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Design and implementation of vibratory bowl feeder control via an industrial network

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Abstract—**Implementing SCADA (Supervisory Control and Data Acquisition) systems to monitor and control industrial applications helps to satisfy the constantly rising demands towards modern industrial products. This paper suggests a possible solution for integrating vibratory bowl feeders, transporting and orientation devices. The featured work deals with the experimental implementation of an electronically controlled regulator of the effective RMS voltage amplitude on the electromagnetic vibrators of vibratory bowl feeders. The regulator has electro-mechanical drives featuring a 50W to 1000W power and oscillation frequency of 50Hz or 100Hz. The Fieldbus is simulated with an emulator and a USB communication interface. By applying a modular organization mode, it is possible to upgrade the solution and achieve an integral one.**

Keywords- Industrial Control Systems; Bowl-shaped vibratory feeder; Fieldbus; regulator of amplitude

I. INTRODUCTION

In order to satisfy the challenging demands of modern production through high automation levels it is necessary for up-to-date information technologies to be applied. This allows to optimize production processes, reduce expenses and increase product quality. SCADA (Supervisory Control And Data Acquisition) systems are an essential part of current IT-based industrial control solutions (Fig. 1). Those are centralized computer systems which perform complete supervision and control over automated industrial machinery and equipment [1].

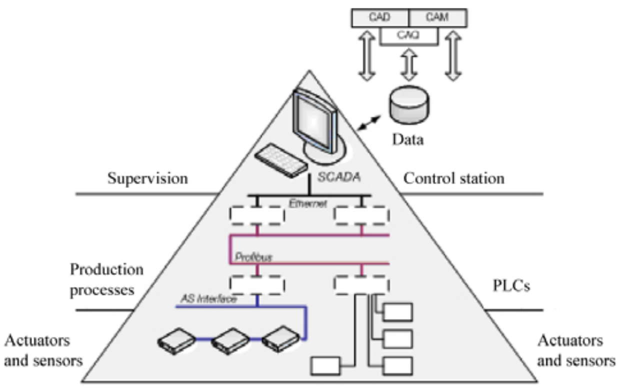

Figure 1. SCADA hierarchy

Bowl-shaped vibratory feeding and transportation devices with electro-mechanical drive (Fig. 2) are among the most common automation devices that form part of automated production lines and units. They are widely used for automated feeding and orientation of a vast variety of parts of different shape, size and weight. Whenever the parts to be manipulated are either small and/or fragile, e.g. in watch manufacturing, vibratory bowl feeders often stand out as the only possible means for automated feeding of the production machines [2].

Figure 2. Vibratory bowl feeder with electro-mechanical drive

The key parameter of vibratory bowl feeders is their output feed rate Q, expressed by the quantity of orientated parts for a predefined period of time. At this stage the output feed rate of a vibratory bowl feeder with electro-mechanical drive is unambiguously controlled by varying the amplitude of effective (RMS) voltage across the electromagnetic vibrator of the drive unit. With conventional vibratory bowl feeders this task is accomplished by the line operator via adjusting an autotransformer, rheostat or other kind of on-spot manually operated voltage regulators [2].

Achieving automated control and supervision over the output feed rate of a vibratory bowl feeder by integrating it into a SCADA system requires the following:

- The vibratory bowl feeder must be equipped with a remotely operated, electronically controlled regulator of the RMS voltage of the electromagnetic vibrator of the drive unit.
- The vibratory bowl feeder must be equipped with an electronic sensory device (e.g. optical or inductive

parts counter) to receive feedback about the current output feed rate.

- Both the voltage regulator and the sensory device have to be connected to the fieldbus network at the lowest level of the SCADA system.

The present work deals exclusively with the subject of the first point, namely the design, experimental implementation and testing of an electronically controlled regulator of the RMS voltage on the electromagnetic vibrator of vibratory bowl feeders with electro-mechanical drive.

II. Fieldbus networks in SCADA systems

Fieldbus networks are a specific type of local networks that serve to connect the actuators and sensors at the lowest level of a SCADA system to the programmable logic controllers (PLCs) and remote terminal units (RTUs) at the upper levels [3].

