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Ideas and Assumptions of a New Kind Helical Metal Expansion Joints

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Abstract. The author of this paper presented the ideas and assumptions with regard to manufacturing and application of a new metal expansion joints type. The manufacturing technology based on a hybrid mechanically assisted laser forming method was briefly discussed. The exculpation for the development of this expansion joints type and their effect on the torques and distortions compensation occurring in industrial pipelines installations was discussed as well. Furthermore, the preliminary experimenter's research results about manufacturing of this expansion joints type were presented as well.

Introduction

In every industrial pipelines installations we deal with variable parameters of the transmitted medium. These are mainly changes in pressure and temperature. As a result of changing working conditions, such an installation is exposed to damage related to a change in its geometry due to e.g. thermal expansion of the material. Therefore, there is a need to compensate for such an installation. The simplest solution is to compensate when changing the direction of the pipeline, e.g. at elbows. However, it is not always possible, e.g. due to collisions with other installations, lack of space, etc. In such a case, expansion joints integrated with that installations are used. Depending on installation operating parameters these may be cloth, rubber or metal expansion joints.

In the case of high pressures, metal expansion joints are used. They are made from a pipe, on which there are upsets in the form of a bellows or a lens. These upsets act as a kind of "spring" which compensate for the above-mentioned deformations. Their design ensures compensation of axial, lateral and angular deformations [1]. On the other hand, they do not compensate for the deformations resulting from the torque moments, which are the operation result of the equipment installed in the installation, e.g. valves, pumps, etc. Therefore, the idea of helical metal expansion joints was born, which was designed to compensate mainly for this type of deformation.

Currently, standard expansion joints are made mainly by plastic cold working, using roller systems, hydroforming methods, etc. [1]. The author of this paper proposed the use of a hybrid mechanically assisted laser forming method to produce helical expansion joints. Currently, laser techniques are widely used, e.g. for cutting [2], welding [3], industrial coatings applications [4], creating textures on the material's surface [5], additive manufacturing [6], etc. Instead the laser forming method uses the phenomenon of distortion in the material as a result of the element's local temperature change. The element is heated by the energy from the laser beam acting on it. The appropriate geometry and trajectory of the laser beam leads to the desired shapes of the element. In this case, the local change in the shape of the element is achieved due to the difference in thermal expansion of the "cool" and "warm" parts of the material. Plastic deformation is obtained as a result of causing internal thermal stresses in the material without the participation of external

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forces, by means of three main mechanisms: temperature gradient mechanism (TGM), upsetting mechanism (UM) and buckling mechanism (BM) [7].

The free-form laser forming method (as we can call it) is, however, a very time-consuming process. That is why the idea of a hybrid method of mechanically assisted laser forming was born. In this method, in order to accelerate the process, apart from laser heating, external forces are also used to create plastic deformations. This approach significantly speeds up the forming process, the process becomes effective, and the method allows for obtaining complex shapes. An example of such an approach is, for example, shaping thin-walled elements made from pipes [8]. Of course, the ideas and assumptions should predict the experiment [9] and make the necessary macroscopic measurements of the obtained elements [10].

Bearing in mind the above, the ideas and assumptions for making helical expansion joints using this method are presented. A preliminary experiment was performed to confirm the validity of the assumptions.

Ideas and assumptions

The necessity to compensate for deformations of industrial piping installations resulting from torque moments led to the idea of making helical expansion joints. The helical expansion joint has bellows on its circumference, but not in the form of classic rings, but in the form of a helix. This helix is similar in appearance to the thread. It can be both dextrorotatory and laevorotatory - Fig. 1.

