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Mathematical Model of Heat Flows from Shelters for Telecommunications Equipments

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Abstract: This paper develops a solution for keeping the ventilation of some isolated rooms (shelters) designed for telecommunications equipment, monitored by a controller which administrates the heating, the cooling and the air exchange with the outside of the room through ventilation. This thing leads to a significant increase of the electricity consumption, to an increase of administration costs which, at present, are very high, but also to an increase of the operational reliability of telecommunications equipments.

Keywords: Parameters, Ambient temperature, Monitoring, Ventilation, Equipment, Telecommunications.

1. INTRODUCTION

The telecommunications equipments installed outside the buildings, in special containers, are called shelters in specialty literature and they need certain temperature and humidity conditions. At present, these conditions shall consider the day/ the night, the season, the climate, the site at the level of the sea or at altitudes higher than 1500 m, where the environment conditions are extreme.

These shelters are in the endowment of the mobile telephony networks Orange, Vodafone, Digi, Telecom, but also in the endowment of the Ministry of Defence, Ministry of Administration and Interior, National Meteorological Administration, of some agencies which deal with the measurement of environment parameters, etc.

The requirements imposed by telecommunications equipments are to keep a temperature between 15ºC and 30ºC, and humidity lower than 90%, which are followed to be automatically ensured by the monitoring and control system.

In order to size the heating/ the cooling equipments, it was taken into consideration the necessary volume of a shelter to host the telecommunications equipments, the heating emanated by these and the thermal transfer of the shelter with the outside environment.

In the first part, is described the structure of the architecture used, insisting on the hardware components, then is presented the mathematical model of a shelter, both the dynamic model resulting from the balance equation for the air volume submitted to the monitoring and control, and the stationary model including the energetic balance of the shelter.

According to the law no. 199 from 13th of November 2000 regarding the efficient use of the energy, the consumers using more than 1.000 tones of oil equivalent per year have the obligation to appoint a responsible for energy, to perform an energetic balance every year, realized by an authorized individual or legal person, to elaborate measurement programs in order to reduce the energetic consumptions, including also investments for which various feasibility studies are carried out. These objectives can be realized through a monitoring and control management of the environment parameters with minimum costs, which shall lead to the decrease of the energy consumption, but also to the decrease of the costs with the maintenance personnel (Law no.199 / 2000).

All these coordination measures will lead to the decrease of the risk of occurring operational failures of the telecommunications equipments, to the extension of the life both of telecommunications equipments and of the ventilation equipments.

The equipments operational safety decreases the number of alarms and accidental stops, leading to an increase of the voice and data communications efficiency and, implicitly, of the gains for the operators of these shelters.

The coordination refers to the monitoring, in real time, of the environment parameters both from the inside and from the outside, then it follows the management activity located at a superior level in respect to the coordination, realizing the keeping of a prescribed temperature and humidity, and, at the same time trying to meet a performance maximum level of the maintenance. This desideratum can be implemented only through an advanced monitoring, control and management system realized by means of a controller.

The monitoring and control system has also the facility to archive the operational data, allowing the putting at the operator's disposal, who can analyze the operation of the ventilation process and which he can optimize in time.

The most important objectives of a management system of the environment parameters control are:

» the decrease of the electricity consumption for ventilation equipments;

» the decrease of the electricity consumption for telecommunications equipments;

» the decrease of the number of failures for ventilation equipments;

» the decrease of the number of failures for telecommunications equipments;

» the decrease of the expenses with the equipments maintenance, but also with the maintenance personnel (Vînătoru and Iancu, 1999).

The meeting of these objectives contributes to the increase of the efficiency for the shelters owners (time and fuel economy, reduction of electricity consumption and, implicitly, decrease of the environment pollution), the increase of the comfort through data and voice services without interruptions for the consumers.

Starting from these objectives, we can map out the essential functions to be fulfilled by the monitoring and control system:

» monitoring of study parameters;

» purchase and transmission of possible alarms in real time to the closest analysis and control centre;

» establishment of optimal orders for keeping the environment parameters;

» procurement of an operational history of the monitoring and control system for statistics and for previous analysis of alarms causes;

» possibility of interconnection with telecommunications equipments;

» evaluation of operational efficiency, in order to elaborate reports;

2. SHELTER'S STRUCTURE AND HEAT FLOWS

The electronic way for shelter's monitoring and control (SMC-01) is a digital system installed inside the shelter with the main charge of optimizing the equipments operation, which ensures the climatic conditions inside the shelter, the monitoring of its functioning, the storage conditions of the events leading to the overtaking of optimal temperature regimes and the launching of alarms corresponding to each event.

SMC-01 module is based on a microcontroller and the module programming has as an objective to get optimal functioning conditions of telecommunications equipments installed inside the shelter. The interconnections of SMC-01 module with the temperature sensors and with the equipments whose operation they handle are presented in figure 1. (Ciobanu, 2006).

