

# Various Support Software Tools Using In Simulation and Identification of a Non-linear Unstable System of Motion

JIRI ZATOPEK

Tomas Bata University in Zlin  
Department of Automatic and Control Engineering  
Nad Stranemi 4511, 760 05 Zlin  
CZECH REPUBLIC  
zatopek@fai.utb.cz

*Abstract:* This article introduces two identification possibilities with emphasis to the use of various support software tools. Mechanical structure with strongly non-linear behaviour was used for the purpose of identification and subsequent simulation and the motion control law design. Deductive identification, the first identification method, is based on physico-analytical principle - corresponding mathematical model is derived using Lagrange equations of the second type. The second identification method is inductive identification. It is an experimental method based on the dependence measurement between independently generated input and the real system measured output. This measurement was carried out on the physical model, which was designed by using SolidWorks 3D CAD software and a SimMechanics library. Control laws are designed for the both identified models and the regulatory processes' results are compared.

*Key-Words:* Motion Control, Identification, Simulation, Visualisation, Matlab/Simulink, Simscape, 3D Animation

## 1 Introduction

Nowadays, a large amount of support software tools is available. These tools facilitate our work in analysing, modelling, simulating and designing a control law for complex mechanical structures. By connecting these resources a considerable simplification of the synthesis can be achieved as well as clarity by using visualisation in 3D space directly in the regulation process, or creating a physical model in Simulink directly from CAD software (SolidWorks), without the need to derive the equations of motion.

The system which is the object of our interest is called "Ball and beam", and the description of the dynamic behaviour is derived in the most general way as possible for use in the control of a real model. The ball and beam are mass objects and are thus situated in the 3D space - only the movement is limited to planar. The system is located in the Earth's gravitational field and has two degrees of freedom. The mass of the ball is chosen to have a significant impact on the movement changes of the beam; the beam may be unbalanced. The ball position is measured from the axis of rotation of the beam (i.e. the axis of the shaft of the driving motor). The Denavit-Hartenberg (DH) notation/method of placement for coordinate systems is used to determine the ball's position in a selected global coordinate system.

First, the whole system is sketched-out for the

purpose of compiling a transformation matrix to determine the position of the ball in the global coordinate system. Using this transformation, the equations of motion of the system are derived (deductive identification) - they include the moments of inertia, the centrifugal/centripetal and Coriolis generalized forces, linear friction, etc. Then, a 3D model was constructed in the CAD design software SolidWorks suite, including all kinematic constraints and the mass distribution of the whole assembly. This model is also useful for detecting the masses or matrices/moments of inertia of complex objects, which cannot be determined analytically. The subsequent CAD model is then export into the SimMechanics format in Matlab/Simulink, which leads to a physical model - including its kinematic link and the distribution of the mass of the whole assembly. This model is used for experimental (inductive) identification and subsequently tests the proposed control algorithm and compares the outputs with a mathematical model.

## 2 Deductive identification

### 2.1 Transformation of coordinate systems

Fig. 1 shows the system drawn for the purpose of determining the transformation matrix from the local coordinate system  $(x_2, y_2, z_2)$  to the global system

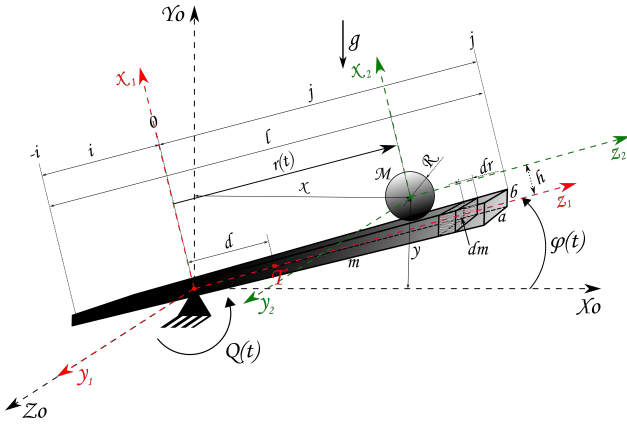


Figure 1: Model with the selected coordinate system placement

$(X_0, Y_0, Z_0)$ . Rotation of the beam is only possible around the global axis  $Z_0$ ; rolling the ball only in direction of local axis  $z_1$  is ideal. The connection of the beam with the frame in the place where the torque actions provide controlled tilting of the beam (i.e. the first degree of freedom) is shown schematically. The second degree of freedom is the movement of the ball on the beam.

