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Position Control – –Watt Controller

Osvald Modrlák, Lukáš Hubka
Steffen Gärtner, Frank Worlitz

4/2015

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CONTENT

1 INTRODUCTION

Often the electric drives in industry application are connected to mechanical systems. The theoretical process analysis shows that these systems are often nonlinear. The mechatronic system considered in this experiment is a representative of this class. The whole system is described by a set of nonlinear equations. The described system was used in the history to control the steam engines rotational speed, it was introduced by James Watt (Watt Controller). The laboratory task, which is investigated in this manual, is constructed to control the actual height of the centrifugal flying balls by a rotational speed of a DC motor.

Aims of the experiment are described by following statements.

a) To find a mathematical model for this system and to carry out simulation experiments with this model. Dynamic curves are measured for the verification of the real process.

b) The focus of the programming work is the development of programs using SIMULINK subsystems and nonlinear blocks.

2 EXPERIMENT DESCRIPTION

A functional diagram of the laboratory test rig focused to the track and a signal representation is shown in Fig. 1. A DC motor is coupled via a transmission (gear box with fixed ratio) with the mechanical centrifugal balls controller (Watt controller) in this experiment. The description is made on the basis of Fig. 1. The plant basement consists of a DC motor (M) with tachogenerator (T) and the transmission gear (P) which drives the Watt controller. The actual position (height) of the balls is measured. All signals are connected to the multifunctional I/O-card (MC). The software package is installed on the PC software. The DC motor axis rotation speed is controlled by electrically manipulated power control unit (PS). This device is connected to an external voltage U_0. This voltage can be generated by computer's I/O measuring card in the range of $0\,..\,5\,\mathrm{V}$ and change the DC motor voltage U in the range $0\,..\,24\,\mathrm{V}$. The speed is measured by the tachogenerator in the voltage range $U_T = 0\,..\,40\,\mathrm{V}$. This voltage signal is through a voltage divider connected to the I/O-card inside the PC as the voltage U_T^*. The range of this voltage signal U_T^* is $0\,..\,5\,\mathrm{V}$. The position sensor (PS) provides a voltage U_P in the range $0\,..\,10\,\mathrm{V}$, which is proportional to the controller's balls level x_H. The voltage signal is measured by the I/O-card inside the PC. The digital meter DM1 displays the signals $U_0(t)$ and/or $U_P(t)$ changed via the switch PR1. The digital meter DM2 shows the signals $U(t)$ and/or $U_T(t)$ changed through the switch PR2. Generally, the controller balls level x_H can be controlled by the external voltage U_0.

Tab. 1: Description of components

AI	Analog input of the multifunctional I/O-card Advantech PCI 1711
AO	Analog output of the multifunctional I/O-card Advantech PCI 1711
DM1	Digital multimeter, PMLED
DM2	Digital multimeter, PMLED
M	Permanent magnet DC motor, P6SZ535
MC	Multifunctional measurement I/O-card, Advantech PCI 1711
PR1	Switch, 2 KNX
PR2	Switch, 2 KNX
P	Gearbox, gear ratio $1{:}8$
PS	Position sensor, CLP13-100
SW	Software package
PS	Power control unit, ZX200-ADJ-24V
T	Tachogenerator, K5A7-00
U/U	Voltage/voltage converter

Tab. 2: Signal description

u	Manipulated variable	Input signal for the DC motor rotation speed $U_0(t) \rightarrow \omega(t)$
y	Controlled variable	Measured balls level $x_H(t) \rightarrow U_P(t)$
y_2	Matlab input signal	Measured DC motor source voltage $U(t) \rightarrow U^*(t)$
y_3	Matlab input signal	Measured output signal of the tachogenerator $U_T(t) \rightarrow U_T^*(t)$

Tab. 3: Signals description and their physical ranges

U_0	Output signal of the I/O card	$0\,..\,5\ \mathrm{V}$	Displayed on DM1
U	DC motor power voltage	$0\,..\,24\ \mathrm{V}$	Displayed on DM2
U^*	DC motor measured voltage (divided)	$0\,..\,5\ \mathrm{V}$	Input signal y_2 in the I/O-card
U_P	Position sensor signal	$0\,..\,10\ \mathrm{V}$	Input signal y in the I/O-card, (on DM1)
U_T	Output signal of the tachogenerator	$0\,..\,40\ \mathrm{V}$	Displayed on DM2
U_T^*	Measured output signal of the tachogenerator	$0\,..\,5\ \mathrm{V}$	Input signal y_3 in the I/O-card

