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Leakage quantification of compressed air using ultrasound and infrared thermography

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ABSTRACT

With the leakage elimination in compressed air systems, it is possible to save up to 40% of energy. With appropriate inspection and maintenance of compressed air systems, leakage elimination should be a routine. This paper describes and compares two different noncontact methods for compressed air leakage quantification, ultrasound and infrared thermography. The potentials and limitations of these technologies are analyzed, as well as the reliability and accuracy of results thus obtained. From the results presented in this paper, it can be concluded that thermography offers good results for the leakage quantification from the orifices greater than 1.0 mm and ultrasound should be used for leakage detection for all the dimensions of orifices, but for the quantification purposes only for smaller leaks. As a support for leakage quantification, we proposed diagrams of a leak flow as a function of sound level and as a function of detected temperature change.

1. Introduction

Beside electric energy, compressed air is nowadays the most universal energy medium used by a number of industries. Despite all its advantages, compressed air is an expensive energy resource. Energy costs contribute to 75% of the total costs for compressed air production. In the EU, compressed air production contributes to 10% of the total electric energy consumption in industry [1], in some industrial branches, such as the glass industry, even 30%. A significant share of compressed air is lost on various accounts. Compressed air losses constitute 25–30% of the total compressed air requirements. However, there are particular systems in which this percent amounting from 30% up to even 60% [2]. Leaks are the most visible and most significant contributors to compressed air losses. Leakage rate varies between 20% and 40% of the total air usage [3]. Beside economic effect, the reduction of compressed air losses is significant for the environment. The reduction of losses also reduces demands for production, which in itself reduces emission of CO_2 and other harmful substances into atmosphere.

In order to reduce leaks and increase energy efficiency it is necessary to detect leaking spots and remove causes of leaks. Clear idea that stands behind this paper is a role of ultrasound and infrared technology for compressed air leak detection and quantification. Due to their small size, leaks are often hard to locate by other methods, which necessitate the use of ultrasound, or infrared technology, depending on the certain situation. A combination of passive ultrasound method and infrared thermography allows detection of very small leaks.

Leakage quantification is possible with several well-known methods [4], but they cannot give the allocation of leakage on the distribution net.

This paper compares mentioned methods, their potential and limitations of individual and combined application

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of ultrasound and IR technology on estimation of losses due to compressed air leaks.

2. Detection and quantification of compressed air leaks

The problem of air and fluid leaks has been in the focus of scientific literature for years. Numerous authors have dealt with the leakage of technical gases (propylene, ethylene, etc.), natural gas, oil, water, and other fluids [5]. There is a relative scarcity of papers dealing with the detection of compressed air leaks. However, due to similar physical and exploitation properties of gases, the problem of compressed air leak detection can be dealt with equivalent to other technical gases.

According to [6–8], all methods of leak detection for gases and liquids can be classified as hardware methods, biological or software methods. All this methods have their specific traits that define their limitations and area of application. Comparison and analysis of these methods and their potential application for leak detection was given by [9], based on seven criteria, but several methods are most popular in the practical detection of compressed air leaks [10].

In many cases, leaks could be detected quite easily. Heavy leaks are easy to hear. However, smaller leaks are harder to detect, and cannot be easily heard. In some cases, a single method is sufficient to detect leaks, while in other cases a combination of methods have to be used in order to detect their location. Once the magnitude of losses is established, the total value of compressed air losses could be calculated based on price of compressed air production per 1 m^3. There exist various methods of compressed air leak quantification [4]. They are based, mostly, on the measurement of compressor operation time, although flow gauges, ultrasound detectors, and IR thermography are also gaining popularity [11].

3. Theoretical background

3.1. Ultrasound technology

Ultrasound is the sound with the frequency above the upper limit of human hearing. The audible frequency range in humans goes from 10 Hz to approximately 20 kHz. Ultrasound technology utilizes sound waves that are beyond human perception, and ranges between 20 kHz and 100 kHz.

Ultrasound testing methods belong to the group of nondestructive testing methods (NDT). Currently, the ultrasound testing method is most popular in medicine. Non-invasive ultrasound diagnostics is mostly used for examination of internal organs [12]. Exposure of cells to ultrasound does not have harmful effects, although the ultrasound waves penetrate relatively deep into human body.

Beside medicine, ultrasound has also been widely used in industrial applications. It has been increasingly used in the processing, chemical, petrochemical, food, metal industry, as well as in civil engineering and architecture. It is most often used for measurement of physical quantities, such as fluid flow, fluid level, material thickness, length, surface area, volume, speed, etc. In addition, it is frequently used for ultrasound cleaning, welding, process automation (ultrasound sensors) [13], analysis of material structure [14], detection of defective machine components and subassemblies, inspection of electrical installations and equipment, detection of foreign bodies in food [15], detection of fluid leaks [16], etc.

Wide spectrum of sounds, ranging from audible to inaudible frequencies, also as ultrasound (also familiar as the white noise) is mostly generated by cavitation or turbulence of air molecules under the pressure, which flow out into the atmosphere through orifices, cracks, and seams. The application of ultrasound on leak detection shall be in the focus of the remaining part of this paper. According to [17], ultrasound leak detection can be classified on active, passive, and vibroacoustic. In this research, the passive ultrasound detection was used for quantification of compressed air leak.

3.2. Infrared thermography

Infrared technology uses IR thermovision cameras to display and measure thermal energy radiated by an object. IR thermovision cameras generate images of infrared or thermal emission, allowing very accurate non-contact temperature measurement. In almost all compressed air systems, the occurrence of malfunction or air leak is accompanied by temperature change. Application of IR thermovision cameras to diagnose such changes can bring substantial savings.

The goal of an infrared investigation is to transmit a packet of energy towards an object under examination, and observe its response to thermal excitation – the development in time of surface temperature distribution. Subsequent analysis can reveal the material structure beneath the surface, possible inclusions, cracks, or processes that occur beneath the surface [18].

The principles of infrared thermography are well presented in [19]. Infrared thermography is also used in agriculture, civil engineering, and architecture [20,21], electric power industry [22], automotive industry [23], medicine [24], manufacturing industry [25], environment protection, and protection of historic heritage [26,27,19], while it is also increasingly used for fluid leak detection [28,29].

The number of scientific papers that deal with the problem of thermographic detection and quantification of compressed air leaks is scanty. Kroll et al. [30] report on a novel method for automatic detection of compressed air leaks using software tools for thermogram analysis and pattern recognition. Lewis et al. [31] give a concise presentation of available methods for gas leak detection in landfills, with emphasis on IR thermography. They conclude that this method can be used exclusively for screening, and not for precise gas leak detection or mathematical modeling of gas emission in landfills.

4. Experimental investigations

In order to establish prerequisites for compressed air leak quantification using ultrasound and IR technology,