ANALYSIS OF INCREMENTAL HOT TUBE BENDING

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Abstract

Hot tube bending is used when bending of large diameters, range 150 to 400 mm and wall thickness in range 15 to 25 mm is needed. Processing of prescribed dimensional characteristics requires two possible bending types which are flat hot tube bending and incremental hot bending. The best process characteristics are obtained with incremental hot bending. This process is still very new and needs further improvement. The article gives detailed description of two types of incremental hot bending. Also, graphic presentation of stresses and strains in a tube wall is given too. This graphical data are reached by numerical simulation using MSC Marc Mentat program package.

1. INTRODUCTION

Tube bending to a predetermined radius is an important part of technological process of steam boiler building and also of building of pressurized delivery pipe. The process is much more demanding then sheet bending because tolerances of arc geometry are strict. Bend is defined by tube radius, wall thickness, and middle bend radius that goes through center of ideally circular cross-section of the tube. During bending process changes of initial geometry occur. Tube is deformed in a way that its wall becomes thicker on the inside radius and with lower thickness on the outside radius. Cross-section is no longer ideally circular and it becomes oval. Appearance of cracking and wrinkling can happen on the outside or inside radius of bend. Tolerances of geometry changes are defined by specifications. Other defects like cracking and wrinkling are not allowed.

Tube appliance in machine building is significant. In dependence of their appliance in exploitation, they can be subjected to high pressure and/or high temperature, like in steam boiler. Formed tubes are used in construction of power plants. They are formed, according demands, by bending, narrowing, drawing etc. Tube bending can be performed in hot state and on room temperature. Hot tube bending is used when bending of large diameters is needed or when large deformation takes place. If tubes of large diameters are subjected to large pressure, their wall thickness must be also great. Bending of such tubes is also performed in hot state using flat hot tube bending or incremental tube bending.

In distinction from flat hot tube bending, incremental tube bending is newer procedure, and is still approved by new acknowledgements and researches. It is showing some advantages regarding flat hot tube bending that was recently standard forming procedure for mentioned purpose.

Forming parameters like temperature and forming speed are different form one procedure to another. When using incremental bending, very rapid are transitions from cold to hot areas. Also, this procedure uses cold area as some sort of a tool. Because of that, stress-strain fields act differently and favourably for mentioned use.

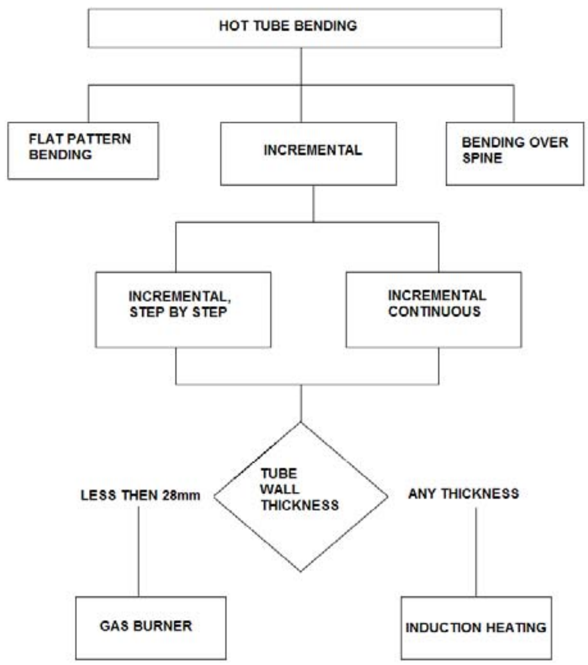

Figure 1. Division of tube bending processes in hot state.

2. HOT TUBE BENDING USING STEP INCREMENTAL PROCEDURE

Figure 2 shows a principle of incremental bending according to patent Nakamura Terisige – Japan. One part of a tube is heated by inductor and using bending moment the tube is formed until specified angle is reached. This procedure is stepped, so that the arc is practically polygon.

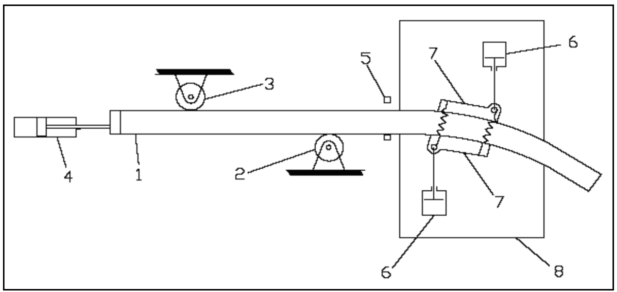

Figure 2. Mechanism for hot incremental tube bending according to patent Nakamura Terisige: (1) Tube, (2,3) Sideward rollers, (4) Hydraulic support, (5) Induction heater, (6) Moment hydraulic cylinder, (7) Lever.

