TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
MECHANICS | MECHANIKA
2-M/2015

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CONTROL SYSTEM OF LABORATORY STAND FOR GEARBOX AND COUPLING TESTING

SYSTEM STEROWANIA STANOWISKA LABORATORYJNEGO DO BADAŃ PRZEKŁADNI I SPRZĘGIEŁ

Abstract

The scheme control system of a laboratory stand for gearbox and coupling testing, capable of fulfilling many miscellaneous requirements has been described in the paper. The innovative solution, as well as the benefits of the application, based on the Program Logic Controller, connected with electrical motor drives and a computer measurement system, have been described and depicted. Special features of the suggested solution, such as flexibility and ability to develop or adjust for another application, have been characterized.

Keywords: *control system, laboratory stand, gearboxes and coupling testing*

Streszczenie

Artykuł przedstawia system sterowania laboratoryjnego stanowiska do badania przekładni i sprzęgieł, który ze względu na swoją programowalność pozwala symulować różne warunki pracy. Opisano i przedyskutowano innowacyjne rozwiązanie oraz korzyści płynące z połączenia układu sterowania PLC z komputerowym układem pomiarowym. Przedstawione rozwiązanie sterowania stanowiska cechują takie właściwości jak: wysoka programowalność, możliwość opomiarowania dowolnej wartości procesu, otwartość na dalszą rozbudowę oraz możliwość zastosowania do innych stanowisk badawczych.

Słowa kluczowe: *system sterowania, stanowisko badawcze, badania przekładni i sprzęgieł*

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1. Introduction

The development of modern engineering science based on electronics, computer measuring systems, and computing technologies gives many possibilities of machine design solutions. Plenty of programs offered on computer markets, measuring boards, control systems in general, can become an obstacle in developing a modern laboratory system for testing mechanical subassemblies, components or parts. The issue of an embedded control system of a laboratory stand for gearbox and coupling testing, that makes programmed tests possible to be performed, and also gives valid measurements for further engineering analysis, has been considered in the article.

Different designs of test rigs for testing subassemblies used in the machine power transmission system, have been presented in the papers [1–8].

Unlike in the commonly used solutions, the developed control system can also be programmed in order to change working parameters of the examined object, while taking measure values into account. In addition, all calculations, measured values and working parameters can be read and stored by the computer measuring system. In an innovative assumption, the control system is electrically separated from the computer measuring system and it is connected with it only via an industrial network that gives the possibility to get all the desired data, using only the computer software tool.

2. Requirements

Designing the solution control system, questions like what should be controlled and why as well as which physical values need to be measured, have to be considered. When the object of the study is a gearbox or a coupling, at least one input shaft and one output shaft have to be attached to the analyzed subassembly. At this point, the stand already requires some control and measurements of the input and output shaft.

When the speed of the input shaft and the load given by the output shaft is determined, some features concerning the analyzed object can be expressed. Performing tests of adjustable gearboxes or couplings requires also a possibility of parameter dynamic changes of the tested object. According to mathematical control rules, a dynamic change of control system output parameters is a function of inputs. If so, some output values based on the examined subassembly measured values have to be calculated and carried out. It is necessary, that the object measurements have to be connected to one embedded control system. The input shaft speed and output shaft load characteristics as well as all calculations have to be performed at the same time by one embedded control system. As all process data is calculated and stored in one memory of the control system (one device), and this memory has to be accessible by some reading software of a personal computer (PC) via some industrial network. All that should be done subsequently is to read and store the desired process parameters on the PC's hard disk at the same timeline for further analysis.

3. Solution draft

The stand for gearboxes and coupling testing has an input and output shaft connected mechanically with the examined subassembly. In most tests the speed of the input shaft with the load on the output shaft are compared. In the described solution the input shaft is powered by the electrical motor alternating current (AC Motor), and the load on the output shaft is provided by the electrical motor direct current (DC motor) (Fig. 1).

