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THE USE OF EVOLUTION ALGORITHMS FOR IDENTIFICATION OF TRANSMISSION BACKLASH

SUMMARY

Mechanical propulsion system including, inter alia, an electric motor, shaft and transmission is characterized by certain parameters whose values cannot be calculated using mathematical methods (transmission backlash) or may vary during operation time. Such parameters have to be known to ensure proper operation of the system. In this article a method for identification of these parameters is described. The method is based on an evolution algorithm. This algorithm utilizes natural selection methods and natural transformation processes within a population, similar to those in animal world. The least-fit individuals are rejected by applying the fitness function. The population will improve, and in infinite time it will be perfect. That means that the perfect solution can be attained in a very long time. This time can be shortened by defining the termination criteria, e.g. the identification can be stopped if one of the population individuals has a very low error. Such identification requires a transition function (model), as well as reference measurement made on a real system.

Keywords: *evolution algorithms, electrical drive, backlash, identification, simulation*

ZASTOSOWANIE ALGORYTMÓW GENETYCZNYCH DO IDENTYFIKACJI LUZÓW W PRZEKŁADNI

Mechaniczny system napędowy zawierający, między innymi, silnik elektryczny, sprzęgło i przekładnię jest określony przez niektóre parametry, których wartość nie może być wyliczona metodami matematycznymi (np.: luzy w przekładni), albo może się zmieniać w czasie pracy. Również te parametry powinny być znane dla zapewnienia właściwej pracy systemu. W artykule opisano metodę identyfikacji takich parametrów. Metoda ta opiera się na algorytmie genetycznym. Ten algorytm używa metod doboru naturalnego i procesu naturalnej modyfikacji wewnątrz populacji, podobnych do procesów zachodzących w świecie istot żywych. Najsłabsze osobniki są odrzucane przez zastosowanie funkcji dopasowania. Populacja staje się lepsza i lepsza; po czasie nieskończenie długim byłaby doskonała. To znaczy, że doskonałe rozwiązanie może być znalezione po bardzo długim czasie. Ten czas może być skrócony przez określenie kryterium zatrzymania, tzn.: jeżeli jeden z członków populacji wykazuje bardzo małą odchyłkę, to identyfikacja może zostać zatrzymana. Aby uruchomić ten rodzaj identyfikacji, potrzebna jest funkcja przejścia (model) oraz wzorcowy pomiar na rzeczywistym obiekcie.

Słowa kluczowe: *algorytmy genetyczne, napęd elektryczny, luz, identyfikacja, symulacja*

1. INTRODUCTION

The goal of this work is to introduce an alternative method for identification of multiple parameters of an electric drive system and then results of identification experiment. The method is based on genetic algorithms and combines evolution theory with technical problems. The algorithms need simulation model of the system to determine the parameters. In order to create a dynamic model of electric drive, its dynamic equations are taken into consideration. These equations are transformed to the state equations form, which are the further basis for a plant model. Such model contains a number of unknown parameters. The model parameters identification shall be performed prior to its application in an electric drive control.

2. GENETIC ALGORITHMS

2.1. Basics

Genetic algorithm utilizes natural selection process to select the fittest individuals out of a completely randomly launched population. Individuals are evaluated by fitness function and compared with other individuals to reject the least-fit offspring. As the evolutionary processes are indefinably long, also the genetic algorithm guarantees a perfect solution in an infinite time. The identification process can be shortened through check if the actual population fits the acceptance criteria. Once of the criteria could be the allowable error of the whole population (mean value). If this error is lower than a given threshold, the parameters are frozen and the solution is ready.

2.2. Workflow

Typical workflow step by step of the genetic algorithms is shown in Figure 1. There are two major sections: the first is responsible for mathematical operations like decoding, evaluation of quality criterion including simulation, the second for the genetic algorithms like selection, crossing and mutation. The first population is generated randomly; the last population represents the solution.