The resulting homogeneous transformation matrix between the coordinate systems is:

$${}^0\mathbf{T}_2 = \begin{bmatrix} -\sin \varphi(t) & 0 & \cos \varphi(t) & -h \sin \varphi(t) + r(t) \cos \varphi(t) \\ \cos \varphi(t) & 0 & \sin \varphi(t) & h \cos \varphi(t) + r(t) \sin \varphi(t) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

For determining the homogeneous coordinates of the ball position relative to the origin of the global coordinate system, the equation is:

$${}^0\mathbf{r} = {}^0\mathbf{T}_2 \cdot {}^2\mathbf{r} \Rightarrow \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = \begin{bmatrix} -\left(R + \frac{b}{2}\right) \sin \varphi(t) + r(t) \cos \varphi(t) \\ \left(R + \frac{b}{2}\right) \cos \varphi(t) + r(t) \sin \varphi(t) \\ 0 \\ 1 \end{bmatrix} \quad (2)$$

In order to determine the square-size of the absolute speed vector (in the global coordinate system), it is:

$$|\mathbf{v}|^2 = (\dot{x}^2 + \dot{y}^2) = \left(\frac{2R+b}{2}\right)^2 \dot{\varphi}^2 + r^2 \dot{\varphi}^2 + \dot{r}^2 - (2R+b) \dot{r} \dot{\varphi} \quad (3)$$

Note, the Ball and beam is only planar in this model (processes take place in 2D).

## 2.2 Motion equations

To be able to use Lagrange equations of the second kind, it is therefore necessary to determine the kinetic and potential energy of the whole system.

The kinetic energy of the balls is comprised of its translational and rotational motion:

$$\begin{aligned} E_{k_{ball}} &= \frac{1}{2} M v^2 + \frac{1}{2} \underbrace{\frac{2}{5} M R^2}_{J_{kul}} \underbrace{\frac{\dot{r}^2}{R^2}}_{\omega_{kul}^2} = \\ &= \frac{1}{2} M \left[ \left(\frac{2R+b}{2}\right)^2 \dot{\varphi}^2 + r^2 \dot{\varphi}^2 + \frac{7}{5} \dot{r}^2 - (2R+b) \dot{r} \dot{\varphi} \right] \end{aligned} \quad (4)$$

The potential energy of the ball is:

$$E_{p_{ball}} = M g y = M g \left[ \left(\frac{2R+b}{2}\right) \cos \varphi + r \sin \varphi \right] \quad (5)$$

The Beam is cuboid in shape, with an optionally-stored rotation axis as shown in Fig. 1. Its inertia matrix has  $3 \times 3$  moments of inertia, and is defined as:

$$\mathbf{J} = \begin{bmatrix} J_{xx} & J_{xy} & J_{xz} \\ J_{yx} & J_{yy} & J_{yz} \\ J_{zx} & J_{zy} & J_{zz} \end{bmatrix} = \iiint_B \rho(x, y, z) \begin{bmatrix} J_{xx} & J_{xy} & J_{xz} \\ J_{yx} & J_{yy} & J_{yz} \\ J_{zx} & J_{zy} & J_{zz} \end{bmatrix} \quad (6)$$

in which  $\rho(x, y, z)$  is the density of the material body. If a new coordinate system is selected such that all the deviance moments will be zero; the torques to the individual axes of the system will be equal to the polar moments of the inertia matrix with respect to these axes. A well established system already meets this assumption, it is not necessary to introduce a new coordinate system and the moment of inertia relative to the axis of rotation (axis  $Z_0$ ) will be equal to the polar moment  $J_{zz}$ .

$$\mathbf{J}_{beam} = J_{zz} = \frac{1}{12} m [b^2 + 4(i^2 - ij + j^2)] \quad (7)$$

The kinetic energy of the beam is:

$$E_{k_{beam}} = \frac{1}{2} \dot{\varphi}^2 J_{beam} = \frac{1}{24} m \dot{\varphi}^2 [b^2 + 4(i^2 - ij + j^2)] \quad (8)$$

The relationship between the mass element and the length element can be expressed as:

$$dm = \rho a b dr = \frac{m}{a b l} a b dr = \frac{m}{l} dr \quad (9)$$

The potential energy of the beam element is:

$$dE_{p_{beam}} = dm g \sin \varphi r = \frac{m g \sin \varphi}{i+j} r dr \quad (10)$$

The potential energy of the whole beam is:

$$E_{p_{beam}} = \int_{-i}^j dE_{p_{beam}} = \frac{1}{2} m g \sin \varphi (j - i) \quad (11)$$

The total kinetic and potential energy of the system is the sum of their partial energies:

$$\begin{aligned} E_k &= \frac{1}{24} m \dot{\varphi}^2 [b^2 + 4(i^2 - ij + j^2)] + \\ &+ \frac{1}{2} M \left[ \left(\frac{2R+b}{2}\right)^2 \dot{\varphi}^2 + r^2 \dot{\varphi}^2 + \frac{7}{5} \dot{r}^2 - (2R+b) \dot{r} \dot{\varphi} \right] \end{aligned} \quad (12)$$

$$\mathbf{E}_p = Mg \left[ \left( \frac{2R+b}{2} \right) \cos \varphi + r \sin \varphi \right] + \frac{1}{2} mg \sin \varphi (j-i) \quad (13)$$