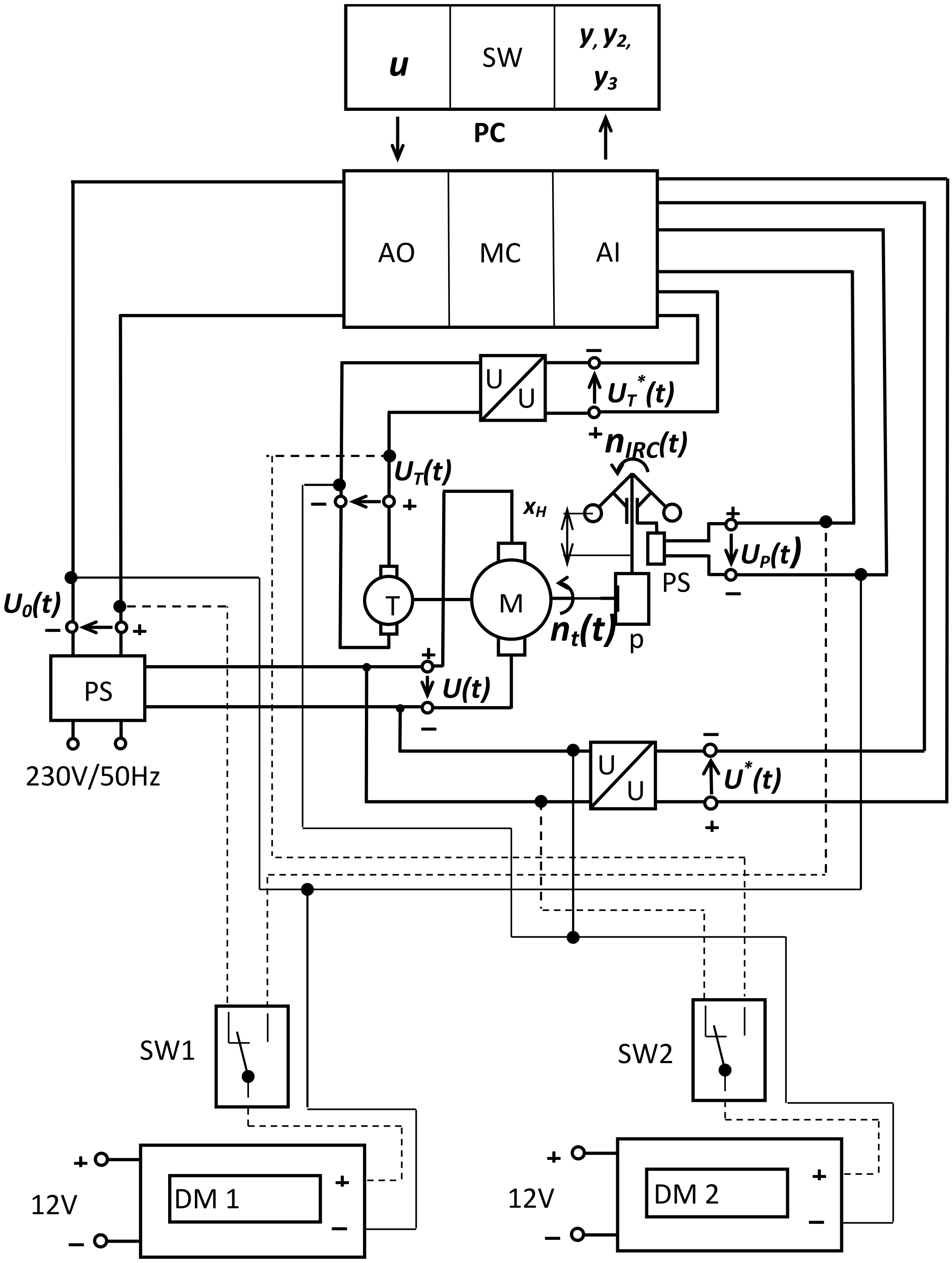

Fig. 1: Functional diagram

3 THEORETICAL PROCESS ANALYSIS

The goal of the experimental study is to perform following tasks:

a) Acquaint with the mathematical and physical analysis for the idealized system.
b) Acquaint with the mathematical and physical analysis for a modification of the technical implementation.
c) Build simulation models and run simulations.
d) Compare results between idealized and modified system.

3.1 IDEALIZED SYSTEM

For the idealized system the following conditions are supposed.

1. All masses of the flying part are concentrated into the balls of the controller.
2. All other flying parts are considered to be weightless.
3. All movements between the mechanical parts are smooth. The end play of all parts is equal to zero.
4. The coordination system is centered in the middle of the ball.

The idealized model is shown in Fig. 2. It consists of the substitution diagram of the DC motor, the gearbox and of the centrifugal ball system.

