let: $$\left(\overline{a_1}(q),..,\overline{a_q}(q)\right) \qquad (17)$$

be the solution of the above mentioned system. By replacing:

$$a_1(q)=\overline{a_1}(q),..,a_q(q)=\overline{a_q}(q) \qquad (18)$$

in the expression of $\xi_n(q)$ we obtain:

$$\overline{\boldsymbol{\xi}}_{\mathbf{n}}(\mathbf{q})=\min_{(\mathbf{a}_1(\mathbf{q}),..,\mathbf{a}_{1\mathbf{q}}(\mathbf{q}))}\boldsymbol{\xi}_{\mathbf{n}}((\mathbf{a}_{1}(\mathbf{q}),..,\mathbf{a}_{1\mathbf{q}}(\mathbf{q})))$$
$$=\boldsymbol{\gamma}_{\mathbf{nn}}(\mathbf{l})+\sum_{\mathbf{k=1}}^{\mathbf{p}}\overline{\mathbf{a}_{\mathbf{k}}}(\mathbf{q})\boldsymbol{\gamma}_{\mathbf{n-k}}(\mathbf{l}). \qquad (19)$$

for the prediction minimum standard deviation error.

For this reason the coefficients have been defined

$$a_1(q),\ a_2(q),\ ..,\ a_q(q) \qquad (20)$$

of the one-step forward predictor as being equal with

$$\overline{a_1}(q),\overline{a_1}(q),..,\overline{a_q}(q). \qquad (21)$$

At this point, the procedure used to determine the estimation $\hat{l}_n(r)$ of the process $l_n(r)$ is finished. The experimental results are in good agreement with the theoretically predicted results for mathematical modelling of the correlation between actuators, showing the possibility of practical implementation of real time control of actuators in continuous flux.

5. System implementation

The aim of implementing the open architecture real time control system for actuators in continuous flux is determining in real time the characteristics, functional parameters and performances of the tested actuators while reducing trial time, increasing measurement precision and realizing complex trial regimes.

The open architecture control system for determining the actuator performances through continuous flux measurements implemented based on the previously elaborated control method is presented in fig.2. The servo-actuator force controller (CSV) has been implemented through a high performance ABB Bivector type frequency converter, usually used in positioning, with the speed control domain higher than 1:50,000. In addition to the magnetic flux control loop there is an exterior loop for control in speed through an incremental EMC transducer. An electro-magnetic separator allows energy supply for the reference servo-actuator SVA, on which the measurement transducers are mounted: three-dimensional vibration measurement VB1, torque measurement between the two actuators SVA and ATs, bearing 1 temperature -TL1, bearing 2 temperature TL2, coil temperature TB1-2. Signals sent from the transducers are scaled to a standard signal form through 6 amplifiers: 3 for vibration measurement on 3 axis, one for torque measurement and two for temperature.