The Lagrangian calculation is:

$$\begin{aligned} L = E_k - E_p = & \frac{1}{24} m \dot{\varphi}^2 [b^2 + 4(i^2 - ij + j^2)] + \\ & + \frac{1}{2} M \left[ \left( \frac{2R+b}{2} \right)^2 \dot{\varphi}^2 + r^2 \dot{\varphi}^2 + \frac{7}{5} \dot{r}^2 - (2R+b) \dot{r} \dot{\varphi} \right] - \\ & - Mg \left[ \left( \frac{2R+b}{2} \right) \cos \varphi + r \sin \varphi \right] - \frac{1}{2} mg \sin \varphi (j-i) \end{aligned} \quad (14)$$

The linear friction - dependent upon the generalised speed (i.e. sliding friction with a friction factor  $k_1$  and rolling resistance with a friction factor  $k_2$ ) will be added to the system. The equations of motion are therefore:

$$\begin{aligned} \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = Q_i \quad \Rightarrow \quad \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{r}} \right) - \frac{\partial L}{\partial r} = 0 \\ \frac{d}{dt} \left\{ \frac{1}{2} M \left[ \frac{14}{5} \dot{r} - (2R+b) \dot{\varphi} \right] \right\} - Mr \dot{\varphi}^2 + Mg \sin \varphi = 0 \end{aligned} \quad (15)$$

$$\frac{7}{5} M \ddot{r} - \frac{2R+b}{2} M \ddot{\varphi} - Mr \dot{\varphi}^2 + k_1 \dot{r} + Mg \sin \varphi = 0 \quad (16)$$

$$\begin{aligned} \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = Q_i \quad \Rightarrow \quad \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\varphi}} \right) - \frac{\partial L}{\partial \varphi} = 0 \\ \frac{d}{dt} \left\{ \frac{1}{2} M \left[ \frac{(2R+b)^2}{2} \dot{\varphi} + 2r^2 \dot{\varphi} - (2R+b) \dot{r} \right] + \frac{1}{12} m \dot{\varphi} [b^2 + \right. \\ \left. + 4(i^2 - ij + j^2)] \right\} + Mg \left[ r \cos \varphi - \left( \frac{2R+b}{2} \right) \sin \varphi \right] + \\ + \frac{1}{2} mg \cos \varphi (j-i) = Q \end{aligned} \quad (17)$$

$$\begin{aligned} M \left( \frac{2R+b}{2} \right)^2 \ddot{\varphi} + Mr^2 \ddot{\varphi} + \frac{1}{12} m [b^2 + 4(i^2 - ij + j^2)] \ddot{\varphi} - \\ - M \frac{2R+b}{2} \ddot{r} + 2Mr \dot{\varphi} \dot{\varphi} + k_2 \dot{\varphi} + Mgr \cos \varphi - \\ - Mg \left( \frac{2R+b}{2} \right) \sin \varphi + \frac{1}{2} mg (j-i) \cos \varphi + 2Mr \dot{\varphi} = Q \end{aligned} \quad (18)$$

After modification, we can write:

$$\begin{aligned} \ddot{\mathbf{r}} = \frac{60A \left[ \begin{array}{l} Q - k_2 \dot{\varphi} + AMg \sin \varphi - Mgr \cos \varphi + \\ + \frac{1}{2} mg (i-j) \cos \varphi - 2Mr \dot{\varphi} \end{array} \right]}{24MA^2 + 84Mr^2 + 7Bm} - \\ - \frac{5 \left[ \begin{array}{l} (12MA^2 + 12Mr^2 + Bm) \cdot \\ \cdot (k_1 \dot{r} - Mr \dot{\varphi}^2 + Mg \sin \varphi) \end{array} \right]}{24M^2A^2 + 84M^2r^2 + 7Bm} \\ \ddot{\varphi} = \frac{6 \left[ \begin{array}{l} 14Q - 14k_2 \dot{\varphi} - 10Ak_1 \dot{r} + 10AMr \dot{\varphi}^2 + \\ + 4AMg \sin \varphi - 14Mgr \cos \varphi + \\ + 7mg(i-j) \cos \varphi - 28Mr \dot{\varphi} \end{array} \right]}{24MA^2 + 84Mr^2 + 7Bm} \end{aligned} \quad (19)$$

in which:

$$\mathbf{A} = \left( \frac{2R+b}{2} \right) \quad \mathbf{B} = [b^2 + 4(i^2 - ij + j^2)] \quad (20)$$

