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Motion control parameter identification using genetic algorithms

Dr. Thomas Haase[1], Bernhard Guddei[1], Jessica Pietri[2]

[1]*Physik Instrumente (PI) GmbH & Co. KG, Germany*
[2]*Hochschule Karlsruhe Technik und Wirtschaft, University of Applied Sciences*

t.haase@pi.ws

Abstract

In production of a wide variety of Micro- and Nano positioning stages, PI (Physik Instrumente GmbH & Co. KG) uses a wide variety of different piezo and electromagnetic actuators. Defining optimal and task specific control parameter for different stages is always time-consuming and requires a thorough understanding of system identification and control technology. Within this paper it will be shown how to use genetic algorithms (GA) to identify individual and optimal control parameters independent of the underlying control concept. GA is a method for solving nonlinear optimization problems based on a so called "natural selection process" that uses methods equivalent to biological evolution. Basis of that approach is an existing system description, e.g. a transfer function, a bode plot or a mathematical model. It will be shown how to use the fundamental idea of defining task specific cost functions describing required task specific properties e.g. step & settle time, bandwidth, phase margin or even any other more complex measurable value of a control system. Additionally the paper will depict how to implement a genetic algorithm for tuning a Nano positioning stage and how to adapt such models to different control systems, e.g. using additional feed forward control. Out coming results in time domain and accuracy are discussed.

Magnetic drives, Control Theory, Genetic Algorithms, Parameter Tuning, Matlab/Simulink

1. Introduction

Physik Instrumente (PI) GmbH & Co. KG is a leading manufacturer for Nano-positioning stages using a wide variety of different piezo- and voice-coil based actuators. Defining robust, customized or maybe only task specific and optimized control parameter for different stages, guiding, travel ranges and actuators is time-consuming and requires a thorough understanding of system identification and control technology. Different suitable approaches and guidelines for setting up e.g. PID control with regard to the crossover frequency and phase margin have been published. The determination of controller parameters can be done according to the setting regulation of Ziegler-Nichols or Chien, Hrones and Reswick. Even methods with regard to robust PID control or Loop Shaping have been published. In addition to these normal, usually mathematical guidelines, different software tools are available to help tuning control parameters, e.g. The Mathworks SISO Design Tool for Matlab/Simulink. Basis of such graphical approaches is the availability of a mathematical system description as shown in figure 1. At PI bode plots as well as derived transfer functions are used to characterize stages in the frequency domain. Within this paper it will be shown that also the use of genetic algorithms might be an option for defining task specific control parameters. This approach is not to compete against state of the art guidelines. It should furthermore be seen as an additional tool to define control parameters semi-automatically and within a minimum of time.

2. Genetic Algorithms – An Introduction

Genetic algorithm (short: GA) is a search heuristic that mimics the process of natural selection. The mathematical functionality is not part of this paper and can be found in [1]. The algorithm repeatedly modifies a population of individual solutions. Compared to classical optimization algorithms, GA defines not only one point (individual) at each iteration step (generation). It defines a complete set of possible solutions (population) within the boundary conditions and for each step. Based on the results, the GA selects the best individuals of the actual population to define the next generation. A user defined fitness function as described in section 2.2 is used to evaluate the quality of a solution and to allow for benchmarking the results. In doing so, GA is an adaptive method for solving search and optimization problems, e.g. determining optimal control parameters.

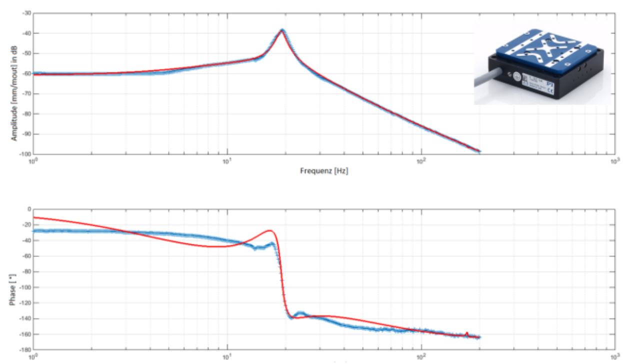

Figure 1. Identified transfer function of a linear voice coil stage with a frictionless and flexure based guiding

2.1. Defining optimization parameter

As example within this abstract a simple PID controller G_{PID} is implemented:

$$G_{PID} = K_p \cdot \left(1 + \frac{1}{T_i \cdot s} + \frac{T_d \cdot s}{1 + T_g \cdot s}\right)$$

The GA is independent of the underlying control structure and will also work with more complex controller like parallel position and velocity control, feed forward control or any other controller design. G_{PID} defines the group of individuals to $I^t = \{\mathrm{K_P}, \mathrm{T_i}, \mathrm{T_D}, \mathrm{T_g}\}$ to be optimized. More complex controller will have more elements within the group of individuals. All individuals are subject to given boundary conditions which limits the search space. Boundary conditions have to be defined for each element of the individuals. As an example, a quite common boundary condition for might be: $\{0 \leq \mathrm{K_P} \leq 1\}$.

