XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

TIME DOMAIN PARAMETER IDENTIFICATION OF ANTICORROSION COATING VIA SOME TYPES OF POLYNOMIAL SIGNALS

Marek Niedostatkiewicz[1], Romuald Zielonko[2]

Gdańsk University of Technology, Faculty of Electronics, Telecommunication and Informatics,
Dept. of Metrology and Electronic Systems, Gdańsk, Poland
[1] niedost@eti.pg.gda.pl
[2]zielonko@pg.gda.pl

Abstract: The paper presents a time domain method of anticorrosion coating diagnosis on the level of equivalent circuit parameter identification, based on applying a set of shape-designed polynomials and measuring the object's responses (so-called observables) at a given time *T*. Equivalent circuit parameters are calculated directly from observables using analytical equations, determined by modelling circuit topology. In the paper the comparison of different polynomial signals (Chebyshev, Legendre, Optimal) against the criteria of stationary error propagation is presented, on the base of analytical and simulation results.

Keywords: anticorrosion coating diagnosis, parameter identification, non-conventional signals.

1. INTRODUCTION

Nowadays, many objects and phenomena (e.g. dielectric materials, anticorrosion coatings [1], biomedical objects), are modelled by electrical circuits, usually in the form of multi-element two-terminal networks.

Particularly, monitoring and diagnosis of anticorrosion coatings is very important, due to losses caused by corrosion of technical objects. The most popular form of anticorrosion protection are thin or thick layer coatings, modelled by high impedance circuits on the level of GΩ [2].

The conventional method of equivalent circuit parameter identification is an impedance spectroscopy. The process consists of two stages. First, the impedance spectrum is measured in a specified frequency range. Secondly, the parameter-dependant function is fitted to the spectrum, e.g. by Complex-Non-linear-Least-Squares (CNLS) method.

The main disadvantage of the impedance spectrum fitting method is the necessity of making many impedance measurements in a wide frequency range, starting from very low frequencies (order of mHz and μHz), resulting in a very long measurement time (order of hours) [2]. Moreover, the fitting algorithms require computational power, thus making the realization of low-cost field anticorrosion testers difficult.

To circumvent these disadvantages, the alternative method of parameter identification equivalent circuit parameters via shape designed measurement signals has been presented by authors in [3]. The early results have confirmed the possibility of measurement time reduction and simplification of the hardware structure of a measurement system.

The idea of the method is explained in Fig.1. Application of shape-designed signals, allows shifting the main effort of the measurement process from the processing of the output (response) signal to design and synthesis of the input (stimulus) non-conventional signal [4]. The Object Under Test (DUT) is stimulated by a sequence of shape-designed, non-conventional signals u_i, synthesized by an arbitrary waveform generator. The DUT response $i_i(t)$ for every signal is sampled at time instance *T*. From set of samples $i_i(T)$, (named observables) the DUT parameters are calculated. The shape of the signals, their number (equal to the number of identified parameters) and time *T* are designed in the pre-testing stage, considering the assumed equivalent circuit topology.

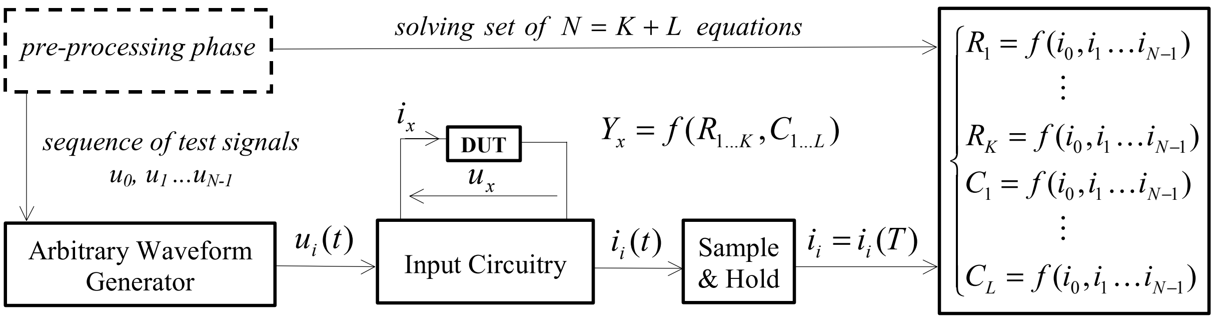

Fig. 1. The idea of equivalent circuit direct parameter identification.

