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Finite element and experimental analysis for cold tube-bending of a power station boiler

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Abstract: Combining the computer simulation, theoretical analysis and experiments, this paper studies the process of tube-bending production of a power station boiler. The FEM-numerical simulation system was set up to study the performance features in the process of manufacturing cold tube-bending, such as ovality, thinning ratio of wall and the equipment driven force. Experiments were carried out in Harbin boiler factory. The parametric FEM model can simulate the force and quality parameters for tube-bending process and the error is within 5%. Experiments have demonstrated that the results achieved by this system are more useful and economical than those obtained through trial-produce method. It greatly reduces the production cost using computer simulation than conducting lots of experiments.

Key words: cold tube-bending; FEM; ovality; thinning ratio
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The tube-bending method has been widely applied in fields of boiler and pressure vessel manufacturing, automotive industry, aviation, aerospace manufacturing, ship craft manufacturing and so on. Researches have shown that cold bending process can raise the surrender strength by 20%-30%. And also the maturity of the NC technologies made it naturalness to use cold bending NC machine tools.

However, the tube-bending process is very complicated, so the process planning is based on analytic solution. Traditional trial-and-error method cannot meet the needs of production and may also cause a lot of waste on time and finance. With the development of computer science and FEM method, it is feasible for us to use large common software for complicated process analysis[1-3]. In this paper, the software ANSYS is used to simulate the cold tube bending process. A rounded tube bending simulation system is built in order to forecast equipments driven force and forming quality effectively, such as ovality, thinning ratio of wall. We also have given experimental verification.

1 Summary of the Cold Bending Process

There are three regularly tube bending methods: pushing method, grinding method and drawing method. Drawing method is shown in Fig. 1[4].

The fan-shaped mould is fixed to the equipment by the cross-like key and is rotated by the equipment. The fixed clamp is fixed to the fan-shaped mould by screw and is used to fasten the tube together with the mobile clamp. Then the rotation of the tube's end is restricted by the slot and all the other moulds rotate to performance the cold bending of the tube.

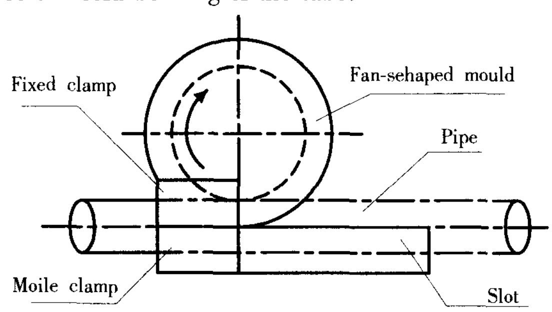

Fig. 1 Diagram of tube-bending process

Quality is the most important thing to evaluate a tube-bending process. Generally, nonideal deformation happened after the bending (as shown in Fig. 2).

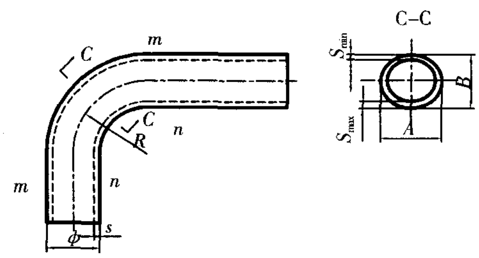

Fig. 2 Shape of the tube-bending

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The tube's outer flank $m-m$ is thinned by the pulling force, while the tube's inner flank $n-n$ is thickened by the pressure force during the bending process. R is the projected bending radius, Φ is the projected external diameter of the tube. The sectional drawing shows that the section shape turns from circle to ellipse, and the wall thickness are non-uniform. A is the long axis of the elliptical section, and B is the minor axis. S is the ideal wall thickness, and S_{min} is the minimum, S_{max} is the maximum. Ovality $a = (A - B)/\Phi$, thinning ratio $b = (S - S_{min})/S$, thickening ratio $c = (S_{max} - S)/S$.

With the enlargement of the boiler's capacity, whether the elbow's quality can meet the higher need, or whether the equipment's driven capability is sufficient turn out to be a serious problem. As soon as we can forecast equipments driven force and forming quality effectively, we can make arrangements for processes and equipments, and we can also make better products to get better benefits.

2 Structure of FEM Simulation System

The cold bending process is very complicated including large plastic deformation, large displacement, nonlinear contact analysis, so we use the software ANSYS and its nonlinear analysis methods to build a rounded tube bending simulation system to forecast equipments driven force and forming quality effectively.

2.1 Preprocessing: Modeling

Considering the symmetry of the model's structure, loads and constraint, we built the analysis model by the moiety to reduce the computation time. Also APDL parameter design language is used to input dimension and material parameters, which insures the reusable log file. Geometric model is shown in Fig. 3.

