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THE USE OF NEW AND IMPROVED VNA HARDWARE IN CIVIL ENGINEERING

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Abstract: Detecting processes of soil erosion in dams, hydraulic heave failure, and corrosion of reinforcing steel in concrete are some of the measurement applications that can be found in the field of civil engineering as a result of impedance analysis. Some of those applications have significant requirements for the measurement hardware. You should think about a standard interface that allows for the rapid sharing of data, high resolution, independent functionality, and straightforward customization of application-specific settings. It is for this reason that a well-known piece of software that is used for monitoring processes in steel mills can be used as a basis for new applications. It is a hardware platform that is based on a vector network analyzer, and it is primarily responsible for satisfying the needs. A new microprocessor with increased processing capability, an Ethernet port for quick and easy data transfer, and a new analog-to-digital converter (ADC) for a quicker sample rate are some of the modifications that are necessitated by this device.

Keywords: impedance analysis; impedance spectroscopy; vector network analyzer; ; 24-Bit ADC; Ethernet sensor network; civil engineering; corrosion processes; hydraulic heave failure; soil erosion

I. INTRODUTION

The impedance analysis is being used to characterize the complex electrical resistance of a device under test (DUT). The analysis of the impedance is a central part of the impedance spectroscopy where frequency dependencies of sensor frontends and their direct environments are investigated. Typical sensor frontends are coils and capacitors.

For instance, the impedance analysis is used in electro chemistry [1], semiconductor industries [2], medical applications [3] and steel industry [4]. The measurement requirements in civil engineering are quite different in comparison to the listed applications. Measuring solutions in steel industry are faced with similar demands of the environment. Thus the measuring hardware platform for steel- mill process monitoring will be used as a development platform [5]. The analysis and modification of this measurement hardware will be presented.

In civil engineering miscellaneous measuring applications occur where impedance analysis offers advantages. For example, the detection of soil erosion in the dam, early detection of hydraulic heave failure and the detection of corrosion processes in reinforced concrete.

A. Detection of soil erosion in the dams for flood protection

Hydraulic processes (suffusion, internal erosion) inside of dams deteriorate the stability and the resistance against flood. For that reason, the aftercare of the dam is an important part of the stability examination. Typical methods for stability examinations are seismology, ground radar and geoelectric surveys [6] as well as exploratory drillings.

B. Early detection of hydraulic heave failure

A high risk of a hydraulic heave is given at locations with different groundwater levels (e.g. excavation pit below the groundwater table). The upward ground water flows below the bottom of the excavation and may lead to a ground failure in front of the retaining structure and a collapse of the pit construction itself [7]. Rules to manage hydraulic heave failure are described in Eurocode 7 (DIN EN 1997-19) [8].

C. Detection of corrosion processes in reinforced concrete

The corrosion in reinforced concrete can lead to cracks and spalling of the concrete surface. Moisture can enter those faulty locations and speed up the corrosion processes. There are some measures to protect the reinforcing steel against corrosion like the cathodic protection system or the galvanized reinforcing steel [9].

D. Measuring hardware

To measure an impedance spectrum, vector network analyzers are well suited. A special system has been developed for process monitoring in the steel-mill. It is using the impedance analysis for determination of the cross-sectional area of a hot rolled rod. The measuring hardware is original based on an open- source project [10] and has been revised to fit this measuring application properly. This specific measuring hardware is based on a vector network analyzer, which is measuring the impedance by determination of the mismatch between the signal source and the device under test. For a true measurement, the measuring hardware needs to eliminate all parasitic influences (e.g. inductances and capacitances) by the electronic parts and cables using an open-short-load-calibration (OSL-Calibration).

By reference of the impedance analysis applications in civil engineering, there are strong requirements for a dedicated measuring hardware:

Common interface for data exchange with a higher-level system

Usually the measurement application in civil engineering extends on a bigger areal layout with more than one measuring site. Thus, data exchange needs to handle long distance transmissions and must be immune to interferences.

The hardware platform is equipped with a RS422 interface for data exchange. The data rate is 1.8 Mbit at its maximum. The problem is the missing popularity on typical laptops and industrial PCs (IPC). Therefore, additional adapters or expansion cards are needed.

To keep the physical benefits of the RS422 interface and solve the problem with the missing popularity, an Ethernet interface should be used for communications in further applications. The maximal data rate will increase, long distance transmissions are possible, immune to interferences and it is possible to build a sensor network with several measuring sites.

High resolution capability to detect small changes in impedance

The corrosion process of reinforced steel extends over a long period of time. The effective cross sectional area of the reinforced steel decreases and causes a change of impedance. To detect small changes of the cross sectional area, a high resolution capability is necessary for this measurement application.

The hardware platform for steel-mill process monitoring is equipped with a 24-Bit ΔΣ-ADC and a sample rate of 156 kSPS. The resolution of changes in the impedance achieves 20 mΩ corresponding to 50 µm change in the cross sectional area for typical rod diameters.

To enhance the resolution capability with statistical methods, a 24-Bit ADC with a much higher sample rate should be used. Moreover, the PCB should be planned with an improved ADC layout for noise reduction and optimization.