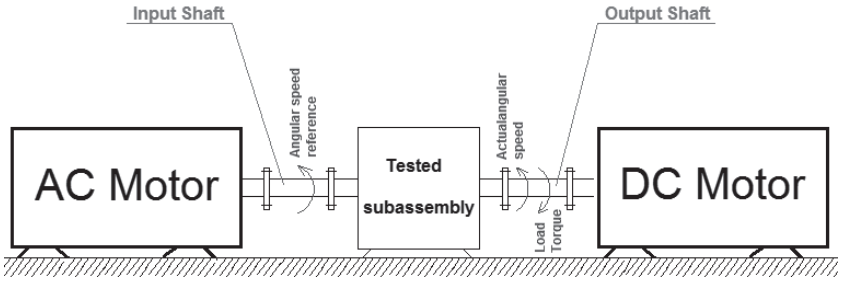

Fig. 1. Motors and examined subassembly connection scheme

As the input shaft angular speed reference and the output load shaft reference characteristics have to be followed by two electrical motors, both of them are powered by drives. As it is shown in Fig. 2 both motors are powered by variable speed drives (VSD): the AC motor is

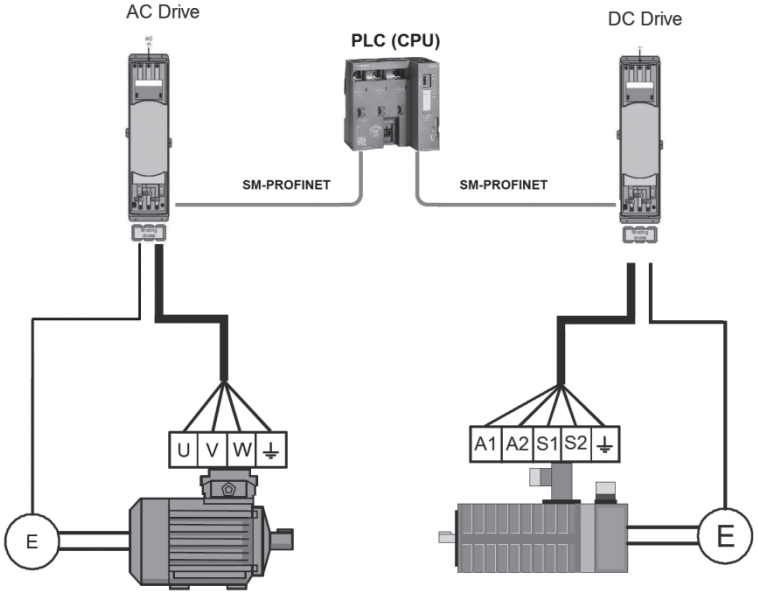

Fig. 2. Electric motors with corresponding drives and encoders [9]

powered by the AC Drive, the DC motor is powered by the DC Drive. Both drives receive the speed feedback from encoders attached to corresponding electrical motors in order to provide a precise speed and load control (Fig. 2).

As motor drives, two Variable Speed Drives from the Emerson company have been chosen. Table 1 contains detailed information about the parts used.

Table 1

Technical data of Variable Speed drives, electrical motors and PLC

Part	Company	Type	Remarks
PLC	Siemens	Simatic DP 6ES7151-8AB01-0AB0	—
AC Drive	Emerson	Unidrive SP 1406	connected with PLC via Profinet Network
DC Drive	Emerson	Mentor MP 25A4R	connected with PLC via Profinet Network
AC Motor	Tamel	3Skg 132S-4	PN =5,5KW Un = 400V In=15,4A
DC Motor	Tamel	G11.05	PN =5,5KW Un = 400V In=15,4A

As both drives have to follow some speed and torque programmed reference characteristics, a master control for both drives has to be established. Taking into consideration the fact that the master control has to:

– exchange data between the master control and both drives in order to perform reference speed of the input shaft and the load torque of the output shaft,
– measure values from the examined subassembly,
– calculate output values,
– be able to communicate with other additional devices, using standard industrial electric signals (output cards) and standard industrial network (Profinet, Profibus)
– be able to extend a new input and output card and be able to communicate with new devices via industrial networks.

