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NON-INVASIVE STEAM FLOW MEASUREMENT AS AN ENERGY MEDIUM BY CLAMP-ON ULTRASONIC METHOD IN CONTEXT OF ENERGY MANAGEMENT CONCEPT IMPLEMENTATION, OPTIMIZATION AND SAFETY

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Abstract

The aim of this study is to present the results of test measurements of steam flow for the development of energy balancies and the design of optimization plans, provide application model for energy management implementation concepts and the safety aspects. Furthermore, to demonstrate innovative technology in field of industrial measurement and theoretical analysis of such technics as a part of modern way of technology improvement. The flow measurement was performed on a low-temperature steam branch. An ultrasonic flow meter from a leading manufacturer of ultrasonic measuring technology was used for the measurement, which supplies non-invasive ultrasonic devices in addition to other process media the clamp-on technology for measuring quantitative parameters of low-temperature and high-temperature steam. Another goal is to use procedures and collected data for further research and deployment of such technology in industrial practice to increase process efficiency and operational safety.

Keywords: Steam flow measurement; Ultrasonic method; Energy management; Operational safety.

1. Introduction

Steam is widely used mainly in industry, but it also finds its place in the energy, pharmaceutical, medical, and other sectors. To monitor consumption, optimize utilization, energy balances and reduce losses, it is necessary to measure its flow reliably and as accurately as possible. Until now, this has been performed by measuring devices that use conventional flow measurement methods, such as e.g., measuring orifice together with differential pressure gauge, etc. All these methods are invasive ones and the integration into the system, repair, or maintenance, require the medium to be redirected to bypass, or in the worst case, shut down of a production section or whole operation. Non-invasive ultrasonic flow meters do not interfere with the process and there is no need to change the operation in any way, which brings huge benefits as financial savings and significantly increases the reliability of the technological process and safety at work.

In case of energy management, precise flow and energy monitoring has a significant place in the whole schematics to provide reliable input data for further proceedings. Nowadays, the ISO 50 001 is a common concept to lead to energy efficiency in a proper and reliable way.

2. Energy management

Sustainable business development and companies market positioning require from companies to maximize added value with minimal resource utilization. The three main goals to optimize are to ensure safety, high efficiency, productivity and economy of „man-machine environment" system [1]. "Our Common Future", a report published by the World Commission for Environment and Development presided by Gro Harlem Brundtland, defines sustainable development as the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2]. Growing load and deterioration of the environment can be interpreted as a result of some external effects interventions. While the positive externalities influence the positive productional and utilizational functions of other subjects, the negative externalities influence the negative ones. Both types of external effects can act as partial or global externalities. Linking of environmental issues to economy and finance is an important sphere [3]. In context of the current socio-economic activities of society, the solution of issues and problems related to environmental pollution is becoming more and more popular. Environmental degradation not only affects densely populated areas, heavy industrial pollution etc., but often affects areas that do not directly attack environmentally unsuitable activities [4]. Innovations refer to the actions required to create new ideas, processes or products. The implementation of new ideas, processes or products leads to positive effective change in a company. The positive effective change in a company is accomplished through savings. Thus, company makes savings in different types of resources via innovations, contribute to social goal or influence the development of technological solutions. In industry, savings via innovations are mostly reflected in redesigning products and processes to cut out unnecessary costs. That type of innovations are called frugal innovations. Frugal innovations represent innovations of existing solutions with accent of achieving resource savings. Nowadays, frugal innovations, which are used in industry, play a vital role in era of fourth industrial revolution, named Industry 4.0 [5]. In the year 2010, Germany initiated the "Industry 4.0" project, in order to promote its economic development and global competitiveness. China issued the "Made in China 2025" strategic plan, in order to transform the country from a manufacturing giant to a world manufacturing power. Japanese government introduced a new concept called "Society 5.0 (Super-smart society)" [6].

Technological progress leads to the implementation of artificial intelligence in the field of industry. Such systems require high reliability of partial blocks and sensors to ensure high reliability of the entire system controlled by artificial intelligence. Contactless systems show a lower failure rate and higher reliability as they are not often in contact with an aggressive process medium, and this makes them an ideal solution for securing input data for processing and controlling the process with artificial intelligence.

Artificial intelligence (AI) is the most important general-purpose technology of our times [7]. It is getting used as an input by many downstream sectors enabling innovations in rapidly growing number of products, services and processes [8]. For some industries, AI is becoming a commonplace. The peak of the main wave of artificial intelligence (AI) tsunami is about to hit industries, governments and societies accelerating the pace of product and service innovation, and putting data in the focus of the business interest [9].