2. PURPOSE

In the paper, the susceptibility of the method to measurement errors is being examined for several shape-designed signals: a normalized mirror power signal and 3 kinds of polynomial signals. As a test object, the 4-elements Beaunier's equivalent circuit modelling the anticorrosion layer in its early stage of degradation has been chosen. The propagation of the stationary measurement errors from the set of observables to the set of moments of impulse response and the set of identified circuit parameters was investigated, both analytically and by means of simulation.

3. THEORETICAL BASICS OF THE METHOD

Transmittance is a popular form of describing dynamic properties of the system – in this case, a two-terminal equivalent circuit of anticorrosion coating.

For voltage stimulation and measurement of the current response of a time-invariant linear circuit, the transfer function is an admittance, which can be described in the form of a rational function with a_i and b_i coefficients dependent on parameters of the equivalent circuit:

$$Y(s)=\frac{a_m s^m+\ldots+a_2 s^2+a_1 s+a_o}{b_n s^n+\ldots+b_2 s^2+b_1 s+b_o}. \qquad (1)$$

Alternatively, the system transfer function can be represented in the form of Taylor's expansion:

$$Y(s)=\sum_{i=0}^{\infty} k_i s^i . \qquad (2)$$

3.1. Description of a circuit by moments of pulse response

The coefficients k_i are in a relation with values of moments of impulse response $h(t)$ defined as a functional of $h(t)$ with power function kernel t^i:

$$\mu_i=\int_0^{\infty} t^i k(t)\,dt, \quad i=0,1,2,\ldots,N-1. \qquad (3)$$

The analytical relation between μ_i and coefficients k_i can be found, by expansion of the kernel function in the Laplace integral:

$$\mu_i=(-1)^i\, i!\,k_i, \quad i=0,1,2,\ldots,N-1. \qquad (4)$$

As the integration range is unlimited, the moments (3) are not measurable. However, in a limited time T, the approximants $\mu_i\,(T)$ of moments μ_i can be measured:

$$\mu_i(T)=\int_0^{T} t^i h(t)\,dt, \quad i=0,1,2,\ldots,N-1. \qquad (5)$$

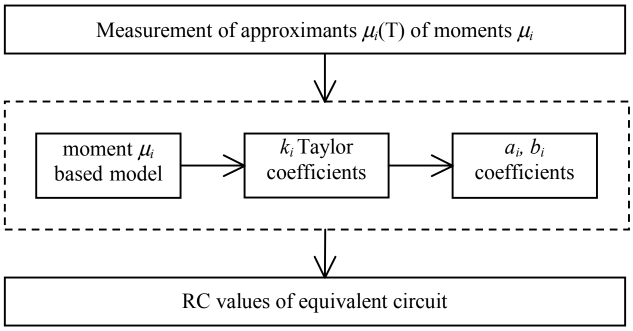

Fig. 2. Calculating RC parameters from values of moments.

The moment measurement results give the possibility of calculation of DUT parameters (Fig.2). The relation between moments, Taylor coefficients, rational function coefficients and RC values has an exact, analytical solution.

3.2. Mirror kernel reflection method

The approximants of moments $\mu_i(T)$ can be measured effectively with mirror power signals, designed according to the mirror kernel reflection principle (MKR) [3]. If the circuit is stimulated with a voltage signal being the mirror reflection (Fig.3) of power signal t^i:

$$u_i(t)=(T-t)^i\,1(t) \qquad i=0,1,2,\ldots,n, \qquad (6)$$

then the output of the circuit at a given time T – upper integration limit in (5) – is equal to the approximant of moment $\mu_i(T)$.

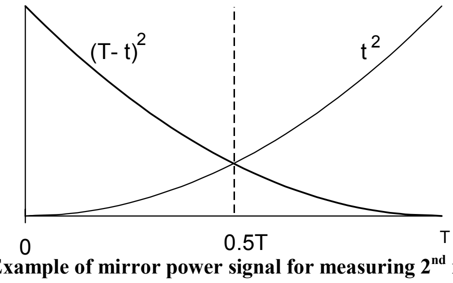

Fig. 3. Example of mirror power signal for measuring 2nd moment.