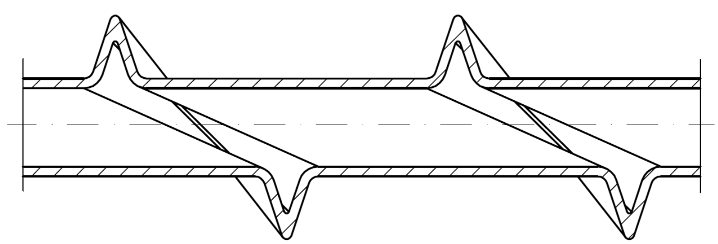

Fig. 1. *Helical expansion joint cross section (idea).*

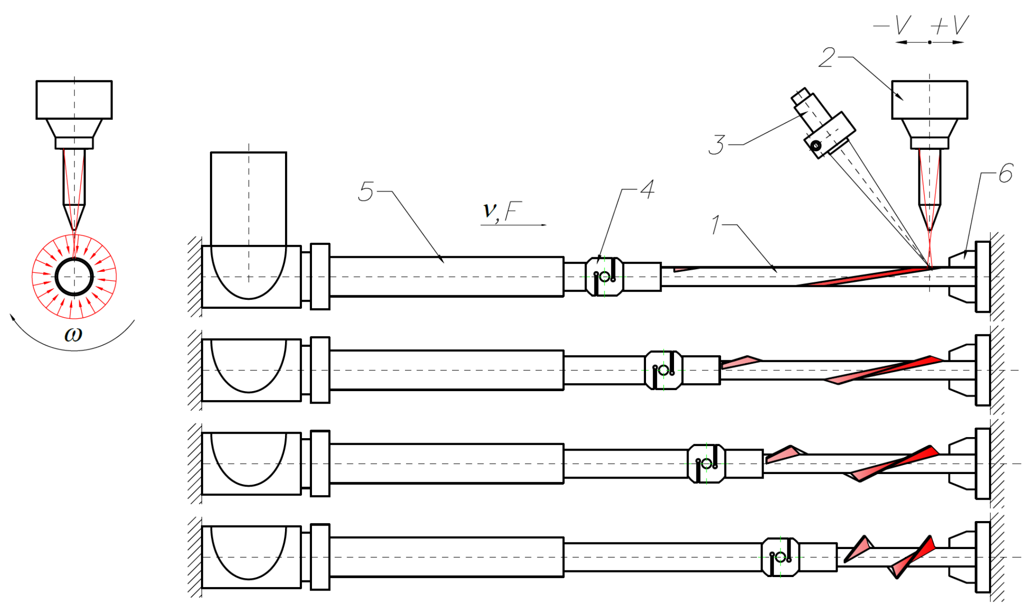

Fig. 2. *Individual steps of helical expansion joints forming (idea): 1 - quickly rotating around its axis pipe, 2 - laser head (pipe heating), 3 - pyrometer, 4 - force sensor, 5 - axial thrust actuator, 6 - swivel handle. The red line shows laser incidence path with pipe surface.*

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Helical metal expansion joints manufacturing process with a hybrid mechanically assisted laser forming method is based on the following assumptions (Fig. 2.):

– the laser beam heats a given area of the element to a certain, preset temperature, which improves the plastic properties in this area,
– evenly and uniformly heating of the element around its entire circumference is achieved by its quick rotation around its axis,
– the laser head moves in a direction parallel to the axis of the rotating pipe at a given speed, creating a helix on its surface,
– an axial force acts on the element simultaneously, which causes its upsetting in the plasticized zone (heated by the laser beam),
– only the part of the pipe that is exposed to the laser beam at a given moment is deformed,
– the remaining part of the formed element, which has a lower temperature, does not deform.

So formulated assumptions were verified as to their validity during the initial experimental study. The description of the experiment and its results are presented in the following chapters.