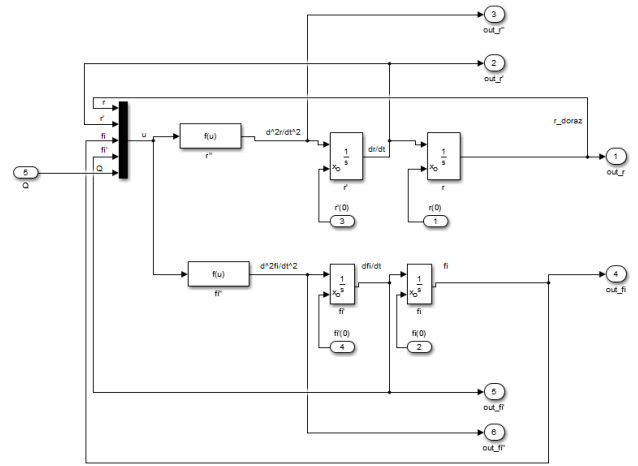


Figure 2: The non-linear mathematical model in Simulink

The block diagram in Simulink that corresponds to the derived non-linear mathematical model was created from the Equation (19). The modified equations of motion are part of the  $r''$  and  $\varphi''$  functional blocks, and it is also possible to choose non-zero initial conditions of the mathematical model.

For the state vector:  $[r \ v \ \varphi \ \omega]^T = [x_1 \ x_2 \ x_3 \ x_4]^T$  and input signal:  $Q = u$  the state-space representation will correspond to the shape of:

$$\begin{aligned} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} x_2 \\ 60A \left[ \begin{array}{l} Q - k_2 x_4 + AMg \sin x_3 - \\ -Mg x_1 \cos x_3 + \frac{1}{2} mg (i-j) \cos x_3 - \\ -2M x_1 x_2 x_4 \end{array} \right] \\ \frac{5 \left[ \begin{array}{l} (12MA^2 + 12Mx_1^2 + Bm) \cdot \\ \cdot (k_1 x_2 - Mx_1 x_4^2 + Mg \sin x_3) \end{array} \right]}{24M^2A^2 + 84M^2x_1^2 + 7Bm} \\ x_4 \\ 6 \left[ \begin{array}{l} 14Q - 14k_2 x_4 - 10Ak_1 x_2 + 10AMx_1 x_4^2 + \\ + 4AMg \sin x_3 - 14Mgr \cos x_3 + \\ + 7mg(i-j) \cos x_3 - 28Mx_1 x_2 x_4 \end{array} \right] \\ \frac{24MA^2 + 84Mx_1^2 + 7Bm}{} \end{bmatrix} \end{bmatrix} \quad (21)$$

From these equations, it can be determined that the system has only one unstable singular point and its steady-state is only given by the ball position on the lever/beam  $x_1$ .

All remaining state variables are zero in singular point. The singular (stationary) point is:

$$[x_1^0 \ x_2^0 \ x_3^0 \ x_4^0]^T = \left[ \frac{m(i-j)}{2M} \ 0 \ 0 \ 0 \right]^T \quad (22)$$

The Steady state is:

$$\begin{aligned} x_1^s &= \frac{u^s}{Mg} + \frac{m(i-j)}{2M} \\ u^s &= Mg x_1^s - \frac{1}{2}mg(i-j) \end{aligned} \quad (23)$$

Linearisation in the working point  $x_1^s$  (i.e. steady state) can be obtained from the transmission of the linear model:

$$G(s) = \frac{X_1(s)}{U(s)} = \frac{b_2 s^2 + b_0}{s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0} \quad (24)$$

in which:

$$\begin{aligned} b_2 &= \frac{60A}{24MA^2 + 336Mx_1^{s^2} + 7Bm} \\ b_0 &= \frac{-60g}{24MA^2 + 336Mx_1^{s^2} + 7Bm} \\ a_3 &= \frac{60MA^2k_1 + 240Mk_1x_1^{s^2} + 84Mk_2 + 5Bk_1m}{M(24MA^2 + 336Mx_1^{s^2} + 7Bm)^2} \\ a_2 &= \frac{(12096AgM^3 + 20160Mk_1k_2)x_1^{s^2} - 10080AgmM^2(i-j)x_1^s + 864A^3M^3g + 1440A^2Mk_1k_2 + 420Bk_1k_2m + 252ABgmM^2}{M(24MA^2 + 336Mx_1^{s^2} + 7Bm)^2} \\ a_1 &= \frac{-60Agk_1}{24MA^2 + 336Mx_1^{s^2} + 7Bm} \\ a_0 &= \frac{-60Mg^2 \left[ 24MA^2 + 336Mx_1^{s^2} + 7Bm - 168m(i-j)x_1^s \right]}{(24MA^2 + 336Mx_1^{s^2} + 7Bm)^2} \end{aligned} \quad (25)$$