This can be proved by calculating the circuit response $i_i(t)$ as a convolution of mirror power signal $u_i(t)$ and circuit impulse response $h(t)$:

$$\begin{aligned} i_i(t)&=u_i(t)*h(t)=\int_0^t u_i(t-\tau)\,h(\tau)\,d\tau= \\ &=\int_0^t [T-(t-\tau)]^i\,h(\tau)\,d\tau \end{aligned} \qquad (7)$$

It is easy to prove, that the sample of the current signal at time T is equal to the approximant of moment $\mu_i(T)$:

$$i_i(T)=\int_0^T [T-(T-\tau)]^i\,h(\tau)\,d\tau=\int_0^T \tau^i h(\tau)\,d\tau=\mu_i(T). \qquad (8)$$

The measurement of higher order moments via signal (6) would be difficult to implement in practice, due to rapidly increasing signal dynamics range. There is a possibility of limiting signal dynamics, by measuring normalized moments of the impulse response:

$$m_i(T)=\int_0^T\left(\frac{t}{T}\right)^i h(t)\,dt=\frac{1}{T^i}\mu_i(T), \quad i=0,1,2,\ldots,N-1, \qquad (9)$$

The mirror power signals has been used for the explanation of the method. Earlier researches [2] have shown, that better results of moment measurement can be obtained by application of shape-designed polynomial signals.

3.3. Measuring moments with polynomial signals

For moment measurement, T-normalized polynomials can be used, given by formula:

$$u_i(t)=P_i\left(\frac{t}{T}\right)=a_{ii}\left(\frac{t}{T}\right)^i+\ldots+a_{i2}\left(\frac{t}{T}\right)^2+a_{i1}\left(\frac{t}{T}\right)+a_{i0}. \qquad (10)$$

A characteristic feature of a polynomial signal is that it is the weighted sum of power signals. If the leading coefficient (weight) is positive and other weights have alternate signs, the polynomial component power signals partly compensate each other, providing internal signal amplitude compression, thus resulting in limited polynomial dynamic range over a limited period $[0,T]$.

The circuit's response to a polynomial signal P_i is:

$$i_i(t) = u_i(t) * h(t) = P_i\left(\frac{t}{T}\right) * h(t) = \int_0^t P_i\left(\frac{t-\tau}{T}\right) h(\tau)\, d\tau\,, \quad (11)$$

The sample of DUT response to P_i stimulus at given time T is named polynomial observable o_i:

$$o_i = P_i\left(\frac{t}{T}\right) * h(t)\Big|_{t=T} = \int_0^T P_i\left(1-\frac{\tau}{T}\right) h(\tau)\, d\tau\,. \quad (12)$$

The relation between observables and moments can be found according to the algebraic theorem, that every polynomial of order N can be expressed as a linear combination of N+1 polynomials of order *0* to N. To find the relation, every exponential kernel of the moments $m_i(T)$ (9), being a special case of polynomial, must be substituted by the weighted sum of N+1 polynomials mirror to P_i of order *0* to N. Thus, the kernel $(t/T)^i$ is:

$$\left(\frac{t}{T}\right)^i = \sum_{k=o}^{i} w_{ik} P_k\left(1-\frac{t}{T}\right). \quad (13)$$

Then, the functional (9) can be written as:

$$m_i(T) = \int_0^T \left(\frac{t}{T}\right)^i h(t)\, dt = \int_0^T \sum_{k=o}^{i} w_{ik} P_k\left(1-\frac{t}{T}\right) h(t)\, dt =$$
$$= \sum_{k=o}^{i} w_{ik} \int_0^T P_k\left(1-\frac{t}{T}\right) h(t)\, dt = \sum_{k=o}^{i} w_{ik} o_i(T), \quad (14)$$

giving the relation expressing the moments $m_i(T)$ as the linear combination of polynomial observables. Calculating the moment values as a combination of several polynomial observables, allows compensation of the measurement errors – it decreases the error propagation from the set of measurands to the set of moments, and as a consequence, to the set of identified object parameters.