Tab. 4: Description of physical values in Fig. 2

Value	Unit	Description
$F(t), F_{ox}(t)$	N	Centrifugal force, centrifugal force in x direction
$G, G_x(t)$	N	Gravity, gravity in x direction
$i_M(t)$	A	DC motor armature coil current
$J_c(t)$	kg·m^2	Total inertia
l	m	Length of the controller arm
L	H	DC motor armature inductance
$M_h(t)$	Nm	Entire drive torque
$M_{ZC}(t)$	Nm	Entire load torque
p	-	Gear ratio $(1:8)$
R	Ω	DC motor armature resistance
$U(t)$	V	DC motor armature source voltage
$U_i(t)$	V	DC motor induced voltage
$x(t)$	m	Distance of the rotating ball from the starting point
$x_H(t)$	mm	Height of the rotating centrifugal balls lift
$\theta(t)$	rad·s^{-1}	Ball system angular velocity (after transmission)
$\varphi(t)$	rad	Centrifugal balls arm deflection angle - idealized model
$\omega(t)$	rad·s^{-1}	DC motor shaft angular velocity

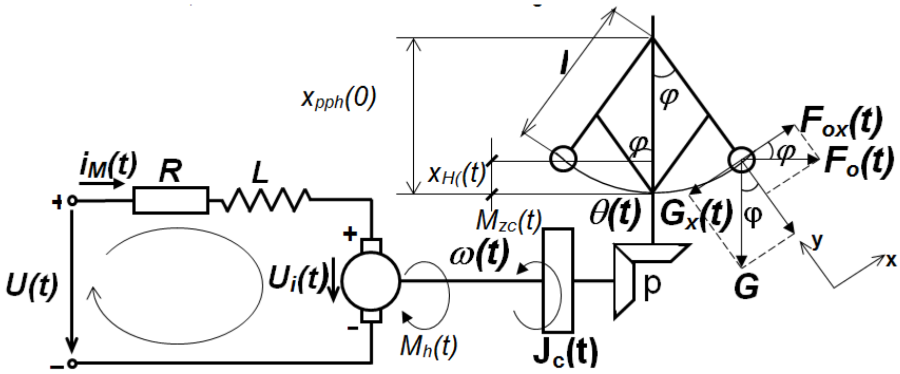

Fig. 2: Idealized model

3.1.1 Mathematical model of the idealized system

By the derivation of the idealized model we use the model of permanent magnet DC motor, the dynamic equilibrium of forces acting on the particle of the ball system (Watt controller) and the d'Alembert principle. Because the DC motor is coupled through a fixed coupling with the ball system, it is possible to get three differential equations, which are also coupled. The resulting mathematical model includes:

- the differential equation for the electrical loop of the motor (1),
- the differential equation of motion of the centrifugal ball system (2),
- the impulse principle for torques (3).

The resulting system is described by the following equations:

$$\frac{di_M(t)}{dt} + \frac{R}{L} \cdot i_M(t) + \frac{km}{L} \cdot \omega(t) = \frac{1}{L} \cdot U(t), \tag{1}$$

$$\frac{d^2\varphi(t)}{dt^2} + \frac{b}{m} \cdot \frac{d\varphi(t)}{dt} + g \cdot \sin\varphi(t) - \theta^2(t) \cdot l \cdot \sin\varphi(t) \cdot cos\varphi(t) = 0, \tag{2}$$

$$J_c(t) \cdot \frac{d\omega(t)}{dt} = [M_h(t) - M_{zc}(t)]. \tag{3}$$

Tab. 5: Values, symbols and basic formulas for calculation the idealized system

$J_c(t)$	Total moment of inertia
$M_h(t) = km \cdot i_M(t)$	DC motor torque equation
$M_{zc}(t) = M_{oc}(t) + M_{zext}(t)$	Total torque of the load
$M_{oc}(t) = M_r(t) + M_{zr}(t)$	The torque of the load due to bearing friction and aerodynamic friction (balls are flying in air)
$M_{zext}(t) = 0$	External torque
$\theta(t) = \frac{1}{p} \cdot \omega(t)$	Angular velocity of the ball system
$\varphi(t)$	Angle of deflection of the ball system arms
b	Friction coefficient
g	Acceleration of gravity
km	Motor constant
m	Balls mass

3.1.2 Calculation of the total moment of inertia J_C

The total moment of inertia is described by the equation

$$J_c(t) = J_{mot} + J_{red}(t), \tag{4}$$

where $J_{red}(t)$ depending on the deflection angle φ of the rotational speed of the centrifugal ball system. $J_{red}(t)$ can be described by the equation

$$J_{red}(t) = \frac{1}{2} \cdot [l \cdot sin\varphi(t)]^2 \cdot m \cdot \left(\frac{1}{p}\right)^2. \tag{5}$$

3.1.3 Calculation of the load torque M_r (bearing friction)

More generally, the load bearing friction torque M_r depends on the angular velocity ω and on the viscosity coefficient B. The bearing friction can be approximated by the formula

$$M_r(\omega) = B(\omega) \cdot \omega. \tag{6}$$

The coefficient B is dependent on the angular velocity ω. The function is shown in the Fig. 3, the function values are given in Tab. 10.

