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Operational Problems in Welded Joints of Flow Sensors Used in Power Engineering

Abstract: The paper presents operational problems present in fluid and gas flow measurement systems. Tests (involving laser welded tubes made using a focused and a defocused beam) were concerned with the quality of welded joints. The tests revealed that the use of the focused beam resulted in the formation of cracks in the welds. In addition, post-weld observations revealed undercuts on the weld face side, responsible for the thinning of the tubes, yet without compromising their service life.

Keywords: power unit, steel, welding, pipes

DOI: *10.17729/ebis.2020.2/7*

Introduction

Measurements of liquid flows play a vital role in metrological monitoring systems and power unit operation. The aforesaid measurements of flows are concerned with various media including cold and hot air, flue gas, water, steam (often characterised by extremely high parameters) or other media such as fuel oil or chemical liquids. The measurements of the streams of the above-named media are often confronted with various difficulties, e.g. related to the selection and location of flowmeters as well as with various deformations of liquid flow rate profiles. Flowmeter indications can also be affected by impurities present in media or by the presence of the second phase, e.g. drops of liquids in gases. Another problem facing the metrology of flows in power systems includes (frequently) very large cross-sections of ducts and the lack of appropriately long straight segments of pipes enabling the mounting of flowmeters. This issue is particularly present in the flow systems used for the distribution of primary and secondary air to the boiler. This complex flow system is dominated by relatively short segments of ducts characterised by large flow cross-sections. The proper measurement and adjustment of air flows are of primary importance as regards the process of combustion in the boiler furnace chamber, incomplete combustion-related losses and the emission of nitrogen oxides.

Frequently, media flowing within a power unit are characterised by extremely high parameters. For instance, in boilers operated using supercritical parameters, the temperature of fresh steam amounts to 600°C whereas its pressure exceeds 25 MPa. High temperatures are also characteristic of air supplied to burner zones and flue gas. The aforesaid conditions eliminate the possibility of using many

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industrially applied flowmeters with exception for impact flowmeters.

As regards steam, typically used impact flowmeters are nozzles. In turn, as regards air streams, commonly applied impact flowmeters are Venturi tubes [1]. For many years these popular flowmeters have been used to reliably measure streams of agents characterised by high parameters. Apart from numerous advantages, the primary disadvantages of these flowmeters include the generation of additional flow resistance and, consequently, additional losses of energy. Presently, power engineering flow systems are increasingly often equipped with flowmeters where an element increasing the flow is a probe averaging dynamic pressure [2–4]. The above-named probe, nearly not generating additional resistance, may constitute an alternative to constriction flowmeters (Fig. 1). However, similar to constriction flowmeters, flowmeters equipped with probes averaging dynamic pressure are sensitive to flowrate profile disturbances at the location where such flowmeters are fixed. This issue is particularly visible in boiler systems, where large duct cross-sections (enabling the fixing of flowmeters) require straight pipeline segments being tens of metres in length or rectangular ducts. Very often, probes averaging dynamic pressure are exposed to difficult operating conditions. In addition to high parameters of agents and their contamination, probes averaging dynamic pressure (particularly those mounted on one side) are exposed to bending stresses. Apart from affecting the probe, bending forces influence the area where a measurement system is connected with the pipeline wall. If there are transient states present in the stream, e.g. the operation of piston compressors, the aforesaid effect may be of fatigue nature. Nearly all probes generate the Karman vortex street. Generated vortices and related limited and periodic changes in the field of flowrate and pressure affect the probe. If the frequency of the separation of Karman vortices overlaps with the frequency of the free vibration of the probe (fixed one or two-sidedly), the probe may quickly be damaged. For this reason, in relation to a given size of a sensor and the manner of its attachment, the manufacturer specifies the range of the agent flow rate, within which the probe should not be operated. The determination of the free vibration of the probe and the identification of unacceptable ranges of the flowrate related to a given sensor are presented in, e.g. publication [5]. The probes are based on various technologies, e.g. sensors containing welded joints of two typical shapes enabling the separation of p+ and p- pressure chambers (e.g. two pipes of different dimeters) [4]. Other methods involve the electrospark cutting of shapes and the drilling of equalisation chambers [3] as well as the stamping of shapes or the use of welding techniques [6,7]. Another issue is concerned with the attachment of the probe with its head (usually provided with a system (block) of valves). The probe is attached on the duct (of a pipeline) by welding a nozzle or a flange into it. Welded joints present at such a location are often exposed to complex mechanical conditions, including high temperatures of flowing agents. It is also possible to install a sensor in a pipeline (the so-called WET-TAP), enabling the removal of the probe (e.g. to clean or check it) without cutting off the flow [7]. The effect of high temperature and pressure (stresses) on pipe walls and vibration triggered by the cyclic effect may lead to damage. The additional bending of pipes can also cause damage to welded joints [8]. Various welding methods include gas, electric, electron beam, laser beam, hybrid and other techniques. The pipes of the probe were joined using the YAG laser-based welding process [9]. In relation to certain types of materials and specific shapes and dimensions of structures, the laser beam is often the only “tool” enabling the joining of elements and making it possible to satisfy joint workmanship-related requirements.