The requirements to fieldbus networks in SCADA systems are determined by the following considerations:

- When proceeding from the top to the bottom level of a SCADA system, the amount of information that needs to be passed on shrinks, while the demand in respect to transfer speed grows, since the applications become increasingly time-critical. Therefore fieldbus networks should strive to approach a real-time networking mode by providing data transfer rates as high as possible.
- All devices connected to a fieldbus use the same transmission medium to exchange data. To avoid collisions between separate data packages the network has to be arbitrated, i.e. for each moment in time it must be clearly stated which device is permitted to transmit and which to receive data. The arbitration protocols should allow as few collisions as possible, but not at the cost of slowing down the network.
- An automated production line or unit could comprise of tens and hundreds of actuators and sensors to be connected to the local controllers via the fieldbus, which leads to a very large amount of necessary wiring and connectors. For the fieldbus network to be remunerative, the expenses for its installation and maintenance should be low in respect to the cost of the production machines and automation devices.

The prevalent types of fieldbus networks in modern automated production are PROFIBUS, CAN and AS-i.

A. PROFIBUS

PROFIBUS (Process Field Bus) is based on a bus topology. The physical transmission medium is a twisted-pair with trace length limited to 4.8km. A PROFIBUS network can support up to 122 devices. Data transfer rates vary between 9.6Kbit/s and 12MBit/s. The arbitration protocol is a hybrid of token-passing and master-slave polling.

B. CAN

CAN (Controller Area Network) consists of two signal lines (CAN-Hi and CAN-Low) and two power lines (GND and positive). Every device in the network has to be equipped with a special CAN controller, supplied by the power lines. CAN features a linear topology, i.e. each device is connected in series to the signal lines. Trace length is limited to 1km. There are no restrictions for the number of connected devices. Data transfer rates vary between 10Kbit/s and 1MBit/s. CAN is arbitrated via a decentralized CSMA/CR protocol (Carrier Sense Multiple Access / Collision Resolution).

C. AS-i

AS-i (Actuator Sensor Interface) is built through a tree topology with one master and up to 31 slave devices. This network uses just two lines, AS-i– and AS-i+, which do not only serve for information exchange, but also supply power to connected actuators and sensors. Supply voltage is 24V, with current restriction of 100mA per slave device and a total of 2A for each branch of the tree topology. Trace length is limited to 100m. Network arbitration is handled through master-slave polling.

III. Structure of the experimental setting

Composing the functional structure of the experimental setting begins with the constitution of a black-box model. For this the input environment X and the output environment Y(X) of the experimental setting need to be defined.

The output environment Y(X) is evident – a vibratory bowl feeder with an electromagnetic vibrator.

The input environment X ideally would have been an authentic SCADA system. Since setting up such a system would have demanded unduly large time and financial resources [4], at this stage in order to prove the performability of the experimental setting a pseudo-SCADA system is used, which is comprised of a PC with an installed TTY (teletype) terminal emulator and an USB communication interface.

The pseudo-SCADA system mimics the basic features of a real SCADA system. The PC substitutes for the SCADA server and the PLC/RTU. The TTY terminal emulator, via which the operator can type in commands and receive reports regarding the state of the experimental setting, serves for a simple human-machine interface. The USB interface, which connects the experimental setting to the PC, takes the place of a true industrial fieldbus network.

The experimental setting consists of four modules (Fig. 3):

- ***Power supply module M0:*** converts 230VAC to 5VDC to supply modules M1, M2 and the low-voltage section of module M3.
- ***Communication module M1:*** provides bidirectional communication between the PC and the microcontroller module M2. In essence module M1 is a data converter that creates a link between two different communication interfaces.
- ***Microcontroller module M2:*** processes commands from the PC and the manual control panel; drives the voltage regulator module M3 in response to these commands; generates and sends status-reports to the PC and the local LCD display; processes error signals

and takes the necessary preventive action (e.g. shutting power off, alarming the operator, etc.).

- ***Voltage regulator module M3:*** adjusts the amplitude of RMS voltage across the electromagnetic vibrator of the vibratory bowl feeder according to instructions received from the microcontroller module M2.

