TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
MECHANICS | MECHANIKA

1-M/2013

JANUSZ KWAŚNIEWSKI*, IRENEUSZ DOMINIK*, KRZYSZTOF LALIK*

REAL-TIME SYSTEM BASED ON FPGA APPLIED TO SELF-EXCITED ACOUSTICAL SYSTEM FOR STRESS CHANGE MEASUREMENT

SYSTEM CZASU RZECZYWISTEGO OPARTY O FPGA ZASTOSOWANY W SAMOWZBUDNYM AKUSTYCZNYM SYSTEMIE POMIAROWYM DO POMIARU ZMIAN NAPRĘŻEŃ

Abstract

In the paper the real-time system based on FPGA applied to control the delay time in feedback loop of the Self-excited Acoustical System is presented. The system can be used for stress change measurement in elastic constructions. Stress changes manifest themselves in small but detectable variations of resonance frequency. This phenomenon can be used to indirect measure stress changes in the material. In the article the limits of the measurement system which occurred during research on the analogue version of the system were eliminated by applying FPGA technology.

Keywords: real-time computing, field-programmable gate array, computer supported experiment

Streszczenie

W artykule przedstawiono wykorzystanie systemów czasu rzeczywistego i układów FPGA do sterowania opóźnieniem pętli sprzężenia zwrotnego w Samowzbudnym Systemie Akustycznym do pomiaru zmian naprężeń w konstrukcjach sprężystych. Zjawisko to może zostać użyte do pośredniego pomiaru naprężeń w konstrukcjach. W artykule wskazano ograniczenia układu pomiarowego, które zostały wyeliminowane dzięki zastosowaniu systemów czasu rzeczywistego oraz układów FPGA.

Słowa kluczowe: systemy czasu rzeczywistego, układy FPGA, komputerowe systemy nadzoru

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* Prof. Janusz Kwaśniewski, PhD. Ireneusz Dominik, MSc. Krzysztof Lalik, AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Department of Process Control.

1. Introduction

The autooscillator also known as the auto-oscillating system is generally introduced as dynamical system capable of performing oscillations. The autooscillation, which appears in the system, is a kind of a non-damped oscillation in a non-linear dynamical system, whose amplitude and frequency can remain constant during a long period of time and are largely independent of the initial conditions. According the soviet physicist A.A. Andronov theory amplitude and frequency are determined by the properties of the system itself [14].

The autooscillators are quite common in practice. The simple non-linear mechanical systems can hold a particular frequency. A good example is the music instrument: reed woodwinds, which gives a constant frequency sound with a wind flowing round.

At the Department of Process Control at AGH University of Science and Technology the Self-excited Acoustical System (SAS), which is a kind of the autooscillator, was developed [1]. The essence of the SAS system is to use a vibration exciter and vibration receiver placed on a sample at a distance with a positive feedback, which causes the excitation of the system. Stress changes manifest themselves in small but detectable variations of resonance frequency (autooscillator frequency). As a parallel to reed woodwinds a sample under load examined by the SAS system changes its length thus the system resonance frequency. This phenomenon can be used to indirect measure stress changes in the material [2, 3].

Non-synchronous autooscillators set the frequency near the resonance frequency of a system [4, 8]. Due to a piezoelectric shaker application the high proper vibration forms are observed. In order to synchronize an autooscillator to the lower forms an additional controlled delay in the SAS feedback loop can be implemented. During a numerous experiments it was deduced that for the high proper vibration forms resulting in the high oscillation frequency of the SAS system it is impossible to use the general purpose operation systems. The problem was solved by working in the Real-Time Operating System (RTOS) implemented in the Field Programmable Gate Array (FPGA) platform.

In the article the principles and basic parameters of the SAS system are described. The used computer methods with reference to the created control application are also explained. The relationship between individual components of the real-time system is also described. The focus is put on influence of the controlled delay in the feedback loop on resonance frequency of the SAS system.

2. Preliminary research

The scheme of the Self-excited Acoustical System is presented in Figure 1. It can be divided into three main parts: electrical, mechanical and software. The mechanical part consists of a sample under examination, fasten points, a base. The electrical part consist of a shaker (vibration exciter E) and accelerometer (vibration receiver R) placed on a sample at a distance. Together with a conditioner, a power amplifier and the RTOS system the positive feedback loop is created.

The software part focuses on implementing the RTOS on FPGA platform. The data acquisition by the measurement card and especially the implementation of the additional controlled delay in the feedback loop are the main parts of the software.