The rational use of energy and energy sources is also a growing challenge, which aims to preserve the environment. Industrial systems, primarily production systems, are the largest energy consumers. The need for this theme is caused by the pressure of European regulation on the implementation of energy saving measures as well as to have positive impact on the environment [10]. Energy Management Concept as part of Green Building Concept is focused to Improve Energy Efficiency Index (EEI) and Water Consumption Index (WCI). The Implementation Energy Management Concept in an office building is based on the management system model of continual improvement ISO 50 001. ISO 50 001 has been developed for an organization that is committed to resolving its impact, saving resources, and improving the result through efficient energy management. Designed to support organizations in all sectors, this ISO standard provides a practical way to improve energy use, through the development of an energy management system (EnMS) [11].

Accurate, fast, and stable electrical energy consumption forecasting plays a vital role in decision making, energy management, effective planning, reliable and secure power system operation. Inaccurate forecasting can lead to the electricity shortage, wastage of energy resources, power outage, and in the worst case, power grid collapse. Contrarily, accurate forecasting enables policymakers and public agencies to make real-time decisions imperative for the energy management and power system's secure and reliable operation [12].

Gryshchenko, I. (2021) published an interesting study on the implementation of ISO 50 001 in the context of current topic, the COVID-19 pandemic [13].

Several studies have been carried out on the implementation of ISO 50 001: 2018. The authors focused on various aspects of this issue in terms of buildings, production and organizational units and regions:

- Kurniawan, R. & A. Feinnudin (2021) - this study focuses on the public building in Indonesia that has implemented an energy management system compliant with ISO 50 001 standard [14].

- Siregar, M. et al. (2019) - implementation of Energy Management Concept and Energy Management System in High Rise Office Building [15].
- Cuanga, O. M. & G. C. Sánchez (2020) - study was carried out in National Bus Company (BEU) Cienfuegos, addressed to the aim of applying energy planning stage tools energy system management in correspondence with ISO 50 001 Standard [16].
- Dall'O, G. et al. (2020) - a case study on energy management for heating load reduction for a social building stock in Northern Italy [17].
- Quispe, E. et al. (2021) - this study presents the application of tools to develop a procedure to estimate the energy saving potentials in a small foundry company in Colombia [18].
- Rovňák, M. et al. (2021) - study focuses on the issue of energy efficiency management in the region of Prešov self-governing region (PSR), Slovakia, as the energy market is liberalized, and the behaviour of electricity consumers is influenced not only by conventional but also by alternative suppliers of this type of energy [19].

3. Steam production

The availability of this medium is essential for industrial production [20]. Steam generation is familiar process of boiling water to make steam. Thermodynamically, the heat energy used results in a change of phase from liquid to gaseous state, i.e., from water to steam. A steam generating system must provide a continuous and uninterrupted heat source for this conversion [21]. The effect of equipment failures on system operation performance and costs are analysed by system reliability, which is contributed by the system configuration, system redundancy, individual equipment failure and repair characteristics, operation mode and mode transfer [22].

4. Methods

For our test measurement a clamp-on ultrasonic portable flow meter was used.

Clamp-on ultrasonic flow meters have the potential to be applied to existing pipes. Therefore, they have been widely used in industrial plants for measuring liquid and gas flow rates. Their principle is based on the time-of-flight (TOF), which changes with the flow velocity along the propagated ultrasonic pulses. Thus, flow rate is obtained based on the transit time difference of the ultrasonic pulses between upstream and downstream sensors. To measure the flow rate accurately, the transmitted ultrasonic signals must be detected. However, the measurement is difficult in the case of steam flow because ultrasonic attenuation in steam is higher than in liquid. Furthermore, the large difference in the acoustic impedance between the pipe material and steam results in a lower intensity of the transmitted ultrasonic signal for clamp-on ultrasonic flow meters. Thus, measuring liquid flow rates is easier than measuring gas flow rates using the clamp-on system [23].

5. Research

For our test we used portable unit Fluxus G601ST with ultrasonic sensors GRK1SC3. Before implementing of the ultrasonic sensors, the thermal insulation of the pipe must be dismounted in proper length. The surface of the pipe must be painted with special noise-damping varnish as shown by Fig. 1.

Variofix mounting brackets were used for sensor fixation on the pipe. Both brackets must be mounted in precise opposite position as shown by Fig. 2.

Fig. 1. Noise-damping varnish on the steam pipe

Fig. 2. Mounted brackets in opposite position

The ultrasonic sensors need to have a good contact with the pipe surface, therefore the dumping varnish between the active size of the sensors and the pipe to be scratched, as shown by Fig. 3.