3. HOT TUBE BENDING USING CONTINUOUS INCREMENTAL PROCEDURE

Searching bending procedure that could be automated, continuous incremental procedure has been developed. It is arranged in a way that tube is fixed to a movable hand and mechanically or hydraulically forced through induction or gas heater. Bending occurs in locally heated part of a tube because movable hand is rotating around center of rotation, and during that rotation tube is bending following the track of the hand. Heated and bended zone needs to be immediately cooled. Cooling is accomplished using air under high pressure, or using water jet. Forcing speed is dependable to a tube thickness, tube material and to a temperature field through the tube wall. Bending radius is determined by adjustment of jaws position on the movable hand.

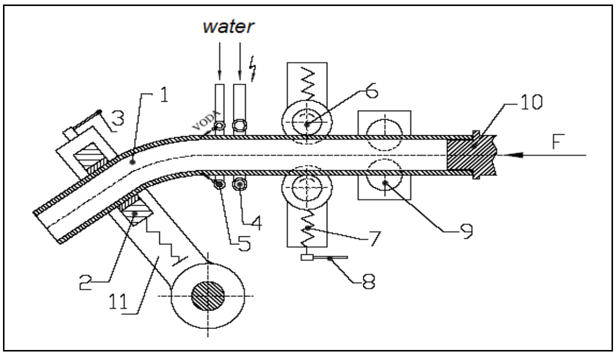

Figure 3. Functional scheme of continuous incremental bending procedure: (1) Tube, (2) Jaw, (3) Handle, (4) Gas or induction heater, (5) Cooling water jets, (6) Support rollers, (7) Leading rollers, (9) Cross slide, (10) Forcing spine, (11) Movable hand.

Bending process on a machine that is shown on Fig. 3 is performed on the following way:

1 – The tube (1) is fixed, in horizontal position, on the machine body, so that the first part of tube arc is in the same plane as heater (4). It is clutched into movable hand jaws (2) and drew onto forcing spine (10).

2 – The position of jaws (2) is determined by demanded bending radius.

3 – Tube heater is activated and starts heating the bended tube zone.

4 – Turning on a machine drive, the forcing spine is moved, it is pushing a tube which is now bended around center of rotation of the moving hand.

5 – Bended part of a tube is cooled using water jets.

4. HEATING PROCEDURES

There are two possible procedures of tube heating. The first and older one, is heating by gas burner. The second is new – heating using electric induction.

4.1. HEATING BY GAS BURNER

The very first models for incremental hot tube bending used gas burner for tube heating before bending takes a part. Gas burner uses mixture of methane and oxygen. When heating with this mixture, the tube is heated on working temperature (~900ºC), but the tube cannot be damaged like it could happen if using mixture of acetylene and oxygen. Heating speed is a little bit lower then it is if electric induction is used, and heated depth is maximally 28 mm. When middle-sized boilers are produced, the tube thickness is rarely greater then 28 mm. Gas burner is made of two apart halves of a ring and each one possesses two chambers: one for the gas, and the other for the water. In the gas chamber the gas mixture is made, it is exuding through a small seam between the chamber and flange.

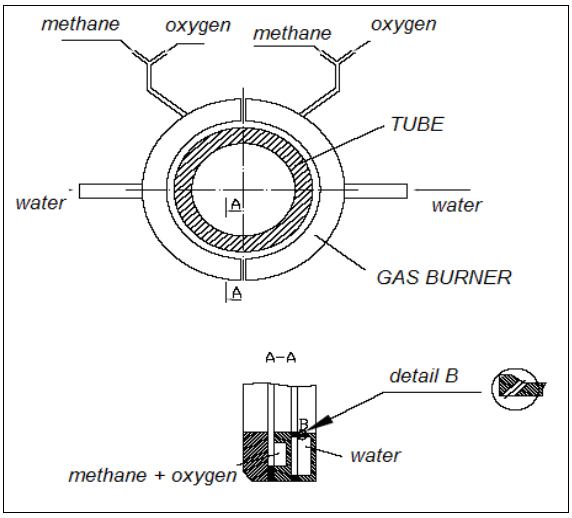

Figure 4. Gas burner that is used on the first machine for incremental hot bending, Czech [5].