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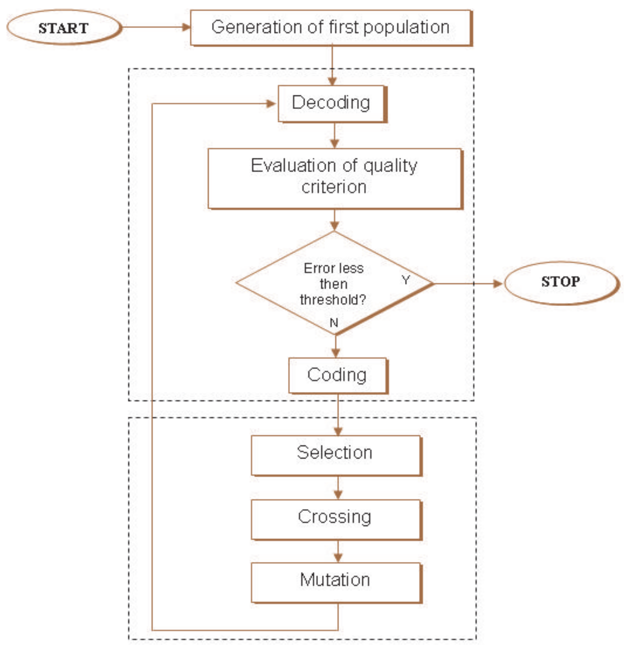

Fig. 1. Step by step workflow

2.3. Selection

One of the most important parts of the identification with genetic algorithms is the selection. Examples of selection methods (Nissen 1997):

- Roulette – a kind of virtual roulette wheel, one of the fields is marked after moving of the wheel, that field belongs to one of the individuals. Stronger individual has more fields on the circle and therefore its chance to pass to the next population is higher.
- SUS – it is faster than roulette since four fields are selected instead of one at one single rotation.
- Tournament – first a group is chosen, then this group fights against another group and finally the strongest groups are nominated to the next generation.

2.4. Crossing

In the natural process of the evolution genes of a child are mixture of genes of both parents. This process is termed “crossing”. Examples of crossing methods:

- One-point crossing (1-Point-Crossover) – two individuals and the point of intersection (for bit exchange) are selected randomly. By bit exchange two new offspring are produced. Those offspring are finally nominated to next generation.
- Multipoint crossing (N-Point-Crossover) – based on a single point crossing, but with multiple points of intersection.
- Uniform crossing (Uniform Crossover) – creation of offspring from two parents, for each single bit it is determined from which parent it will be taken.

2.5. Mutation

Mutation or inversion (Nissen 1997) means a change inside genetic pattern, previously not present inside the population. It appears very rarely, but impacts the average value of the population. This change can cause both: positive and negative effects. Positive could be finding a way out from local minimum. Negative effect appears if the probability is too high. In this case the populations are not getting stabilized and it is difficult to find the final solution.

3. POPULATION ASSESSMENT

After decoding the phenotype of individuals of the population to decimal format, an assessment is performed. For this purpose a transition function is necessary. This is nothing else then the Simulink model of an electric drive. Simulation outputs are compared to the measurement results and the comparison yields the error of each single member of the population. Thus the population assessment is available for next steps of the identification like checking if the error is small enough to interrupt the algorithm and finalize the solutions or to make the selection possible.

Error is calculated from modular error equation:

$$F_b = \frac{1}{N}\sum_{i=1}^{N}\left|y_i - f_i\right| \tag{1}$$

Where:

- y – results of measurement,
- f – result of simulation,
- N – number of iterations.

4. ELECTRIC DRIVE WITH AN ELEMENT INTRODUCING NON-LINEARITY

The tested system is presented in Figure 2. It consists of asynchronous motor (AsM 18.5 kW), rotation mass, which is a synchronous machine (SyM1 34 kW). This machine simulates also the load torque. Between those two machines a second asynchronous motor (SyM2 30 kW) is coupled, which is used exclusively as additional mass. Since in the normal production process the speed of the drive shaft between the motor and transmission is not measured, it was not used in the identification process.

This system is described by dynamic equations including mechanical and electrical parameters (Beck 1998):

$$\dot{n}_1 = \frac{M_N}{2\cdot\pi\cdot n_N}\cdot\frac{1}{J_1}\cdot\left(m_{eld} - m_{1,2}\right) \tag{2}$$