Fig. 3. Scratched noise dumping area under sensor`s active side

By transit time method the sensors need to be heated up on minimum 100 °C to get signal. This can take one hour until the sensors reach the limit. In our case, the sensors were preheated on the surface of another steam pipe on 70 °C to shorten the time of heating up. Before starting of the measurement, the control unit to be configured on proper process parameters. After the parameterisation, the ultrasonic flow meter unit software leads the operator through diagnostic parameters to ensure the reliable measurement. The fluid parameters were following:

- Outer diameter: 275.00 mm.
- Pipe wall thickness: 7.20 mm.
- Pipe wall material: Carbon steel.
- Roughness: 0.10 mm.
- Fluid: Low pressure steam.
- Fluid sound speed: 505.92 m/s.
- Fluid temperature: 187.00 °C.
- Fluid pressure: 9.50 bar(g).
- Unit of measurement: kg/h.
- Damping: 10 s.

Software supplied by the flow meter producer allows the operator to see the shape of the ultrasonic signals with the diagnostic values, simultaneously. Such screen is shown on the following picture.

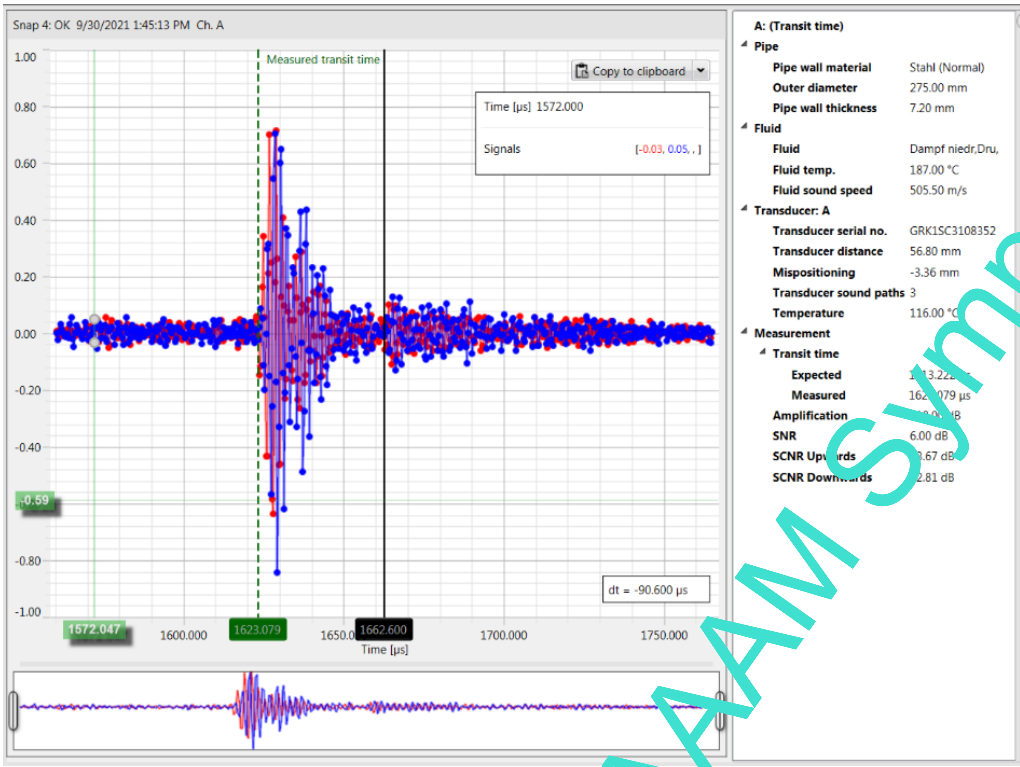

Fig. 4. Diagnostic screen of the steam flow measurement process using FluxDiag program

There is an internal data logger integrated in the flow meter unit. In our case, the data logger was set to store the data as average in ten minutes intervals. The measured data are shown in the Table 1. Graphical interpretation of the data from table 1 is in the Fig. 5.