Linearisation is derived in the general position of the working point, so it is possible to continuously recalculate it. In case of configuration with Equation (26)

$$\begin{aligned} g &= 9.81 \text{ m} \cdot \text{s}^{-2}; & i &= 0.3 \text{ m}; & j &= 0.29 \text{ m}; \\ b &= 15 \text{ mm}; & R &= 15 \text{ mm}; & k_1 &= 3 \cdot 10^{-3}; \\ k_2 &= 5 \cdot 10^{-4}; & m &= 1.24 \text{ kg}; & M &= 0.125 \text{ kg}; \end{aligned} \quad (26)$$

the transfer function is in the following format for this configuration and linearisation at equilibrium:

$$G(s) = \frac{0.431s^2 - 187.9}{s^4 + 0.0305s^3 + 0.3193s^2 - 0.0127s - 231.9} \quad (27)$$

### 3 Inductive identification

This method of identification is based on the dependence measurement between independently generated input and the real system measured output. This requires having a real system which is possible to measure on. Currently it can be replaced by the 3D

model quite well. This model has integrated links between the system elements, masses (materials), frictions, gravity, force effects, disturbances, bumpers, etc. For this purpose was used SolidWorks 3D CAD software and MATLAB/Simulink - especially Simscape library.

3D model of the system will be constructed firstly. It will have linkages and materials of all the individual parts (i.e. mass and the associated moments of inertia, center of gravity, etc.). This model will be exported as .xml format and then it will be imported into MATLAB. It is appears as a normal Simulink model. Physical quantities are introduced to this model - actuators are connected to signals in Simulink and they utilizing the variables/waveforms of MATLAB.

#### 3.1 SolidWorks

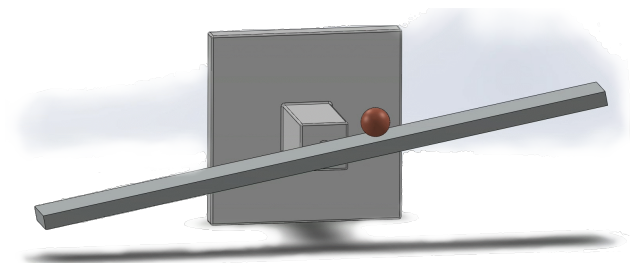


Figure 3: The complete assembly in SolidWorks

The considered system consists of three basic parts: the base, the beam and the ball. All of these parts are material. Ideally, a rigid base is connected to the frame so its physical properties are not relevant to the dynamic behaviour of the system.

#### 3.2 The SimMechanics physical model

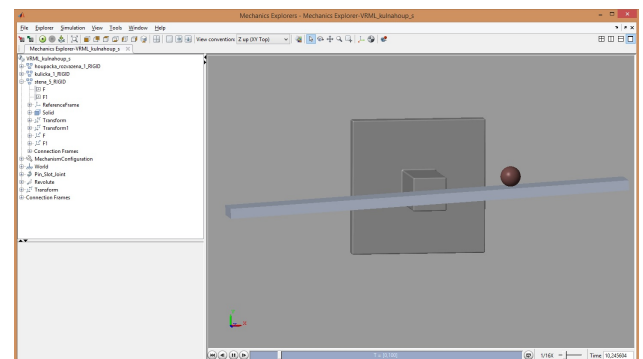


Figure 4: A Real-time visualisation using the SimMechanics Second Generation suite

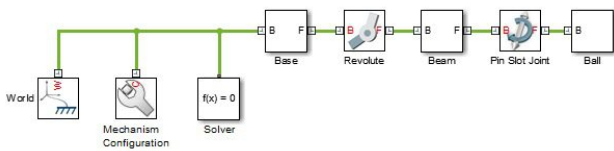


Figure 5: A separate model in the SimMechanics environment

The SolidWorks 3D CAD model (Fig. 3) was exported in SimMechanics second generation *xml* format and then imported into the MATLAB/Simulink environment as a Simulink scheme (Fig. 5). The link were revised because - between SolidWorks and SimMechanics; some are unknown or illicit.

### 3.3 3D Animation

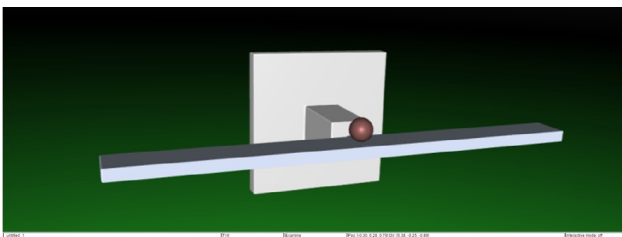


Figure 6: Visualisation using a 3D Animation Toolbox in a web-browser

This model is also exported from the SolidWorks suite - but in the *wrl* format , which is loaded into a special block through the 3D Simulation toolbox. As inputs to this block are used, outputs from the mathematical model are converted through the transformation matrix (HD notation) into the translational and rotational motions of the individual parts of the assembly. Visualisation has more visualising options, e.g. a Web browser can also be used (Fig. 6).

