maxon Auto Tuning

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I. Automatic controller setting for electric drives

Perfect control of current, speed and position is a fundamental requirement for modern positioning control. However, optimum setting of all control parameters and feed-forward control values is by no means trivial. An intelligent, automated setting procedure handles this complex task.

Currently, servo amplifiers are expected to not only optimally perform the drive task and the fast, precise drive control, but also provide user-friendly functions for operation, configuration and diagnostics for the given application. To achieve this goal the maxon EPOS2 positioning controllers (EPOS; Easy to use POsitioning System) offer a number of convenient functions for quick, easy setup of the drive. Focus is placed on electronic aids that relieve the user from the tedious and time-consuming setting of the controller. The user is guided through the startup process by a menu. To determine all necessary controller parameters, the automatic, exceptionally effective set-up procedure described in this report ("Auto Tuning") is performed. With this procedure, all necessary parameters of the current controller, the speed controller and the position controller, as well as any feed-forward values ("Feed Forward") are automatically and optimally determined.

The digital EPOS2 positioning controller from maxon motor is suitable for DC and EC motors with incremental encoders. EC motor is a description for brushless DC motors (BLDC motors). The EPOS2 controllers are available in various sizes for motors with a rated power from 1 to approximately 700 watts. Various operating modes, such as "Profile Position Mode", "Profile Velocity Mode", and "Current Mode", cover a wide range of applications in various devices, machines and industrial equipment. Many of these controllers can be connected to drive networks, using the widely implemented communication interface CAN (CANopen according to CiA 402).

Fig. 1. EPOS2 controllers: EPOS2 24/5 (left), EPOS2 50/5 (right)

II. Controller structures

The EPOS2 product series can configure three different controller types: current controllers, speed controllers, and position controllers.

A. *Current controller*

The current controller is designed to quickly set the motor current to the resistance of the motor inductance and thus generate the desired motor torque. The current controller can also handle external disturbances such as fluctuations in the supply voltage. This makes it possible to obtain complete control over the motor current, independent of the motor properties and supply voltage. In addition to an improvement in dynamic performance, current limits or torque limits can be reliably observed.

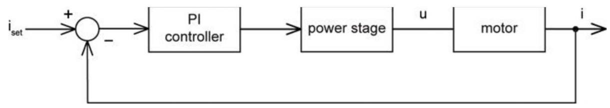

Fig. 2. Current control structure.

B. *Speed controller*

The speed controller with subordinate current controller is used to quickly follow changes to the desired speed. Disturbances, such as changes to the load torque, can also be compensated. Speed controllers with a subordinate current controller are used in numerous applications, such as pumps, centrifuges, transport systems, conveyor systems, winding machines, etc.

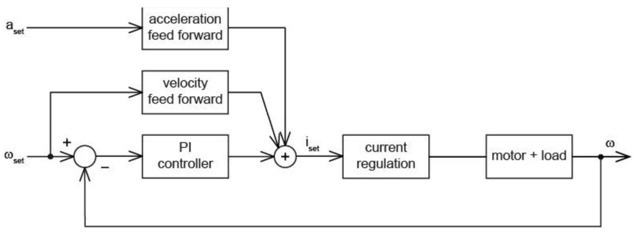

Fig. 3. Speed control structure.

C. *Position controller*

For highly dynamic, precise positioning operations, position controllers with a subordinate current controller are used. These controllers quickly and reliably perform positioning operations while observing the specified acceleration and braking profiles and maximum speeds.

Typical applications are found in automation technology, such as control of robots or positioning of a workpiece under a mill head.

Proceedings of the 1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM2013), IIT Roorkee, India, Dec 18-20 2013

The current or speed controllers are designed in the EPOS2 as PI controllers. Optimal setting of the PI controller ensures an instant response to setpoint deviations for current and speed and guarantees stationary accuracy through compensation of stationary disturbances. The position controller in the EPOS2 is designed as PID controller (proportional, integral, derivative controller). This makes possible even greater controller dynamic response and a faster transient response to the desired target position. The damping effect of the D component greatly reduces overshoot that can result from large controller errors.

In many drive applications, such as contour milling of a workpiece, the control variable must follow a trajectory exactly at all times. This is not optimally achieved solely by the controller – a following error between actual and target value occurs. To minimize this effect, EPOS2 offers a model-based feed-forward structure. By its nature, a controller can only take corrective action once a control deviation is present. Due to the delays in the control loop, the deviation and following error described above occur. As a path generator specifies the desired path or trajectory, at any point in time, in addition to the desired position, the required speed and acceleration can also be derived. If the track properties, in particular the inertial mass and the friction parameters are known, the feed-forward values for the desired system dynamics can then be calculated. With these feed-forward values, the motor current can thus be set with no delay so that the target trajectory is achieved exactly in the ideal case. The position controller then only needs to compensate the minimal remaining deviations.

