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FINITE ELEMENT ANALYSIS OF FLOW TUBES IN SOLAR THERMAL COLLECTORS

Raluca LATES[1], Ion VISA[1]
[1]University of Braşov, Department of Product Design and Robotics
e-mail: latesr@unitbv.ro, visaion@unitbv.ro

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Abstract: Stresses and displacements in flow tubes of solar collectors are essentially influenced by heat carrier and ambient temperatures and their construction. In the paper these influences are analysed by finite element method for three different flow tubes types (geometries) in the same conditions of temperatures, tube materials, and liquid heat carrier. At temperatures of 120^0C, the harp and spire geometries exhibit stress values higher than the admissible ones. A new optimized geometry is proposed and analysed; the ellipse geometry shows stresses lower than the maximal admissible values.

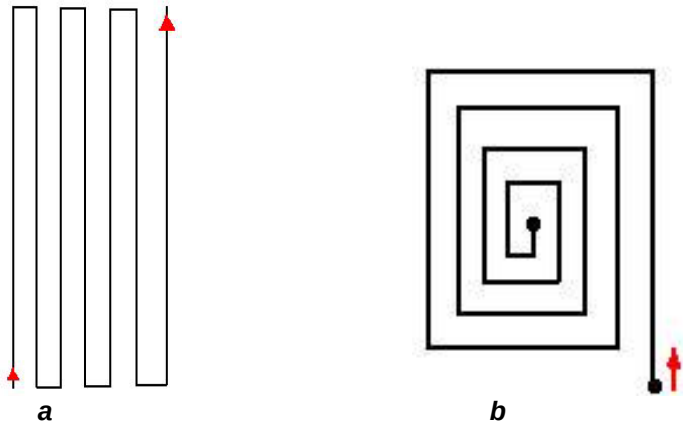
1. INTRODUCTION

In the last years, due to the problems caused by the global warming as well as the problem of the limited amount of conventional energy sources, the politicians and engineers turned their interest to find and to promote non-conventional sources for energy. The sun is the main renewable source, either direct, as solar energy, or indirect as wind energy, biomass, tides etc. The solar energy is collected by different types of devices, depending on the type of the output energy. The solar collectors are used to transform the solar energy into heat [11].

The paper refers only to the serpentine design from the collector. There are chosen three of the most representative types. Strength and displacements analysis are made with finite element method in CATIA.

2. COMPONENTS OF SOLAR COLLECTORS

The construction of solar thermal collectors can vary a lot. From the shape point of view, collectors can concentrate the radiation or to receive it with their entire active surface. The paper refers to flat plate collectors, which are not concentrating the solar radiation, with liquid heat carrier. The main components of a flat plate collector are: one or two protection glasses, absorber plate, flow tubes circuit, insulation, casing, input and output pipes. The paper discusses the flow tubes serpentine which shape can be different from one collector to another [12].



a *b*

Fig.1a. Meander type circuit; b. Spire type circuit

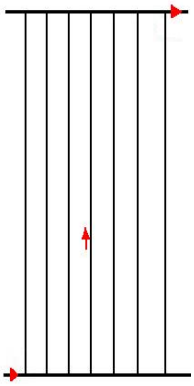


Fig. 2. Harp type circuit

Three of the most used flow tube circuits are analyzed as those shown in the following pictures, Figure 1a – meander type, Fig. 1b – spire type and Fig. 2 – harp type [4]. All of them are used because they have different efficiencies. The flow depends on the shape of serpentine. The losses are increasing with the number of angles pipe [15].

In the case of these three types, tubular profiles are used for the pipes. The most common material for them is copper. Steel, stainless steel and aluminum are also used.

The diameter of the tubes has to be low and the values are between 35 and 58 mm. The distance between the tubes is of 278 till 650 mm [16].

For the same dimensions in the three different cases of circuits, finite element method analysis is made.

3. FINITE ELEMENT ANALYSIS (FEA) ALGORITHM

Some concrete steps have to be followed to obtain the analysis results of the finite elements modeling in CATIA. The algorithm is shown in Fig. 3:

The first step in the algorithm is to describe the components which are going to be analyzed. In this way the shape and the dimensions are defined. The second step is to apply the materials, which means that the Young modulus, Poisson coefficient, specific heat, linear expansion coefficient, thermal conductivity are defined.

The next step is to define the restrictions (e.g. clamps) and then, the loadings. After running the analysis the results are obtained.