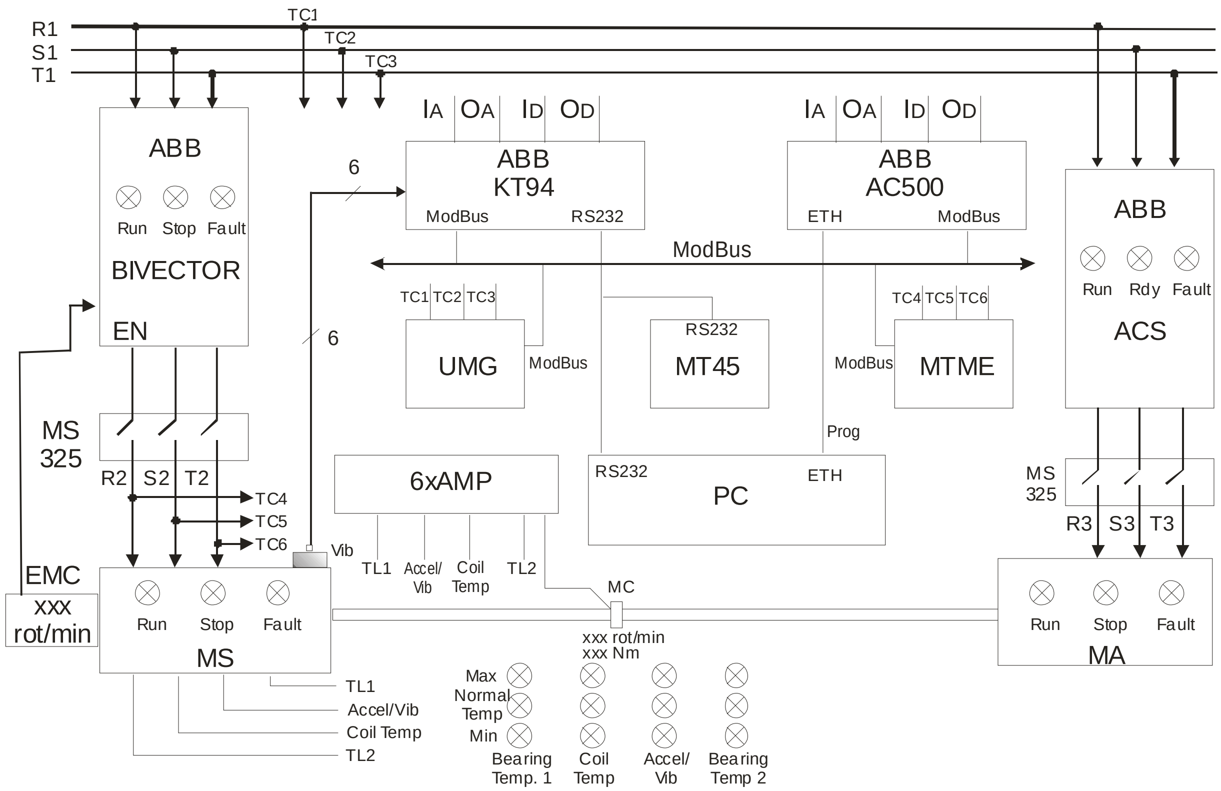

Fig.2 The real time control system architecture for actuators in continuous flux

These signals are processed by the open architecture system SCAD which consists of two PLCs, one of which has the master role, two modules for the measurement of energy parameters (phase currents, tensions on phase and line, total power, active power, reactive power, distortions up to harmonic 15, etc.).

One of the UMG modules measures energy parameters for the reference servo-motor SVA and the second MTME measures these parameters for the input system.

Data exchange between the SCAD modules is done through a MODBUS communication bus, at a speed of 115kbps. Communication between the slave PLC and the process PC is done on a RS232 bus, to which a MT45 intelligent terminal is also connected for graphical interface with the operator.

The master PLC communicates with the process PC through a very fast Ethernet data bus. It is noteworthy that the tested servo-actuator does not have any transducers mounted on, energy supply being provided by a CATs frequency converter with normal technical performance.

6. Experimental results.

The resulting graphs of the actuators' characteristics are compared in figures 3 and 4, with the first being measured directly and the second obtained through correlation and mathematical prediction, using a reference actuator according to the proposed control method. Thus, it can be seen in both figures that the measurement error is less than 1% between.

Figure 3 presents the behaviour of the tested actuator measured directly, where the mechanical rated power 3,8 KW (a), 4,2 KW (b), current to continuous torque 9,8A (a), 15A (b) and rated speed 3000 rpm (a) respectively 1500 rpm (b). The experimentally measured range of the tested actuator are represented by a-Max, b-Max for maximal values and a-Min, b-Min for minimal values.

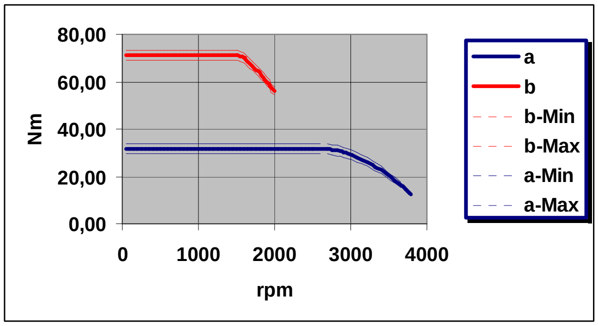

Fig. 3. Comparative torques' graphs related to the method's performances

In figure 4 the comparative graphs of effective power related to the method's performances are shown, where curve (a) represents the actuator's efficiency through direct measurement, respectively maximal (a-Max) and minimal (a-Min) values. It is to observe that the actuator performance is within the "premium" range according to the NEMA standard (USA National Electrical Manufacturers).

