PARAMETER ESTIMATION OF ELECTROMECHANICAL SYSTEMS

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ABSTRACT

During the test phase of electromechanical systems, such as DC-drives, stepper motors, linear drives, etc., it is important to determine whether the system parameters match the values specified during design and development. Unfortunately most of the parameters are very hard to determine precisely, for example the torque constant of a DC-drive or the damping behavior of a system in general. This paper describes an elegant method to estimate such parameters automatically in a time efficient way.

1. INTRODUCTION

In development programs for space mechanisms, a tight schedule is often the determining factor for many decisions. On one hand, times for integration or functional tests have to be shortened or optimized, but on the other hand, a complete characterization of the mechanisms before flight is highly desired. The reason herein might be the need to collect data for further developments, to provide data for higher system level analysis, to compare mechanisms of the same series for quality reasons, or to optimize a system for a better performance. Hence, a detailed characterization of complicated mechanisms was often an empirical and therefore time-consuming procedure, the desire for a fast and standardized method was always high.
Within the framework of a current production program at Astrium for fast steering mirrors, which comprises 6 flight models, the experiment attempted to develop a generalized procedure to characterize these mechanisms.
The focus herein was on the following aspects:

- It should be possible to use the process for other mechanisms without any adaptation.
- The process should be automated and therefore timesaving, as much as possible.
- The process should allow determining all parameters of the system with a high accuracy.

After successful testing of the parameter estimation procedure with the fine steering mirrors, other components of mechanisms are investigated. In the following chapters the paper describes the estimation process performed for a stepper motor, used in antenna pointing mechanisms, and a DC-drive-bearing combination, used in the coarse pointing assembly of a laser communication terminal.

2. THEORETICAL APPROACH

To determine the functional parameters of a system, a identification-function was commanded to the mechanism and its answer was compared to the answer of a mathematical model. Afterwards the parameters of the model have to be adjusted until both answer functions are congruent (see Figure 1).

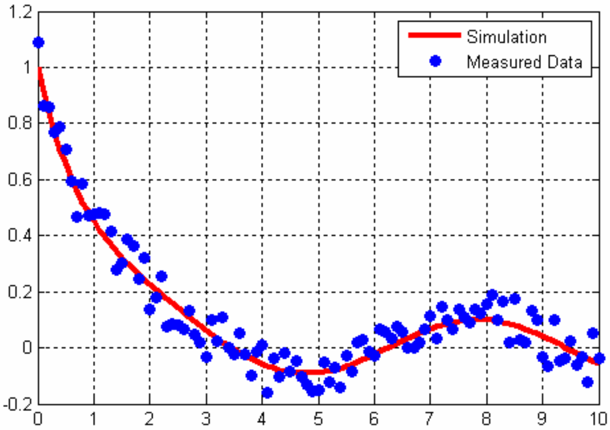

Figure 1. Approximation of a Simulation Model to a Set of Measured Data.

This is a very simple procedure as long as the mathematical model is linear and the order is not too high. For many real world problems, however, a linear mathematical representation is not possible. Some examples in this respect are the stick slip effects of a ball bearing, saturation effects, mechanical or electrical limitations or the backlash of a gear system.
To solve these nonlinear problems the parameter estimation procedure provides a number of iterative algorithms such as:

- Nonlinear Least Squares
- Gradient Descent
- Pattern Search
- Simplex Search

The detailed description of these algorithms is, due to their complexity, not part of this paper.

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3. P.E. FOR FAST STEERING MIRRORS

3.1. Mechanisms Description

As mentioned in the introduction, the parameter estimation procedure was introduced within the production program of Astrium's fast steering mirrors (FSM), which form part of a laser communication terminal (LCT) that is successfully flying on TerraSar-X, for example.