Time hh:mm	Flow velocity [m/s]	Mass flow rate [kg/h]	Sound speed [m/s]	Volumetric flow rate [m³/h]	SCNR [dB]	SNR [dB]
5:07	1.31	1334.09	505.33	250.97	29	11
5:17	1.32	1343.28	505.21	252.7	30	11
5:27	1.35	1375.[illegible]4	505.36	258.84	30	11
5:37	1.34	[illegible]	505.21	256.92	30	11
5:47	1.37	[illegible]	505.53	263.45	26	10
5:57	1.36	1392.28	505.39	261.91	28	10
6:07	1.35	1377.98	505.31	259.22	30	11
6:17	1.37	1398.4	505.36	263.06	30	11
6:27	1.31	1339.2	505.49	251.93	28	10
6:37	1.32	1348.38	505.28	253.66	27	10
6:47	1.41	1439.23	505.46	270.74	28	10
6:57	1.31	1339.2	505.29	251.93	28	10
7:07	1.27	1293.26	505.38	243.29	25	10
7:17	1.27	1296.33	505.53	243.86	25	11
7:27	1.21	1229.98	505.25	231.38	28	10
7:37	1.16	1187.11	505.45	223.32	30	11
7:47	1.07	1095.24	505.41	206.03	27	10
7:57	1.08	1098.31	505.44	206.61	28	10
8:07	1.06	1086.06	505.52	204.31	27	11
8:17	1.07	1088.1	505.35	204.69	30	10
8:27	1.06	1080.95	505.62	203.35	31	11

8:37	0,99	1013,58	505.26	190.67	30	11
8:47	0,94	955,4	505.5	179.73	31	10
8:57	0,98	999,29	505.63	187.99	31	11
9:07	0,91	932,95	505.39	175.5	29	11
9:17	0,87	889,06	505.53	167.25	31	11
9:27	0,85	871,7	505.45	163.98	27	10
9:37	0,87	885,99	505.43	166.67	31	11
9:47	0,86	880,89	505.64	165.71	28	11
9:57	0,78	793,11	505.48	149.2	29	11
10:07	0,81	827,81	505.61	155.73	30	11
10:17	0,73	741,05	505.46	139.4	30	11
10:27	0,8	814,54	505.48	153.23	30	11
10:37	0,75	770,65	505.37	144.97	31	11
10:47	0,74	759,42	505.51	142.86	31	11
10:57	0,65	660,41	505.65	124.24	31	11

Table 1. Logged data during steam flow measurement in eight minutes interval and ten seconds period

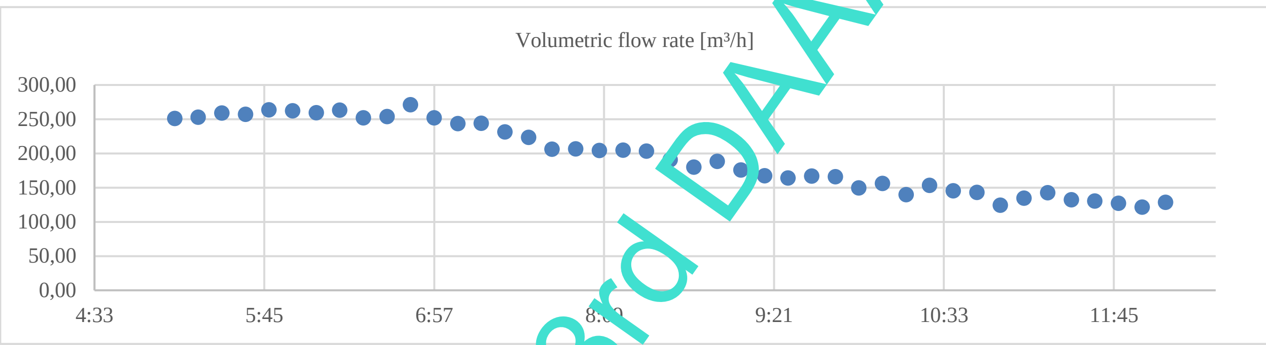

Fig. 5. Volumetric steam flow rate in eight minutes interval

Using the software supplied by the flow meter producer, there is possibility to generate a report with the uncertainty of the measurement. The uncertainties are shown in the Table 2. Graphical evaluation of the measurement uncertainty is shown in the Fig. 6.

