SELECTED ENGINEERING PROBLEMS
NUMBER 7
INSTITUTE OF ENGINEERING PROCESSES AUTOMATION AND INTEGRATED MANUFACTURING SYSTEMS

Mateusz SUMERA, Mariusz Piotr HETMAŃCZYK[1]

[1]Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Faculty of Mechanical Engineering, The Silesian University of Technology, Gliwice, Poland
*mariusz.hetmanczyk@polsl.pl

# THE LABORATORY STAND FOR OPTIMIZATION OF SWING VALUES OF THE PHYSICAL PENDULUM - CONTROL SYSTEM

**Abstract:** The article presents algorithms used to control swings of the physical pendulum. The division of control function blocks and a configuration of the control system were also described. The configuration contains a set of control algorithms, a PLC controller and a frequency converter. Additional element is a visualization of states, especially the drive system, allowing forcing and reading control signals. The configuration parameters of the equipment and industrial network were also shown.

## 1. Introduction

Development and optimization of control algorithms used in transportation equipment constitutes one of the main tasks in modern production systems [1,4]. Minimization of fluctuation impacts of transported elements results in improving the flow of process, reduction of energy consumption and increasing the safety of handling systems.

The laboratory stand has been designed to optimize swing values of physical pendulum. Physical model is equipped with components enabling realization of the control process with very high accuracy what has been achieved also through implementation of advanced algorithms. Communication between devices is made using PROFINET network, which provides the required data rate and reliability.

## 2. The control configuration and the drive subsystem

The control subsystem has been built with the following components (Fig. 1): the MDX61B0008-5A3-4-00 frequency inverter (with the DFE32B and the DER11B optional cards), the SIEMENS SIMATIC S7-1200 PLC controller (CPU 1214C DC/DC/DC, 6ES7 214-1AG31-0XB0), the HMI panel (Siemens KTP600 Basic Colour PN 6AV6 647-0AD11-3AX0).

The developed algorithms can be executed in different modes:

- the manual mode with a buttons control,
- the automatic mode (continuous run between end sensors),
- the PLC mode (control is done by the PLC controller connected with the KTP600 HMI panel)

*Fig. 1. View of 3D model of the laboratory stand (a mechanical subsystem and control units)*

In order to define the operating parameters of the electric motor, a configuration of the frequency converter was done. For this purpose, the MOVITOOLS MotionStudio was used. Parameterization was performed with usage of the Start-up environment but additional configurations were modified by using the Parameter Tree (Fig. 2).

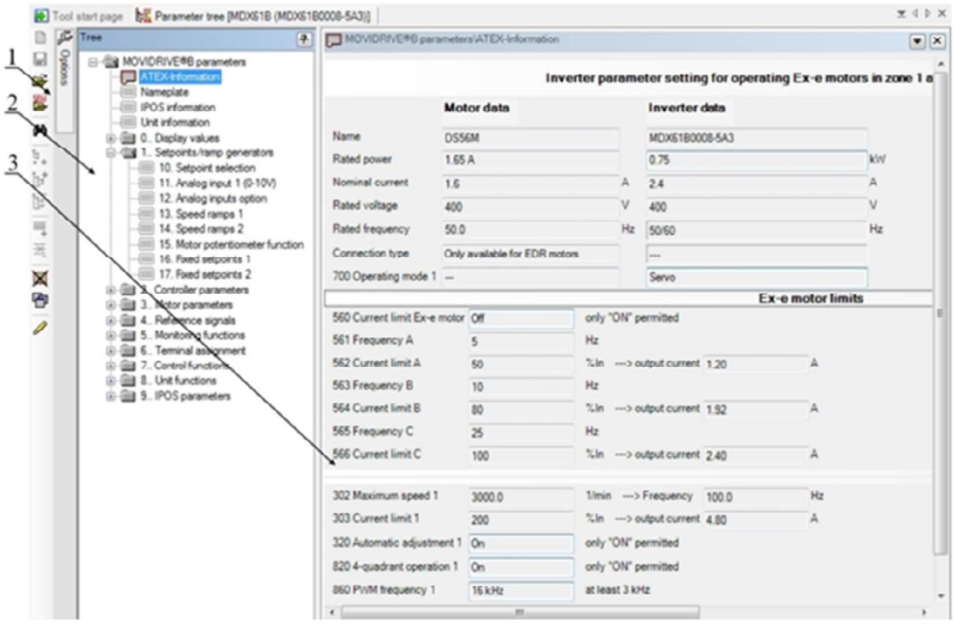


*Fig. 2. View of main functions of the Parameter tree, where: 1 - ribbon options 2 – the parameter tree, 3 - a view area of selected parameters*

All of the SEW inverters are equipped with an integrated positioning and sequence controller programmed by the IPOSplus language [5]. Prepared programme contains all the necessary commands required to perform a control process, communication via PROFINET, appropriate cooperation with the PLC controller and exchange of operating parameters via MoviLink channel. An example of the program that provides control with usage of manual mode is shown in listing 1.