High sample rate to detect fast changes in the impedance

All calculations and interpretations of the impedance analysis are accomplished on an industrial PC (IPC) of the process monitoring system, communicating with the measuring hardware using the RS422 interface. Due to this fact, the sample rate is limited on the data rate of this interface. To increase the sample rate, all calculations and interpretation of the impedance analysis should be carried out on the microcontroller of the hardware platform. By using a 24-Bit ADC with a higher sample rate, the current sample rate can be increased furthermore. The control of the ADC and data processing needs a fast microcontroller. Thus, an ARM® processor with DSP functionality should be used to match the demands.

Independent functionality without additional computer

In practical field use the measuring hardware will not always be accessible by operators, for that reason an independent functionality must be guaranteed. By the help of the Ethernet interface it is possible to administrate the configuration or even the firmware of the measuring hardware from a single operation point. A suitable concept of the firmware and the choice of a high-performance microcontroller makes it possible to handle the total measuring control, calculations and interpretation of the impedance analysis on the measuring hardware.

II. RESULTS AND DISCUSSION

The analog circuitry, PCB layout and components of the measuring hardware should not be changed; the optimizations will be occurring primarily on the digital parts. Due to the requirements and the introduced approaches, the following changes will be made. The measuring hardware will be equipped with Table 1 shows the comparison of the main properties between the existing dsPIC30F5011 of the hardware platform and the STM32F407.

TABLE I. MICROCONTROLLER COMPARISON

	dsPIC30F5011	**STM32F407**
Clock	118 MHz	168 MHz
Voltage	2.5 V – 5.5 V	1.8 V – 3.6 V
SPI	10 MBit	42 MBit
Ethernet	no hardware support	MAC, RMII available
Memory	66 Kbyte Flash 4 Kbyte RAM 1 Kbyte EEPROM	1 Mbyte Flash 64 Kbyte RAM 192 + 4 Kbyte SRAM

The data exchange will be realized with an Ethernet interface. The STM32F407 is able to connect to an Ethernet- PHY (e.g. DP83848) directly, but a software IP-Stack is required. Thus, the Ethernet-Controller W5500 will be used, because it is based on a hardwired IP-Stack and can be simply connected to the STM32F407 by the SPI bus. Table 2 shows further benefits.

By the introduced requirements, approaches and single electronics of the hardware platform, a test assembly has been created. Fig. 1, shows the specimen.

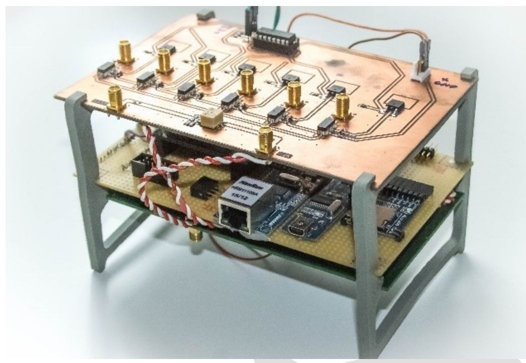

Fig 1.Test assembly with the modified hardware.

Essentially the test assembly is based on a modified PCB from the hardware platform and an additional PCB for mounting the new electronic components. Prefabricated modules have been used to shorten the development time of the experimental assembly.

Fig. 2, shows as a block diagram of the connection overview of the digital components. The analog connections are not shown.

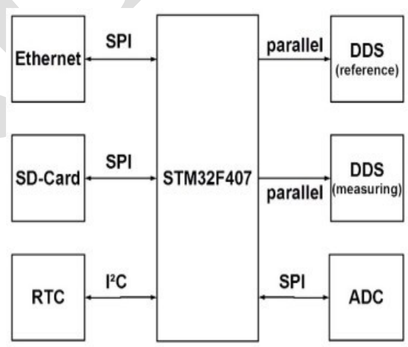

Fig. 2. Block diagram of the digital electronic

To verify the new hardware with the original functionality as a cross sectional measuring device, the test assembly has been put into operation and a basic firmware has been developed. After that, the test assembly has been compared with the hardware platform for process monitoring. Table 4 shows the comparison of the original ADC of the hardware platform and the ADC with a higher sample rate. The results are showing the average over 10 voltage readings of the calibration standards and a single device under test.

TABLE II.COMPARISON OF THE VOLTAGE MEASUREMENT

	AD7764		LTC2380-24	
	Real	**Imaginary**	**Real**	**Imaginary**
Open	-41 mV	-110 mV	-33 mV	-85 mV
Short	-120 mV	-109 mV	-137 mV	-85 mV
Load	-108 mV	-109 mV	-85 mV	-85 mV
DUT[a]	-108 mV	-119 mV	-85 mV	-135 mV

The table illustrates that the integration of the faster ADC has been successfully. The tendency and magnitude of the measurements are similar. The minimal varieties are caused by the variability of the PCBs. Because of the OSL-Calibration the varieties are negligibly. Table 5 shows the impedance measurement of a single device under test at five signal frequencies. Each measurement has been averaged over 10 readings.

III. CONCLUSION

Based on the findings, it appears that the alterations that were made using the new electronic components were ultimately successful. Through the use of the test assembly, it is possible to obtain the functionality of the original device, which was a cross-sectional measurement device for process monitoring. Once the measurement platform has been redesigned, it will be possible to tailor it to the specific requirements of measuring applications in civil engineering.

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