Programmable Logic Controller (PLC) has been used [10]. PLC communicates and exchanges data between both drives using the industrial Profinet network [11, 12], see Fig. 2 and Fig. 3. Generally, the solution with variable speed drives controlled by a PLC is based on industrial control systems that are widely used around the world.

In the described control system, the PLC controls both drives by exchanging data with them via the industrial Network Profinet [11]. Electronic input and output cards have been added to the PLC. Chosen parameters of the examined subassembly (temperature, pressure), using industrial standards, are measured by input cards 4 .. 20 mA or 0 – 10 V. Based on the measurements and the loaded program, the PLC provides feedback to the tested subassembly, using output cards with industrial standards (4 .. 20 mA, 0 – 10 V) or by means of the industrial network. In Fig. 3 the connection with the Controllable Power Supply via the

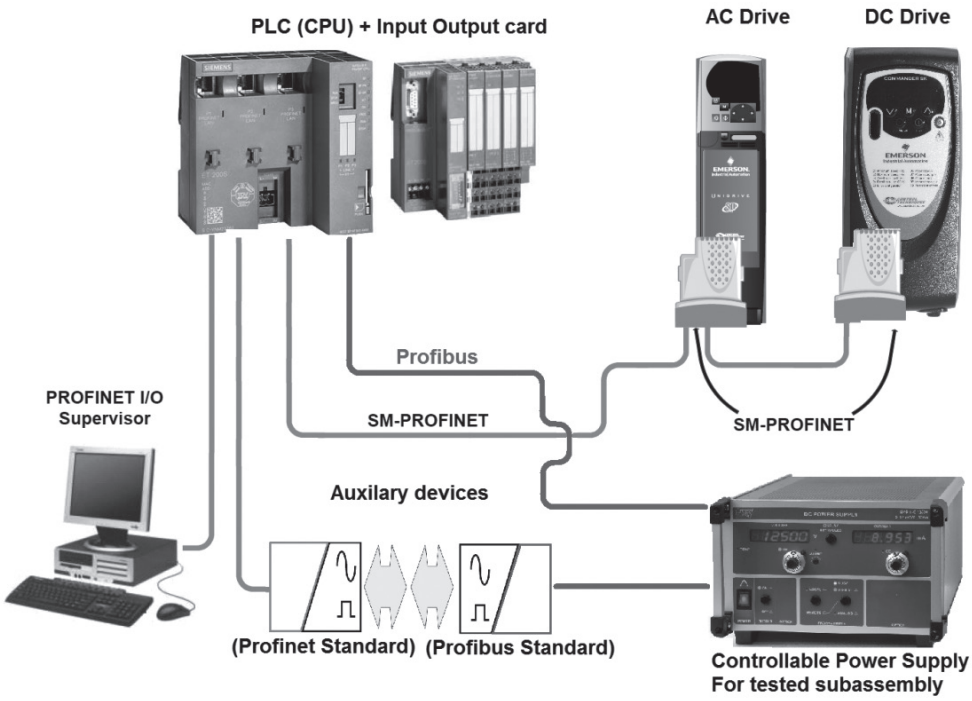

Fig. 3. Scheme of industrial network device connection: Profinet I/O Supervisor – computer used for reading data; PLC (CPU) with input-output cards; SM-Profinet – industrial network used to connect PLC to Drives; Controllable Power Supply used to power tested subassembly if necessary; Potential extensions (Profibus or Profinet standard)

industrial network Profibus has been shown. Due to the fact that the chosen PLC can "communicate" using Profinet and/or Profibus network, it is possible to connect it with other auxiliary devices which makes the described control system very flexible for any modification during the laboratory stand extension. When the "communication" between PLC, motor drives and input-output cards has been established, the PLC is ready to carry out the loaded program. When all the systems are connected together and configured, the program loaded to the PLC can be very easily and quickly modified, which gives the possibility to perform various tests. This feature is especially important at the beginning of the subassembly test when sophisticated knowledge concerning its features is limited. In order to program a PLC, a personal computer with a dedicated program has to be used.