In EPOS2 two types of feed-forward control are implemented. Acceleration feed-forward control provides additional current that is required for the acceleration or braking operations of the inertial mass of the drive. Velocity feed-forward control can compensate viscous friction, which is proportional to the speed.

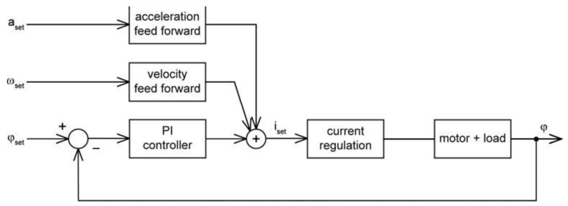

Figure 4 Position control structure

D. Auto Tuning

Startup and optimal parameterization of the controller and feed-forward values for a specific system can be difficult, as in practice prior knowledge of the system parameters (mass, friction, etc.) is not typically available. A numerical determination of the controller or feed-forward parameters is thus either impossible or difficult and time consuming. To overcome this problem, EPOS2 offers a guided startup procedure with which the controller and feed-forward parameters are automatically determined.

maxon Auto Tuning is a model-based, automatic setup procedure, which takes place in the main steps:

- System identification
- Calculation of controller and feed-forward parameters

System identification is performed in the frequency domain. The response of the plant is determined by a continuous oscillation process. For this procedure, a two-point element is added to the control loop that excites the nonlinear control loop with a suitable selection of the parameters to characteristic natural vibrations (Figure 5). The fundamental oscillations at the input X and output Y of the plant are measured. Their ratio of magnitude and phase provide a point for the desired frequency response. Using an adaptive algorithm, the gain of the two-point element is set automatically so that a steady-state continuous oscillation at the output of the path Y achieves a specific amplitude. By adjusting the time constant T of the low pass accordingly, the phase delay of the system is also set. By changing the gain and time constants, different characteristic frequencies can be set. Thus, additional values of magnitude and phase can be obtained for reconstruction of the frequency response of the path. Using the calculated transfer function of the path, the controller parameters can be calculated, for instance using the pole placement method, as can the feed-forward parameters. Suitable controller and feed-forward parameters can thus be automatically identified with the press of a button. Practical experience has shown that this automatic setup procedure is extremely reliable in delivering optimal controller and feed-forward values even for extremely different plant properties.

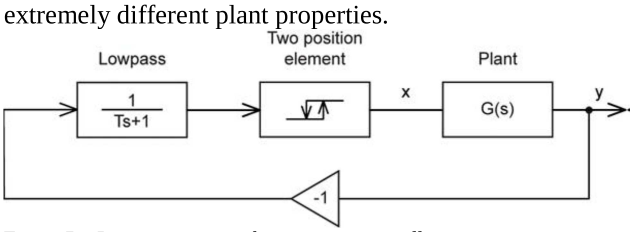

Figure 5 Loop to generate the continuous oscillation

Depending on the application or requirements, the controller settings can be "soft" or "hard" configured. The "soft" setting leads to a slow but well damped control behavior. The "hard" setting, on the other hand, provides a less damped but faster transient response to the setpoint.

Example from a practical application

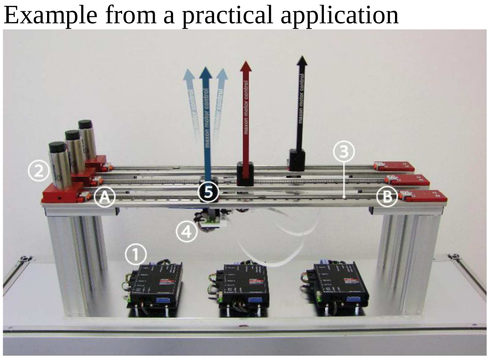

Figure 6 Model structure with three parallel linear axes: (1) EPOS2 position controller (2) Drive (motor, gears, encoder) (3) Belt drive (4) Carriage (5) Load Description of the model: A pendulum is

mounted on the carriage by a rotary axis. At rest, the arrow (pendulum) points down. The carriage is set in motion by the drive, so that the pendulum swings up completely and comes to rest at the top dead point. In this (fundamentally instable) position, it is held in balance and moved by the carriage in the longitudinal direction.