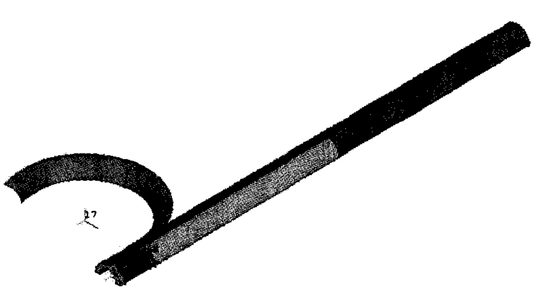

Fig. 3 Geometric model of the tube bending

In FEM model, PLANE42 is used to describe the tube's section. VISCO107 is used to describe the viscoplastic sold tube that can use to analysis large plastic deformation. Comparing to the tube, the deformation of the fan-shaped mould, fixed clamp and mobile clamp is so small to ignore. Thus we take the mould as rigid body and tube as flexible body to analyze it using ANSYS's rigid to flexible contact model[5]. In order to get the mould force, we use three contact pairs. The surface of fan-shaped mould is target element TARGE170, and the tube attach to it is contact element CONTA173. The surface of slot is TARGE170 and the tube attach to it is CONTA173. The surface of mobile clamp is TARGE170 and the tube attach to it is CONTA173. Contact stiffness is taken as 0.65 between the theoretical domain 0.01 and 100 to get good precision and efficiency.

2.2 Solving: Applying Loads

In the tube-bending simulation process, large nonlinear plastic deformation is solved by N - R method and multi-step loads control. Large deformation, predictor, auto step size are turned on to accelerate the convergence. Pilot node is also used to control the motion of the rigid body. We constrain the displacement slot, apply pushing force to the end of the tube, and then rotate the mould and mobile clamp by ramp. After the rotation, an unloading step is applied to remove the clamp and slot.

2.3 Postprocessing: Getting the Result

After the calculation is converged, solution is saved and processed by these steps:

1) Exhibiting the tube-bending process dynamically: By the function ANIMATE we can exhibit the tube bending process dynamically and save it to avi file. We can choose only the tube except the mould in order to observe the deformation of tube more clearly.

2) Getting the reaction force of the mould: In POST26, the node solution option REACTION FORCE can help us to get the moment of the mould, the pushing force of the slot, and the chucking force of the mobile clamp.

3) Calculating the quality parameters: Q-SLICE option can help us to get the section's deformation shape, contour chart of the stress and strain at any position. We can also use GEOM CHECK option to get information of every node, and then calculate the quality parameters at any position, such as wall thickness, ovality, thinning ratio, thickening ration and so on.

3 Comparison between Experiments and Simulation

In order to certificate the precision of the FEM simulation system, experiments were carried out in Harbin boiler factory by the two tubes:

Tube A: diameter 168 mm, thickness of the wall 30mm, bending radius 400 mm, material 20 G

Tube B: diameter 141 mm, thickness of the wall 25mm, bending radius 350 mm, material 20 G

3.1 Comparison of the Mould Force

The bending moments of tube A and B from simulation are shown in Fig. 4.

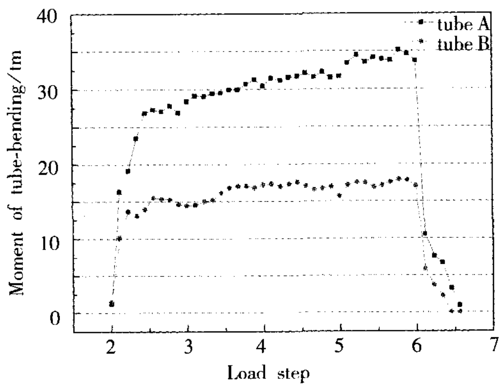

Fig. 4 Diagram of the bending moment

Loading process begins at time 2 and finishes at time 6, while unloading process is from time 6 to time 7. From each single curve we can see that the bending moment soon increased to a high level at the beginning, and then increased slowly as bending. This make it out that the main stress part focus on the beginning part of bending, and this is coincident with Ref. [6]. The maximum bending moment for each curve appeared at the largest deformation, this is coincident with the monometer in experiments. It is clear that tube A needs higher driven force for equipment than tube B that will help us to make arrangements for equipment more reasonably.

3.2 Comparison of the tube Bending Quality

The section's ovality of tube A and B from simulation are shown in Fig. 5.

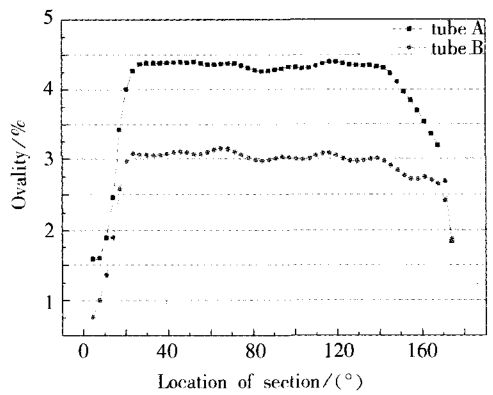

Fig. 5 Diagram of the ovality

It's clear that for 180° tube-bending the maximum ovality is not on the 90° position we usually supposed, and the real position is associated to the relative bending radius to some extend. The simulation error is defined as the percent of difference between simulation and experiments. Tab. 1 reveals the comparison of sectional ovality.