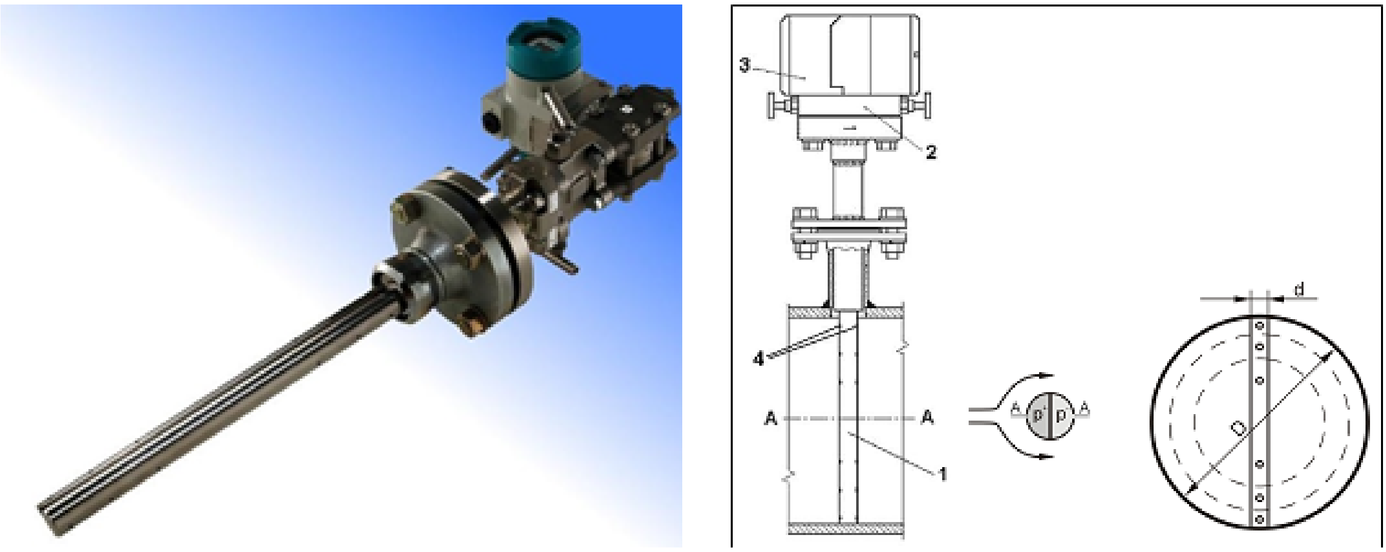

Fig. 1. Exemplary probe averaging dynamic pressure mounted on the pipe: a) flowmeter configuration, where: 1 – probe, 2 – system of valves, 3 – pressure difference transducer, 4 – pulse apertures b) [10]

The research work discussed in the article aimed to present problems accompanying the operation of gas and liquid flow systems and related to cracks present in welded joints of measurement probe pipes (made of steel X10CrAlSi25) subjected to cyclic operation.

