A Simplified Calculation Method Applied To Thermal Systems Design Using A Mathematical Model Of Structural Calculation Of Pipes Systems

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***Abstract*—In this paper we intend to present a simplified calculation method for the identification of reactions which appear in the piping systems that transport warm fluids, with a view to ensuring the functionality and safety in exploitation. The program that we propose is a general program of spatial frames based on the matrix method of the movements which makes use of a pre-processor dedicated to the piping systems and it generates data taking into account the particularities of the piping systems. We intend to address the calculation proposal to the designers of thermal networks in order to facilitate the design process, in order to be able to easily switch between different network configurations made of different materials. The authors have presented different network configurations, they have established their rightful dimensions and they have found out the forces that are transmitted to the supports, their influence on the deformation states and on the tension in pipes**.

Keywords—state of efforts; deformations; piping systems; spatial frame systems; design.

I. INTRODUCTION

In order to establish the optimal material and dimension variants in the pipes that transport the fluids it is necessary to calculate them mathematically and thermally. In the paper[1] there is a simple mechanical calculation while the author of the paper [2] studies the discharge manner on fixed and mobile supports of the pipes' loads. The calculation problems get complicated in the case of complex configurations, the existence of the knuckles, the angle of the supports, the variations of temperature and the use of different materials. Such a pipe or a pipe system through which high parameters thermal agents run, alternate cyclically the heating modes from the environmental temperature to the functioning temperature with a semi-constant mode corresponding to the functioning temperature and the cooling mode from the functioning temperature to the environment's temperature. Such linear and angular differences between the situations when cold and when heated represent movements. During the functioning of the pipes there may take place movement of the hook-up points of the pipes to machines. These aspects require the finding of some simple calculation methods and the check-up of the pipes', knuckles', supports' dimensions. In paper [3] there is an original program which uses a softwarepackagefor pipes named CCRT-CNE-Tip Z software. For the checkup of the results by the mentioned method, the authors propose a matrix calculation of the pipes, which is simple and it obtains corresponding results that under certain circumstances can be checked practically.

The mechanical calculation intends to establish the thickness of the pipes, the establishment of the type and intensity of the tensions which appear in the most solicited points, the decision upon the number of the types of support elements for the pipe. At a random point from a spatial system of pipes, its own weight and the born loads produce a complex state of solicitations containing moments and forces oriented in parallel directions to the axes of a rectangular reference system. The calculation of the systems of pipes charged with loads distributed and concentrated is a mechanical calculation of the bar systems statically undetermined in the exterior. The calculation can be made analytically for pipes with simple configurations by using methods from the resistance of materials [1], [4]. For straight pipes with fixed and mobile supports we use the method of the three moments [2], [4]. In the case of more complex configurations we use specialized calculation programs [5]. The primary tensions which appear in a pipe are triggered by the loads which act upon the pipe and are the result of the equilibrium conditions of the forces and internal and external moments. The secondary tensions which appear in a pipe are owed to the movements (stopped dilatations, deformations, etc.) or in other words, constraints of the structures. The top tensions in a pipe appear thanks to the local thermal loads, these are taken into consideration as a possible source of damage by the overlapping of primary and secondary tensions. The primary, secondary and top tensions lead to different damage situations and because of this the calculation norms for pipes introduce limitations of the tensions at admissible values for each category separately, as well as their combinations. The used calculation methods will allow the establishment for the compensation of the thermal dilatations and of the other movements by using: self-compensation[12] [13] [14]: - pipes with knuckles and curves which trigger the direction change. The use of the compensators necessitates a verification calculation on the basis of the results obtained by the two calculation methods by using different methods, for example: the method moments [8], the method of the elastic center [4], [6], [7], the method of the minimal work [9], the method of the distribution of moments [10], the method of analysis with finite elements [1], [11].

II. MATERIALS AND METHODS

2.1. The mathematical structural calculation of the pipe systems

In order to establish the state of efforts and deformations in the pipe systems we use a calculation model based on spatial bas systems. The solving out of the spatial bar systems is made by the matrix method of the movements by the help of the program C3D (spatial frames), which run under SCILAB, but with minimal adaptations it could run under MATLAB, as well.

The program **c3d** is a general program, which has been written for the purpose of solving problems with a study-, research-character. The structure is made of prismatic bars connected at joints. For solving it out, the joints and the bars are counted and we adopt a reference system, to which the coordinates of the joints and loads are reported.