There are two methods of calculating the w_{ik} coefficients. The first of them is based on evaluating the right sides of the equations (13), constructed for variable x equal to t/T:

$$\begin{aligned} x^0 &= w_{00}P_0(1-x) \\ x^1 &= w_{10}P_0(1-x) + w_{11}P_1(1-x) \\ x^2 &= w_{20}P_0(1-x) + w_{21}P_1(1-x) + w_{22}P_2(1-x) \\ &\vdots \end{aligned} \quad . \quad (15)$$

After evaluating and collecting coefficients for powers of x, e.g for Chebyshev polynomials, one can obtain:

$$x^2 = 6w_{22}x^2 + (-2w_{21} - 6w_{22})x + (w_{20} + w_{21} + w_{22}). \quad (16)$$

Thus, a simple set of linear equations can be formed:

$$6w_{22} = 1, \quad -2w_{21} - 6w_{22} = 0, \quad w_{20} + w_{21} + w_{22} = 0\,, \quad (17)$$

which allows to calculate w_{ik} coefficients.

The second method can be used with self-mirror polynomials (symmetric or anti-symmetric, depending on order), e.g Chebyscev or Legendre. The calculations become simpler due to the self-mirror property, defined as:

$$T_i\left(1-\frac{t}{T}\right) = (-1)^i T_i\left(\frac{t}{T}\right). \quad (18)$$

By substituting (18) into (12), for a sequence of stimuli:

$$o_i = i_i(T) = \int_0^T P_i\left(1-\frac{\tau}{T}\right) h(\tau)\, d\tau = \int_0^T (-1)^i P_i\left(\frac{\tau}{T}\right) h(\tau)\, d\tau =$$
$$= \int_0^T (-1)^i \left[\sum_{k=0}^{i} a_{ik}\left(\frac{\tau}{T}\right)^k\right] h(\tau)\, d\tau = \quad (19)$$
$$= (-1)^i \sum_{k=0}^{i} a_{ik} \int_0^T \left(\frac{\tau}{T}\right)^k h(\tau)\, d\tau = (-1)^i \sum_{k=0}^{i} a_{ik}\, m_k(T)$$

it is easy to form and solve a linear set of equations describing relations between observables o_i and moments m_i for a self-mirror polynomial, defined by stimuli polynomials coefficients a_{ik}:

$$\begin{aligned} o_0 &= a_{00}m_0(T) \\ o_1 &= -a_{10}m_0(T) - a_{11}m_1(T) \\ o_2 &= a_{20}m_0(T) + a_{22}m_1(T) + a_{22}m_2(T) \\ o_3 &= -a_{30}m_0(T) - a_{31}m_1(T) - a_{32}m_2(T) - a_{33}m_3(T) \\ &\vdots \\ o_i &= (-1)^i \sum_{k=0}^{i} a_k\, m_k(T) \end{aligned} \quad . \quad (20)$$

3. INVESTIGATION METHODS

3.1. Test Object.

As the method is oriented for diagnosis of anticorrosion coatings, the Beaunier's model has been chosen as a test engine to compare propagation of errors for different stimuli. This model represents an anticorrosion coating in its early stage of degradation by a two terminal 4 elements network, shown in Fig.4:

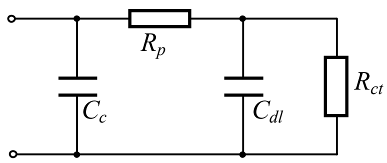

Fig. 4. Beaunier's model of anticorrosion coating.

The transfer function (admittance) of Beaunier's model has the form of:

$$Y(s) = \frac{(C_c R_p C_{dl} R_{ct})s^2 + (C_c R_p + C_c R_{ct} + C_{dl} R_{ct})s + 1}{(R_p C_{dl} R_{ct})s + (R_p + R_{ct})}. \quad (21)$$

Although earlier simulations have been done for parameters equivalent to a real anticorrosion coating, at this stage of investigation, the simulated equivalent circuit values have been chosen lower than for a real coating, in order to allow experimental verification of the method with conventional laboratory equipment. The chosen parameters are:

$$R_p = 1000\Omega, \quad R_{ct} = 1000\Omega, \quad C_c = 10uF, \quad C_{dl} = 100\mu F\,.$$

Identification of such an object requires measurement of four moments m_0 to m_3.

3.2. Shape-designed stimulation signals tested.

The proposed method's susceptibility to an observable measurement error has been tested with several stimuli: a normalized mirror power signal and 3 polynomial signals: Chebyshev, Legendre and so-called Optimal polynomials (designed to limit the propagation of random measurement error). The signals' notations, presented below will be written using the variable x equal to t/T.