Experiment

In order to perform the experiment, an execution and measurement stand was built based on the TRUMPF TruFlow 6000 CO_2 laser, generating laser radiation with a wavelength of λ=10.6 μm with a maximum power of 6kW and operating in CW laser mode. Stainless steel grade X5CrNi18-10 pipes with dimensions of ϕ20x1 mm (diameter x wall thickness) and length of 250 mm were used for the experiment. The element was installed between axial actuator with a maximum pressure force of 5kN (4) and swivel handle (6). The surface of the sample was covered with a special absorber (matt black enamel) in order to increase and uniform the absorption coefficient of the laser radiation. The treatment parameters were as follows:

– laser power: P=1200 W,
– process temperature: approx. T=1100°C (X5CrNi18-10 steel hyperquenching temperature which guarantees the preservation of the austenitic microstructure after process),
– pipe compressive force: max. F=1.2 kN,
– compressive length: s=30 mm,
– pipe rotation speed: ω=10000 °/min,
– pipe compressive speed: v=10 mm/s.
– initial beam pitch: p=80 mm.

The circularly polarized laser beam was incident perpendicularly on the rotating pipe surface. Furthermore the laser beam traveled along the pipe axis, creating a heated, convoluted thread-like strip on its surface. It was a zone of heating and its plasticization. After obtaining the appropriate temperature T, recorded by the sensor (3), the actuator (5) was started. The actuator pressed the pipe axially with the force F (4) and by velocity v.

Results, Discussion and Conclusions

The final result of the preliminary experiment was the helical expansion joint manufacturing. Fig. 3 and Fig. 4 show an exemplary element with a macrograph gained shape analysis.

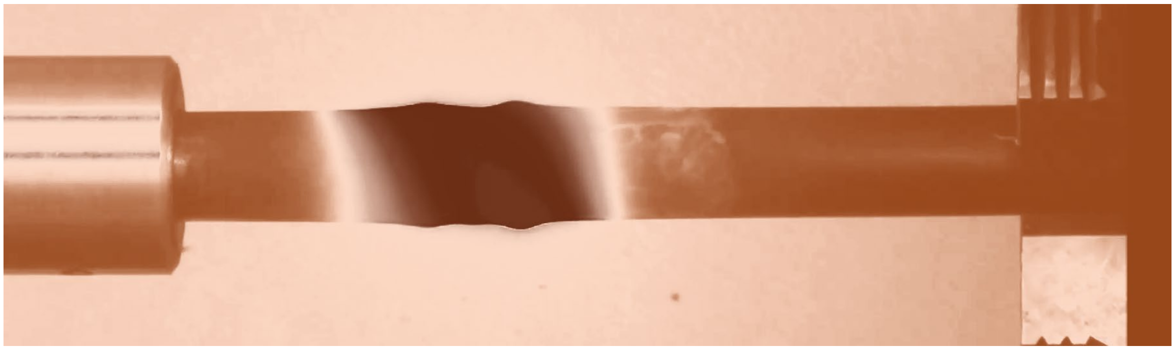

Fig. 3. *Helical expansion joint view after processing – a graphic filter was used for better image analysis.*