2.1.1. The stages of the matrix method of movements

The stages of the solving out of a structure by the matrix method of the movements are:

1. The introduction of the data. The data that are introduced are:

- the coordinates of the joints;
- the characteristics of the sections of bars – axial, cutting, torsion, bending rigidities;
- the connections and the type of the bars' sections;
- the support conditions –we can have rigid supports (not deformable) or elastic;
- the trials –we can have trials with forces and moments concentrated at joints and loads on the bars;

2. The making-up of the rigidity matrices $\mathbf{k}_{12x12}$ for each bar.
3. The assembly of the rigidity matrices of the bars in the **K** rigidity matrix of the whole structures. (The assembly is the algebraic sum-up of the bars' matrices taking into account their connection to the structure.)
4. The assembly of the vector of the loads on the structure.
5. The introduction of the support conditions.

In the case of rigid supports, we suppress the K structural rigidity matrix the lines and the columns corresponding to the fixed movements. In the case of elastic supports, we assembly the rigidity of the supports to the rigidity of the structure.)

The equilibrium equation system of the whole structure is of the form: **Ku**=**F**

Where **u** is the vector of the joints movement.

6. Solving out the system of the equilibrium equation.
7. The calculation of the loads in the bars: Sb=$\mathbf{ku}_b$

here $\mathbf{u}_b$ represents the vector of the movement of the joints of the current bar "b".

2.1.2. The program c3d - Spatial Bar Systems

For the calculation of a structure we choose a global reference system, we numerate the bars, the joints and the degrees of freedom (the movement of the joints). Each joint will have six movements.The entrance data can be taken from all units; on condition they should be homogenous. We recommend meters and kiloNewtons. The results offered by the program are the movements of the joints, the efforts in bars and the reactions in the joints blocked in supports. The efforts in bars are given under the form of joint forces from the ends of the bar reported to the local reference system of the bar as in Figure 1.

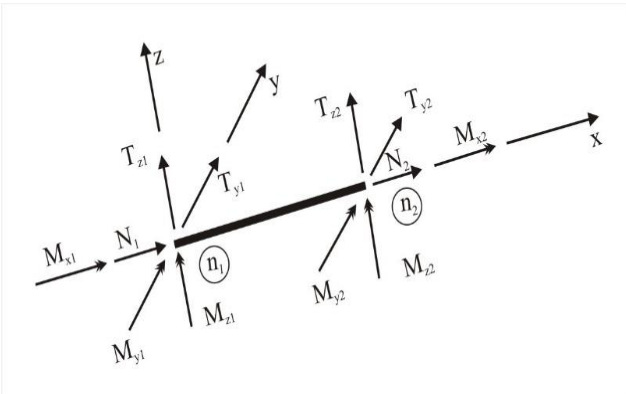

Fig. 1 *Positive efforts in the joints at the ends of the bar*

2.1.3.The influence of the bending at the thin-walled pipes

The bent pipes in the shape of the arch are approximated by the help of some straight bars on a polygonal contour. If the sides of the approximation polygon correspond to the angles at the center smaller than 30^0, we obtain results with an acceptable precision in the engineering calculations (the movements and the efforts have errors lower than

2%). Moreover, we correct the axial forces and the cutting forces in bars, on the basis of their recalculation taking into account the direction of the tangent and of the normal to the theoretical curve.

As it is indicated in the specialty literature ([3], [4]), in pipes the knuckles are elements which create special problems in as far as the evaluation of the state of deformation and tensions are concerned. A curve tubular element, submitted to bending, get oval, which makes its flexibility increase than what might result from the theory of a straight bar. Concomitantly, the state of tensions becomes more complex and it cannot be determined by Navier's formula, as in the straight parts of the pipes.

The tensions are expressed depending on the maximal tension calculated by the help of Navier's formula, by introducing over-unitary correction factors. The flexibility factor is defined as a report between the rigidity and the bending corresponding to the theory of a straight bar and the real rigidity of the knuckle.

2.1.4.The program prepc – preprocessor for piping systems

„ Taking into consideration the particularities of the pipe systems we have settled a **prepc** preprocessing program, which generates data for the **c3d** program on the basis of a simple set of data, adapted to the pipe systems. (We avoid the introduction of the data that can be pre-defied, or that result from the regularities of the structures, the curve bars are divided, etc.)

The prepc preprocessor generates the data for the pipe systems.

Entrance data:

dTt – temperature variation – in the absence of these explanations, this value is applied to all bars. This value can be absent.

The secc *element*=[D s E cdt] – the characteristics of the sections of the pipes. D is the diameter, s is the thickness of the wall, E is the module of longitudinal elasticity, cdt is the co-efficient of thermal dilatation. A line is completed for each type of pipe.

The X *element* = [x y z] contains the coordinates of the joints. For each joint there is introduced a line with the coordinates x, y and z, resulting a total number of nN lines.