### 3.4 Physical model identification

Torque impulse from system steady-state was chosen as input signal for identification. Nelder-Mead simplex method was chosen to minimize the quadratic functional (*fminsearch* in MATLAB). It does not use derivation for minimum finding. It is capable to find only a local minimum so it is necessary to properly choose the initial conditions in the case of multiple local minimum function. Quadratic functional was chosen as difference between the actual and the estimated response to control effort, squared.

It is the only acceptable solution due to the instability of the system. Despite the perfect conformity compared with the real system response, experi-

mentally determined transfer function is usable in the vicinity of linearisation point only - because of the fast-changing dynamics of the controlled system. The size of the input signal was also necessary to change judiciously. Approximately every tenth determined transfer function is applicable to control the system around the equilibrium state, but to a limited distance only. The transfer function shape was chosen the same as the deductive identification.

One of the successful identification course is shown in Fig. 7.

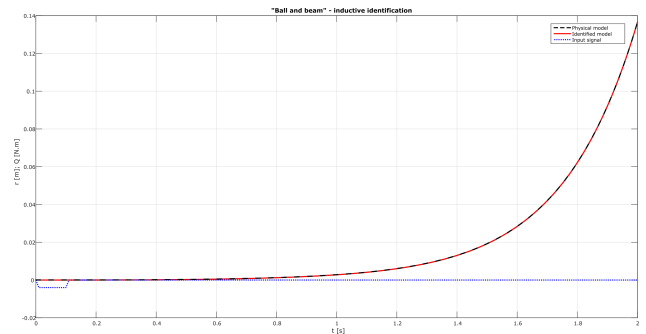


Figure 7: Physical model response vs identified model response

The transfer function of inductive identification (numerical calculation) for the parameters in Equation (28):

$$G(s) = \frac{0.6575s^2 - 277.1}{s^4 + 0.7536s^3 - 2.254s^2 - 11.27s - 364.6} \quad (28)$$

## 4 Control and results comparison

### 4.1 Cumulative Numerical Error

The large numbers of trigonometric functions and multiples of rounded state variables it contains leads to the generation of cumulative numerical error. Thus, despite placing the ball in equilibrium, the system will set itself into motion - as is apparent from Fig. 8.

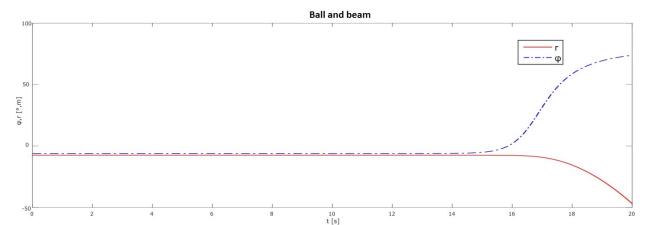


Figure 8: Cumulative Numerical Error

### 4.2 Simulink control circuit

The system is controlled by a linear regulator with 1DOF designed by the pole placement with a continu-