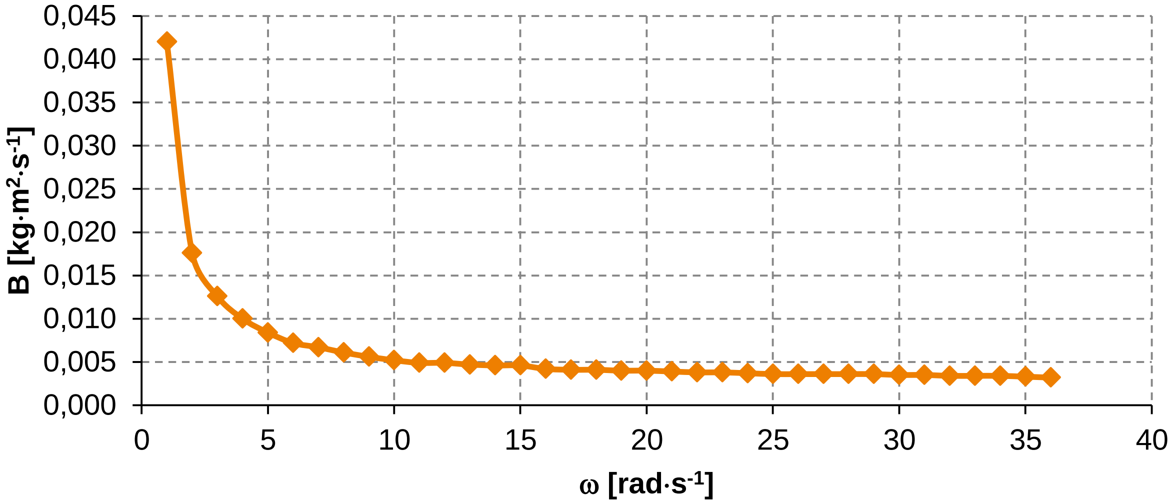

Fig. 3: Coefficient *B* function

3.1.4 Calculation of the load torque M_{zr} (aerodynamic friction)

The load torque M_{zr} depends on the speed of the flying balls subsystem. It is a moment of friction and is caused by friction forces in the bearing and by aerodynamic friction forces of the flying centrifugal balls through the air.

One of many possible approximations of the load torque $M_{zr}(t)$ has the form

$$M_{zr} = \frac{1}{2} \cdot \theta^2(t) \cdot [l \cdot sin\varphi(t)]^3 \cdot C_x \cdot \rho_{air} \cdot S_{zyl}, \tag{7}$$

where C_x is the coefficient of air resistance, ρ_{air} is the specific density of the air and S_{zyl} is the surface of the flying centrifugal balls.

3.1.5 Friction coefficient b

The coefficient b in the equation (2) depends on the angular velocity θ of the flying balls subsystem. The measured function values are given in Tab. 11 and an approximation is shown in Fig. 4.

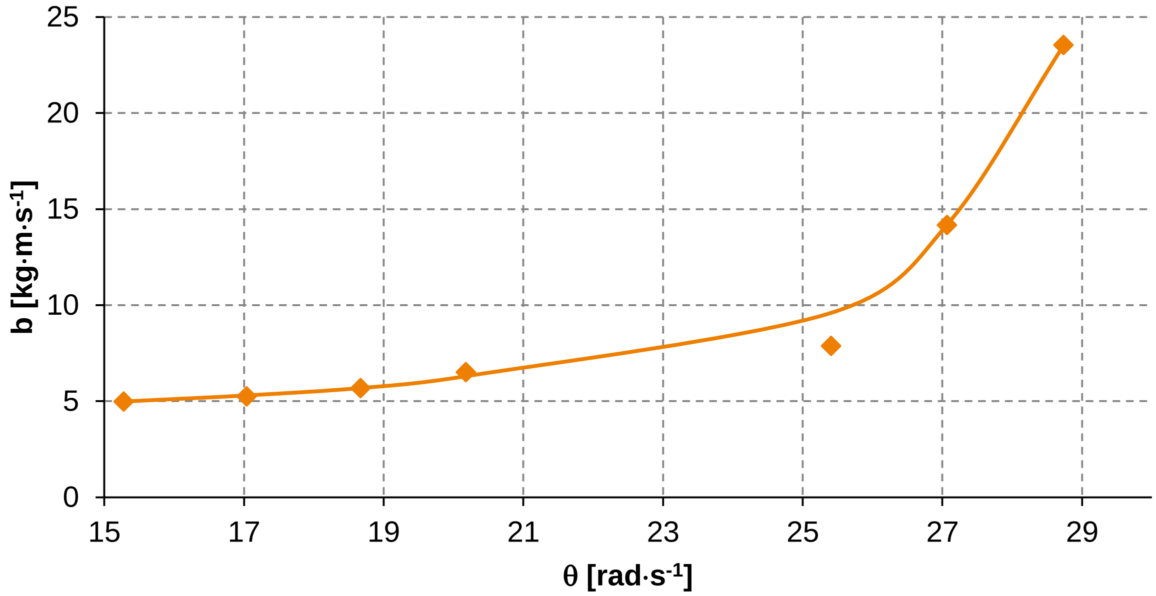

Fig. 4: Friction coefficient *b* function

3.1.6 Calculation of the balls height x_H (in mm)

The ball height is the value that has to be controlled and is calculated from the following formula (in mm !!!)