The Elc *element* = [n1 n2 sect] contains the description of bars no.1 and no.2 which are indices for the joints of the bar, sect is the type of the section in the secc. element. For each bar we introduce a line, resulting in a total of nE lines. In the case of pipes without ramifications, the element Elc can be absent. In this case, the bar i will have the joints i and i+1 and the section 1 from the secc. element.

The Elr *element* = [nod r kf] – joining elements (knuckle). The pipes that meet in the joint 'nod' will be connected by a pipe having the 'r' radius of a circular axis, and the rigidity of the bar will be corrected by the kf factor of flexibility, given in the specialty literature ([1], [2]), which takes into consideration the geometric elements of the knuckle.

The codrez *element* = [nod dir dep flex] – supports codes. In the joint 'nod in the direction "dir" is applied a support with the imposed movement "dep" and the flexibility "flex". If flex = 0, the support is not deformable. The movements can be imposed only in the direction of the not deformable supports.

The Fn *element* = [nod dir val] – loads with forces concentrated in joints. The joint "nod" in the direction "dir" we apply the force with the intensity "val". This element can be absent.

The fc *element* = [el p qX qY qZ] – trials distributed on pipes. On the pipe "el" the p pressure will be applied and the load distributed on the pipe length unit having the components qX, qY and qZ in the direction of the structural axes. This element can be absent.

The dT *element* = [el dT] – temperature differences. The pipe "el" will have the temperature difference "dT". This element can be absent.

Control example - pipe

For the exemplification and verification of the correctness of the programs are considered in the following example:

The pipe in the above figure is submitted to a temperature increase by 100 ^{0}C.

$$E=2,1*10^8\ kN/m^2$$

$$D=0,6\ m$$

$$s=0,008\ m$$

$$\alpha = 1,2*10^{-5}\quad (K^{-1})$$

c3d PROGRAM

TABEL 1 List of entrance data

1	disp('ex2c - conducta')
2	clear
3	dTt=100;
4	secc=[.6 .008 2.1e8 .3 1.2e-5];
5	X=[0 0 0;30 0 0;30 20 0;50 20 0];
6	codrez=[
7	1 1 0 0;1 2 0 0;1 3 0 0;1 4 0 0;1 6 0 0
8	4 1 0 0;4 2 0 0;4 3 0 0;4 6 0 0];

The results that are obtained after the running of the programs prepc and c3d are provided in Tab .2 below:

TABEL 2. Results of calculations

n1	n2	N1	N2
1	2	5,1879	-5,187
2	3	3,27518	-3,275
3	4	5,1879	-5,187

n1	n2	Ty1	Ty2
1	2	3,275	-3,275
2	3	-5,187	5,187
3	4	3,275	-3,275

n1	n2	Mz1	Mz2
1	2	42,08	56,16
2	3	-56,16	-47,59
3	4	47,59	17,9

gdl	reaction	gdl	reaction
1	5,18	6	42,08
2	3,27	19	-5,18
3	0	20	-3,27
4	0	21	0
		24	17,9

In the below figure there is the M_z bending moments diagram. When representing graphically these efforts we have used the classical sign conventions. The moments are represented on the side of the stretched fiber and they are positive on the inferior side (y<0) of the bar.

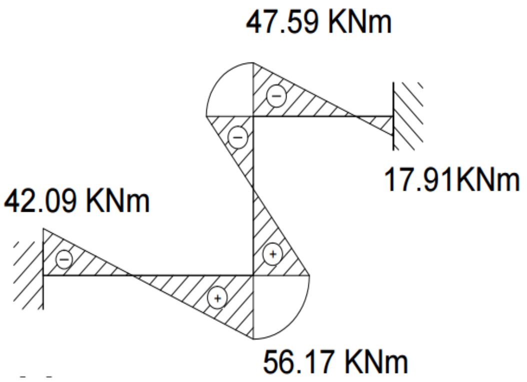

Fig. 2.*The diagram of the bending moments*

III. CONCLUSIONS

1. The theoretical calculation presented in [4] și [1] by using acknowledged calculation relations is difficult and imprecise; the proposed method can be applied for every configuration of pipe network
2. One can notice from the presented example that the obtained result by the application of the two programs differ very little, under 9 %. For example, the bending moment from the A joint by the CCRT[3] program 4628 daN m, respectively in the joint 1 by the program c3d have the value of 4209 daN m;
3. The c3d program the spatial bar system is easy to use, the stages are clear, well indicated, the user can offer correct solutions in due course.
4. The method helps to the determination of the stress state and to the precise dimensioning of the fix points placed in the path of the pipe.
5. The dimensions of the supports for pipes are established with great precision, in this way, over-dimensioning is avoided.
6. The influence of the bending at the tubes with thin walls (pipes) does not influence significantly the state of tension from that joint from the structure of the network.

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