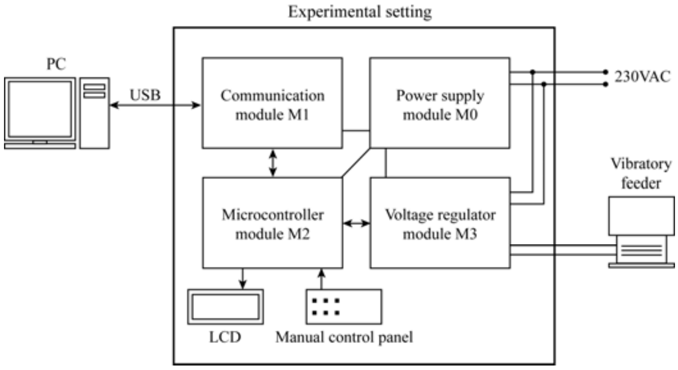

Figure 3. Modular structure of the experimental setting

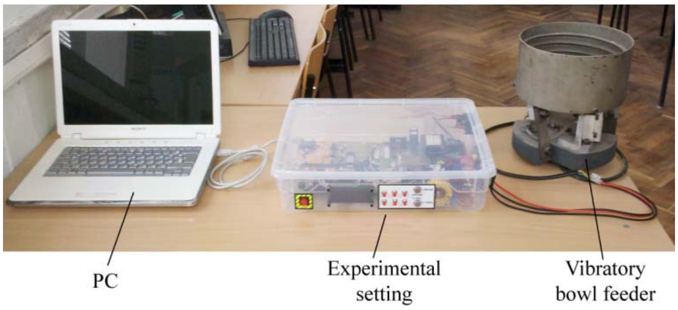

Figure 4. General view of the experimental setting

IV. IMPLEMENTATION

A. Communication and microcontroller modules

The principal element of the communication module M1 is the USB-UART converter UM232R by FTDI Chip (Fig. 5).

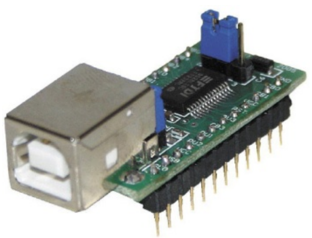

Figure 5. The UM232R USB-UART converter

The UM232R converter serves as a mediator between the PC and the microcontroller module M2. It reorganizes data from USB to UART when the PC sends to the MCU and vice versa, from UART to USB, when the MCU sends to the PC.

The UM232R converter and the microcontroller module M2 are optically isolated from each other. This provides galvanic separation of the communication system into two electrically independent loops A and B (Fig. 6). Loop A is supplied via the USB bus of the PC and loop B is supplied via the power module M0 of the experimental setting.

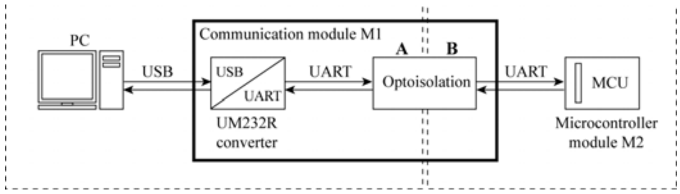

Figure 6. Block schematic of the communication module M1

The PC exchanges data with the communication module M1 via the software application MCS Simple Terminal by MCS Electronics, which is a TTY terminal emulator. The OS of the PC emulates a virtual COM port (VCP) and the TTY terminal emulator communicates with it as if it were a true hardware COM port, but the data between the PC and module M1 is actually transferred using the USB interface.

The operator controls the experimental setting, respectively the vibratory bowl feeder, by typing in text commands in the TTY terminal window (Fig. 7). There are three main commands:

- "*set X*", where X=[1÷100]% to adjust vibration amplitude;
- "*off*" to shut down the feeder;
- "*rst*" to restart the MCU.

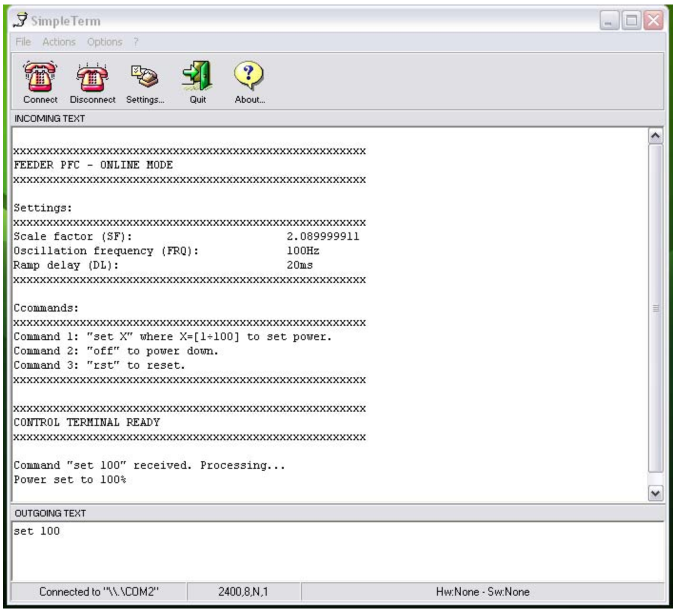

Figure 7. The TTY terminal window

The microcontroller module M2 is built on an ATmega16 microcontroller by Atmel. It is a general use 8-bit AVR RISC architecture microcontroller with 16Kbyte FLASH memory and a maximum clock frequency of 16 MHz.