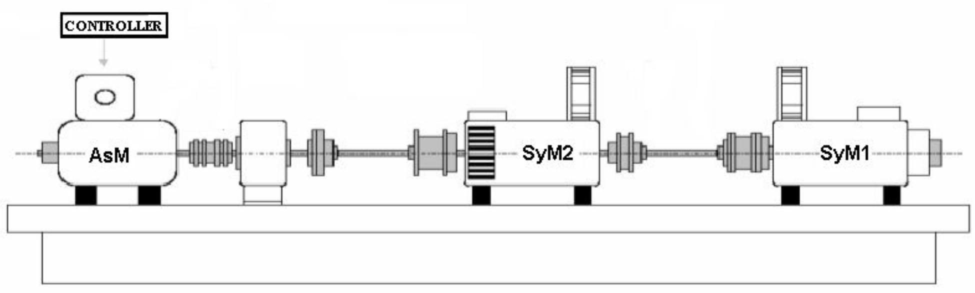

Fig. 2. The tested electric drive system

$$\dot{m}_{1,2} = \frac{2 \cdot \pi \cdot n_N}{M_N} \cdot c_{1,2} \cdot (n_1 - n_2) \quad (3)$$

$$\dot{n}_1 = \frac{M_N}{2 \cdot \pi \cdot n_N} \cdot \frac{1}{J_2} \cdot (m_{1,2} - m_{load}) \quad (4)$$

$$\dot{m}_{eld} = \frac{1}{T_{el}} \cdot (m_{sp} - m_{eld}) \quad (5)$$

Where:

- n_1 – rotational speed of driver machine,
- n_2 – rotational speed of the load machine,
- n_N – rated rotational speed,
- $m_{1,2}$ – mechanical torque of the shaft,
- m_{eld} – electrodynamic torque of the driver,
- m_{sp} – torque setpoint,
- m_{load} – load torque,
- M_N – rated torque,
- T_{dr} – time constant of the driver,
- T_{of} – own frequency (time constant),
- T_{el} – time constant of the electric circuit,
- J_1, J_2 – moments of inertia of the driver and load,
- $c_{1,2}$ – coefficient of elasticity of the shaft.

The rotational speed of the drive (asynchronous motor) was used for the control system. Main goal of the control is to keep the rotational speed within the defined window. Fulfillment of this requirement is decisive to ensure quality of the manufactured product.

In order to create the Simulink model, the dynamic equations of the electric drive were transformed to the form of equations of state. Block diagram of the complete drive system is presented in Figure 3.

The most interesting parameter is the transmission backlash. It introduces non-linearity into the system (Poradnik inżyniera elektryka 2007). The transmission backlash is simulated by the dead-zone block. Total slack is denoted "e" and multiplied with 360^o to get an angular value.

For the identification of the simplified mathematical model of the electric drive following parameters were used:

- T_{dr}, T_{of}, T_{el} – time constants of the driver, own frequency of the system and time constant of the electrical circuit,
- v – the ratio of masses (moments of inertia) of the driving and the driven machine,
- e – transmission backlash,
- T_d – delay introduced by the speed controller.

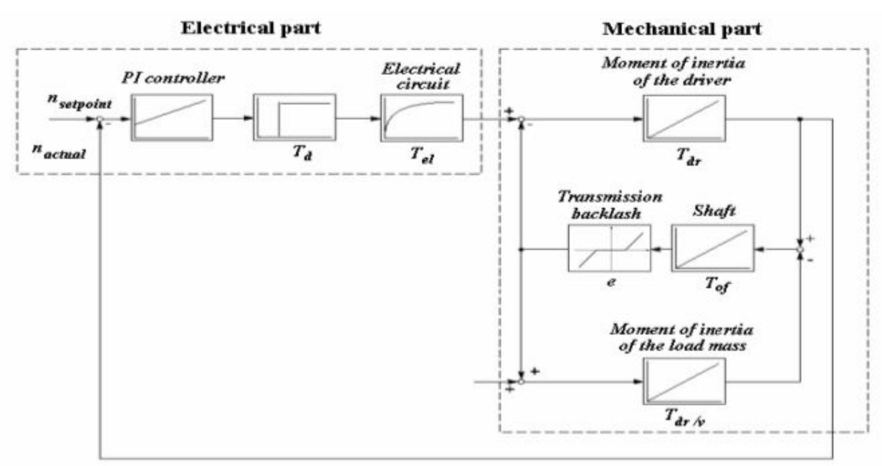

Fig. 3. Block diagram of electric drive

5. SIMULATION

For the purpose of simulation and testing the genetic algorithm a special program called BioHunter was written in Matlab language by the author. To facilitate the work with the genetic algorithms, a graphic user interface was developed. All necessary simulation parameters can be entered using the graphic interface. Before starting the simulation the following basic settings have to be predefined: probability of occurrence of crossing, mutation or inversion, time of simulation, possible average population error, bit length of the parameters, number of individuals within the population and number of generations.