When the gas mixture is out of the chamber it is burning and making concentric flame around the tube. The water chamber is cooling a gas burner, and also directing a water jet to a bended tube. The water is now cooling the tube. Every tube diameter has its own gas burner. Clearances between the gas burner and the tube must be optimal. Gas burner position in relation to tube is very fine regulated so that the clearance on the tube rim is continuous. The great advantage of gas burner toward electric induction is simple achieving of intensive heating of internal arc radius. Figure 4 shows the scheme of the gas burner.

4.2. HEATING USING ELECTRIC INDUCTION

The main characteristic of electric induction tube heating in relation to heating by gas burner is that heat is generated in the tube itself and the time of heating is very short.

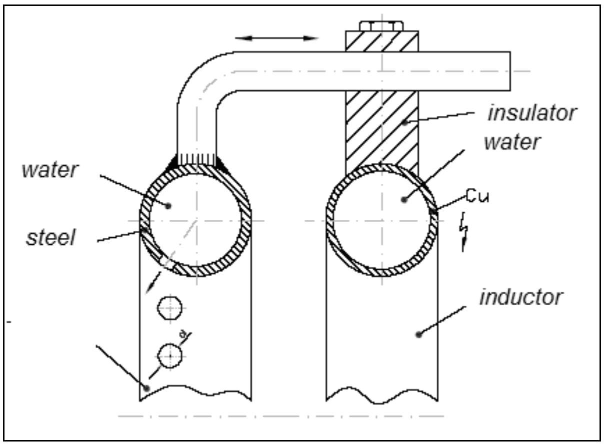

Figure 5. Functional scheme of induction heater and cooling setup [5].

Figure 5 shows functional scheme of induction heater. Its structure is very simple and composed of two tubes bended in a circle. The first – made in copper is inductor that is cooled by water circulation from the inside. The second tube – made in steel is used for cooling of bended part of the tube (working part). It has holes through its wall that direct trickles under pressure on bended tube. The distance between inductor and cooler can be regulated. To represent the temperature layout through the tube wall, some measurements have been carried out and they are shown on the figure 6. Measurements have been performed for two different moving speeds.

Heating process is dependable to an intensity of magnetic field around inductor, to a distance between inductor and working part, and to material properties of working part. Heating time depends on power that inductor brings to a working part. Lower power demands longer heating time. Inductor – heating tool, is made from copper tube, and is cooled with water from the inside. Inductor heats a zone that is just several millimetres wider from it.

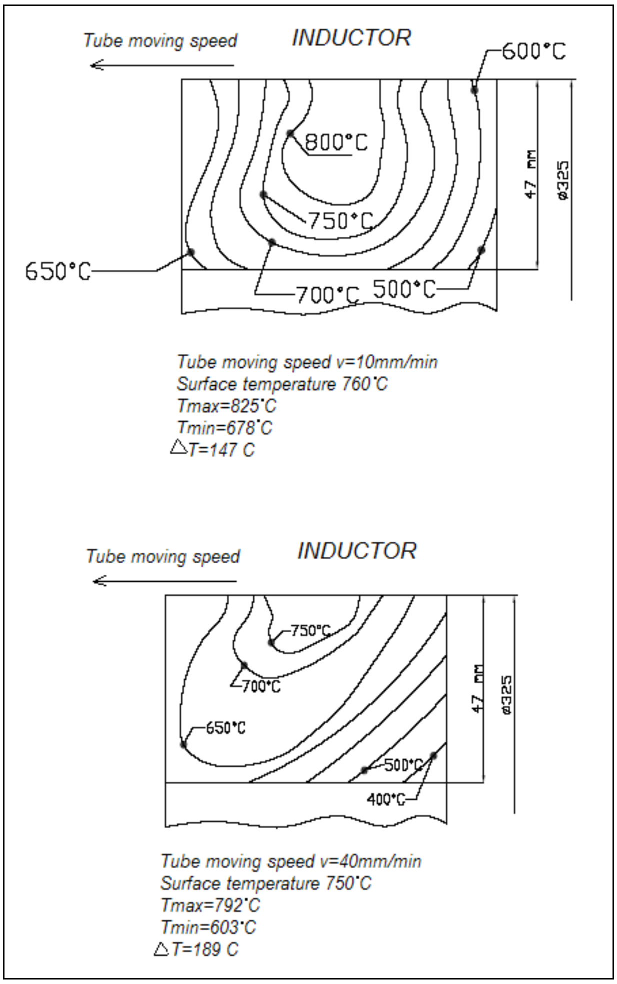

Figure 6. Temperature layout through the tube wall for heating by electric induction and for two different moving speeds [3].