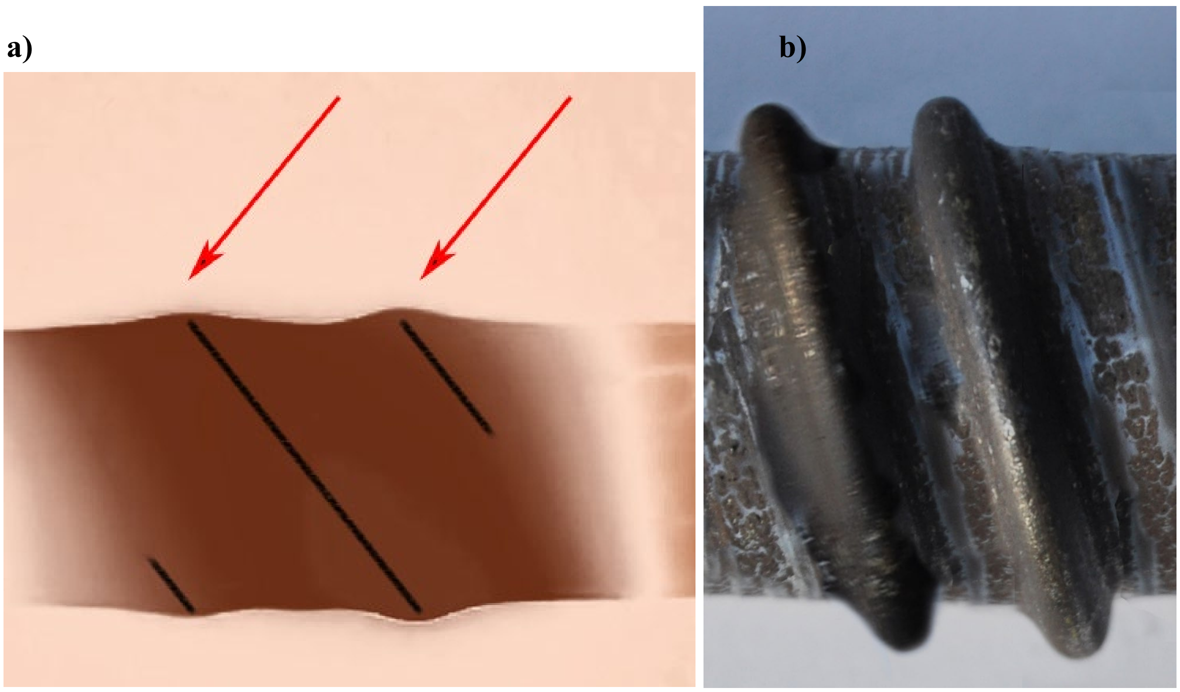

Fig. 4. *Magnification of the image with marked peaks a) and helix coils b).*

Analyzing the photographic documentation presented in Fig. 4a), we can observe the creation of bulges formed on the circumference of the pipe (marked by red arrows). These are the upsets of the emerging helical expansion joint. Moreover the upset path is marked with a black lines. Appropriate selection of the process parameters leads to the formation of a helix. After many experimental tests with the selection of parameters, it was possible to make a helical expansion joint with two coils on the perimeter. The final product is shown on Fig. 4b). However, a number of trials were required to obtain such a shape. In particular, it is problematic to control the temperature of the process and to start upsetting at the appropriate time. In many cases, the tubular element was burned or the element was squeezed out. In both cases, it resulted in the expansion joint tearing, loss of material cohesion or unforeseen deformations. It is also difficult to select an appropriate initial pitch and initial pitch speed. Too small pitch leads to a slight upsetting of the pipe on the perimeter. On the other hand, too large pitch causes the necessity to use a lot of force in order to upset.

Summary

The results of the experiment seem to confirm the idea validity of manufacturing metal helical expansion joints with the use of a hybrid mechanically assisted laser forming method. However, mastering this process caused some problems, mainly technological. Many of the attempts made have been unsuccessful. Appropriate selection of process parameters turned out to be very important. The process is started and ended manually, not automatically. The final effect therefore largely depends on the experience of the operator. However, this approach leads to the lack of repeatability of the final elements. Moreover the final shape of element depends on many variable factors.

The improvement of the process will be the aid of further works planned in the future. Furthermore, it is planned to carry out a FEM analysis in order to recognize thermoelastic and thermoplastic phenomena occurring during the process. It is planned to study the microstructure of the obtained expansion joints. In order for the expansion joint to have the expected strength properties, the microstructure should not change and remain an austenitic. The selection of parameters (temperature) should ensure this, however, detailed research in this matter will give the answer what the real microstructure is. It is also planned to perform strength tests of the created expansion joints in order to determine their utilitarian suitability in industrial applications.

The obtained results may be interesting for analogous cases of laser processing [11-13], preparing parts for highly loaded devices in waste treatment [14, 15] or producing responsible parts of military equipment [16, 17]. It would be also very interesting to consider the thermomechanical analysis of the problem using the adjustment calculus with supplementary data [18, 19] and non-parametric methods [20, 21].

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