Due to the fact that a PC is connected to the PLC via an industrial network (in this case – Profinet), it can be used both for programing tasks and for measuring purposes. Based on the fact that all the input data (measured speeds, currents, torques from drives, real measurement on input cards), calculated values, and references for devices and output cards) are stored in the PLC's memory, all that remains to be done is to use the computer to read and save the chosen data on a time plot, directly from the PLC. In order to do this, no measuring cards are required. What is needed, is the special software that is programmed to read and store data from the PLC's memory. As it has been mentioned, the connection between the PC and PLC

via an industrial network for programing purposes, allows also to carry out measurement tasks, which means reading data from the PLC's working memory to the PC's memory. The PC has to be programmed for this activity. Because preparing software is not an issue in this case, the program IBA-PDA by IBA AG company has been chosen to read and save data from the PLC's memory to the PC's memory. This software provides real time plots (Fig. 4) and saves data for further off line analysis (Fig. 5). This method is not direct because, for example, shaft speeds are measured by drives via encoders and then are sent to the PLC via an industrial network.

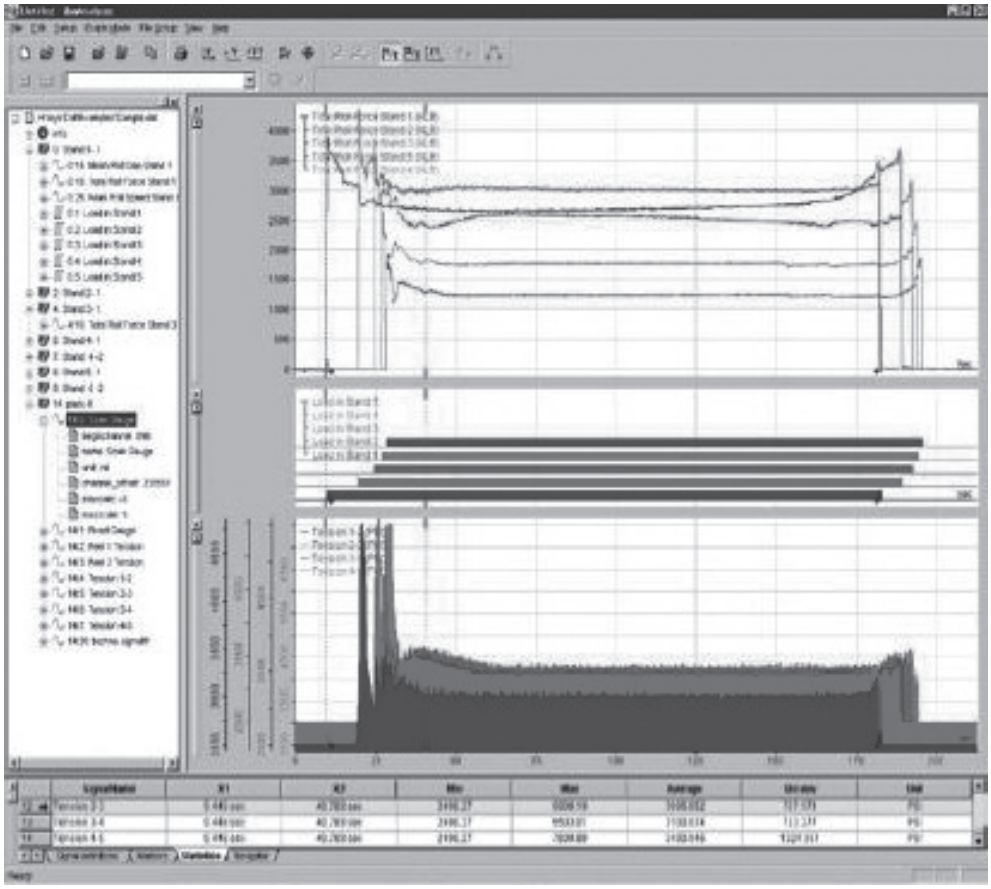

Fig. 4. Example of real time recording and plotting carried out by IBA PDA software

The sampling time is a significant limitation of indirect measurements (reading data from the PLC). Sampling time of measurements is the maximum value from the PLC program loop time and PC software reading time, and can be expressed as follows:

$$T_{samp} = \max(T_{lt}, T_r) \tag{1}$$

where:

T_{samp} – sampling time,
T_{lt} – PLC program execution loop time,
T_r – PC reading time.