*Code listing 1. An automatic mode code*

```
Auto()
 { if (LS_R == 0)
   {
    _BitClear(ControlWord, 2);
    _BitSet(ControlWord, 3);
   }
   if (LS_L == 0)
   {
    _BitClear(ControlWord,3);
    _BitSet(ControlWord, 2);
   }
 }
```

movement in left direction

movement in right direction

The process of motion control is done by a corresponding change in the value of the control word (No. H484), which individual bits trigger relevant functions (e.g. a permit for movement, direction of rotation etc.).

The controller programming was carried out in the Siemens TIA PORTAL environment. The hardware configuration is shown in figure 3. New devices have been added by the function Devices&Networks from the project tree. Created system represents a physical connection of devices in the PROFINET network, identification of given device is realized by the IP address and a device name.

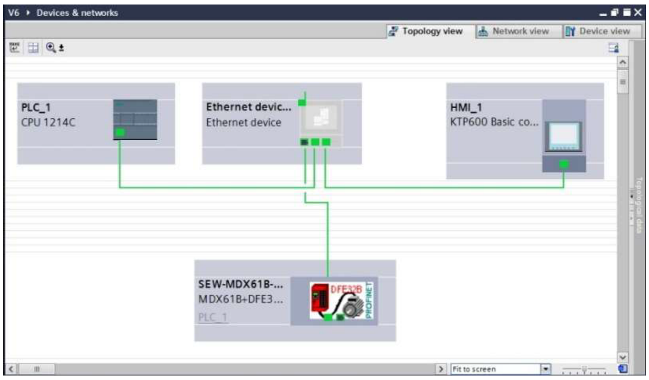


*Fig. 3. View of the Configuration tree*

Listing 2 shows a skeleton of the main block, by means of which are called several function blocks that enable implementation of the program. Described block is performed on the basis of conditional statements (IF) which check the actual condition (the status of the inverter - fault or warning). With the proper operation of the frequency inverter, described block is subjected to continuous processing (used to determine the parameters of the pendulum block and process variables associated with operational states of electric drive). Instruction of multiple-choice (CASE) is used for control mode selection. The condition scans variable “Ride_Type” refreshed by the master unit, based on preset settings.

*Code listing 2. Structure of the Main (OB) block*

```
(*Receiving of data packages*)
"Communication_Receive"(Hardware_ID:="DB_Control"....);
(*Control functions*)
IF NOT "DB_Control".Drive.PI.Fault_Warning THEN
    "DB_Control".Drive.PO.Controller_Inhibit := False;
  (*Pendulum Cycle*)
    "Period_FB_DB"(Number_Swings=>"DB_Control"....);
  (*Control mode*)
    CASE "DB_Control".HMI_Control.Ride_Type OF
        0: (*Main Screen*);
        1: (*Hand_Mode*);
        2: (*Automatic_Mode*);
        3: (*Pendulum*);
        4: (*Reference_Travel*);
    END_CASE;
  (*Dane*);
ELSE
    "DB_Control".Drive.PO.Stop := False;
    "DB_Control".Drive.PO.CW := False;
    "DB_Control".Drive.PO.Controller_Inhibit := True;
    "DB_Control".Drive.PO.WORD_EMPTY := 1;
END_IF;
(*Sending of data packages*)
    "Comunnication_Transmitter"(Hardware_ID:="DB_Control"....);
```

For the PLC controller and the HMI panel following control modes have been implemented:

- a manual mode - the driven saddle movement with parameter values defined by preset settings, movement to the determined position,
- the automatic mode - movement between end sensors or between programmed positions,
- the vibration optimization mode of the physical pendulum - movement on the basis of direct information from angle sensor or movements due to predicted consecutive values of swing angles.

Optimization of the pendulum swing is achieved by usage of one of the algorithms presented in code listing 3.

*Code listing 3. Structure of the Pendulum_FB function block*

```
CASE #HMI_Pendulum_Algorithm OF
1: Algorithm Encoder;
2: The dampening algorithm of harmonic distortion
  CASE #HMI_Pendulum_Ride OF
   1: Unilateral damping;
   2: Bilateral damping;
   END_CASE;;
END_CASE;
```

The main task of the algorithm is a compensation of the current tilt of the oscillator and application of the drive to damping of movements (based on feedback from the encoder).

The algorithm starts the initialization process, whose aim is to drive a saddle with pendulum to the centre position. Thereafter, method assumes movement between the end sensors at a constant speed of 1000 rpm in the automatic mode. In case of swing of the pendulum from its original position the control system performs a process of movement damping. Obtaining proper operation requires the speed damping.