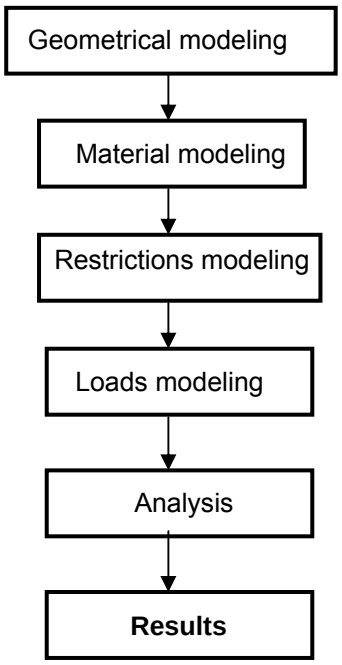


Fig. 3. FEA algorithm

4. ANALYSIS

The analysis is made for concrete examples of circuits of three collectors with the same dimensions.

The meander type circuit, with copper tubes, their exterior diameter being of 40 mm, the interior is of 38 mm and the distance between the tubes of 400 mm [7].

The spire and harp circuits have the same dimensions as the previous one [10].

As mentioned in the algorithm, the first step is to make the geometrical modeling of the serpentines. The dimensions are those above mentioned. The material is for all cases copper. Inside the tubes water circulates.

After the geometrical and material modeling is made the restrictions are to be applied. In this way, clamps are used at the input, respectively, output of the fluid for all three cases. As loadings, thermal fields are applied on the outer part of the serpentine, of 20^0C, and inside temperatures of 60^0, 80^0, 100^0 respectively 120^0.

The last but one step is to run the analysis and then, the results are obtained

5. RESULTS

In the first case, of the meander circuit type, the stresses can be seen in Fig. 4 (for 60^0), the highest values being shown in the paper with arrows:

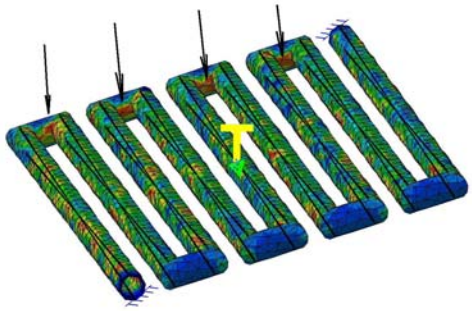


Fig. 4. Stresses for the meander circuit type

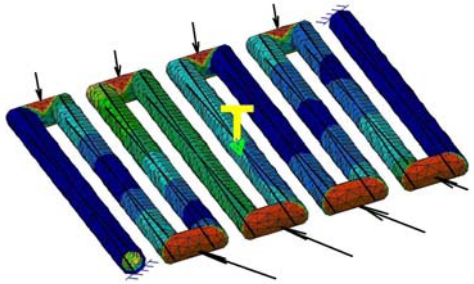


Fig. 5. Displacements for a meander type circuit

Examples of displacements for meander at 60^0C are shown in Fig. 5:

The values for stresses obtained for the four cases of different temperatures for the meander type are shown in the chart of Fig. 6:

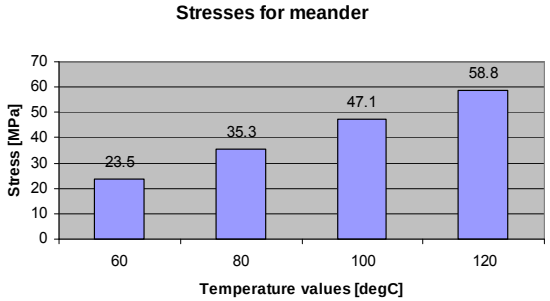


Fig. 6. The stress values for meander type

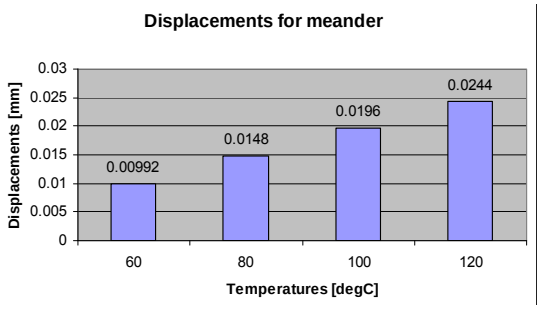


Fig. 7. Displacements values for meander type

The displacement values for the four cases of temperatures are illustrated in Fig. 7:

For the spire type the stresses results at 60^0C in CATIA are shown in Fig. 8.

The displacements for the spire type at 60^0C are shown in Fig.9.