Standard uncertainty component	**Source of uncertainty**	**Value of standard uncertainty**		**Sensitivity factor**	**Flow velocity**			
					0.10 m/s	**0.37 m/s**	**1.36 m/s**	**5.00 m/s**
					Transit time difference			
					9.682e^{-8} s	**3.582e^{-7} s**	**1.317e^{-6} s**	**4.841e^{-6} s**
$u(x_i)$		$u(x_i)$	$u_r(x_i)=u(x_i)/x_i$	$c_{r,i}=c_i*x_i/\acute{v}$	Contribution $\lvert c_{r,i}u_r(x_i)\rvert$			
$u(K_{Re})$	Flow profile		0.28 %	1	0.28 %	0.28 %	0.28 %	0.28 %
$u(A)$	Cross sect. area		0.08 %	1	0.08 %	0.08 %	0.08 %	0.08 %
$u(K_\alpha)$	Acoustical cal. factor		0.96 %	1	0.96 %	0.96 %	0.96 %	0.96 %
$u(\Delta t)$	Transit time difference	6e^{-10}		1	0.62 %	0.17 %	0.05 %	0.01 %
$u(t_o)$	Delay time		0.37 %	0.03	0.01 %	0.01 %	0.01 %	0.01 %
$u(t_r)$	Transit time		0.01 %	-1	0.01 %	0.01 %	0.01 %	0.01 %
Standard uncertainty $u_r(\acute{v})=u(\acute{v})/\acute{v}$					**1.18%**	**1.02%**	**1.00%**	**1.00%**
Expanded uncertainty					**2.36%**	**2.03%**	**2.00%**	**2.00%**

Table 2. Total uncertainty overflow velocity generated by the software FluxDiag

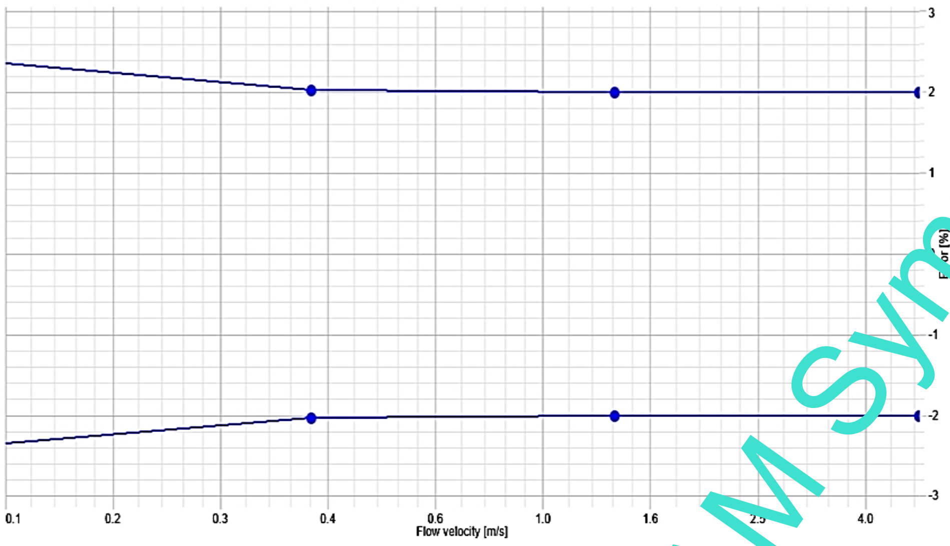

Fig. 6. Graphical evaluation of the steam flow measurement uncertainty generated by the software FluxDiag

5. Discussion

The measurement was done without any problems or data interruption. The signals SCNR and SNR are in stable and proper level, normally the SCNR should be kept higher than 25 dB to get the real and correct data. SNR is the signal provided by the electronics to be kept around 10 dB. One of the most important diagnostic parameters is the sound speed of the media shown in the Table 1. This value must correlate to the sound speed value awaited at the real media temperature. When it is correlating then the measurement is precise and provides correct measurement results. The data are compared to an existing older in situ flow meter and they are correlating what makes place for modernisation of the process control using ultrasonic technology.

Such system provides very high precision of calibration and of course very high precision in the process. This system called transit time is nowadays suitable only for the steam parameters between 130 and 200 °C but there is a new principle invented by Flexim to be able to measure high temperature steam using non-invasive ultrasonic principle, so called CFM.

6. Conclusion

The goal of this measurement was to perform the steam flow measurement with innovative clamp-on ultrasonic measurement technology for balances and the design of optimization plans. Second target was to use collected data for further research and deployment of such technology in industrial practice to increase process efficiency and operational safety.

One of the big advantages of clamp-on technology is the possibility to change the measuring point without any process interruption. This type of flow meter has the possibility to also measure gases and liquids as well. These units are calibrated by the producer using a special kind of calibration, invented by the producer itself, where the fluid is in stable state and the sensors mounted on a moving system with very precise movement control are moving on the surface of the calibration fluid.

Results of this study were presented to specialists from energy management as a progressive measurement method of measurement to be implemented in energy strategy plans. Ultrasonic monitoring systems by specific configuration allow to monitor the energy consumption and have a potential for implementation in energy consumption reduction concepts in industry and facility management as well. Comparing to standard heat energy monitors is the price higher but precision and technical and mechanical properties do this kind of measurement devices high valued and comfortable mounting and operation.

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