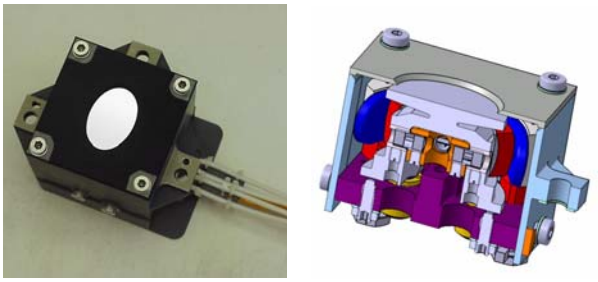

Figure 2. Astrium Fast Steering Mirror

The task of these mirrors within the LCT is to compensate satellite micro vibrations during data transmission. To do this, the mirror is carried by flexural pivots aligned in a cardanic (universal joint) configuration, which allows pointing in two axes. The system is driven by four spherically aligned linear motors in a closed loop control with four eddy current sensors facing the bottom of the mirror.

3.2. Model Information

The model of the FSM contains the digital controller, the current amplifier, the mechanism itself and the sensor electronics, as shown in Figure 3.

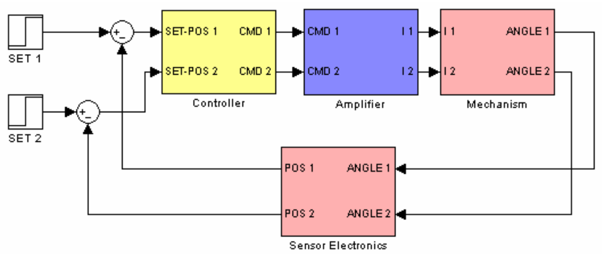

Figure 3. Two Axis Closed Loop Model

Here the following parameters are of interest:

- Mechanisms mass moment of inertia
- Mechanisms damping constant
- Mechanisms flex pivot spring constant
- Sensor electronics common axis scaling
- Mechanisms coil saturation
- Bandwidth of the system

Model non-linearities in this case are:

- Current limitation of the amplifier
- Motor coil saturation
- Mechanical angular limitation
- Signal discretization due to digital controller

3.3. Estimation Results

To estimate these parameters, a step function was applied to the mechanism and the simulation results are compared step by step with the measured data. For the estimation of the FSM parameters, the results were adequate after only a few approximation steps (see Figure 4), as a result of the excellent signal to noise ratio.

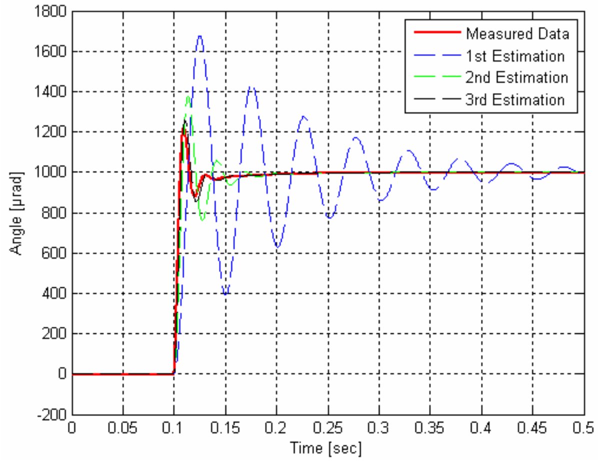

Figure 4. Step Response & Estimation Steps

As an example for the information, obtained from the estimation process, the spring constant of the flex pivots was defined to be 2.26 Ncm/rad, but after the estimation it has changed to be 1.58 Ncm/rad.

In the next step the mechanisms behavior within the frequency domain was investigated to determine further eigenmodes which are not visible in the time domain approach. Therefore the closed loop bandwidth was measured (see Figure 5) and the mathematical model of the mechanism (derived from an ADAMS Model) was optimized to fit the data, as shown in Figure 6 and Figure 7.