Experimental tests

The experimental tests involved the use of probe pipes made of heat-resisting ferritic steel X10CrAlSi25, used in elements exposed to high temperature (up to 1150°C). Impact pressure tubes being the subject of the tests are manufactured in Zakłady Remontowe Energetyki (ZRE) (Power Engineering Repair and Maintenance Company) from Katowice S.A. under the commercial name of Twin Bar. The chemical composition of the material is presented in Table 1 [11]. The laser welding process, affecting several segments, the length of which was restricted within the range of 20 mm to 30 mm (Fig. 2), was performed using the YAG laser. The welding process was performed at Instytut Spawalnictwa in Gliwice [11]. The welding parameters applied during the argons-shielded welding process included a focused laser beam power of 2000 W and a defocused laser beam welding power restricted within the range of 4000 W to 5000 W as well as a welding rate of 2 m/min and restricted within the range of 1 mm to 2 m/min respectively.

The diameters of the pipes used in the system were 25 mm and 15 mm. The thickness of the pipe walls amounted to 2 mm, whereas the maximum length of the pipes was approximately 1200 mm. The pipes presented in Figure 2 were provided with several welds at 20 mm long segments along the entire pipeline.

Test results and analysis

The tests involved the laser welding of impact pressure tubes performed within a wide range of welding parameters. Figure 3 presents the fixing and positioning station used in the welding

Table 1. Chemical composition of steel X10CrAlSi25 [11]

Chemical composition [%]								
C	Mn	Si	Cr	Cu	Ni	S	P	Al
≤0.12	1	1.3–1.6	23–25	0.3	0.5	0.030	0.045	1.3–1.6

Fig. 2. Joining of the pipes welded at 20 mm long segments

of the pipes. The tests involving the focused laser beam welding process (where the laser beam diameter amounted to 0.4 mm) not preceded by preheating revealed the presence of cracks in the weld, observed on the weld face side, in the final part of the welding area. Macroscopic tests (Fig. 4a) revealed that the cracks were initiated on the side of the weld root, i.e. the area, where the welding thermal cycle was the most intense. At the final stage of the welding process the cracks propagated towards the weld face surface. The cracks might have been triggered by stresses generated during the welding process.

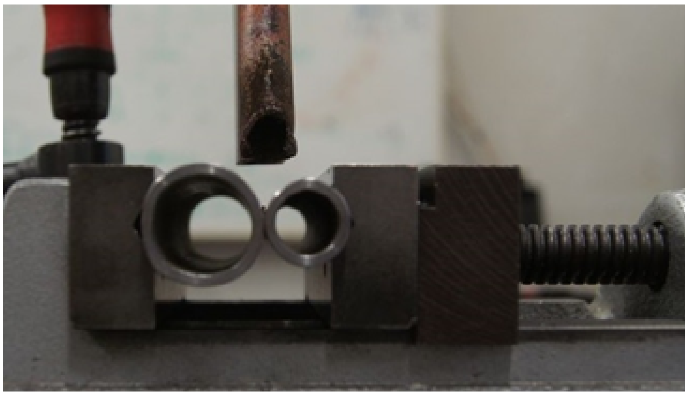

Fig. 3. Pipes prepared for welding

In terms of the process performed using the defocused laser beam having power restricted within the range of 4000 W to 5000 W, the obtained welds were characterised by the wider face and the more favourable distribution of stressed generated during the solidification of the weld (Fig. 4b). The welding process was followed by heat treatment, i.e. annealing performed at a temperature restricted within the range of 750°C to 850°C, and cooling in air. The heat treatment proved to have no significant effect on the quality of the weld as regards the presence of geometric welding imperfections (in accordance with PN-EN ISO 13919).

Figure 5 presents the welded pipes of the probe, mounted along with the flange and the system of valves.