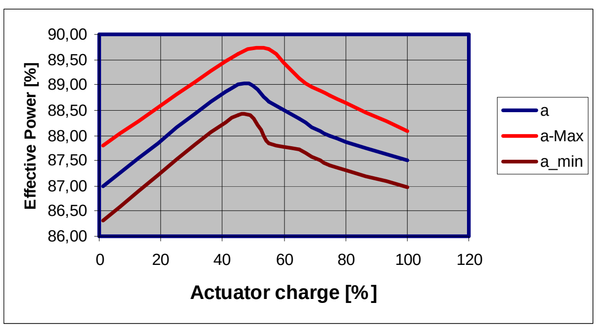

Fig. 4. The comparative graphs of effective power related to the method's performances

The performances achieved for the control system, that allow controlling the actuators through the presented method, consist of the processing and monitoring with +/- 1% accuracy graphic displays on the computer of the following parameters: apparent, active, reactive power, phase and line currents, phase and line tensions, distortions measurement, harmonics up to level 15, frequency, cosine, vibrations on 3 axles with graphic representation of the medium value of the vibrations and monitoring, temperatures in the engine's bearings and coiling, torque at the engine's shaft.

7. Conclusion.

The method is based on an innovative solution patented by the authors, winner of the gold medal at the Geneva World Convention 2008, and has been implemented both for industrial applications but also as a trial stand for students from universities with electric profile, namely for preparing their masters degree or other postgraduate studies.

The main advantage of this new method is that it allows real time control for determining the characteristics, the functional parameters and performances of the actuators, in continuous flux, without the input signals being generated by the tested actuator.

This leads to a decrease in the trials' duration, an increase in the accuracy of the measurements and the realisation of complex trial regimes.

Fig. 5. Actuators control device in continuous flux

Theoretic and experimental results have shown that the characterisation errors of the actuators that have been tested through the proposed method, as opposed to the direct measurement method, are less than 1% while the testing duration is over 30 times less.

The device created based on the newly proposed control method is show in figure 5. Other theoretic studies and experimental trials are still being carried out in order to improve the characterisation error of the tested actuators, both through identifying some mathematical prediction models of high precision in determining the characteristics of the tested actuators as well as through the development of mathematical models by using the fuzzy method.

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References:

[1] Frantisek Solc, Michal Vasina, Modeling and Control of SMA Actuator, *WSEAS Transaction on Circuits and Systems, Issue 9, Volume 3,* November 2004, pg.1840-1845, ISSN 1109-2734

[2] Luige Vladareanu, Top technologies in Solid Mechanics, cap.7, Advanced Engineering in Applied Mechanics, *Published by Romanian Academy Printing House 2006*, pp.29, pg. 397-434, ISBN-13 978-973-27-1370-9; ISBN-10 973-27-1370-4

[3] António Espírito Santo, Maria R. A. Calado, et.all, Position Control of Linear Switched Reluctance Actuator With a Digital Signal Processor, *WSEAS Transation on Power Systems, Issue 2, Volume 1, February 2006,* pg. 366-372, ISSN 1790-5060

[4] Vladareanu L., “Real Time Control with PLC in the Solid Mechanics.”, vol.1, *Ed. Bendic 2005, Seria Universitaria*,pp.232, ISBN 973-684-432-7

[5] Jozef Hooman, Onno van Roosmalen **,** Formal Design of Real-Time Systems in a Platform-Independent Way, **V**olume 1, no. 2 (June 1998), Published as *Parallel and Distributed Computing Practices (ISSN 1097-2803)*

[6] S.I. Chien and J. Luo **,** Optimization of Dynamic Ramp Metering Control with Simultaneous Perturbation Stochastic Approximation, *WSEAS Transaction on Control and Intelligent Systems, 2008 Issue 1, volume 36/2008*, pg. 1808-1820, **ISSN**: 1480-1752

[7] Vladareanu L., “The Open Achitecture (OAH) Control in Real Time for the Contour Robots” – *AMSE 2003- International Conference of Management and Technology MT’2003,* April 23-25 2003, Habana, Cuba, pg. 131-139,CD, WSEAS

[8] Xiaofang Yuan, Yaonan Wang, Lianghong Wu, Adaptive Inverse Control of Excitation System with Actuator Uncertainty, *WSEAS Transation on Systems and Control, Issue 8, Volume 2, August 2007,* pg.411-418, ISSN 1991-8763.