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RECTILINEARITY OF LARGE SIZED SHAFTS

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Abstract: *The article deals with the problems connected with straightening of large sized shafts. They are used, among others, in papermaking industry and their length ranges up to several meters. Due to the complex manufacturing technology only few factories can meet its requirements. The criterion of geometric axis rectilinearity poses significant difficulties, hence the process involves the necessity of using straightening by means of heat. The study includes a description of an automated test stand, using a modern measurement system, as well as a difficult process of strengthening.*

Keywords: large shafts, centering shaft, centering plugs, straightening pipes

1. Introduction

Large sized shafts are used in different industries e.g. cement industry, paper making industry or wood industry. They are constructed from pipes with plugs on their ends, fig. 1 . The length of such an element can range up to several meters.

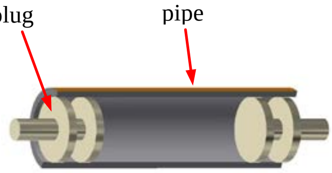

Fig. 1: A pipe with plugs

Shafts perform their function in technological processes by rotating e.g. they squeeze out excessive amount of water from the paper pulp by exerting pressure and stress, and therefore they need to be rectilinear. The rotation speeds are not high. In order to provide stable and long operation of the shaft, the pipe that makes up the shaft, should be straight and have possibly small shape deformities. Moreover, the plugs of the pipe should be mounted coaxially in relation to it. Operation of an element, manufactured in such a way, is characterized by a small radial beating. In practice, the most important operations involved in shaft manufacturing are:

-measurement and potential correction of rectilinearity of the pipe geometric axis,

-mounting and positioning of plugs in the pipe.

Displacement sensors located along the axis are used to verify performance correctness of the above mentioned operations. The traditional method uses mechanical clock sensors whose indications are manually recorded in the function of rotation. Simultaneous recording of the values measured from a few sensors is time consuming. Therefore, in order to facilitate the process, a fully automated test stand for straightening pipes and alignment of pipe plugs has been constructed. As compared to the traditional method, the time of manufacturing has been shortened, the process accuracy has been improved and the probability of error occurrence on the side of the operator has been reduced.

The purpose of this work is to present technological operations which are involved in large sized shafts manufacturing, with special emphasis on the process of straightening.

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2. Characteristics of the stand

The test stand for pipe straightening and alignment of plugs is presented in figures 2, 3.

Fig. 2: A test stand for straightening pipes and centering plugs

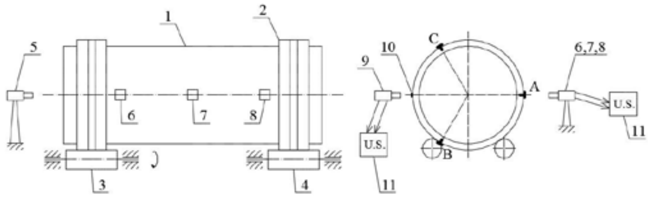

Fig. 3: Scheme of a test stand for straightening pipes and centering plugs

First, pipe 1 is mounted in centering rings 2 by means of twelve bolts located in two rows, six in each row, fig. 4.