The values for the stresses for the four temperature cases are displayed in Fig. 10.

The values for the displacements for the four cases of temperatures are displayed in Fig. 11.

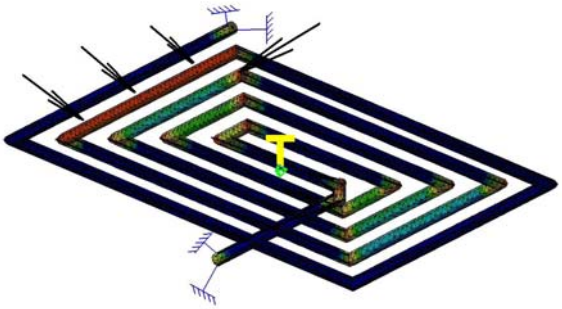


Fig. 8. The stress values for spire type

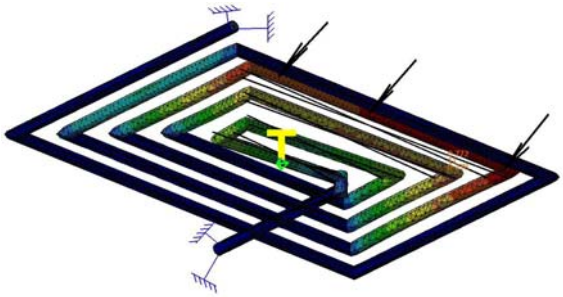


Fig. 9. Displacements for spire type

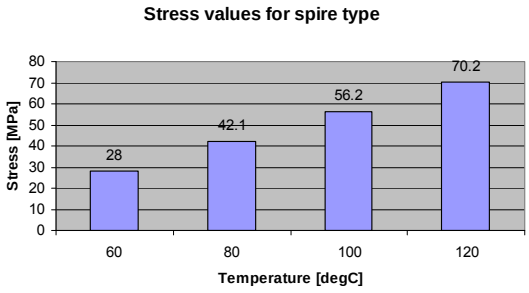


Fig. 10. The stress values for spire type

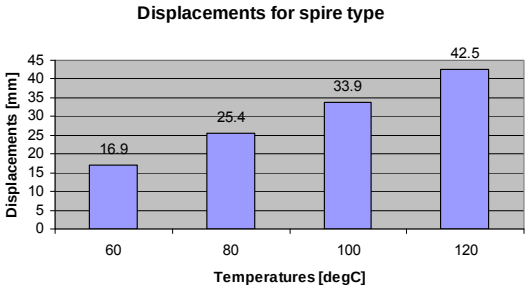


Fig. 11. Displacements values for spire type

The stresses for the harp type in case of 60^0C inside the tube are shown bellow:

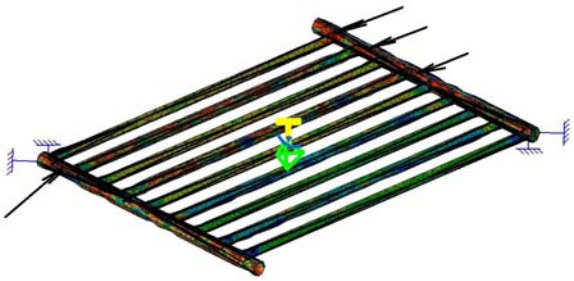


Fig. 12. Stresses for harp type

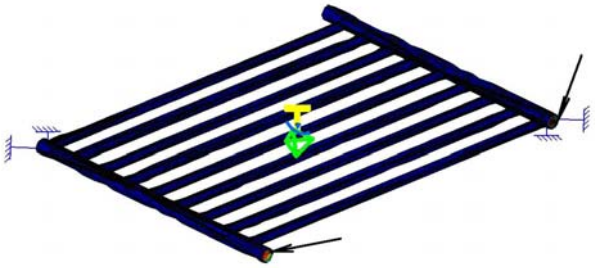


Fig. 13. Displacements for harp type

The displacements for the harp type:

The values for stresses in case of harp type for the four cases of temperatures are shown in Fig. 14:

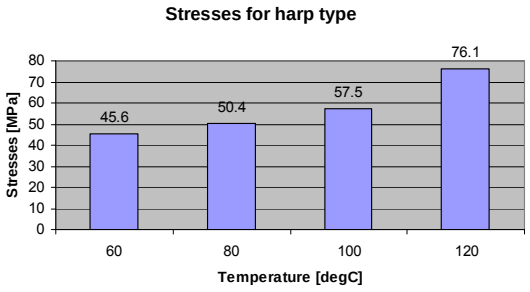


Fig. 14. Stresses for harp type

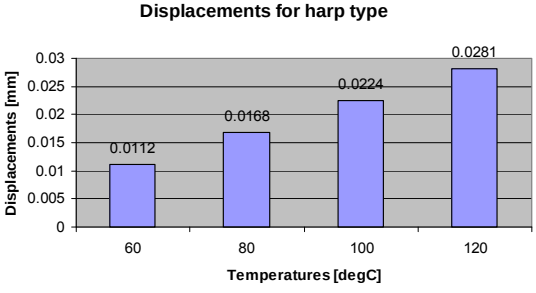


Fig. 15. Displacements for harp type

The displacement values for the harp type are shown in Fig. 15.

6. RESULTS ANALYSIS AND RECOMMENDATIONS

After running the analysis for four different cases of temperatures inside of tubes, 60^0, 80^0, 100^0 respectively 120^0, the results can be analyzed.

In the case of meander flow tubes type the values for stress are increasing with the temperature. The highest value is 58.8 MPa, which is smaller than the admissible stress value (60MPa) [16]. The displacements have very low values which cannot affect the system's functionality.

The spire type flow tubes have stresses which are increasing also with the temperatures. The highest value for stress, obtained at 120^0C, is higher than the admissible value. In this case it is not recommended to use this type for high temperatures or to make optimizations for it. The displacements are high too.

The stress values for harp type flow tubes are increasing, also, with the temperatures. At 120^0C the admissible stress is exceeded [16]. The displacements, in this case, are low, so they cannot affect the system's functionality. The harp type flow tubes are not recommended to be used in case of very high temperatures.

The best behavior, from the stresses and displacements point of view, was proved by the meander type flow tubes. The other two, exceed the admissible stress value for 120^0C. From the displacements point of view, the spire flow tubes have very high values. For this reason it is not recommended to use at high temperatures spire or harp flow tubes. The solution can be optimized in order to reduce stresses.

7. OPTIMIZATION

As shown, the admissible stresses are exceeded in case of spire and harp flow tube types. It is chosen the spire type to be optimized in order to increase the strength. The new type remains spire but the shape is not rectangular but ellipse one, Fig. 16. The overall dimensions are the same as in the case of the initial ones; the dimensions of tubes, space between tubes, and number of spire are the same too. The material of tubes is also copper and inside circulates water with properties as the previous ones. The restrictions are defined as well as it was done before. The loads are maintained the same.

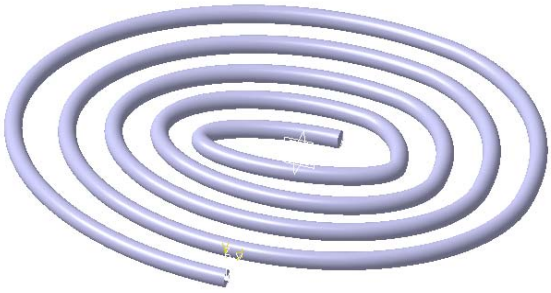


Fig. 16. Optimized shape

The analysis is made in same conditions. The stresses at a temperature field inside the tubes of 120^0C are shown bellow:

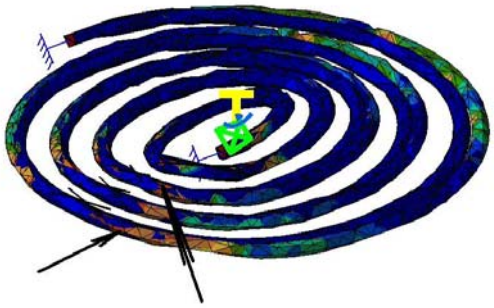


Fig. 17. Stresses at 120^{0}C

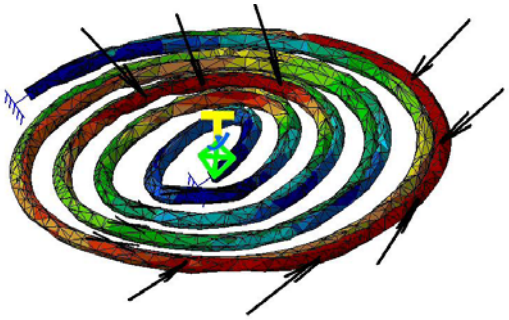


Fig. 18. Displacements at 120^{0}C

The displacements at 120^{0}C are shown in Fig.18.