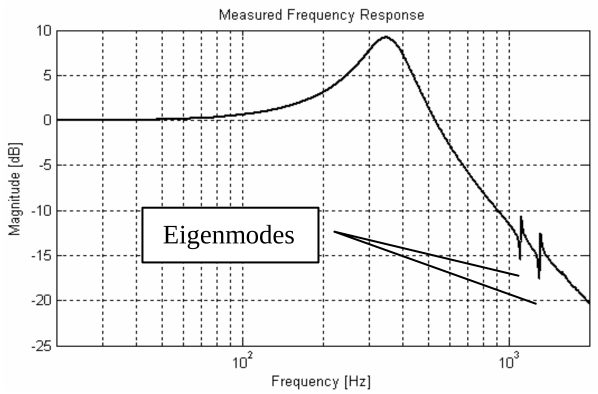

Figure 5. Measured Frequency Response

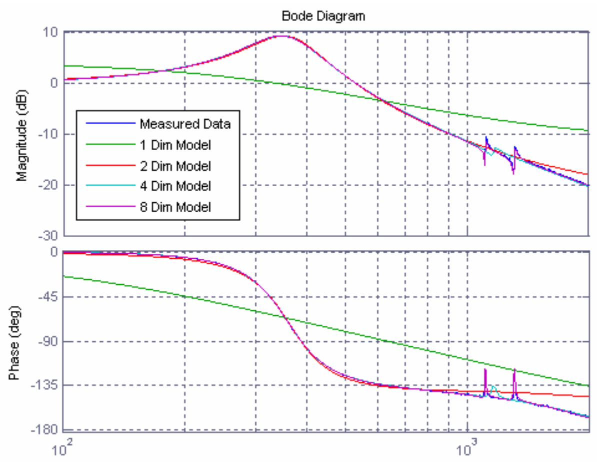

Figure 6. Frequency Domain Estimation Steps

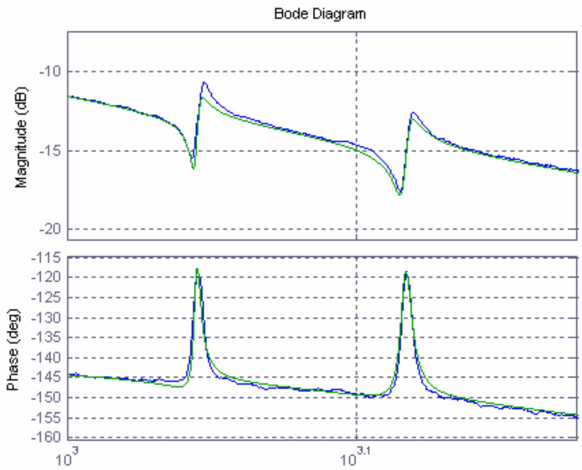

Figure 7. 8th Estimation Step – Detailed View

4. P.E. FOR APM STEPPER MOTORS

4.1. Mechanisms Description

Stepper motors are commonly used in space mechanisms for pointing and deployment. The Antenna Pointing Mechanism (APM) developed at Astrium uses two stepper motors, each combined with a planet gear and a link lever for precise pointing.

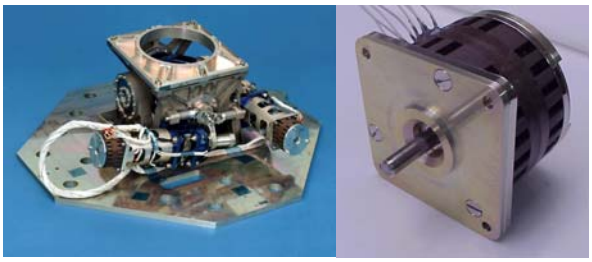

Figure 8. APM & Stepper Motor

After integration, the stepper motors have to prove their functionality using a special torque test rig. The estimation task was to determine motor parameters like torque constant and coil inductance within a short test run.

4.2. Model Information

The model used for the estimation process contains the motor amplifier, the stepper motor itself and the model representation of the torque test rig, as shown in Figure 9.