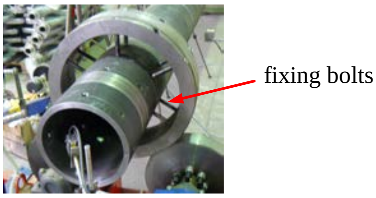

Fig. 4: Pipe mounted in centering rings

The main positioning of a pipe in the rings is performed by A, B, C rings placed, at every 120°. The remaining bolts are supposed to improve stability of the mounting. Then the pipe is put on positioners 3 and 4 (element 3 is a drive element, whereas 4 - guides the pipe) and checks centricity of its mounting in the rings. Laser sensors 6, 7, 8 which record displacement of the shaft in three planes (during centering plugs 6 and 8, while straightening 7) play a very important role in centering a pipe in the rings and mounting the plugs. Sensors 6 and 8 are placed on the ends of the pipe, whereas sensor 7 in half of its length. Correctness of the sensors position in relation to the pipe axis is checked by means of a laser beam generated by laser 5, projected the pipe external plane. Measurements of displacements are performed in the function of the shaft rotary motion. A rotary - impulse converter was used for synchronization of readings of parameters from sensors with the current diameter of the shaft. Its initial location is marked by magnetic marker 10, whose position is recorded by photo - optic sensor 9. Signals from all the listed sensors will be transmitted to control device 11. It consists of control and steering systems based on a freely programmable controller as well as an operating system, fig. 5. The elements work in Ethernet system. The terminal is equipped with control functions, and it enables recording and imaging of measurement results in the form of diagrams and tables with the shaft displacement (Kasprzyk, 2002).

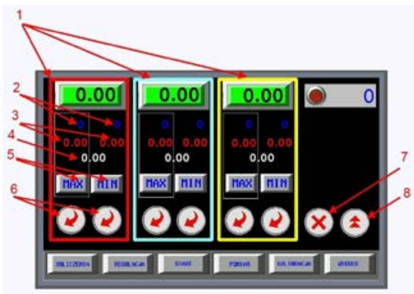

Fig. 5: A control terminal: 1 - measurement columns,2,3 - values of angular positions and maximum and minimum displacements, 5 - search for maximum and minimum values of measurements, 6 - automatic rotation of shaft into its maximum and minimum position, 7 - deletion of search, 8 - rotation by 90° in relation to actual position

3. Straightening a pipe in centering rings

Before straightening the pipe is mounted in centering rings (fig.4) and put on positioners. The pipe straightening can be started after it is properly centered in both rings. This is done on the basis of measurements performed by means of three laser displacement sensors. The measurement procedure is carried out in three steps:

- calibration of the measurement system,
- measurement of strains and assigning to them angular values of the rotating pipe,
- searching for characteristic points, maximum and minimum values assigned to the angular position.

Measurement results in the form of three diagrams (fig. 6) allow, in the first place, to center the pipe in rings and then its straightening.

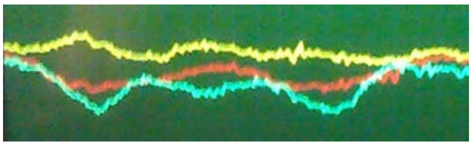

Fig. 6: Diagrams obtained from three measurement sensors

Centering the pipe in plugs is considered to be correct if diagrams of sensors 6 and 8 approach horizontal lines within the assumed tolerance. Interpretation of the diagrams in terms of pipe straightening, which is performed on the basis of the recordings from sensor 7, is similar.

The most difficult stage of pipe centering and straightening is the process of straightening. It is done with the use of a burner, fig. 7.

Fig. 7: Heating a pipe with a burner to straighten it

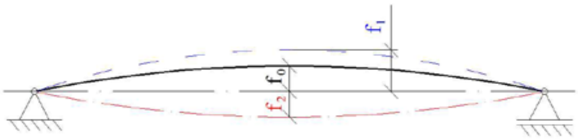

Fig. 8: Deformation of the pipe depends on its heating

In the first place the pipe flexure value is determined on the basis of the diagram from figure 6. Then the pipe is turned so that flexure f_o will be on its top (fig. 8). The pipe is heated in the area of its maximum flexure. During heating the flexure arrow grows to reach position f_1, and position f_2 after gradual cooling. This process will be finished if f_2 is equal to 0. So far searching for $f_2=0$ has been done by operators with the use of their intuition. The pipe was repeatedly heated and cooled. Thus, it is planned to carry out experiments in such a way that relations between f_o and f_1, will be $f_2=0$. For this purpose a laboratory test stand has been built (fig. 9), where a certain section of a pipe will be heated and cooled. During this time measurements of strains will be performed by means of an extensometer placed in the middle of the pipe and traditional clock sensors mounted on its ends (Jajubiec&Lesiński&Czajkowski, 1980; Czuchryj&Papkała&Wniowski A, 2005; Karlikowski, 2005).