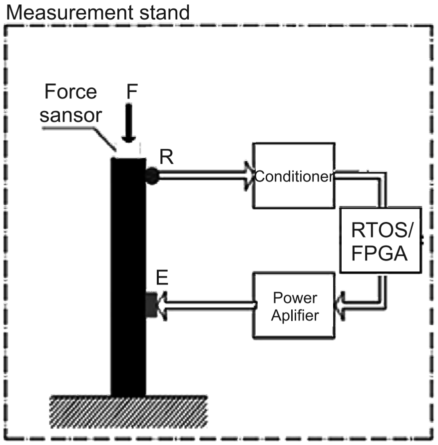

Fig. 1. The scheme of the Self-excited Acoustical System, where E – exciter, R – receiver, F – applied force
Rys. 1. Schemat Samowzbudnego Systemu Akustycznego, gdzie E – wzbudnik, R – odbiornik, F – przyłożona siła

According to the theory proposed in [1] and [5] for the design SAS system the following relationship may be delivered:

$$\frac{\Delta f}{f_0} = -\frac{\Delta\tau}{\tau_0} - \frac{\tau_E}{\tau_0}\frac{\Delta f_E}{f_0} - \frac{\tau_R}{\tau_0}\frac{\Delta f_R}{f_0} - \frac{\tau_{\text{comp}}}{\tau_0} \tag{1}$$

where:

f_0 and τ_0 – are the frequency and delay for preliminary load of the sample,
f_E and τ_E – are the frequency and delay for exciter – amplifier connection,
f_R and τ_R – are the frequency and delay for receiver – conditioner connection,
τ_{comp} – a controlled delay of the feedback (part of software in RTOS).

It is proved that increasing any of the delays (in Eq. 1) can decrease the resonance frequency of the autooscillator (Eq. 2). Thus the frequency of the whole system is decreased. It enables usage of the longer window functions in the Fourier analysis and as a result it improves measurement accuracy [6, 7].

$$f_0 = \frac{m}{\sum \tau_{0i}} \tag{2}$$

where m is a integer number, which is estimated as number of wavelengths λ on a distance l: $m \approx l/\lambda$.

Figure 2 presents the results of applying two types of the exciter to the SAS system. The upper piezoelectric exciter has time response of 500 ns while the lower electro-acoustic exciter of 50 μs. In both cases the main idea of the SAS system can be observed: the resonance frequency of the system is changing in accordance to the compressive force applied to the sample.

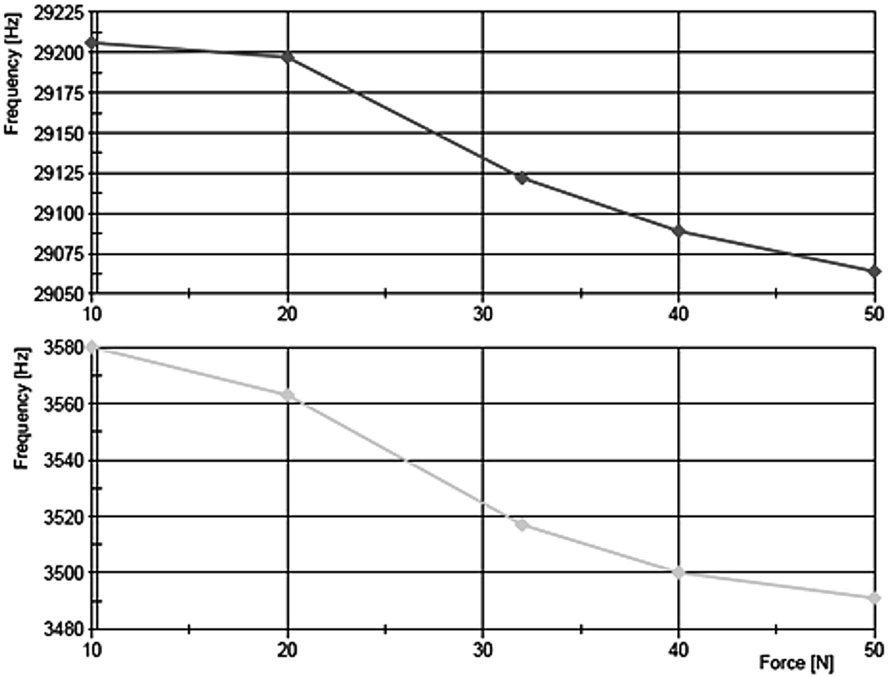

Fig. 2. The dependence between the autooscillator resonance frequency and the load force of the sample for the piezoelectric exciter (above) and the electro-acoustic exciter (below)
Rys. 2. Zależność pomiędzy częstotliwością autooscylatora i siłą obciążającą badana belkę dla wzbudnika piezoelektrycznego (góra) i wzbudnika elektroakustycznego (dół)

The results indicate that using the slow electro-acoustic exciter decreased the system frequency which allows the SAS system work properly without the powerful specialized hardware. On the other hand the bigger delay time in the system the narrowed pass band – in the case of some high frequency constructions the SAS system may not work properly. That is why the best solution seems to be usage of the fast piezoelectric exciter with the controlled delay in the feedback loop implemented in FPGA platform.