$$x_H(t) = 1000 \cdot x_{pp} - [1000 \cdot l \cdot cos\varphi(t)], \quad (8)$$

where $x_{pp} = l \cdot cos\varphi(0)$ when $\varphi(0) = 0 \rightarrow x_{pp} = l$, l is the length of the balls arm, $\varphi(0)$ is the limit angle of the balls arm.

3.2 MODIFICATION TO THE TECHNICAL REALIZATION

The extension of the ideal mathematical model to the more real one includes some effects of the real world and configuration (see Fig. 5).

1) The mass of the bearing and the teflon disc that allow the measurement of the distance of the ball from the starting point is added. The gravitational force that acts against the ball movement is included. Because the gravitational force acts on both arms with the same force, it is necessary to divide the mass of the teflon bearings by two.
2) The actual geometry is represented as an approximation of the real one. Not any positions of the real flying arms can be achieved.
3) The control arms are not fixed directly in the axis of the rotation, but with a given distance from this axis. The formula for centrifugal force must be changed. The construction is not weightless, so that has to be further corrected.

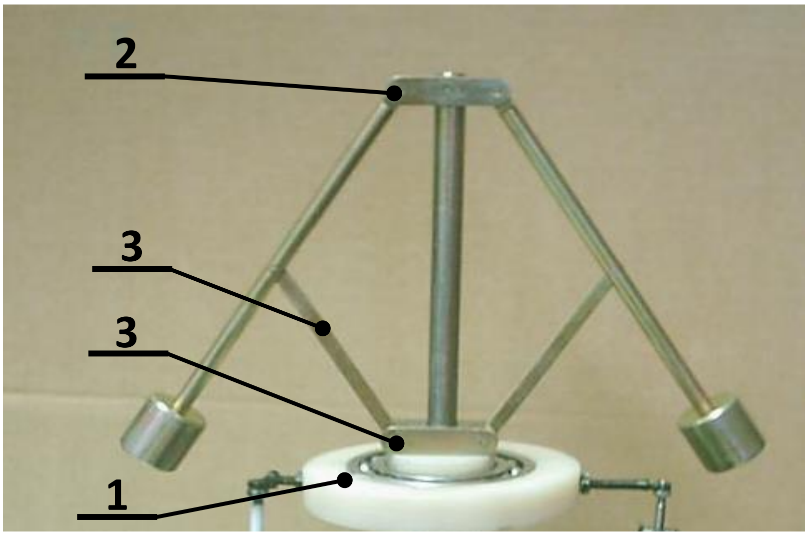

Fig. 5: Detail picture of the real flying ball subsystem (1–bearing, 2–main arm fixing, 3–flying ball support arm)

The mathematical model of the real governor is described by the following equation set. Equations (9) to (12) are the basic differential equation to reconstruct the dynamic of the system. Equations (13) to (19) describe the basic relations. The symbols meaning is described in Tab. 6

$$\frac{di_M(t)}{dt} = \frac{1}{L} \cdot U(t) - \frac{R}{L} \cdot i_M(t) - \frac{km}{L} \cdot \omega(t), \quad (9)$$

$$\frac{d^2\varphi(t)}{dt^2} = -\frac{b}{m_1} \cdot \frac{d\varphi(t)}{dt} - g \cdot sin\varphi(t) - g \cdot \frac{m_2}{m_1} \cdot sin\varphi(t) + \\ +\theta^2(t) \cdot cos\varphi(t) \cdot [l \cdot sin\varphi(t) + p_r], \quad (10)$$

$$\frac{d\omega(t)}{dt} = \frac{1}{J_c(t)} \cdot [M_h(t) - M_{zc}(t)], \quad (11)$$

$$\theta(t) = \frac{1}{p}\omega(t), \quad (12)$$

$$J_c(t) = J_{mot} + J_{red}(t), \quad (13)$$

$$J_{red}(t) = \frac{1}{2} \cdot [l \cdot sin\varphi(t)]^2 \cdot m_1 \cdot \left(\frac{1}{p}\right)^2, \quad (14)$$

$$M_h(t) = km \cdot i_M(t), \quad (15)$$

$$M_{zc}(t) = M_r(t) + M_{zr}(t), \quad (16)$$

$$M_r(\omega) = B(\omega) \cdot \omega, \quad (17)$$

$$M_{zr}(t) = \frac{1}{2} \cdot \theta^2(t) \cdot [l \cdot sin\varphi(t)]^3 \cdot C_x \cdot \rho_{air} \cdot S_{zyl}, \quad (18)$$