The highest values for stresses in four cases of temperatures are shown in the chart from Fig. 19:

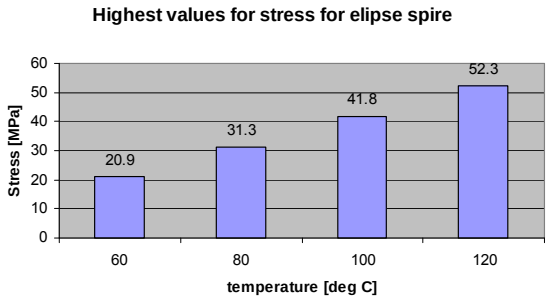


Fig.19: Stresses for ellipse spire

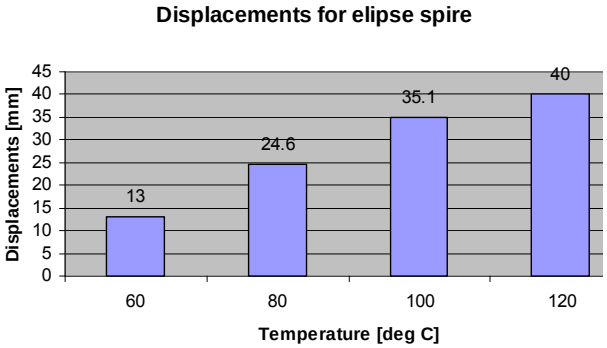


Fig. 20. Highest displacements for ellipse spire

The highest values for displacements are shown in Fig. 20.

The highest value for stress, achieved at 120^{0}C, is 52.3 MPa which is less than the admissible strength. The displacements are quite high, till 40 mm. By optimizing the spire type flow tubes, the stress is highly reduced, in order to have smaller values than the admissible one.

In the following two figures, the maximum values for stresses, respectively for displacements, are displayed for the three circuit types as well as for the optimized one.

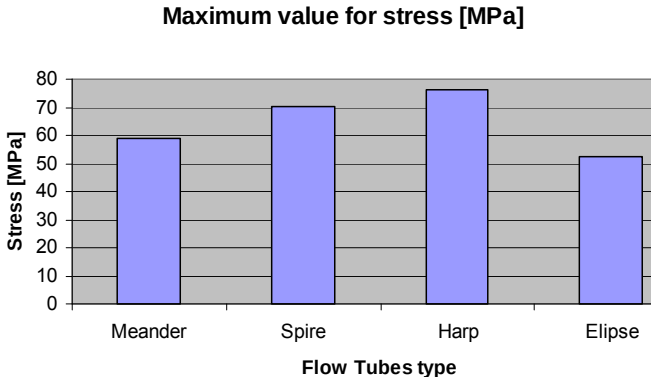


Fig. 21. Comparison of maximum stress

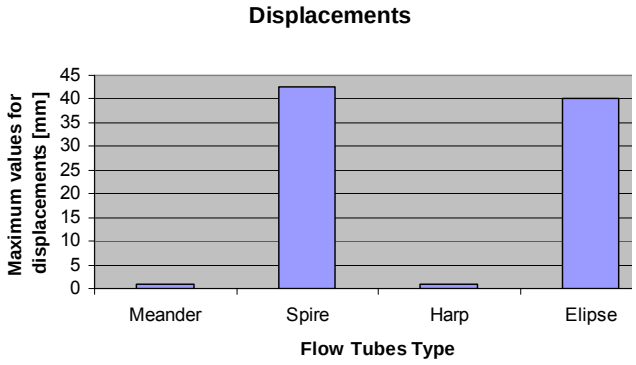


Fig. 22. Comparison of maximum displacement

Making a comparison between the circuits, it can be seen that the optimized one has the lowest maximum stress value. From the displacement point of view, the optimized circuit has higher values than meander and harp but smaller than the spire one.

8. CONCLUSIONS

The paper presents the stress and displacement analysis for three types of flow tubes: meander, spire and harp. The analysis is made with finite element method in the same conditions of dimensions, materials, constraints, loads: the external thermal field is of 20^0C and inside there are applied fields of 60^0, 80^0, 100^0, respectively 120^0C. At the highest temperature case, the spire and harp are exceeding the admissible stress values. It is chosen the spire circuit to be optimized in order to reduce stresses and displacements. The last ones are reduced, comparing with the spire type, using an ellipse shape spire circuit. In this case the stresses are reduced, and they are the lowest, comparing with the other cases.

So, the optimization was made successfully.

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