The principle of work of the damping algorithm consists in determining the angle of swing of the physical pendulum, which will be reached at the next movement based on the characteristics of earlier inclinations.

For this purpose the equation of harmonic vibrations damping was implemented. The control algorithm allows prediction of value of vibration characteristics in time. Used algorithm allows to determine the ϴ angle (between the arm and an axis of rotation of the oscillator).

Damping factor (Code listing 4) determines atrophy level of vibrations (with the growth of coefficient value the vibrations are damped in a shorter time). The vibration amplitudes are taken from the table (stored in a separate function block).

*Code listing 4. Code for estimation of the damping coefficient*

```
#LN_Damping_Coef := ABS(LN((#An / #"An+1")));
#Damping_Coef := (#LN_Damping_Coefficient / (#Period_Time / 1000));
```

Seeking value of inclination is determined based on the equation of damped harmonic oscillations [3,4]:

$$x = A * e^{-\beta * t} * \cos(\omega_1 * t + \varphi) \quad (1)$$

where:

- $A$ - amplitude of vibrations $[cm]$,
- $\beta$ - damping coefficient,
- $t$ - time $[s]$,
- $\omega_1$ - frequency of damped vibrations $[\frac{rad}{s}]$,
- $\varphi$ - initial phase value $[rad]$.

Correct operation requires an adequate coupling of hardware, software with control logic. For this purpose in the TIA PORTAL environment the WinCC for programming operator panels was used [2]. Described control modes have been presented in a graphical manner that creates simple visualization of the laboratory stand.

Figure 4 presents the view of an exemplary visualization of the operation mode used to optimization of pendulum vibrations. Status beam of the frequency inverter informs about the current state of the device, information are gathered from the PLC controller.

In order to enable a rapid response to changing the status of the device, beam area changes colour in accordance with a current state: operation (green), lack of permit to movement (orange), emergency stop (yellow).

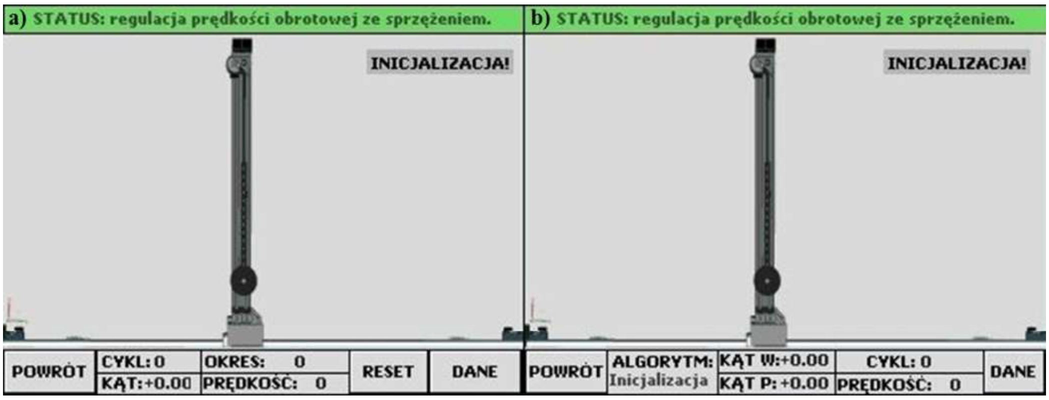


*Fig. 4. View of vibration damping screen visualization: a) encoder mode, b) the algorithm of vibration damping*

It is possible to activate the damping mode based on the current value indicated by the angle transducer (by choosing the Encoder button) and vibration damping (based on the predicted inclination angle).

## 3. Conclusions

Optimization of vibrations was realized for the rapid damping and preventing the formation of excessive vibrations of the pendulum.

Operation of swings optimization algorithm of the physical pendulum is based on feedback information from the rotation angle sensor (which is mounted in the axis of rotation). The laboratory stand can be controlled also via switches placed in the front plate of control box. The developed algorithms ensure adequate process control while achieving motion of pendulum without oscillations.

Communication between devices is made using industrial PROFINET network, which provides the required data rate. Through the implemented solutions founded tasks have been completed.

### References

1. Bryan E.A, Bryan. L.A.: Programmable Controllers: theory and implementation. USA: Industrial Text Company, 1997.
2. Boyer S.: SCADA: Supervisory Control and Data Acquisition. USA: ISA, 2004.
3. De Silva C. W.: Mechatronics: an integrated approach. New York: CRC Press, 2005.
4. Mianowski B.: Determination of the period of small and large swings of physical pendulum. Lodz: Publishing House of Technical University of Lodz, 2009.
5. SEW-EURODRIVE: Programming Manual. Positioning and sequence control IPOSplus®. 1999.