$$x_H(t) = 1000 \cdot x_{pp} - [1000 \cdot l \cdot cos\varphi(t)]. \quad (19)$$

Tab. 6: Values and symbols for calculation the real system

Value	Unit	Description
b	kg·m·s^{-1}	Friction coefficient (function from tab. 11 or constant)
g	m·s^{-2}	Acceleration of gravity
$J_c(t)$	kg·m^2	Total moment of inertia
$i_M(t)$	A	DC motor armature coil current
km	V·s	Motor constant
L	H	DC motor armature coil inductance
l	m	Length of flying balls arm
m_1	kg	Ball mass
m_2	kg	Bearing and teflon disc mass
M_h	Nm	DC motor torque
$M_{zc}(t)$	Nm	Total torque of the load
pr	m	Displacement of the arm from the rotational axis
R	Ω	DC motor resistance
$U(t)$	V	DC motor voltage
$\theta(t)$	rad·s^{-1}	Angular velocity of the ball system
$\varphi(t)$	rad	Angle of deflection of the ball system arms
$\omega(t)$	rad·s^{-1}	Angular velocity of the motor shaft
J_{mot}	kg·m^2	DC motor inertia moment
p	1	Gearbox ratio
$B(\omega)$	kg·m^2·s^{-1}	Viscosity coefficient (function from tab. 10 or constant)
C_x	1	Coefficient of air resistance
ρ_{air}	kg·m^{-3}	Air density
S_{zyl}	m^2	Surface of the flying balls
x_H	mm	Ball height
x_{pp}	m	$x_{pp} = l \cdot cos\varphi(0)$, when $\varphi(0) = 0 \rightarrow x_{pp} = l$

4 MODEL PARAMETERS

The simulation calculations of the mathematical models are to be carried out with parameters described in Tab. 7, Tab. 8 and Tab. 9 for the DC motor and the real flying balls subsystem. There is described the viscosity coefficient dependency on the rotational speed in the Tab. 10 and the friction coefficient dependency in the ball's angular velocity in the Tab. 11.

Tab. 7: DC motor parameters

Parameter	B_{fix}	J_{mot}	km	L	R
Unit	kg·m^2·s^{-1}	kg·m^2	V·s	H	Ω
Value	0.0045	0.0008	0.0973	0.0011	0.6200

Tab. 8: Real centrifugal balls subsystem parameters

Parameter	b_{fix}	C_x	g	l	m_1	m_2	p	pr
Unit	kg·m·s^{-1}	1	m·s^{-2}	m	kg	kg	1	m
Value	4.20	1.12	9.81	0.142	0.0652	0.1185	8	0.0140

Tab. 9: Real centrifugal balls subsystem parameters (continue)

Parameter	S_{zyl}	x_{pp}	ρ_{air}	$\varphi(0)$
Unit	m^2	m	kg·m^{-3}	rad
Value	0.0015	0.1308	1.2760	0.4

The dependency for $B(\omega)$ is shown in the Tab. 10 and the dependency for $b(\theta)$ in the Tab. 11.

Tab. 10: Measured viscosity coefficient dependency on the rotational speed

ω [rad·s^{-1}]	4.87	10.99	17.00	23.77	29.62	37.07	43.03	50.85	56.48
B [kg·m^2·s^{-1}]	0.0420	0.0176	0.0126	0.0100	0.0084	0.0072	0.0067	0.0061	0.0056
ω [rad·s^{-1}]	63.99	70.31	76.11	83.19	89.97	96.77	104.37	110.44	116.36
B [kg·m^2·s^{-1}]	0.0052	0.0049	0.0049	0.0047	0.0046	0.0046	0.0042	0.0041	0.0041
ω [rad·s^{-1}]	122.70	129.63	136.33	143.03	149.26	156.00	163.09	169.85	175.93
B [kg·m^2·s^{-1}]	0.0040	0.0040	0.0039	0.0038	0.0038	0.0037	0.0036	0.0036	0.0036
ω [rad·s^{-1}]	181.35	189.18	196.09	202.17	216.16	222.51	229.13	236.40	243.25
B [kg·m^2·s^{-1}]	0.0036	0.0036	0.0035	0.0035	0.0034	0.0034	0.0034	0.0033	0.0032

Tab. 11: Measured friction coefficient dependency on the balls angular velocity

θ [rad·s^{-1}]	15.28	17.04	18.67	20.18	25.41	27.07	28.74
b [kg·m·s^{-1}]	4.983	5.252	5.685	6.513	7.875	14.160	23.538

5 CONVERSIONS OF MODEL INPUT AND OUTPUT

The equations (1) to (8) describe the idealized system, the equations (9) to (19) the modified (real) system. These equations constitute a model whose input is the voltage U (armature voltage of the DC motor) and the output is the change in the deflection angle of the control arm φ (see Fig. 6).