3.2.1. Normalized Mirror Power Signal

This signal is described by equation:

$$u_i(t) = (1-x)^i 1(t) \qquad i = 0,1,2,...,n\,, \tag{22}$$

and the observables for such stimuli are equal to normalized moments of impulse response:

$$m_i(T) = o_i\,. \tag{23}$$

3.2.2. Chebyshev polynomials

Chebyshev polynomials of the first kind, normalized and shifted in the interval [0,1] are defined as:

$$u_i(t) = P_i\left(\frac{t}{T}\right) = a_{ii}\left(\frac{t}{T}\right)^i + \ldots + a_{i2}\left(\frac{t}{T}\right)^2 + a_{i1}\left(\frac{t}{T}\right) + a_{i0}$$

$$a_{00} = 1, \quad a_{ik} = (-1)^{i-1} 4^k \frac{i}{i+1}\binom{i+1}{i-1}. \tag{24}$$

The polynomials have the form of:

$$\begin{aligned} &P_0(x) = 1\,, \qquad P_1(x) = 2(x) - 1\,, \\ &P_2(x) = 8(x)^2 - 8(x) + 1 \\ &P_3(x) = 32(x)^3 - 48(x)^2 + 18(x) - 1 \end{aligned} \tag{25}$$

One of the advantages of Chebyshev polynomials is that they have the greatest leading coefficient among all polynomials having equal amplitudes in a fixed period, which implies maximum internal power signal compression. Moreover, these polynomials are self-mirror, which simplifies calculation of w_{ik}.

The shape of Chebyshev polynomials is in Fig.5:

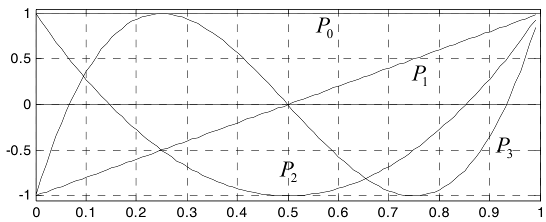

Fig. 5. Chebyshev polynomial signals.

The relations between Chebyshev observables, and the moments m_i are:

$$\begin{aligned} &m_0(T) = o_0 \\ &m_1(T) = (o_0 - o_1)/2 \\ &m_2(T) = (3o_0 - 4o_1 + o_2)/6 \\ &m_3(T) = (10o_0 - 15o_1 + 6o_2 - o_3)/32 \end{aligned} \tag{26}$$

It is worth noticing, that signal $u_0=1(t)$ has the same form for both power and polynomial signals. Moreover, signal $P_1(x) = 2(x) - 1$ is the same for all 3 kinds of examined polynomial stimuli. As a result, the moments m_0 and m_1 are calculated in the same way (26) for all 3 presented polynomial stimuli.

3.2.3. Legendre polynomials

The Legendre polynomials are defined as:

$$P_i(x) = \frac{1}{n!}\frac{d^n}{dx^n}[x(x-1)]\,. \tag{27}$$

$$\begin{aligned} &P_2(x) = 6(x)^2 - 6(x) + 1 \\ &P_3(x) = 20(x)^3 - 30(x)^2 + 12(x) - 1 \end{aligned} \tag{28}$$

The shape of Legendre polynomials is presented in Fig.6.

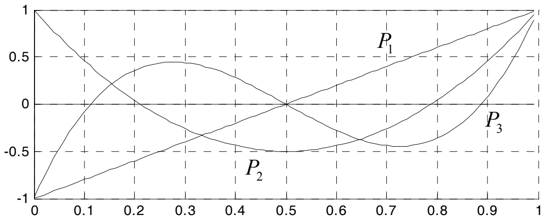

Fig. 6. Legendre polynomial signals.

These polynomials are also self-mirror. The relations between Legendre observables, and the moments m_i are:

$$\begin{aligned} &m_2(T) = (2o_0 - 3o_1 + o_2)/6 \\ &m_3(T) = (5o_0 - 9o_1 + 5o_2 - o_3)/20 \end{aligned} \tag{29}$$

3.2.4. Optimal Polynomials

The Optimal Polynomials were designed to obtain minimum propagation of random errors [3]. They are defined as:

$$P_i(x) = \sum_{j=1}^{i} (-1)^{i-1}(i+1)\binom{i}{j}(x)^j\,. \tag{30}$$

The polynomials of order 2 to 3 are:

$$\begin{aligned} &P_2(x) = 3(x)^2 - 4(x) + 1 \\ &P_3(x) = 4(x)^3 - 9(x)^2 + 6(x) - 1 \end{aligned} \tag{31}$$

The shape of Optimal polynomials is presented in Fig. 7.