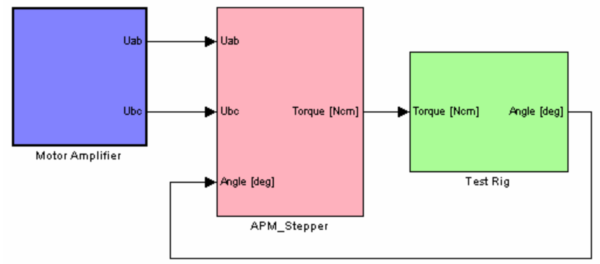

Figure 9. Model of Stepper Motor with Test Rig

Due to the need to operate the motor without any forces, applied to its bearings, the coupling between torque test rig and motor axle was designed with little play and additional rubber spacers.

The parameters of interest are:

- Stepper motor torque constant
- Coil inductance
- Play between test rig and motor axle
- Stiffness of the test rig

Model nonlinearities in this case are:

- Play between test rig and motor axle

4.3. Estimation Results

As shown in Figure 10, the measured data are highly deformed by the nonlinear effects mentioned in the model information chapter. However, the data produced, by the estimation routine, still comes very close to the actual signal.

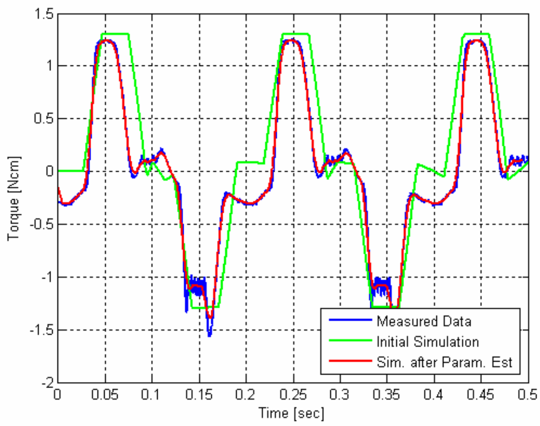

Figure 10. Stepper Motor Estimation Results

5. P.E. FOR A BEARING DC-DRIVE COMBINATION

5.1. Mechanisms Description

The CPA (Coarse Pointing Assembly) in combination with the FSM form a part of the laser communication terminal as mentioned in chapter 3. The CPA consists of two independent drive systems in combination with two SiC mirrors to allow spherical pointing of the laser beam (see Figure 11).

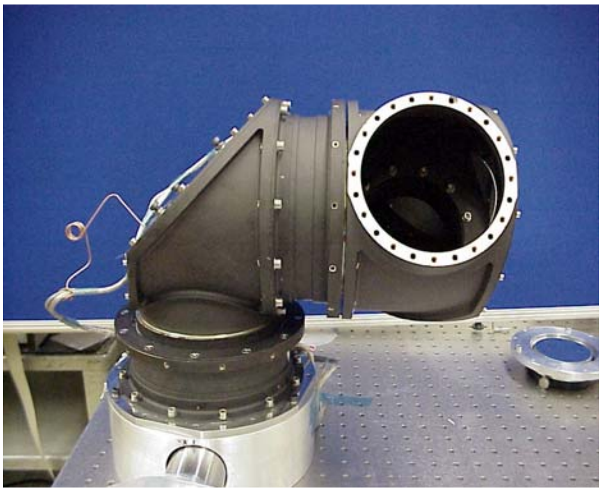

Figure 11. Coarse Pointing Assembly (EM)

The drive systems of the CPA contain MoS_2 coated bearings in combination with a brushless DC-drive (see Figure 12).

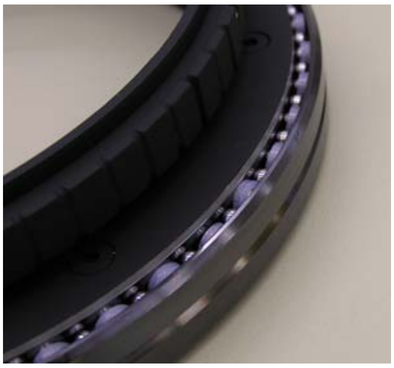

Figure 12. Thin Section Bearing Systems

5.2. Model Information

The most critical case for these bearing systems is the cold start up scenario after vibration. Here the highest start up torque can be measured. This torque peak correlates to the distance between balls, as a cause of MoS_2 coating deformation due to Hertzian stress between ball and bearing races.