Substituting the PLC program execution loop time T_{lt} = 12 ms and PC reading time T_r = 20 ms to equation (1) the sampling time of measurements can be calculated as T_{samp} = 20 ms.

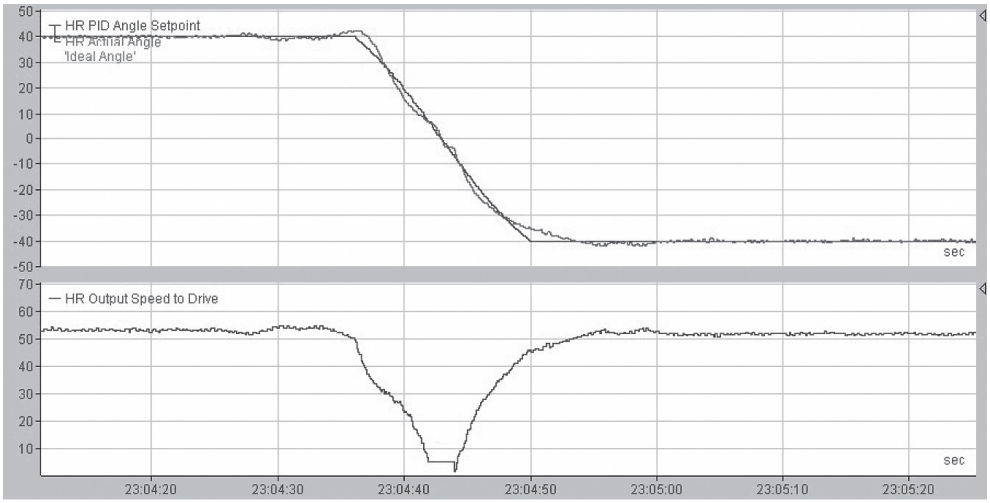

Fig. 5. Example of off line analysis made with IBA Analyzer software tool

In order to assign a certain time moment for each sample, it is necessary to program the real timer inside a PLC. Reading this timer together with other desired data (speeds, torque etc.) gives certain information when the data sample has been collected. This feature needs to be applied only when general features of the examined subassembly are discovered and next steps in the examination are necessary to be done, such as Fourier analyses of signals or statistical calculations.

Because of sampling time, the limitation of measurements should always be taken into consideration during the experiment preparation.

Although sampling time can be an obstacle, flexibility of the recorded data is remarkable. In the described solution, up to sixty values can be read simultaneously. This limitation is only the limitation of the IBA reading software license. Nevertheless, sixty signals are enough to examine a gearbox or a coupling. In order to measure the values, no electrical connection or measuring boards are necessary. All the working parameters and input values from the stand are read and stored in the PLC's memory. The PC "reads" the chosen values from the PLC's memory, using the IBA software. The values from the PLC that have to be stored, are chosen in the IBA software. It is also worth mentioning that the control system based on a PLC (widely used in most modern industrial applications) is able to be connected to any auxiliary systems with industrial standard features. This makes the described control system solution open for any further extension.

4. Conclusions

The control system of the laboratory stand for gearbox and coupling testing has been described in this paper. Basic schemes of the stand mechanical part and the idea of gearbox and coupling test performance have been shown.

On the basis of the undertaken analysis of the stand control system the following conclusions can be formulated:

1. The control method based on a PLC and measurements performed by the IBA-PDA software is suitable to set out requirements such as flexibility for modification and extension;
2. The capability of recording many parameters at the same time base plot and free and the speed of choosing them from the control system is a remarkable advantage;
3. Sampling time can be a limitation of the proposed solution but methods of dealing with it have been described;
4. It must also be underlined that the control system is able to 'communicate' with all devices via standard industrial protocols;
5. The collected experience and knowledge during setting up this kind of control systems can also be useful and desired in commercial engineering.

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