Fig. 9: A test stand for measurements of the pipe flexure

Fig. 10: Examination of a pipe whose one side was fixed

The authors plan to find the discussed dependencies in a theoretical way. However, it is an extremely difficult task. In order to confirm the phenomenon, initial experiments were carried out with the use of a simple model. It was a pipe whose one side fixed and it was heated downward the fixing zone (fig. 10). Measurement of the flexure was performed on the pipe free end. The pipe was being heated to reach the temperature to make its free end fall by 1,66 mm and rise, in relation to the initial position after cooling, by 0,06 mm above the initial.

During industrial straightening it is necessary to remember that under the influence of the deadweight it undergoes a static strain (fig. 11), which has to be included in calculations.

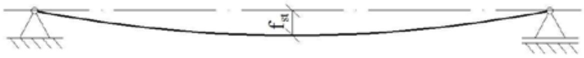

Fig. 11: Static flexure of a pipe under its own weight

It is the highest in the middle of its length. Equation of the flexure arrow is as follows:

$$f_{st} = \frac{1}{EI}\left[\frac{5ql^4}{384}\right] \tag{1}$$

where: E – module of longitudinal elasticity [MPa], I – moment of inertia [mm^4], q – constant loading [N/mm], l – length of the beam [mm] (Holka & Jarzyna, 2014).

4. Centering plugs in the pipe

The successive step in the shaft manufacturing is its mounting and centering plugs in the pipe. It is carried out in the following way:
- plugs are inserted into both ends of the pipe, fig. 12,

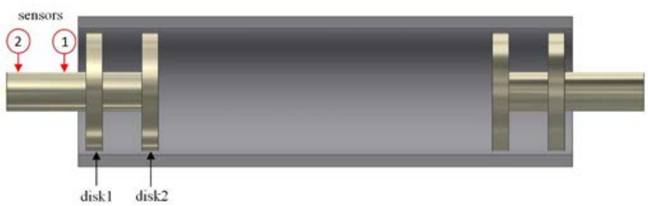

Fig. 12: Plugs mounted in the pipe

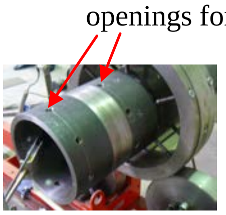

Fig. 13: Openings for fixing bolts

- four bolts, uniformly arranged on the circumference, situated in two rows per each plug, whose task is to perform initial positioning of the plugs, are screwed into the mounting holes, fig. 13,
- centering a plug in the plane of sensor 1 is performed by turning and stopping the shaft with the use of bolts fixing the disk 1 (fig. 12),
- beating of the shaft against the plane of sensor 2, which is corrected by bolts fixing disk 2 (the system behaves like a lever), is performed in a similar way
- correction in both planes is carried out until obtainment of satisfactory results,
- fillet weld is used to connect disk 1 with the pipe,
- another verification of beating is performed by means of sensors 1 and 2 or it is corrected by welds in the remaining openings presented in figure 13,
- after the fixing bolts are unbolted the holes are welded and correctness of the plug centering is checked,
- the procedure is repeated for the second plug.

5. Conclusions

1. The discussed, fully automated test stand enables significantly faster performance of pipe straightening and plug centering processes for large sized shafts. The number of processes has been increased and the number of errors has been decreased.

2. Precise assessment of strains that can occur after heating the pipe is very difficult. The carried out experimental tests and attempts to describe the analytical process will allow to improve the whole processes of heating and straightening.

References

Kasprzyk J. (2002) Programowanie sterowników przemysłowych. WNT, Warszawa.

Holka H., Jarzyna T. (2014.) Statyka i wytrzymałość materiałów. WUUTP, Bydgoszcz

Jajubiec M., Lesiński K., Czajkowski H. (1980) Technologia konstrukcji spawanych. WNT, Warszawa.

Czuchryj J., Papkała H., Wniowski A. (2005) Niezgodność w złączach spajanych. Istytut Spawalnictwa, Gliwice

Karlikowski J. (2005) Thermal stresses from one – side heating of asymmetric composite span. Archivest of Civil Engineering 4.