Abstract—This paper deals with the design of an ON-LINE diagnostic system named as “industrial data concentrator”. The paper looks at the design itself in a comprehensive way and brings together parts such as defining useful process variables, and the actual design of the industrial data concentrator both in terms of hardware and software.

Index Terms—Industrial data logger, ON-LINE diagnostic system, Technical condition monitoring, ESP32-S3, IEPE

I. INTRODUCTION

Collecting and analysing data is a normal part of our everyday lives, but along with technological advances, data analysis has been massively applied in recent years in fields where it was not possible before. One of these fields is industrial automation, in which data collection and analysis now has an irreplaceable place. The tool that deals with this task is technical diagnostics. It deals mainly with the determination of the technical condition of equipment and machines, the choice of the determining diagnostic variable, the methodology of data measurement, the identification of faults and the optimization of the production process. [1]

However, the main aspect of why technical diagnostics is becoming increasingly popular in industry is primarily economic. Thanks to the outputs that technical diagnostics provides, it is possible to plan maintenance or replacement of machine parts at the optimal time and thus avoid financial losses, which is also the main motivation for the design of the technical diagnostic system called "industrial data concentrator" that is the focus of this paper. [1]

Such devices are already available on the market, but most of them (found in my research) are not economically acceptable enough to be deployed on a massive scale in industry. Therefore, the aim was to design an industrial data concentrator as an ON-LINE diagnostic system that continuously monitors and evaluates the technical condition of the equipment and will measure all relevant process variables to determine the technical condition of rotating machines (e.g. induction motors). At the same time, an effort was made to select system parameters and component pricing to make the data concentrator competitive.

In practice, the industrial data concentrator plays the role of DAQs (Data Acquisition System). It is a device placed next to the diagnostic object to which external sensors measuring the relevant diagnostic variables are connected. The measured data is then processed inside the data logger and sent via the local network to a local database server.

II. REQUIREMENTS

Before designing the actual circuit solution, the functional, hardware and software requirements for the device were determined based on a comparison of commercially available products (e.g. IFM VSE-series, Flir SV87-kit, Siemens simotics connect 400, Bently Nevada 2300-series, National Instrument cRIO/cDAQ, Dynapar OnSite) and practical tests of measuring process variables. The individual requirements for the data concentrator are listed below.

• Functional requirements:
  − sending the measured data to the database server,
  − of data processing (e.g. FFT (Fast Fourier Transform), STFT (Short-Time Fourier Transform), correlation analysis, ordinal analysis),
  − indication of the operating state of the electric motor (on/off),
  − for counting operating hours,
  − counting the start of electric drives,
  − non-invasive current measurement,
  − multichannel temperature measurement,
  − vibration measurement,
  − magnetic field measurement,
  − speed measurement.

From a hardware point of view, a data concentrator is a device designed for installation in a small switchboard located in the immediate vicinity of the technical object of interest. The device itself does not contain any integrated sensors, all converters of process variables are external. The interface of the data concentrator was designed to support universal external sensors IEPE (Integrated Electronics Piezo Electric), RTD (Resistance Temperature Detector), digital in, digital out) but for integration reasons some interfaces were chosen as proprietary (e.g. interface for the current transformer). More detailed hardware and software requirements are listed below.

• Hardware requirements:
  − 24 VDC power supply,
  − optional 230 VDC power supply,
- ESP32-S3-WROOM-1 microcontroller,
- Ethernet communication interface,
- RS-485/PROFIBUS expansion interface,
- IEPE interface for piezoelectric accelerometers (one channel),
- temperature sensor interface RTD, NTC, PTC, KTY (two channels),
- CT (Current Transformer) current measurement interface (three channels),
- power digital outputs (two channels),
- isolated digital inputs/outputs (four channels each),
- analogue inputs (three channels),
- EMC (Electromagnetic Compatibility) compliant,
- DIN (Deutsches Institut für Normung) rail mounting.

- Software requirements:
  - using FreeRTOS (Real Time Operating System),
  - configuration via internal web server,
  - sending measured and processed data to local MySQL server.