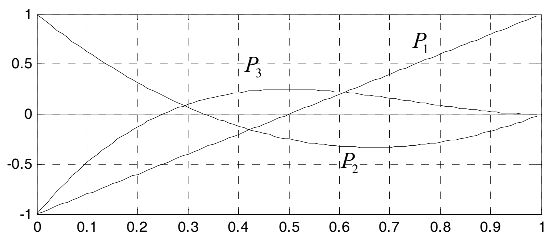

Fig. 7. Optimal polynomial signals.

The relation between observables, and the moments m_i for Optimal polynomials is:

$$\begin{aligned} &m_2(T) = (o_0 - o_1 + o_2)/3 \\ &m_3(T) = (o_0 - o_1 + o_2 - o_3)/4 \end{aligned} \tag{32}$$

3.3. Simulation.

The measurement of moments via shape-designed signals has been simulated in the Matlab transient state simulator, taking into consideration the output resistance and limited slew-rate of the AWG output amplifier. The stimulation signal length T was equal to test circuit time constant τ multiplied by 10.

3.4. Measurement error modelling.

In order to test the sensitivity of the presented method to measurement errors, two components of errors have been examined: systematic multiplicative error and systematic additive error. The propagation of these errors has been tested from the set of measurands, both to set of moments and to set of identified parameters. The first one depends only on the stimulus signal and thus its results are more general and not limited to the currently tested object. The propagation of errors from moments to parameters is dependent on the relations between moments m_i and circuit parameters, defined by test object topology. Thus the results of that investigation provide valuable information on possibilities of application of the method to anticorrosion coating diagnosis.

4. RESULTS AND DISCUSSION

4.1. Observable values.

The values of observables at the test object for the stimulation signals described above are presented in Tab.1:

Table 1. Values of observables for stimulation signals.

observable	Value [μA]			
	Mirror Power Signal	Polynomial Signal		
		Chebyshev	Legendre	Optimal
o_0	487.80	487.80	487.80	487.80
o_1	-33.31	554.43	554.43	554.43
o_2	-2.49	734.34	672.70	59.13
o_3	-0.38	979.84	820.31	-5.96

The observable values show, that Chebyshev and Legendre signals will be easier to implement in practice, as the observable values are unipolar and in the same range, despite the rank of the polynomial. On the contrary, the mirror power signal and optimal polynomial observables are heavily dependant on the rank of the polynomial or the power of the stimulation signal – their values decreases 10-fold for consecutive signals in sequence. As a result, for these signals identifying objects modelled by an equivalent circuit with several elements would require a measurement system with a big dynamics range.

4.2. Propagation of systematic multiplicative error.

The systematic multiplicative error represents the uncertainty of measuring system parameters affecting proportionally the measured values, for example current-voltage converter parameters. The error is assumed stationary for the time of measurement, and its absolute and relative values are denoted as ε^m and δ^m. The propagation from to the set of moments can be calculated:

$$\varepsilon_{m_i}^m = \sum_{k=o}^{i} w_{ik}\varepsilon_o^m = \sum_{k=o}^{i} w_{ik}\delta_o^m o_i = \delta_o^m \sum_{k=o}^{i} w_{ik} o_i = \delta_o^m m_i$$

$$\delta_{m_i}^m = \frac{\varepsilon_{m_i}^m}{m_i} = \frac{\delta_o^m m_i}{m_i} = \delta_o^m . \quad (33)$$

These relations show, that the relative value of the systematic multiplicative error for moments and observables is the same.

The propagation of multiplicative measurement errors to the identified parameter domain has been examined by means of simulation. The investigations have shown, that the relation between the systematic relative error of observables and systematic relative error of identified parameters, presented in Fig.8 is independent on the type of signal.

The reason is that both the propagation of error between moments and parameters, and the propagation of systematic multiplicative errors between the set of observables and the set of moments is signal-independent.