3. Real time operating systems

An Embedded System is usually a computerized system integrated with a bigger system. Embedded systems are associated with the concept of real - time operations. A real-time operation is an operation of the unit, which is dependent on the time of its execution. It results in a constant competition between the two systems: external (environmental) and internal (real time device). In order to keep pace with the environment, in which the unit works, there are special criteria for limiting the development time for RTOS. This limitation and a system repeatability to fulfill those restrictions is the basis for quality assessment of the real time operating system [9].

Real time operating system is able to execute the program reliably, even with its specific requirements for the synchronization and coordination. The special operating system –RTOS is a key to build a real time unit. The Authors used a dedicated real-time system built in the LabVIEW environment to control the SAS system delay duration in the feedback loop. Unfortunately, the built in real-time systems have the software frequency limitation. The restriction for LabVIEW amounts to 1 kHz [10]. For this reason, it was necessary to use a FPGA system additionally.

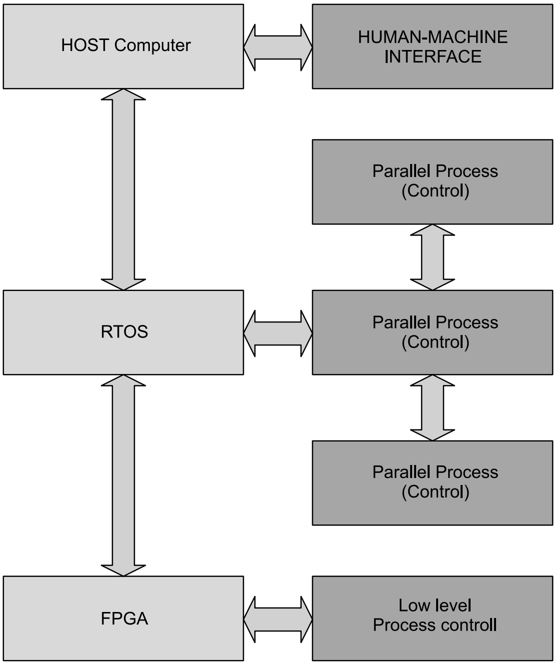

Fig. 3. The communication architecture: HOST/RTOS/FPGA

Rys. 3. Architektura komunikacyjna HOST/RTOS/FPGA

Figure 3 shows a popular architecture, which can be used as a starting point for the most control and monitoring applications. The host program provides the user interface based on the system events so the operator has access to the built-in system and can interact with it [11]. A real-time operating system performs the high level control while the FPGA system is engaged in the low-level control.

4. FPGA systems

For the system designer FPGAs (Field Programmable Gate Array) performs the same function as dedicated built-in systems, which are constructed for the implementation of the defined tasks. The difference between them lies in the fact that FPGAs may be reprogrammed many times after their design and installation in a target circuit. Thus FPGAs are the excellent tool for building real time embedded systems [12, 13].

The system architecture shown in Figure 3 consists of each device processes and data communication paths. Processes are represented by gray blocks. Target hardware devices, which execute those processes are marked as yellow blocks. Data communication paths are represented as white arrows. Major tasks of the designed software are shown in Figure 4.