The microcontroller was programmed with the software product BASCOM-AVR by MCS Electronics. It is an integrated development environment (IDE) specially designed for AVR microcontrollers and utilizes a high-level procedural programming language built on BASIC. A significant advantage of BASCOM-AVR over other IDE tools is the built-in support of numerous AVR-specific library functions and routines, which considerably simplifies and shortens the process of writing the source-code.

B. Voltage regulator module

The key element of the voltage regulator module M3 is the T830-800W triac by STMicroelectronics. The triac (Triode for Alternating Current) is a semiconductor device with three leads: gate G, cathode A1 and anode A2. It is turned on by a low-power pulse on the gate and allows current flow in both directions, i.e. from A1 to A2 and from A2 to A1 [5].

The amplitude of RMS voltage on the electromagnetic vibrator of the feeder is varied by driving the triac in phase-fired mode. Phase-Fired Control (PFC) is a popular solution for operation control of lighting and heating systems, asynchronous electric motors and electromagnets [6].

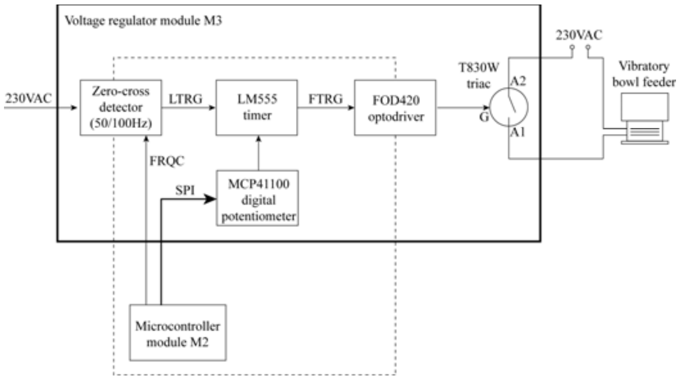

Figure 8. Block schematic of the voltage regulator module M3

The sinusoidal waveform of the 230VAC grid first enters an optically isolated zero-cross detector block built on a H11L1M Schmitt-trigger optocoupler by Fairchild Semiconductor. This block monitors the momentary voltage value and produces a short pulse LTRG a little before the sine wave runs trough the zero-cross point. The LTRG pulse can be generated on either every half-period (output frequency 100Hz) or on every full period (output frequency 50Hz) to suit the electromagnetic vibrator type. The output frequency is switched between 50/100Hz by the FRQC signal from the microcontroller module M2.

The LTRG pulse turns on the LM555 timer, which after the run-out of a certain time τ produces the FTRG pulse. The time delay τ depends on the resistance value of the MCP41100 digital potentiometer by Microchip Technology. The resistance value of the MCP41100 can be linearly varied from 125Ω to 100kΩ in 256 steps and is controlled via the SPI interface of the microcontroller module M2.

The FTRG pulse turns on the FOD420 optodriver by Fairchild Semiconductor, which in turn fires the power triac T830W. The FOD420 is a specialized IC purposed for optically isolated phase-fired control of triacs and SCR thyristors.

Since the T830W triac is turned on at a certain angle α after the zero-cross point of the 230VAC waveform, it only conducts the part of the sine wave after the angle α, which is also known as the *delay angle* (Fig. 9). The *conduction angle* is therefore $\beta = \pi - \alpha$. When the voltage sine wave descents trough the zero-cross point and the current decreases to zero, the T830W triac turns off independently and stays off until the next trigger pulse FTRG [5], [7].