Using the example of a liner axis with belt drive and a mass to be moved, the extraordinary performance of the Auto Tuning procedure can be demonstrated.
The load shall be moved quickly and with the smallest possible controller error from point A to point B. The motor drives the belt drive through a gear. A maxon EC-i motor, rated at 50 W, is used. This type of motor is characterized by excellent dynamic performance and high torque density. The load control of the carriage position or the mechanical load is performed indirectly by the encoder integrated in the motor. The positioning controller is an EPOS2 50/5.
For automatic adjustment of the current controller, the plant is first identified using the procedure described above and then the PI current controller parameters are calculated. For the position controller, the procedure is repeated in the same basic manner and in addition to the PID position controller parameters, feed-forward parameters are also calculated.
The following figures show the improvement of the dynamic performance when Auto Tuning is applied to this practical example.

Figure 7 shows the properties of the current controller before Auto Tuning. The reaction of the motor current to a setpoint step of 100 mA is slow; the motor current oscillates significantly around the desired value.
Figure 8 shows the same situation after successful Auto Tuning of the current controller. The motor current follows the setpoint without overshoot in significantly less than 1 msec. The remaining, very small fluctuations are primarily due to the finite resolution of the current measurement.
The dynamic behavior of the position control for a positioning procedure of the carriage corresponds to a setpoint change of 0 qc to 5000 qc (qc = quadcount, a pulse of the encoder unit corresponds to 4 qc) which is recorded in Figure 9. The significant oscillation around the target trajectory can be recognized, stimulated by the acceleration and braking operation of the positioning procedure.
In contrast, after Auto Tuning the path of the position of the carriage is practically perfect. The following error is extremely low, the steady-state accuracy is achieved in a short period of time (Figure 10).

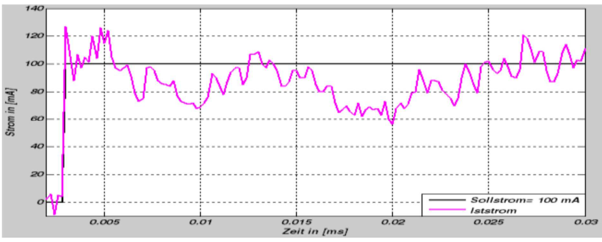

Figure 7 Properties of the current controller before Auto Tuning

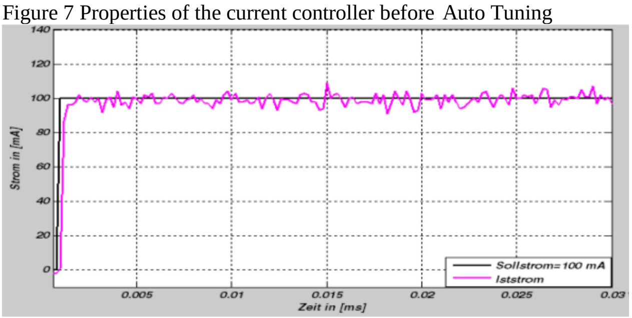

Figure 8 Properties of the current controller after Auto Tuning

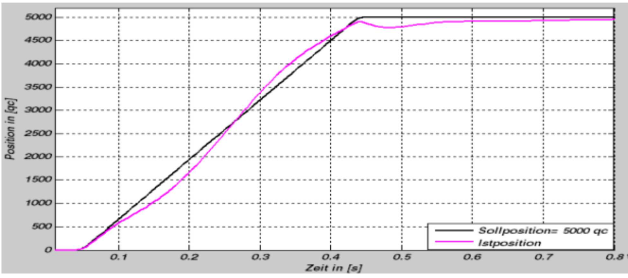

Figure 9 Positioning dynamics before Auto Tuning

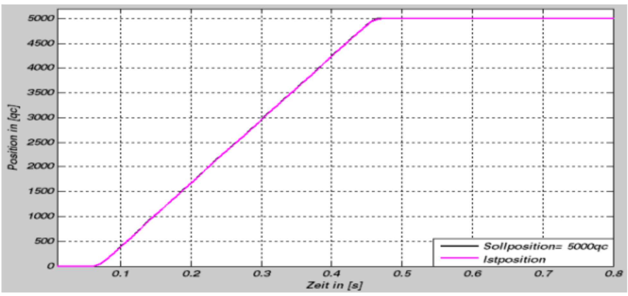

Figure 10 Positioning dynamics after Auto Tuning

Figures 7 to 10 impressively demonstrate the improvement in the control dynamics. Specialized control engineering skills are not required. Because this procedure for automatic adaptation of the controller settings is performed extraordinarily quickly and reliably, the position controller can be put into operation in a matter of seconds.