Induction procedure has several advantages regarding other similar procedures:

- Very simple bending principle,
- It is not possible to overrate tolerable curvature and wall thickness loss,
- Heating temperature of the tube is constant through the whole arc length,
- It is possible to perform bending operation on high alloyed steels using simple additional heat treatment,
- The majority of procedure operations are automated,
- Regulation of the time/temperature relation is very precise,
- The procedure is economic regarding power demands,
- There is a possibility to bend more arcs on one tube length,
- Fine precision of angle and tube radius are easy to achieve.

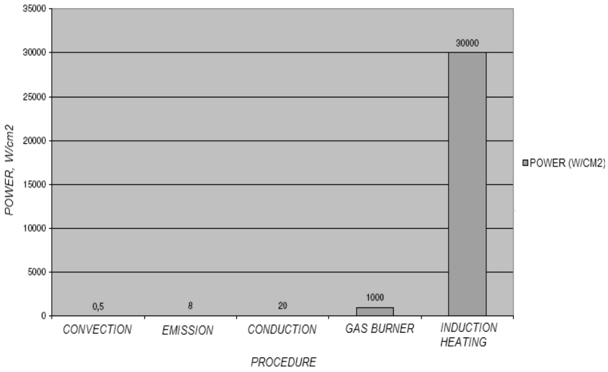

Figure 7. Power that can be transmitted using different procedures of transmission [5].

Figure 7 shows graphically values of the heat energy that can be transmitted on cm^2 of the heated areas. It is easy to notice an enormous advantage of induction heating towards the others. If all the processes are compared in relation to continuous incremental procedure, then induction heating is thirty times faster then heating by gas burner. That is the reason why continuous incremental procedure increasingly uses induction heating.

5. SIMULATION OF BENDING PROCEDURE

The main intention of numerical simulation of incremental tube bending was to visualise stresses that occur in a tube wall. All possible cracks and wrinkling are the result of those stresses. The numerical analysis was performed using MSC Marc Mentat elasto-plastic program package. In the presented bending problem the full Newton-Raphson iterative procedure is chosen to solve the iteration process and nonlinear equations of motion. This method has quadratic convergence properties and the stiffness matrix is reassembled in each iteration. Since material elements rotate during bending process, large displacement, finite strain plasticity and updated Lagrange procedure need to be adopted in calculation. In the Lagrangian approach, the element stiffness is assembled in the current configuration of the element, and the stress and strain output is given with respect to the coordinate system in the updated configuration of the element [2].

The stiffness is formed using four point Gaussian integration. Because of large displacement request, an additional contribution needs to be made to the stiffness matrix. By default, the analysis program uses full stress tensor at the last iteration, which results in fastest convergence [2].

3D model was modelled by 3D shell elements. It is four nodes, thick shell element with global displacements and rotations. Bilinear interpolation is used for the coordinates, displacements and rotations. The membrane strains are obtained from the displacement field, the curvatures from the rotation field. The transverse shear strains are calculated at the middle of the edges and interpolated to the integration points. This 3D model is particularly interesting because wrinkling occurrence can be easily detected.

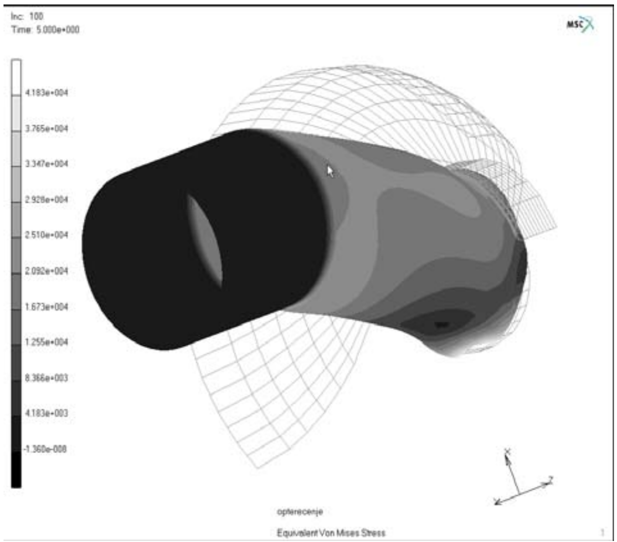

Figure 8. Equivalent stress in tube bending process calculated using MSC Marc Mentat

As it is shown on Fig. 8, if mathematical model consists similar conditions as the real incremental bending problem, the simulation result shows no possible cracks and wrinkling.

6. CONCLUSION

In this article the hot incremental tube bending process has been presented as newer technology for very specific purposes in bending operation. Also, supporting heating systems have been described and their advantages and disadvantages that can be helpful when choosing the best solution in solving a specific production problem. Finally, numeric simulation confirmed an assertion about usableness of described process.

7. REFERENCES

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