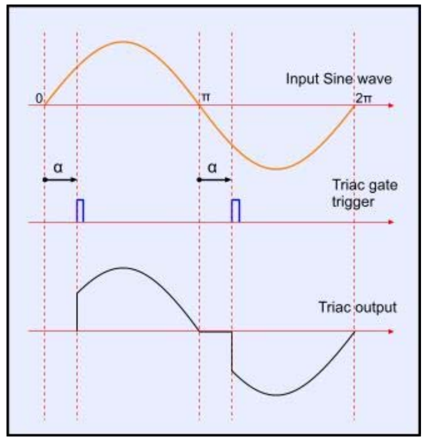

Figure 9. Principle of triac phase-fired control

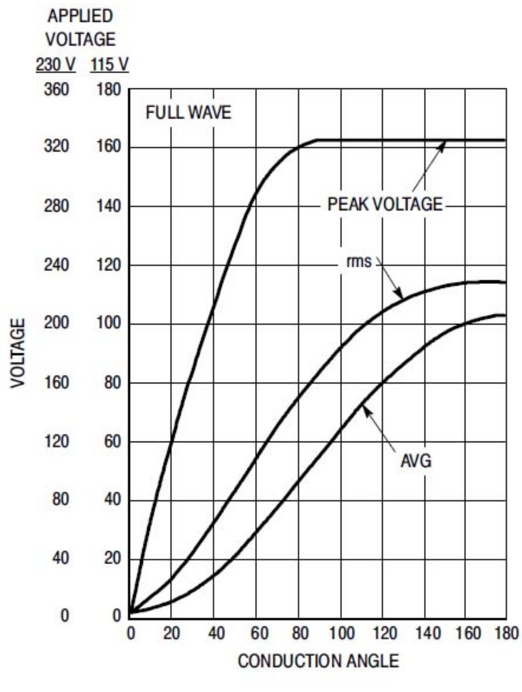

Figure 10. RMS voltage vs. conduction angle β

The amplitude of RMS voltage across the load is a function of the conduction angle β (Fig. 10) [5]. The value of β solely depends on the time delay τ of the LM555 timer, as set by the resistance value of the MCP41100 digital potentiometer. In conclusion, the RMS voltage on the electromagnetic vibrator of the feeder, therefore its vibration amplitude, is simply adjusted by controlling the MCP41100 via the microcontroller module M2.

Both the FOD420 optodriver and the T830W power triac are special models designed for driving highly inductive loads (as is a vibratory bowl feeder) and demonstrate elevated critical dV/dt and dI/dt values compared to general use optodrivers and triacs, which ensures reliable operation of the experimental setting. Triacs for inductive load control feature a hybrid structure resembling two separate back-to-back SCR thyristors, but situated on a single chip. Such triacs are manufactured under various brand names by several companies: „Hi-Com“ by Philips, „Alternistor“ by Littelfuse, „Snubberless“ by STMicroelectronics.

Since the zero-cross detection block as well as the FOD420 driver are optically isolated, the signal section of the voltage regulator module is galvanically separated from the power section and the 230VAC grid (Fig. 8).

V. RESULT AND DISCUSSION

Within this work was presented the design and implementation of an experimental setting of an electronically controlled regulator of the RMS voltage of the electromagnetic vibrator of vibratory bowl feeders with electro-mechanical drive. The setting is fully operational and at present stage functions in a pseudo-SCADA environment, consisting of a PC with a TTY terminal emulator and a USB communication interface.

The experimental setting is designed for driving vibratory bowl feeders rated from 50W to 1000W with vibration frequency of either 50Hz or 100Hz. The amplitude of RMS voltage on the electromagnetic vibrator of the feeder can be adjusted from 8.2V to 229V in 100 steps by typing in the corresponding command in the TTY terminal window. Voltage amplitude is altered smoothly in both increase and decrease directions, whereby the ramp-delay can be set by the operator. The experimental setting can be operated in either automatic or manual control mode; switching between the two modes is possible at every moment in time. Information about the state of the setting is visualized simultaneously on the TTY terminal window and a local LCD display. The experimental setting is capable of performing simple self-diagnosis, registering predefined alarm and emergency events and taking the necessary preventive action.

The developed experimental setting presents several technical resolutions that allow the output feed rate of a vibratory bowl feeder to be controlled by a SCADA system. In this way a significant part of the problem of integrating a vibratory bowl feeder into a SCADA system has been covered, nevertheless, the experimental setting is not yet a complete solution.

In respect to this, the modular structure of the experimental setting proves to be a considerable advantage, allowing for the setting to be further modified and expanded:

a. A primary task for the future development of the experimental setting is designing a new communication module that should serve to connect the setting to a true industrial fieldbus.

b. With the aim of achieving an integral solution, it is expedient to design a sensory device that would measure the weight of feeder load (the total of all parts in the bowl) and adjust the vibration amplitude according to the current load.

c. It is also reasonable to equip the vibratory bowl feeder with a sensory device for monitoring its output feed rate.

The completion of these steps would elaborate the experimental setting to a stage that covers all essential aspects of integrating vibratory bowl feeders to SCADA systems.

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