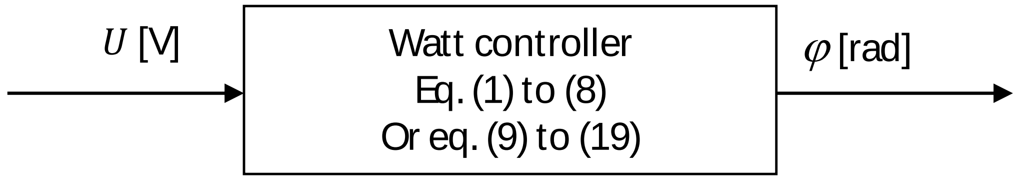

Fig. 6: Watt controller model

The Matlab "Real Time Toolbox" input signal u was set to the range $< -1\,..\,1 >$ during the measurement and therefore conversions are necessary.

5.1 CONVERSION OF THE MODEL INPUT

The measured input signal u of the mathematical model is measured/controlled in a Simulink program through the block "From Workspace" (see Fig. 7). The input signal u is converted from the range $< -1\,..\,1 >$ to the armature voltage of the DC motor. Firstly the Matlab input signal u is converted to the voltage range of the I/O card $< 0\,..\,5\ \mathrm{V} >$. Therefore the signal is multiplied by a gain of size 2.5 and then shifted by 2.5 up. The power control unit includes a pre-filter with the transfer function

$$F_{FILTER}(s) = \frac{25}{(s+5)^2}. \tag{20}$$

Finally the voltage supplied by the power control unit U is in the range $< 0\,..\,28.8\ \mathrm{V} >$.

This voltage is calculated by a gain block (Gain1) of the size $28.8/5$ to U_0.

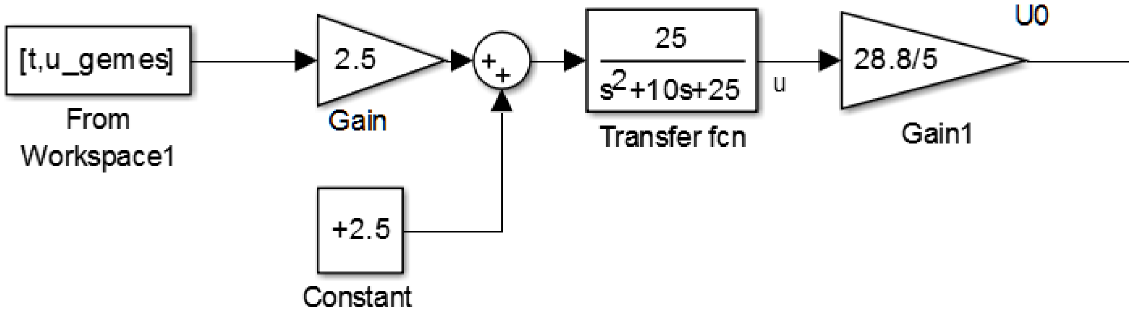

Fig. 7: Input signal transformation

5.2 CONVERSION OF THE MODEL OUTPUT

The necessary conversions (see Tab. 12) are

- voltage of the position sensor U_P (via y) $\rightarrow$ centrifugal ball height $x_H(t)$,
- voltage of the tachogenerator U_T^* (via y_3) $\rightarrow$ angular velocity of the motor $\omega(t)$

Tab. 12: Conversion table

Physical input	Matlab input	Conversion formula	Physical output
U_P in V $< 0..10\ \mathrm{V} >$	$y < 0..1 >$	$\boldsymbol{x_H} = 116.9289 \cdot \boldsymbol{y}$	x_H in mm
U_T^* in V $< 0..5\ \mathrm{V} >$	$y3 < 0..1 >$	$\boldsymbol{\omega(t)} = \frac{1000}{20} \cdot 5.6 \cdot \boldsymbol{y3}$	$\omega(t)$ in rad·s^{-1}

6 TASKS

6.1 THEORETICAL PROCESS ANALYSIS

Perform the mathematical and physical analysis and explain the presented differential equations.

6.2 PREPARATION OF THE MODEL WITH MATLAB/SIMULINK

Create a model in the Matlab environment. In a principle, the simulation program is written in Simulink (mdl-file) that is initialized and controlled from the Matlab program (m-file). This means that all the necessary parameter calculations and control operations are programmed in m-file.

The parameters for the simulations are given in Tab. 7 to Tab. 9.

Optimize parameters from tables to minimize the deviations between model and real system. The measurements from the real system are available for the verification as Matlab files.

6.2.1 Task 1 – equations of idealized system

Determine the equations for the Simulink subsystems

- DC motor,
- Transmission (Gear Box),
- Centrifugal balls!

6.2.2 Task 2 – measured data review

The measurements of the real system are stored in the file named 'Wattmess.mat' with the following variables (see also Tab. 2):

$[t;\ u\_gemes;\ y\_gemes;\ y2\_gemes;\ y3\_gemes]$.