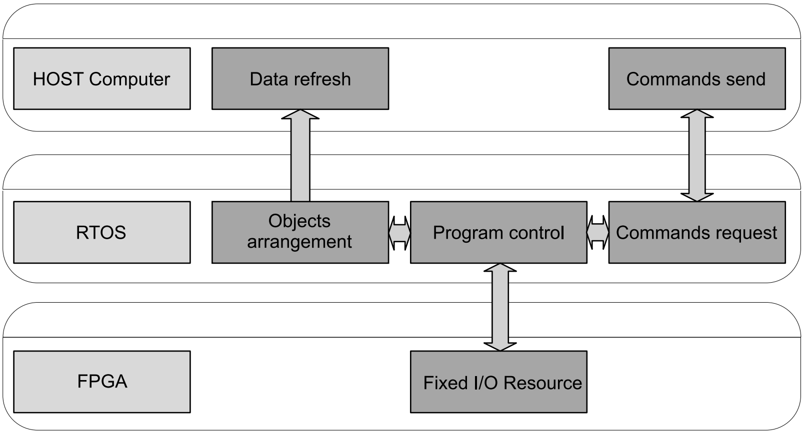

Fig. 4. The basic tasks of the control architecture components: HOST/RTOS/FPGA

Rys. 4. Podstawowe zadania komponentów architektury HOST/RTOS/FPGA

The LabVIEW Interface mode enables the physical adaptation of the FPGA, including programming of a real time processor. It allows achieving the performance that typically required a dedicated hardware. An exemplary FPGA process for delay duration control of the Self-excited Acoustical System is shown in Figure 5.

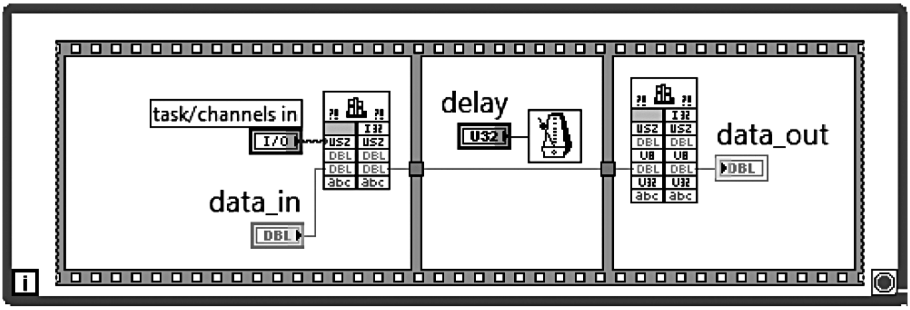

Fig. 5. FPGA process for delay duration control

Rys. 5. Proces FPGA ze sterowalnym opóźnieniem

By default FPGA communicates with I/O modules automatically. It provides a deterministic I/O field for a real time processing. The system allows a real-time control program to access

I/O with the jitter shorter than 500ns. FPGA can be also directly programmed in order to further customization and improvement of the system. The valid circuit diagram for the communication between RTOS and FPGA is shown in Figure 6.

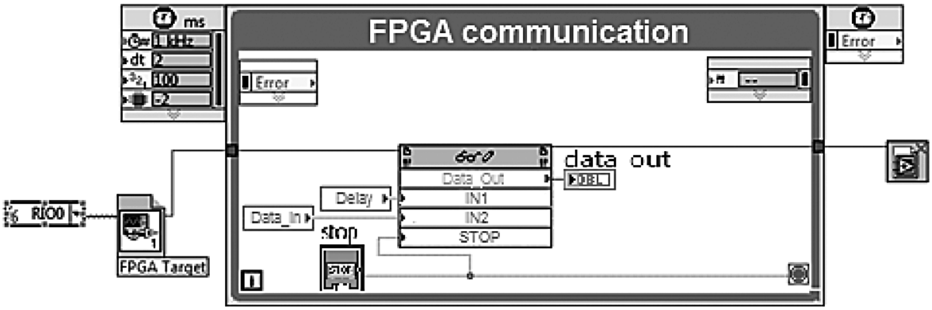

Fig. 6. The FPGA-RTOS communication program diagram

Rys. 6. Program odpowiedzialny za komunikację z układem FPGA

5. Conclusions

This paper presents the real-time system based on FPGA applied to control the delay duration in feedback loop of the Self-excited Acoustical System for stress change measurement.

The computer-aided system is highly flexible, which is achieved at the programming level. The application of the real-time operating system and the field programmable gate arrays allowed completing the control system. It allows to determine the delay duration of the feedback loop in SAS system. The FPGA technology gave the possibility of interference in the acoustic signals that go beyond the human ear audibility.

The main task of FPGA implementation to the SAS system was fulfilled – the user can control the feedback delay time and thus reduce the measurement system sampling frequency. As a result the level of the hardware requirements is lowered – there is no need to use very expensive high frequency shakers and advanced measurement systems.

In the further system development phase variety of filters will be applied and tested using LabVIEW and FPGAs. The whole set of filters, starting from classic and ending with advanced filters, based on artificial neural networks will be considered. The embedded filter will select a frequency bandwidth. It allows the system to eliminate any possible frequency shift resulting from the changes in the form of vibration in the tested material under load.

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