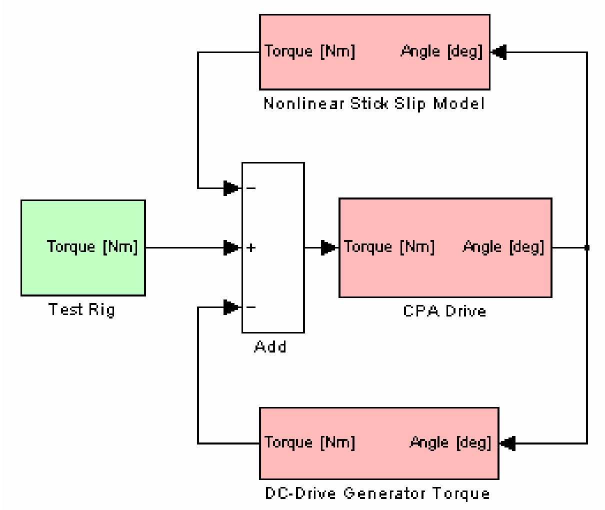

Figure 13. Model of CPA Drive Assembly

The model representation includes a mechanical drive model with inertias and a conventional velocity dependent friction formulation. In addition to this, two separate models, representing the non-linear stick slip effect and the DC-drive generator torque were included in the model.

The parameters of interest are:

- DC-drive generator constant
- Conventional bearing friction
- Stick slip behavior in general

Model nonlinearities in this case are:

- Stick slip formulation

5.3. Estimation Results

As shown in Figure 14, the estimation results do not match the profile of the measured data correctly. One reason for this bad correlation is caused by the structure of the measured data, where the torque peak in relation to the rest of the profile is very sharp and thin and therefore very hard to handle by the algorithm.

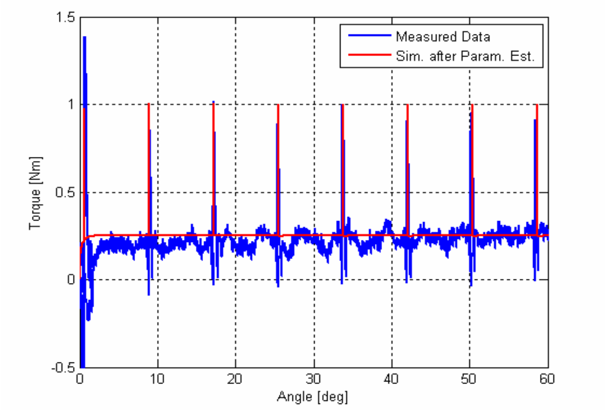

Figure 14. CPA Drive Estimation Results

Here further model refinement has to be done, which is still in progress.

6. LESSONS LEARNED

6.1. Measured Data

The quality of the estimation strongly depends on the structure of the measured data. If the data profile is steady and smooth, like the stepper motor torque profile, the probability for a successful estimation is much higher than for a data profile with sharp peaks, observed at the CPA drive bearings.

6.2. Software

The Matlab software package has emerged as a good tool for optimization tasks with a wide range of predefined functions and algorithms.

6.3. Estimation Process

The number of estimation steps depends significantly on the quality of the measured data and the complexity of the model structure (e.g. the amount of nonlinear effects such as saturation or current limitation).
Estimation results which are not satisfying after numerous iteration steps might be the cause of a wrong model, this requires further model refinement.

7. OUTLOOK

In future projects, the information gained from previous investigations will be used to estimate a mechanisms behavior in the early design phase. One example in this respect might be the controller dimensioning of a DC-drive in combination with a bearing torque behavior described in chapter 5.
It is intended to use the parameter estimation procedure for future projects such as scanning mechanisms, pointing and deployment mechanisms.