As defined above, the industrial data concentrator should be connected to the local network and be able to send processed data to the database server. The way this has been designed is shown in Figure 1.

III. CIRCUIT SOLUTION

The circuit design is the main and most important part of the submitted work, based on the defined requirements. The device is divided into functional blocks shown in the block diagram in Figure 2. The individual parts are discussed below.

A. Microcontroller

The microcontroller was chosen with regard to the minimum price in relation to the required parameters, availability (as well as other components discussed in the paper) but above all due to the author’s previous experience with this microcontroller. With this in mind, the microcontroller was selected from the Espressif catalogue, specifically the ESP32-S3-WROOM-1U-N16R2. It is a dual-core 32-bit microcomputer whose cores can operate at a frequency of up to 240 MHz. The multi-core solution is important mainly in terms of data processing, where one core can process the measurements and the other can send the data to the server. Another important feature is the support for extended instructions dedicated to FFT that support the butterfly algorithm. The microcontroller also has internal hardware support for IEEE 802.11 b/g/n Bluetooth LE v5.0 wireless protocols, which are used in the initial configuration.

Individual peripherals can be mapped to almost any physical GPIO (General Purpose Input Output) microcontroller using a GPIO matrix (slow speed), or an IO MUX (direct fast connection). This allows for great variability in the choice of peripherals.

The suffix "U" in the chosen microcontroller model series indicates the version compatible with IPEX antenna. The antenna is integrated on the integrated PCB (Printed Circuit Board) as standard, it was chosen with regard to parasitic interference in industrial environment and therefore the need to use metallic (shielded) mechanical construction.

B. Power supply

The input supply voltage has a choice of industry standard 24 VDC or direct line voltage from 85 VAC to 305 VAC. The power circuit topology is multi-stage due to the requirement for a large variety of voltages for peripherals.

The power distribution is mainly made up of switching power supplies due to power dissipation, but for analog power circuits the power supply branches are supplemented with appropriate filters and linear regulators so that the output of the switching power supplies is not subject to interference. The galvanic isolation of the power supply circuit must be located in the external 24 VDC source, if the power is supplied via the optional 230 VAC input the galvanic isolation is internally provided. The power circuits shall also include a 24 VDC isolated power supply to meet the needs of galvanically isolated digital inputs and outputs.

Of particular importance for the power supply is the correct connection of the grounds of the individual power circuits, therefore the device has been implemented on a four-layer PCB where the power and ground can be routed in separate layers.

C. Current measurement

The interface for current transformers is universal and depends only on the choice of the burden resistor in the specific circuit.

First, the signal from the current transformer is converted to voltage by the burden resistor, which is chosen with respect to the maximum output voltage. Next, the signal is fed to a precision rectifier to double the dynamic range of the measured current. Operation amplifiers operate with asymmetrical supplies of 0 VDC to 3.3 VDC, so it was necessary to select a rail-to-rail amplifier (MCP6244). The precision rectifier has a gain of 0 dB therefore a non-inverting amplifier with selectable gain was included behind it. The entire current transformer interface cascade is terminated by a second order anti-aliasing filter (-40 dB/dec) of Sallen-Key topology.

The input ADC of the microcontroller is used to digitize the analogue quantity from the transformer, which has a resolution of 12-bit and a sampling rate (RTC controller) of 100 kS/s before the multiplexer. The wiring is chosen so that one ADC (Analog To Digital Converter) is in charge of three current transformer inputs. The set sampling frequency is therefore 10 kHz, which allows, according to Nyquist’s theorem, to measure a frequency up to 5 kHz, so that no aliasing effect occurs. The internal ADC has a programmable attenuator option which allows the measurement range to be changed programmatically.

