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A signal pre-processing algorithm designed for the needs of hardware implementation of neural classifiers used in condition monitoring

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ABSTRACT

Gearboxes have a significant influence on the durability and reliability of a power transmission system. Currently, extensive research studies are being carried out to increase the reliability of gearboxes working in the energy industry, especially with a focus on planetary gears in wind turbines and bucket wheel excavators. In this paper, a signal pre-processing algorithm designed for condition monitoring of planetary gears working in non-stationary operation is presented. The algorithm is dedicated for hardware implementation on Field Programmable Gate Arrays (FPGAs). The purpose of the algorithm is to estimate the features of a vibration signal that are related to failures, e.g. misalignment and unbalance. These features can serve as the components of an input vector for a neural classifier. The approach proposed here has several important benefits: it is resistant to small speed fluctuations up to 7%, it can be performed in real-time conditions and its implementation does not require many resources of FPGAs.

1. Introduction

Condition-based maintenance is an effective method of maintenance in the industry. It assumes that the potential breakdown of a machine is predicted through regular Condition Monitoring (CM). Such an approach allows to obtain significant economic benefits by eliminating unplanned downtime and repairs as well as by early planning of any component replacements. It is especially important for industries which apply machinery that must run continuously, e.g. in an opencast mine even the smallest unplanned downtime of a bucket wheel excavator causes large economic losses. Methods based on maintenance at regular intervals of time or on the exploitation of machines until they broke down were commonly used before the development of condition-based maintenance. Run-to-break maintenance is characterized by the longest time of exploitation between shutdowns, but failures can be catastrophic and can even result in safety hazards. Preventive maintenance is carried out at regular time intervals which are shorter than the expected time between failures, but this method is characterized by large consumption of replacement components [1].

Continuous monitoring and assessment of the machine's condition is crucial, especially in an industry where the costs of unplanned downtimes outweigh the costs of repairs; also, early prediction of failures ensures safety of exploitation. Assessment of the condition of the

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object can be carried out on the basis of vibroacoustic signals generated by the machine and by the application of different signal processing methods [2–4]. In practice, machines work in non-stationary operations, therefore it is necessary to monitor their operating parameters, such as rotational speed and loading. Gearboxes are the main component of the machines and the most vulnerable one, especially Planetary Gearboxes (PGs), which are complex mechanisms and their dynamic interactions have a significant influence on the durability and reliability of the whole machine. PGs are distinguished by compactness of construction, high ratio, and the ability for high power transmission, and they are used widely in the industry, especially in such sectors as automation of manufacturing, mining, wind turbines as well as in the power transmission systems of helicopters. Recently, many researchers have focused on developing reliable condition monitoring methods for planetary gearboxes [5], as the development of such methods is a challenging task, especially for machines working in non-stationary operations.

Neural networks are being used more commonly in engineering applications due to their flexibility and ability to work in real-time conditions. Currently, extensive research is being conducted on the application of neural networks in condition monitoring [6–9]. Neural classifiers allow for a quick and effective association of symptoms and enable to identify the condition of the machine, where categorization of symptoms by mathematical formulas is ambiguous. It has been shown that neural networks can be successfully used for recognizing the condition of gearboxes [6,10], as they allow for the detection of potential failures which were not known at the time of training the network [11], and they can be applied for identifying the condition of variable-speed transmissions [12,13]. Hardware implementation of neural networks is becoming more important due to very high efficiency and adaptability to working parameters. In engineering applications, neural networks differ in scale, topology, transfer functions, and learning algorithms. They require significant computational power and flexibility of implementation. Field-Programmable Gate Arrays (FPGAs) have created a new possibility for implementing Artificial Neural Networks (ANNs), as they provide flexibility of implementation, reprogrammable properties and parallelism of computing. The implementation of ANNs using programmable devices has been presented in many papers [14–18].

Neural networks can be used to assess the condition of gearboxes [6,8,10], but what is crucial for their successful application in condition monitoring is a proper definition of the technical state vector, as such a vector contains estimates indicating the condition of the object; another important aspect is to properly determine the training data set. In this paper, the signal pre-processing algorithm allowing to calculate the technical state vectors for a planetary gearbox working in non-stationary operation is proposed, and it is dedicated for hardware implementation on FPGAs [19–21]. The purpose of the algorithm is to estimate features of the vibration signal that are related to the investigated failures, then these features can serve as components of an input vector for a neural network. Proposed approach has a few important benefits: algorithm is resistant to small speed fluctuation up to 7% by a proper definition of the filters cut-off frequencies and can be performed in real-time conditions as well as its implementation does not require many resources of FPGAs.

2. FPGA technology

Field-Programmable Gate Arrays allow to implement any logical function designed by the customer. The structure of the programmable logic of an FPGA consists of a two-dimensional array of Configurable Logic Blocks (CLBs) based on Look Up Tables (LUTs). Each CLB can be configured to implement any Boolean function. The CLBs are connected by programmable routings, which can be vertical and horizontal. The routing channels, consisting of wires of different length, can be connected together by connection boxes, which are a set of programmable links. The programmable I/Os of FPGAs allow the pins of the FPGA chip to function as input pins, output pins or input/output pins [22]. Fig. 1 presents the design of an FPGA device.

The logic blocks in the FPGAs are connected by programmable routing resources, but this comes with a serious problem – it is difficult to predict the timing parameters of the implemented project, which depends on the logic synthesis algorithms implemented in the design system. This is the most serious disadvantage of the FPGAs. The propagation time of the signal in an FPGA chip depends on the delay on each line. The propagation time will change if the project is implemented in another way (other transmission paths). The architecture of the FPGAs forces designers to create synchronous projects, which is the only way to guarantee stable operation over the entire frequency range [22].

The FPGAs, due to their structure and tasks, can be classified between DSP processors and ASIC devices. In contrast to the processors, FPGAs do not take the code of the task from the memory, as the configuration memory is directly embedded in their structure. The main advantage of FPGAs is that all functions are performed simultaneously; on the

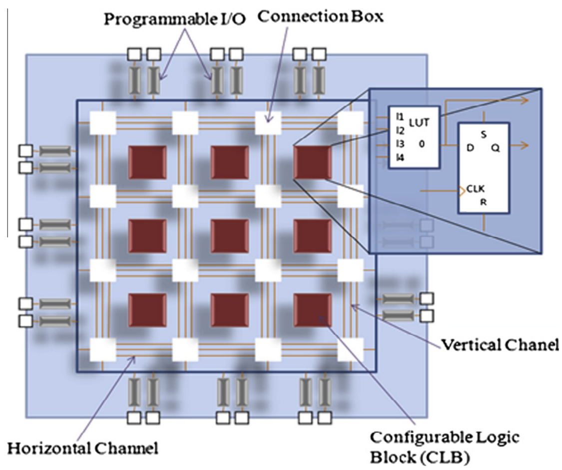

Fig. 1. Design of the FPGA device.