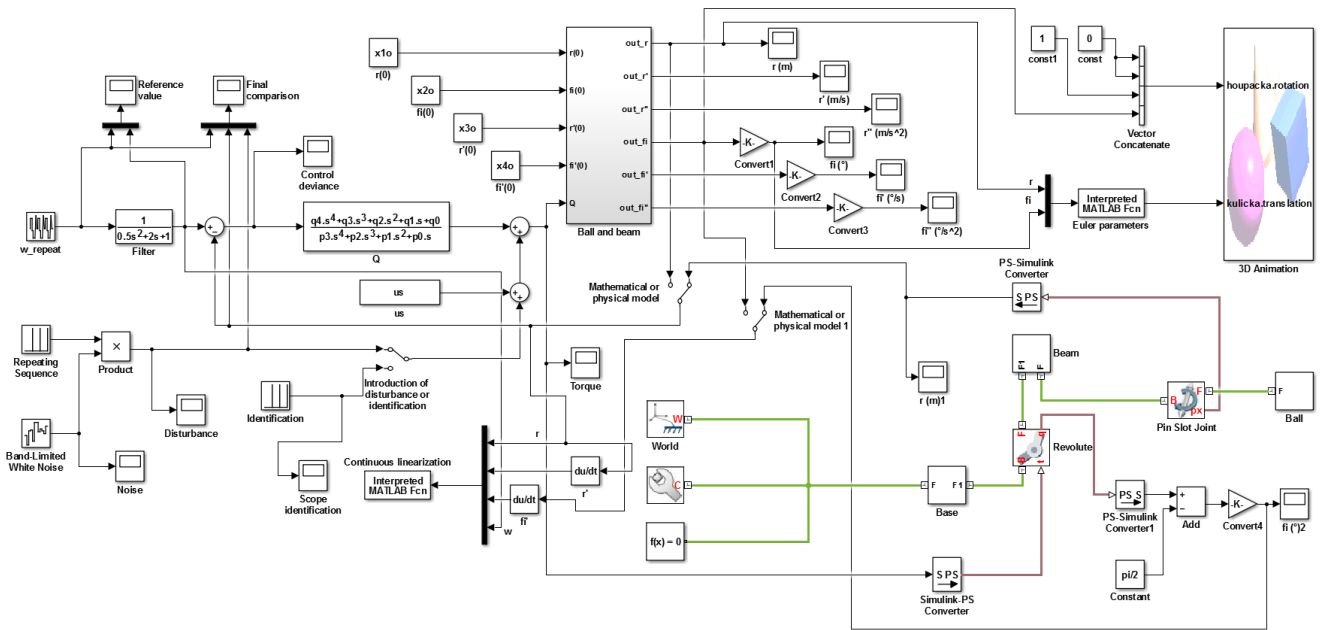


Figure 9: Complete Simulink scheme

ous linearisation in case of Equation (27) use - deductive identification. The controller parameters - resulting from the transfer function, are derived generally so that they can be updating continuously. Continuous linearisation is not possible for Equation (28) - inductive identification, because the transfer function is derived for equilibrium impulse response only. The final regulator then, has the form:

$$Q(s) = \frac{U(s)}{E(s)} = \frac{q(s)}{p(s)} = \frac{q_4s^4 + q_3s^3 + q_2s^2 + q_1s + q_0}{s(p_3s^3 + p_2s^2 + p_1s + p_0)} \quad (29)$$

The step-changes in the reference value will be followed by step-changes in the control deviation; then there will be a problem with the physical realisation of a step changes in the torque - and thus to the rapidly-changing tilt of the beam. In combination with the centrifugal forces and inertia of the system, the process will oscillate; and sometimes will be an unmanageable state. In case of Equation (28) use, the step-changes are big problem for control process and often destabilizes the control system. Therefore, a filter that prevents such step-changes was introduced into the system.

Complete Simulink scheme with SimMechanics and 3D Animation is shown in Fig. 9.

Fig. 10 shows configuration, where the ball initial position ( $x_0$ ) is 6 centimetres from equilibrium and reference value ( $w$ ) is set to equilibrium. Regulatory process course based on the inductive identification model (black curve) is more oscillating and slower stabilized than the course of deductive identification model (red curve).

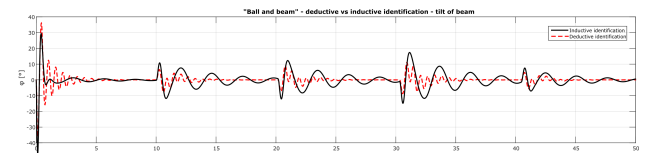
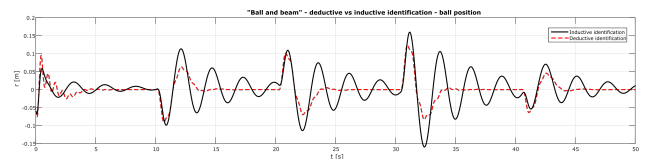


Figure 10: Deductive vs inductive identification -  $w = 0 \text{ cm}$ ,  $x_0 = -6 \text{ cm}$

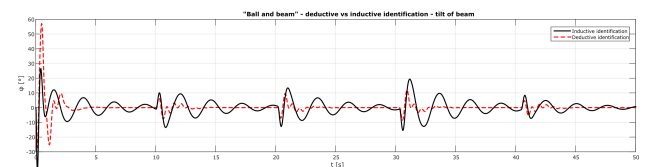
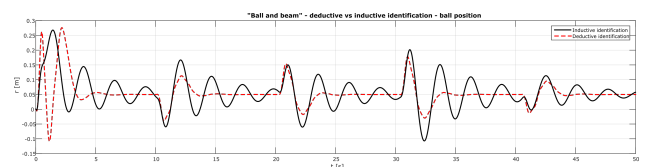


Figure 11: Deductive vs inductive identification -  $w = 5 \text{ cm}$ ,  $x_0 = 0 \text{ cm}$

