Modification of the optimization model for simulation of large-diameter pipes bending

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Abstract. This paper presents a modification of the existing optimization model in order to increase the accuracy of the solution in the initial and the end part of the bend. Developed optimization algorithms are implemented in the program MATLAB, and the simulation of the bending process is solved in the FEM program ADINA. Created optimisation program automatically generate model for FEM analysis and automatically analyses obtained results from FEM analysis.

Keywords: Finite element method, pipe bending, pipe tickness, induction heating, splay cooling

1 Introduction

The created optimization model for determining the shape of a blank for bending large-diameter tubes with induction heating is showing several insufficiencies [1]. The proposed changes aim to improve the behavior of the calculation model and to increase the accuracy of the resulting shape of the tube after bending. Bending of large diameter tubes with induction heating changes the thickness of the wall of the pipe. The thickness of the pipe wall increases on the inside of the bend and the thickness of the pipe wall decreases on the outside of the bend. The blank is machined from the outside, so that after bending, the thickness of the pipe wall is the same at all locations. The technological process of the pipe bending with the induction heating is shown in Fig. 1.

2 Modification of optimization model

The old optimization model divides the geometry of the bent pipe into three parts. The new optimization model has the geometry divided into three parts, dividing geometry into three parts is adequately and accurate:

- Initial bend zone. In this zone, the plastic deformation of the pipe is not yet fully realized as in the middle part of the pipe. The old model optimizes the thickness of the pipe wall in three places: at the beginning, centre and end of this zone. The new model optimizes the wall thickness of the pipe in five places with the same spacing.

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- Ending bend zone. There are the same changes at the ending zone as at the initial bend zone. There was created the same changes. In the end bend zone, as at the initial bend zone, the number of places for optimizing the wall thickness is increased from three to five.
- Middle bend zone. Geometry model for this zone is the same for old and new model. The optimization of the wall thickness is counted for three places in this middle zone.

Fig. 1. Bending pipe with induction heating and spray cooling

The computational model contains optimization parameters for the length, that change the position of the individual optimization zones, further parameters change the thickness of the pipe wall in these zones. When the all optimization parameters are used in the same time, the optimization task is not convergent. The solution is to divide the optimization parameters into three groups and to use the method of the cyclical change of the optimization parameters. We create three sets of parameters:

- The first set of parameters. Optimization of the outer dimensions and position of the area of plastic deformation on the pipe. The parameters of this group determine the position of the beginning of the plastic deformation, the position of the end of the plastic deformation, and the total displacement coefficient of the pipe at bending. The actual displacement is larger than the theoretically calculated displacement to achieve the prescribed bending angle of the pipe. The plasticization of the pipe bending is shortened.
- The second set of parameters. This parameters are used for optimization of the length of the initial and ending plastization zones. They determine the interface between the initial and central plasticization zones similar to the central and ending plastization zone.
- The third set of parameters. This parameters are used for the optimization of the wall thickness of the pipe in seven vectors of the wall thickness of the pipe. The thickness of the pipe wall is defined at 19 points halfway through the pipe circumference. In this group of optimization parameters, optimization of the overall displacement of the pipe is also

redefined – when changing the thickness of the pipe wall, the size of the pipe pressure is changed.

In both the old and the new computation model, the second and third set of parameters are changed.

When optimizing the first and second parameter sets, the modified Golden Cut method is used. The modified Full Stress Design method is used to optimize the wall thicknesses of the pipe. The new geometric model used in the modified optimization model is shown in Fig. 2.

Fig. 2. Geometry model for optimization model

3 Finite element model

Half of the pipe geometry is created, model symmetry is used in the FEM model. The symmetry condition is defined in the plane of symmetry. The bending arm is meshed by truss elements. All degrees of freedom are removed, at the end of the bending arm. The combination of truss elements and the removal of all degrees of freedom at the end of the rods allows rotation around this point. A displacement is prescribed in the direction of the pipe axis, all other degrees of freedom are removed, at the free end of the pipe This displacement causes the pipe bending [2-7].

The bilinear thermal depend material model is used in both the old and the new model. The linear elastic material model is used for other parts of the model.

Induction heating and cooling sprayer are modeled using contact with heat transfer [8-10]. A set of bodies with one element is created, in the place of the inductor and the sprayer. These elements have the heating temperature 950°C and the temperature of the cooling water is 20°C. Replacing induction heating and water sprayer by the contact with heat transfer sufficiently accurately models the heat flow in the pipe. Such replacement is very time-efficient and makes it possible to significantly increase the speed of the optimization model.

The model of the pipe is designed as a volume model, and linear hexahedron elements are used to mapped meshing. Four elements are generated on the wall thickness of the pipes. The finite element model is shown in Fig. 3.

Fig. 3. Geometry model for optimization model

4 Comparison of old and new model

We compared the suitability of changes in the optimization model by comparing the calculation using both the old and the new optimization model. We performed a series of calculations for a 10 inch pipe diameter, 24 mm wall thickness and with the following bending radiuses of 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5. Comparison of models with respect to convergence of computational models is presented in Tab. 1.

A comparison of the required number of cyclical changes of the optimization parameters as well as the number of iterations needed to convert a single cyclic parameter change is given in Tab. 2.

The resulting shape of pipe bend for the new optimization model is shown in Fig. 4 and for old optimization model in Fig. 5.

Table 1. Convergence for old and new model

Bending radius	Old model	New model
1.5	Not converged	Not converged
1.6	Not converged	Not converged
1.7	Not converged	Converged
1.8	Not converged	Not converged
1.9	Converged	Not converged
2.0	Converged	Converged
2.1	Converged	Converged
2.2	Converged	Converged
2.3	Converged	Converged
2.4	Converged	Converged
2.5	Converged	Converged

Table 2. Number of iteration for convergence old and new model, bending radius 2.0-2.5

Parameter group	Bending radius											
	2.0		2.1		2.2		2.3		2.4		2.5	
	new	old	new	old	new	old	new	old	new	old	new	old
1.	14	8	15	8	12	9	12	9	12	8	12	8
2.	15	3	14	3	15	3	13	3	14	3	14	3
3.	7	11	5	11	5	12	5	11	5	11	8	12
1.	10	9	12	9	11	9	11	9	10	9	10	9
2.	10	2	11	2	12	2	12	8	12	2	12	2
3.	3	8	2	8	3	9	3	10	3	9	3	8
1.	-	10	-	10	-	10	-	11	12	-	12	10
2.	-	2	-	2	-	1	-	1	11	-	11	1
3.	-	10	-	10	-	19	-	10	2	-	4	10
1.	-	-	-	-	-	2	-	-	-	-	-	-
2.	-	-	-	-	-	7	-	-	-	-	-	-
Total	54	59	54	55	53	72	50	58	73	37	78	55

Fig. 4. New optimization model $R = 2.5$

Fig. 5. Old optimization model $R = 2.5$

5 Conclusion

The new optimization model shows the following improvements:

- Improved shape in the initial plastic zone, reducing the corrugation on the internal bend radius.

- Improved shape in the end plastic zone, reducing the corrugation on the internal bend radius.
- Reduction of the total number of necessary iterations.

Model changes were tested for one diameter and one pipe thickness. In practice, pipe bends are made with a large number of combinations of wall thicknesses and pipe diameters at different bending radii to the diameter of the pipe. In the following research, it is necessary to test a new calculation model for further combinations of pipe wall thicknesses and pipe diameters as well as to experimentally verify the obtained results and material structures of pipes [11-22].

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