Create a Matlab program (m-file) that displays the variables u_gemes, y_gemes using the 'plot' command!

6.2.3 Task 3 – data conversion

Perform the conversion of $u(\_gemes)$ and $y(\_gemes)$ to the physical quantities $U(t)$ in volts and $x_H(t)$ in mm and make their graphical representation!

6.2.4 Task 4 – idealized system parameters

Create a Matlab program (m-file) which contains all the parameters and conversions for the subsystems! Form groups of parameters and calculations for a better overlook. Parameters B and b will **remain constant**! The groups correspond to subsystems:

- DC motor parameters,
- Transmission (Gear Box) parameters,
- Centrifugal balls parameters and
- Conversions for the initial conditions.

6.2.5 Task 5 – idealized system simulation model

Write stepwise Simulink programs for the subsystems and test each subsystem separately!

- DC motor (the motor drive, only with J_{mot}).
- Gear Box (gear ratio).
- Centrifugal balls (control the steady state for the selected speed).
- Power source (filter).

Connect all subsystems together (Fig. 8) and analyze the dynamic.

For the full model the input should be the motor armature voltage U in volts and outputs should be the balls height $x_H(t)$ in mm and the deflection angle of the balls arm angle in degrees.

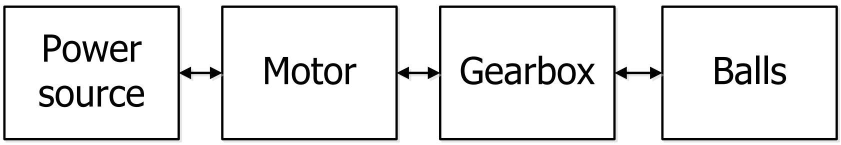

Fig. 8: The model created from subsystems – block schema

Verify the behavior of your model with the data from the real system and focus to differences.

6.2.6 Task 6 – remote start of simulation

Extend the program from the Task 4 so that the Simulink program is started from the Matlab program (m-file) and all important graphical outputs are presented as figures from m-file.

6.2.7 Task 7 – viscosity and friction implementation

Implement into your simulation the change of the load torque $M_r(\omega) = B(\omega) \cdot \omega$ (the variable viscosity coefficient) and the coefficient of the friction $b = b(\theta)$.

Verify the behavior of your model with the data from the real system. Try to optimize some parameters to get the minimal difference between the model response and the measurement.

6.3 DISCUSSION OF RESULTS

The protocol must include mainly the following points.

1. Developed programs/models in Matlab and Simulink.
2. Model verification and simulation results.
3. Time courses of the major inputs and outputs.
4. Discussion of the results. The main focus has to be to the differences between model and real system dynamic, especially in the case of the constant B and b parameters.
5. Tables of parameters that result in a sufficient agreement of the real system with the model!

7 LITERATURE

[1] FÖLLINGER, O.: Regelungstechnik, Heidelberg, Hüthig, 1984, 4. Auflage.

[2] UNBEHAUEN, H.: Regelungstechnik I, Vieweg & Sohn mbH, Braunschweig/Wiesbaden, 1992.

[3] REINISCH, K.: Kybernetische Grundlagen und Beschreibung kontinuierlicher Systeme, VEB Verlag Technik, Berlin, 1974.

[4] GRACE, A.; LAUB, J.A.; LITTLE, J.N.; THOMPSON, C.M.: Control System Toolbox, For Use with MATLAB, User's Guide, The Math Works Inc., 1995.

[6] HOFFMANN, J.: MATLAB und SIMULINK, Beispielorientierte Einführung in die Simulation dynamischer Systeme, Addison-Wesley Longman Verlag, 1998.

[7] MODRLAK, O.: Einführung in MATLAB, http://www.hszg.de/index.php?id=5484

[8] MODRLAK, O.: Einführung in Simulink, http://www.hszg.de/index.php?id=5484

[9] HAMPEL, R.: Begleitmaterial zur Vorlesung Prozessautomatisierung, Hochschule für Technik, Wirtschaft und Sozialwesen Zittau/Görlitz, FB Elektrotechnik, FG Meßtechnik/Prozeßautomatisierungstechnik, 1997.

[10] GOCHT, U.; HAMPEL, R.: Arbeitsmaterialien für Vorlesung Prozeßautomatisierung, Hochschule für Technik, Wirtschaft und Sozialwesen Zittau/Görlitz. FB Elektrotechnik, FG Meßtechnik/Prozeßautomatisierungstechnik, 1998.

[11] Deutsche Norm DIN 19221 Regelungstechnik und Steuerungstechnik Formelzeichen, DK 62-52/-53: 003.62, Mai 1993.

[12] Deutsche Norm DIN 19227 Graphische Symbole und Kennbuchstaben für die Formelzeichen für die Prozessleittechnik, DK 62-52/-53: 003.62, Mai 1993.