In the next step it has to be decided which selection method will be used. Choice of the selection method depends on the identification subject. Main criteria are: accuracy of the model, number of parameters and system complexity. A more complex model and larger number of parameters require more powerful selection method. Roulette wheel works slower compared to the tournament that means next population gets more individuals with lower value. The tournament method determines the population with the best individuals relatively fast, but the probability is used less in this method as in the roulette wheel.

In total: three selection, three crossing and two mutation methods are available. There are in total eighteen combinations. Identification process can be repeated many times with the same measurement. It gives the user opportunity to check, through interactive observation of simulation results, which one of all the available variants is the best one. Additional feature supporting decision-making is that after each optimization course the diagrams of average error value throughout all the generations and final simulation result (electric torque, rotation speed or mechanical torque) are displayed.

For the above described electric drive, the most suitable configuration was:

- selection based tournament,
- uniform crossing,
- mutation.

Results of example simulation are shown in Figure 4. The diagram on the left shows the simulation results with the first population. Both lines are not overlapping. On the right side the simulation was done with the last population. The lines are overlapping much better, the error was less then maximally allowed and finally the identification delivered satisfying results.

6. CONCLUSIONS AND OBJECTIVES

Unlike traditional optimization methods, genetic algorithms (Rutkowska 1997) start searching with a number of solutions represented by a population, process the identification with encoded form of parameters, use only the fitness function without computing the differentials and apply probabilistic instead of deterministic selection methods. In the case of a drive system with non-linear elements like transmissions, the traditional methods are not widely used. In the identification process the quality of the simulation model has a decisive impact on the quality of solutions. The closer to the reality, the better identification results can be expected. In this work the mathematical model was simplified to reduce the number of unknown parameters to minimum. However, the obtained results motivate to use the genetic algorithms as an excellent method for optimizing more complex tasks. Considering also their flexibility it is a very good alternative to other methods. In the next step, once the system parameters are identified, the identification of the controller parameters can be made.

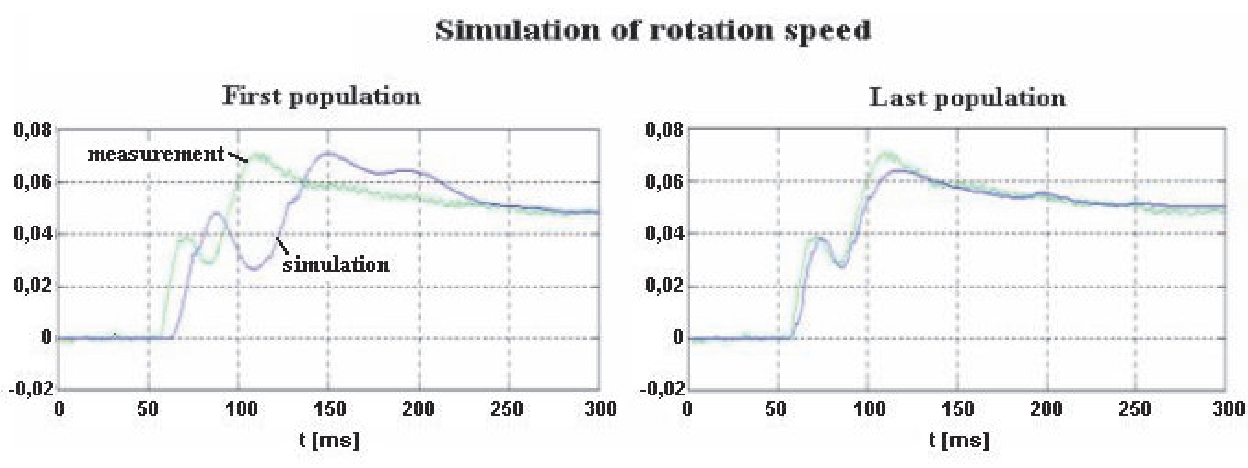

Fig. 4. Rotation speed of first and last population

Abrasion of mechanical components and variability of operating conditions are the cause of continuous changes in the physical properties of such mechanical systems. In such cases, the accuracy of the rotational speed controller may be reduced through static or dynamic error and, consequently, deteriorate of the end product quality. This disturbance may be eliminated by the identification of parameters during drive operation. The identification can be performed by a microcontroller with special identification software designed for the on-line operation. In case of positive results the step to industrialization of on-line application with genetic algorithms on board will be very small.

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