2.2. Defining a Fitness Function

To determine and benchmark optimal individuals of a population a decision criteria is required. As one of many different possibilities an optimization criteria could be the sum of the tracking error (ISE: integral square error) as shown in figure 2 and the distance of the actual closed loop phase margin P_M to a desired phase margin $P_{M,opt} = 50°$. Both criteria are merged to a fitness value Y_{FIT} using a fitness function.

$$Y_{FIT} = c_1 \cdot ISE + c_2 \cdot (P_M - P_{M,opt})$$

Parameter c_1 and c_2 are optional values to balance the influence of ISE and P_M. The fitness function is user defined and has to map the control target into a mathematical description.

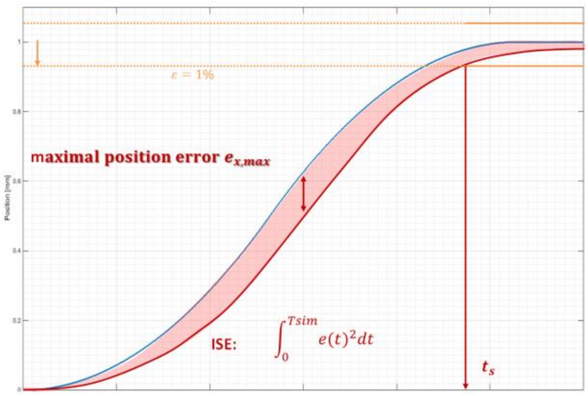

Figure 2. optimization criteria: ISE (integral square error)

3. Using GA to define control parameters

The basis of using GA for defining optimized control parameters is a given simulation model of the plant and the control structure. If the plant is well known and available as transfer function or bode plot, Matlab/Simulink can be used to simulate the dynamic behaviour of the closed loop system as shown in figure 3.

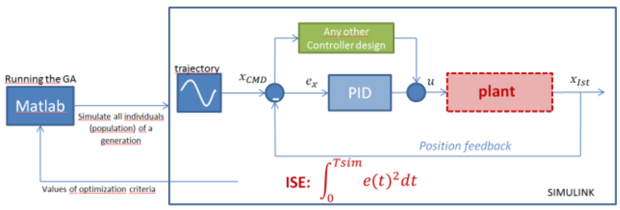

Figure 3. Design of the Optimization Process with genetic algorithms using Matlab/Simulink

3.1. Starting the genetic optimization process

Initially the GA starts to search for optimal parameters by defining a population of individuals $I^0 = \{K_P^0, T_i^0, T_D^0, T_g^0\}$ based on the given boundary conditions. As shown in figure 3:

- The genetic algorithms defines the initial population of initial individuals I^0
- The Simulink model is executed for the complete population and therewith for each individual on after the other. Values of all optimization parameters are recorded (e.g. ISE: tracking error and phase margin)
- The fitness function (cost function) is calculated using given simulation results $Y_{FIT} = c_1 \cdot ISE + c_2 \cdot (P_M - P_{M,opt})$
- After simulating the results for all individuals (the population) of an actual generation, the algorithm randomly selects individuals from the current population and uses them as parents for the next generation
- Over successive generations and within the search space defined by the boundary conditions, the population "evolves" towards an optimal solution.

4. Results

As a result within this abstract it could be shown that the results of the GA are at least equal to results achieved with mentioned methods as described in section 1. Figure 4 shows results of the GA using the controller G_{PID} of section 2.1 and the fitness function of section 2.2 and compares it with results of alternative tools achieved within the same expenditure of time.

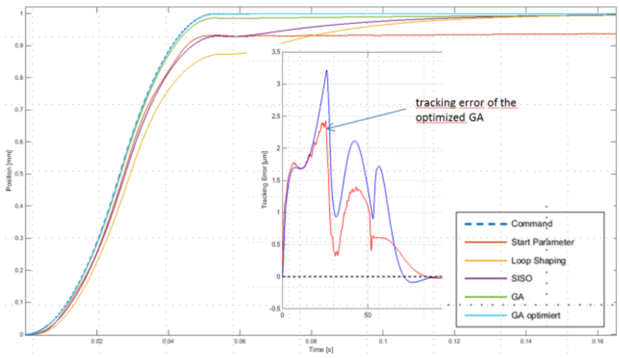

Figure 4. Tracking error of the optimized system in [µm]

5. Conclusion

Within this paper it is shown how to use the methods of genetic algorithms to set up an optimization problem to define task specific control parameters. The use of GA is a valid method and easy to implement. It optimizes given parameters of an underlying control structure using simple to define optimization criteria (fitness function). Fitness functions offer the possibility to integrate optimization criteria into the semi-automatic process. Basis of this approach is a given, identified transfer function of the controlled system.

References

[1] Beasley David, Bull David R, Martin Ralph R, An Overview of Genetic Algorithms: Part 1, Fundamentals, 1993