D. Temperature measurement

Temperature measurement is one of the key process variables in industrial data application concentrator, so it must meet the criteria for accuracy and reliability of measurement.
In the search for an efficient solution, the resistive principle was finally chosen for integration, combining good accuracy, temperature range and affordability. Finally, a dual-channel variant was proposed for temperature measurement. Analog Devices MAX6657MSA+ circuitry was used. The circuits integrate 15-bit ADC and associated input circuitry, so that optional support for two, three and four wire resistive sensor connections. The circuits declare the accuracy of 0.5 °C and a resolution of 0.125 °C. Various nominal sensor resistance values (PT100, PT1000, NTY, NTC) but the circuit must be reconfigured programmatically. [4]

E. Vibration measurement

Vibration measurement is the most important process variable that the data concentrator allows to measure. Measurement is possible either via the analogue IEPE interface (accelerometers based on the piezoelectric principle) or via the PROFIBUS to which a MEMS (Micro Electro Mechanical Systems) accelerometer can be connected.

The IEPE interface works on the principle of changing the internal resistance of the sensor depending on the magnitude of the deflection, this is accompanied by a change in the output voltage from the sensor.

The interface therefore consists of a programmable current source in the range of 2 to 20 mA with a voltage limitation up to 30 VDC. This is provided by the XTR111 circuit which operates in CC (Constant Current) mode depending on the input voltage from the DAC5311 circuit. The input is complemented by a control of the disconnected and shorted circuit using two comparators.

The signal is then stripped of the DC component by a coupling capacitor and fed into an attenuator consisting of a resistor network which provides attenuation of -6 dB, -12 dB, -18 dB and -24 dB. It is not possible to programmatically change the attenuator transmission, so a non-inverting amplifier with programmable gain of 6 dB, 12 dB, 15 dB and 18 dB was added (changing the value of the feedback resistor using the TS3A5017DR programmable analogue multiplexer).

The signal then passes to a differential anti-aliasing filter, which provides greater immunity to consensual interference than standard circuitry. The wiring is of the Sallen-Key type and is supplemented by a standard passive low-pass filter. The filter is third order, and the pass band is set to 20 kHz.

The filter output is further connected to a 24-bit sigma-delta ADC AD7768 with a sampling rate up to 1024 kS/s. The ADC has been chosen with regard to component availability, so the sampling rate will be limited to approximately 400 kS/s so that the input signal is sampled at 20 samples per period. This limited sampling rate, as opposed to the maximum, also gives me the ability to implement two measurement channels by multiplexing into one ADC in a future version of the data concentrator. With respect to the required data flow from the ADC, the respective buses were dimensioned.

Setup and data readout from the ADC is done programmatically via the SPI (Serial Peripheral Interface). The converter also includes a REF6025 voltage reference with a nominal
output voltage of 2.5 V and a low temperature drift of 5 ppm/°C. The converter is clocked by an external 16.384 MHz oscillator. [5]

**F. Communication interface**

The communication interface mediates communication between the MCU (Micro Controller Unit) and external devices. Within the data concentrator, the Ethernet is used as the primary communication interface and Wiznet W5500 circuit is used as the transmitter. The interface is isolated using coupling transformers integrated into the RJ-45 input connector.

As mentioned in the introduction, the device has a Wi-Fi interface, but for stability reasons it is intended for initial configuration. In case the device cannot be configured wirelessly, a USB 2.0 configuration interface with USB-C connector is added. However, such configuration is limited and primarily intended for defining the network parameters of the device.

The external RS-485/PROFIBUS expansion interface is isolated (using iCoupler technology) and communicates in half-duplex mode. The communication is handled by the ADM2486BR transmitter. This is complemented by a terminator switch and also an isolated 5 V output power supply for the other transmitters on the link. The interface can communicate at up to 20 Mbps.

**IV. CONCLUSION**

In the paper I dealt with the complex design of industrial data concentrator as an ON-LINE diagnostic system. The comprehensive design consisted of a survey of current commercially available solutions and then drawing implications in parameterizing the requirements for the data concentrator. At the same time, relevant process variables were selected with respect to the technical diagnostics of rotating machinery.

The main part of the work was to design a circuit solution to meet the defined requirements and this was implemented. The circuit diagram and the printed circuit board were designed. Now the device is in the production phase and testing will be carried out.

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