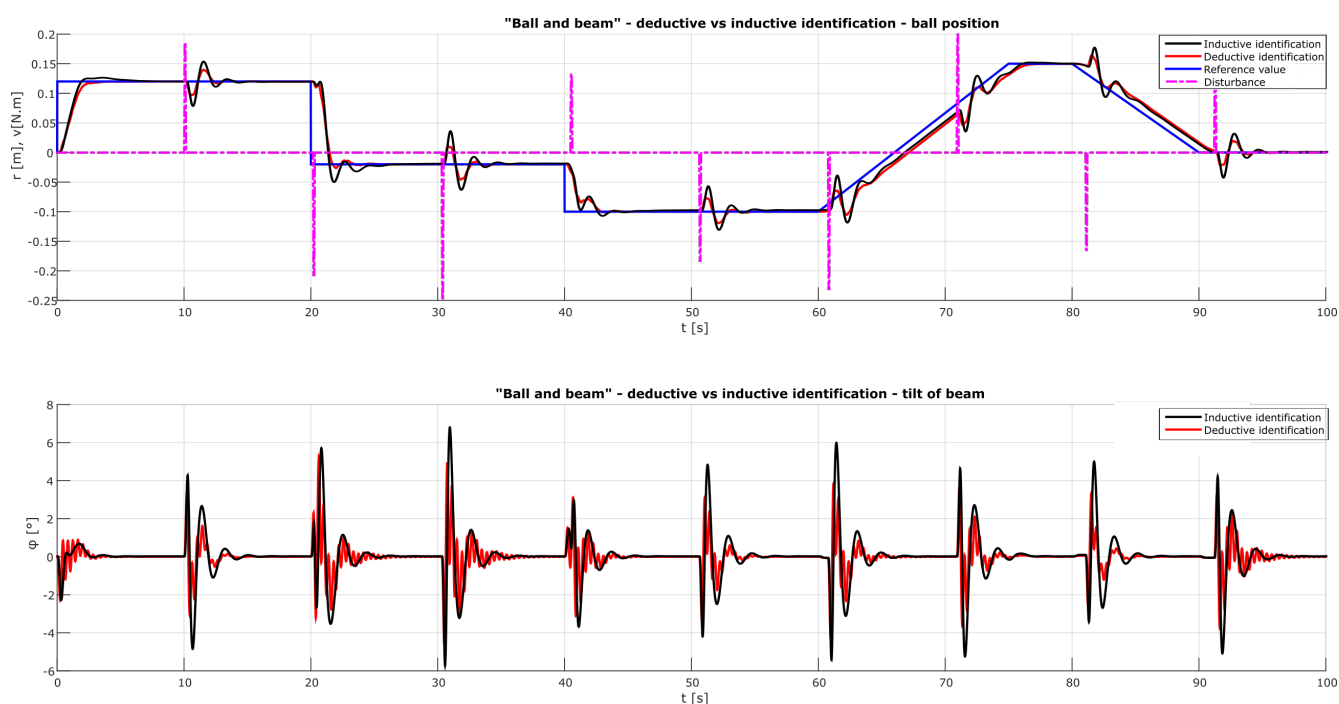


Figure 12: Control processes for inductive and deductive identifications methods

Fig. 11 shows another configuration for the ball initial position in equilibrium and reference value is set to 5 centimetres from equilibrium. Control process is similar to the previous simulation - Fig. 10.

Transfer function identified by inductive identification will never be as accurate as well deductively derived transfer function, because it does not contain the complete dynamics of the system and when any system parameter is changed, system should be re-identified.

As shown in Fig. 12, the control processes of both identification methods are nearly identical, but the inductive identification curve has the same shortages as in Fig. 10 and Fig. 11. The controller is designed to compensate for disturbance and the reference value is in the shape of a step-change, so a lag fault will appear in the transition part of the process at the ramp-shaped reference value. The trend of the reference value however, replicates very well.

## 5 Conclusion

This article contains a complete control design solution of a system known as a Ball and beam.

The first substantial part of the article relate to the derivation of systems motion equations from their energy balance and subsequent transfer function derivation; deductive identification. The model was - through to the definition of transmission, derived in a quite general manner and corresponds to motion equa-

tions linearised at the operating point. Therefore, it is possible to carry out a continuous linearisation efficiently - and with low computational effort. This description however, applies only in the area surrounding the working point. When this point changes, linearisation is needed again.

The second part of the article is inductive identification. It requires the use of software tools because the identification method is based on a numerical calculation. The transfer function corresponding this type of identification is derived from the system impulse response and because of the great system instability is valid in the vicinity of equilibrium only - the identification was done here. From this purpose it does not contain the complete dynamics of the system and when any system parameter is changed, system should be re-identified.

Linking with 3D CAD software and Matlab/Simulink, while using toolboxes for physical modelling (SimMechanics) and 3D visualisation outputs (3D Animation) is a very visual and effective control tool for the presentation of the results. In real time, it is possible to observe dynamic processes occurring in the system and for instance - for to slow then down or to pause them for the purpose of detailed motion analysis or the exploration of the energy interactions between system components.

The third part is control the system. The control methods designed a described herein are tested on a unbalanced system with variable reference course and

disorders. To achieve the desired quality of regulation (particularly for inductively identified model), it is necessary to eliminate a step-change in the control deviation and to stabilize the course of the regulatory process.

As shown Fig. 10, Fig. 11 and Fig. 12, control process quality is more valuable in case of deductive identification - it has not a high overshoot and it has more stable courses.

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