Thinning of outer wall is the most serious defect. By the simulation we can forecast the extent and position of the thinning, and then decide whether we need to make an effort to improve it. It reveals thinning of outer wall for the whole tube in Fig. 6.

Tab. 1 Comparison of ovality between simulation and experiment

Project	Max ovality/%		
	Simulation	Experiment	Error
Tube A	4.39552	4.57142	3.848
Tube B	3.15115	3.28269	4.184

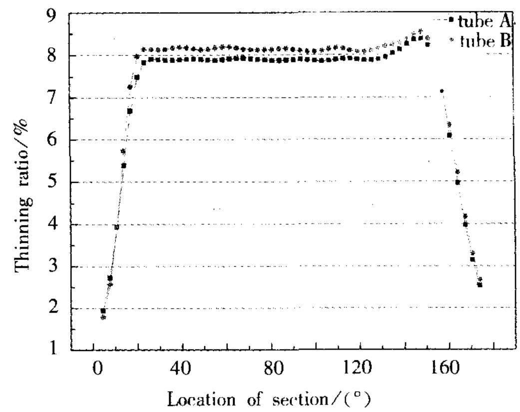

Fig. 6 Diagram of the thinning ratio

From it we can see the early bending part has been under tension stress and gets large plastic deformation. Tab. 2 shows comparison of thinning ratio between simulation and experiments.

Tab. 2 Comparison of thinning ratio between simulation and experiment

Project	Max thinning ratio/%		
	Simulation	Experiment	Error
Tube A	8.36758	8.73235	4.177
Tube B	8.53180	8.91572	4.306

The parametric FEM model built in this paper can simulate the force and quality parameter for tube-bending process within 5% error. Considering the impact of simple method for data acquisition and many other real factor, we can accept this result and use it for the performance of equipment and quality's forecasting, that is more effective results than which obtained in trial-produce.

4 Research on Improvement of the tube Bending Quality

Numerical simulation by FEM can not only forecast the equipment's capability and quality of the tube-bending process but also optimize the process by finding some affect factors, which would help us to take measures to improve the quality. Then we will discuss the affection of the rotational velocity and back pushing force.

4.1 Impact of the Rotational Velocity

Plastic deformation of metals definitely associates the velocity of deformation, so the rotational velocity is related a lot to the quality of the tube bending. We will bend the same tube by different velocity: 0.4 rad/s, 1.0 rad/s and 1.6 rad/s to compare the ovality, just as shown in Fig. 7.

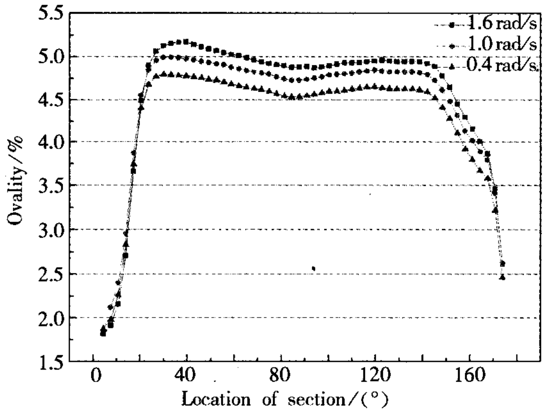

Fig. 7 Comparison of ovality among different rotational speed

Obviously the higher the velocity we use, the shorter time the tube have to deform, so more worse we will get the quality of the tube. It gives us suggestion that slowing down will benefit the quality.

4.2 Impact of the Back Pushing Force

In the practical production, back pushing force is always taken to get better quality, here comes the simulation (as shown in Fig. 8).

We can see that the larger force we push the end of the tube, the better quality we will get. But the effect is not prominent because in this modularized simulation we have neglected the influence from the structure of reversible deformation. If this structure is taken, just as the real production, materials will flow to the gap of the structure that will benefit the quality parameter greatly. Besides, rotational moment reduces a lot after the pushing force has been applied, that will be significant to the bending of large tube.

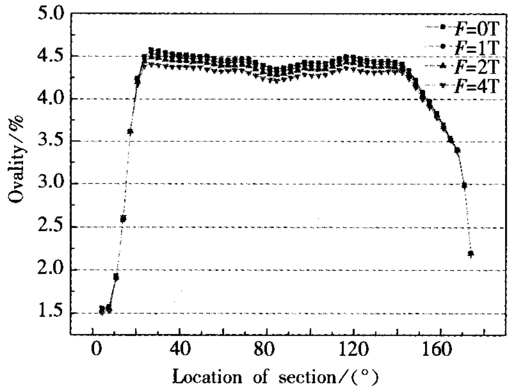

Fig. 8 Comparison of ovality among different pushing force

5 Conclusion

A FEM-numerical simulation system is built to study performance of cold tube-bending, such as ovality, thinning ratio of wall and equipments driven force. Planning deform is forecast and planning parameters are optimized by the computer simulation. Compared with practical production, the simulation method is proved to be more effective and economical than those obtained through trial-produce method.

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