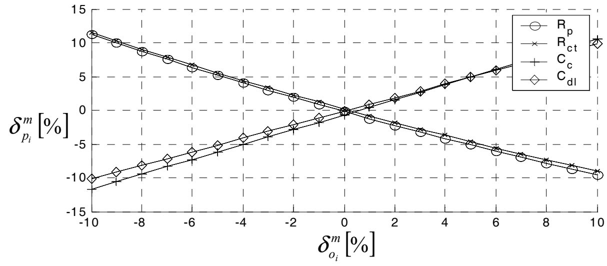

Fig. 8. Relation between systematic multiplicative relative error of observable and relative error of identified parameters p_i.

Another interesting feature, is that systematic relative measurement error are propagated to the parameter domain with coefficient near to –1 or 1.

4.3. Propagation of systematic additive error.

The systematic additive error is usually created by voltage or current offsets in the measurement set-up, for example in input circuitry. The propagation of the systematic additive error from theset of observables to the set of moments for normalized power signal is equal to 1 ($\varepsilon_{m_i}^a = \varepsilon_o^a$), as value of moment is equal to the value of observable. For polynomial signals the propagation can be calculated as:

$$\left(m_i + \varepsilon_{m_i}^a\right) = \sum_{k=o}^{i} w_{ik}\left(o_i + \varepsilon_{o_i}^a\right) = m_i + \sum_{k=o}^{i} w_{ik}\varepsilon_o^a \quad (34)$$

$$\frac{\varepsilon_{m_i}^a}{\varepsilon_o^a} = \sum_{k=o}^{i} w_{ik} \quad (35)$$

Eq. 35 shows, that stationary systematic error compensation is dependent only on coefficients w_{ik} describing the relation between moments and observables. It is obvious that for moment m_0 equal to observable o_o there is no error compensation. For higher order moments measured with Chebyshev (26) or Legendre (29) polynomials, the sum of coefficients w_{ik} is equal to 0. As a result, the stationary systematic additive error of measuring observables should be totally compensated. For Optimal polynomials (32):

$$\frac{\varepsilon_{m_i}^a}{\varepsilon_o^a} = \sum_{k=o}^{i} w_{ik} = \begin{cases} 0 & i = 1,3,5... \\ \dfrac{1}{n+1} & i = 0,2,4... \end{cases} . \quad (36)$$

These polynomials allow compensating additive measurement error of observable, for moments of odd rank. Even moments are calculated with uncertainty dependant on their order.

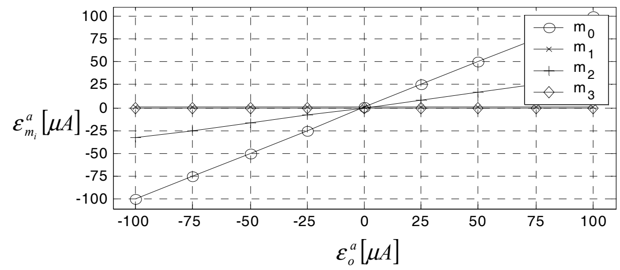

Fig. 9. Relation between systematic additive absolute error of observable and absolute error of moment m_i.

For all examined polynomials, total compensation of the additive error for the moments m_1 and m_3 can be seen in Fig.9, same as lack of compensation can for the moment m_0.Although Optimal polynomials do not guarantee total compensation of additive errors for calculation of odd moments like m_2, the propagation of error is still reduced 3-fold as compared with the normalized power signals method.

The propagation of the systematic additive error to the set of identified parameters for Chebyshev and Legendre polynomials is presented in Fig.10.

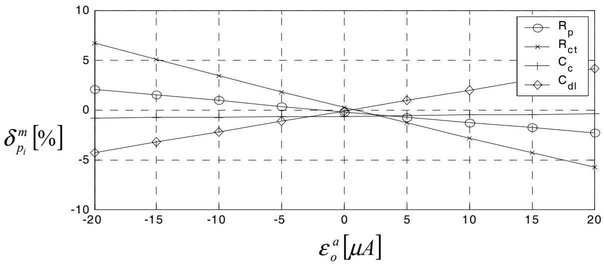

Fig. 10. Relation between systematic additive absolute error of observable and relative error of identified parameters p_i for Chebyshev and Legendre polynomials.

The lack of compensation for moment m_0 allows additive measurement error to propagate to the set of parameters. The $20\mu A$ additive error (about 2-4% of observable value for these polynomial signals) produces a parameter identification error in the range of –5% to 7%. It can also be seen, that parameters of elements "buried" in the equivalent circuit (R_{ct} and C_{dl}) are more sensitive to measurement errors.