Fig. 5. Probe (Twin Bar) along with the flange and the system of valves

Figure 6 presents systems enabling measurements of volatile media. The photograph on the left is concerned with the measurement of the flow of air having a temperature of 320°C, whereas the photograph on the right is related to the flow of blast-furnace gas having a temperature of 30°C. During the operation of the entire device, in spite of vibration and the temperature of the flowing liquid reaching 120°C, no damage to the welded joints was observed.

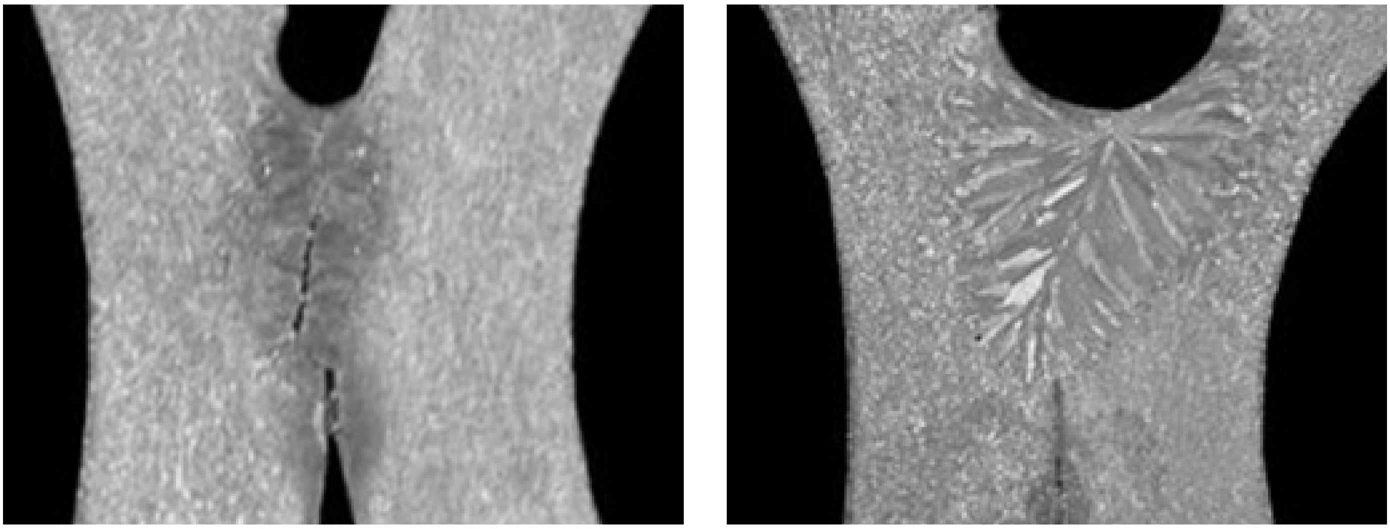

Fig. 4. Macrostructure of the laser welds in the impact pressure tubes made of steel X10CrAlSi25: a) cracks in the root of the weld made using the focused laser beam and b) proper weld made using the defocused laser beam [11]


Fig. 6. Gas and liquid flow system with flowmeters containing laser welded impact pressure tubes

Summary

The tests discussed in the article and involving the laser welding of the impact pressure tubes of flow metres made of steel X10CrAlSi25 revealed that the proper adjustment of welding parameters enabled the obtainment of crack-free laser welds without the necessity of applying preheating, required in relation to arc welding processes involving the above-named steel grade.

The use of the defocused laser beam enabled the obtainment of crack-free welded joints and the weld thickness comparable with the thickness of the pipe wall. The cross-section of the welds revealed the presence of undercuts on the weld face side, resulting in the reduction of the pipe wall thickness. The pipe wall thickness reduction increased along with increasing welding linear energy. Although the detected undercuts were relatively gentle, they still constituted a geometric notch in the joint area.

The tests involved the systems for measurements of liquid and gas streams as well as related welded nodes. During the operation of the flow meter subjected to cyclic loads no cracks in the welded areas were detected.

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