The situation gets worse for Optimal polynomials and is presented in Fig.11.

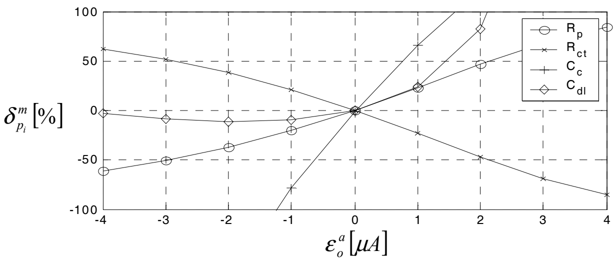

Fig. 11. Relation between absolute error of observable and relative error of identified parameters p_i for Optimal polynomials.

For Optimal polynomial signals, not only the error compensation is less efficient, but also the values of observables are much smaller and the constant additive measurement error about $1\mu A$ is 0.2%–50% of observable. As a result, the parameter identification relative error reaches 100% even for such a small measurement error.

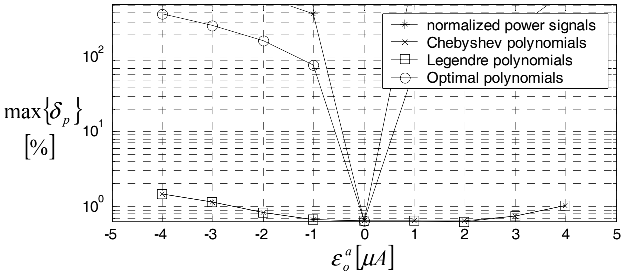

Fig. 12. Comparison of investigated signals against the criteria of maximum relative error of parameter identification.

In order to compare different stimulation signals, a criterion has been proposed: a maximum absolute value of relative error of parameter identification, defined as:

$$\delta_{\max}\left(\varepsilon_o^a\right) = \max\left\{ \left|\delta R_p\right|, \left|\delta R_{ct}\right|, \left|\delta C_c\right|, \left|\delta C_{dl}\right| \right\}. \qquad (37)$$

The plot of δ_{max} against the value of observable measurement error ε_o is presented in Fig.12.

5. CONCLUSIONS

The earlier investigations [2] have proved the usefulness of the method for parameter identification of the 4-element Beunier's model of anticorrosion coating. The results presented in this paper, confirm the benefits of measuring moments via polynomial signals, as they possess the property of stationary additive error compensation and the method propagates the multiplicative relative error of measurement unchanged. Even the polynomials with weak error compensation still give better results than a normalized power signal. Among tested polynomials, the Chebyshev and Legendre signals seems to be particularly interesting, due to total compensation of the additive error for moments of order higher than 1.

However, in order to select the best signal, the susceptibility of the method to random additive error has to be tested. If the Optimal polynomial signals achieve the expected compensation of random error, the precise offset compensation procedures will have to be implemented in the measurement system in order to avoid propagation of additive error.

Although the high sensitivity to observable measurement error caused by non-convenient numerical relations between moments and parameters is still a disadvantage of the method, the proposed solution seems to be well suited for the realization of low-cost, portable anticorrosion coating testers. This method, with properly selected polynomial allows to reduce measurement time, while maintaining similar accuracy in comparison with conventional methods, presented in [2].

REFERENCES

[1] P. L. Bonora, F. Deflorian, L. Federizzi: Electrochemical impedance spectroscopy as a tool for investigation underpaint corrosion", *III International Symp. on Electro-chemical Impedance Spectroscopy*, 1995, Nieuwport, Belgium, pp.1073-1082.

[2] J. Hoja, G. Lentka, R. Zielonko: "On the use of bilinear transformation for parameter identification of anticorrosion coatings", Metrology and Measurement Systems, vol. X (1/2003), pp 17-31.

[3] R. Zielonko, M. Niedostatkiewicz: "Impedance parameter identification of anticorrosion coatings in time domain with shape-designed signals"; 10th IMEKO TC10 International Conference on Technical Diagnostics, Budapest, 9-10 June 2005.

[4] R. Zielonko: "Some theoretical foundations of analog signal shape design for measurement and testing"; Measurement Vol.17, (1/1996), pp 29-37.