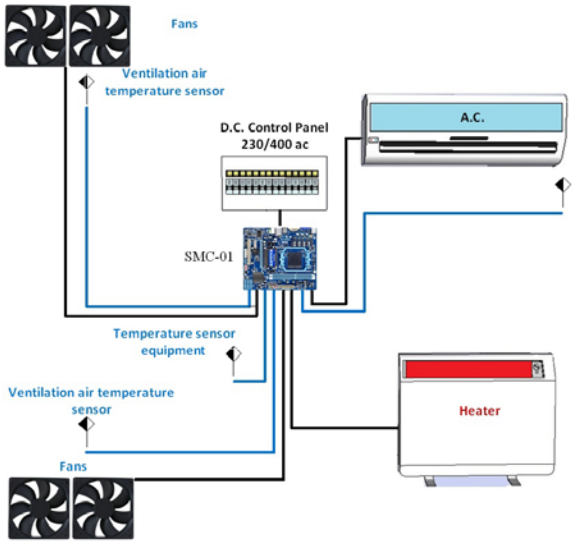

Figure 1. The interconnection chart of the elements handled by the monitoring and control system.

SMC-01 measures the inside/ outside temperature in various points and then it orders the ventilation elements from the shelter.

Depending on the power dissipated inside the shelter and on the outside temperature, SMC-01 activates at most one of the ventilation elements mentioned above.

In figure 2 is presented the shelter's structure and the heat flows from the inside and from the outside of the shelter.

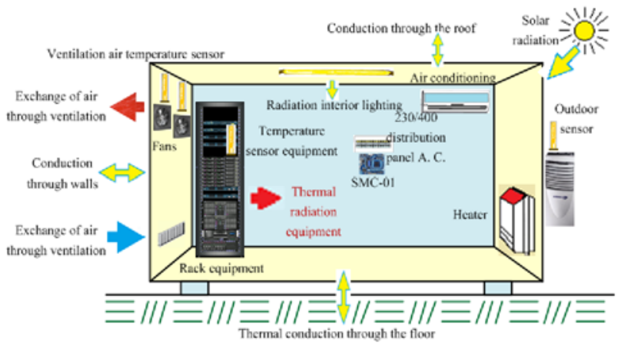

Figure 2. Main ventilation elements and heat flows of a shelter.

The shelter is fitted with the following ventilation elements:

» the heating source used when the outside temperature is lower than 15^0C and the temperature inside the shelter inclines to decrease under 15^0C;

» the air conditioning source (cooling source) used when the outside temperature is higher than 30^0C and the temperature inside the shelter inclines to increase over 30^0C;

» ventilation system for the introduction of the air from the outside if the outside temperature is between 15^0C and 30^0C, in forced regime when the temperature exceeds 35^0C, if the voltage 220 V c.a is interrupted or if the air conditioning doesn't stand.

3. HEAT, AIR AND HUMIDITY FLOWS THROUGH THE COVER OF A SHELTER

3.1 The cover of the construction:

The cover of a building is composed of all surfaces, marginal construction elements, which delimit the inside volume (heated or cooled) from the outside environment or from the unconditional spaces from the outside of the building. The cover of the building separates out the inside volume of the building from:

- the outside air;

- the ground (at plates in direct contact with the ground, located either over the height of the systematized land or under this height, and also at the walls in contact with the ground). (Vînatoru et al. 2008).

The cover protects the inside of the building against sun rays, wind, rain and snow. Moreover, it gives the structural support for walls and roof, protects the structure against deterioration, and allows the use of natural light and the access in the building.

The surface of the cover of the building (A) – represents the amount of all surfaces of marginal construction elements of the building through which takes place the thermal transfer and which is calculated with the formula:

$$A = \sum A_j, [m^2] \quad (2.1)$$

where: Aj represents the surfaces of construction elements which form the cover of the building.

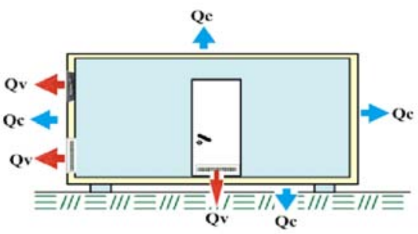

Figure 3. The temperature flows in a telecommunications shelter.

A global approach of the cover represents the key of a performing thermal isolation. For an efficient isolation of the cover, we shall take into account all its parts. But in practice is not so simple giving the fact that these parts shall meet various and distinct requirements (transparency, mobility, mechanic characteristics). Often, an equilibrated isolation of all the parts is impossible. The keeping of climatic conditions wanted for the inside is realized through the control of heat, air and humidity flows between the inside and the outside of the building. The presence of these flows is illustrated in figure 3, where the heat flows Q_C (losses through the walls) are different from the air and humidity flows realized through ventilation Q_V.

3.2 The cover and the heat flow.

An important condition for meeting the inside comfort is represented by the endowment of the building with a heating system which provide heat during the cold season. The heat supplied shall be kept at the inside of the building, thus the electricity consumption of the heating system be minimum necessary.

The transfer mechanisms (or ways) of the heat are the thermal conduction, the thermal convection and the thermal radiation. The heat flow through the cover can be realized through one, two or through all the tree ways.

The thermal radiation is showed at any temperature level and, as opposed to conduction and convection, it doesn't need a transporting agent.

Through the walls, it takes place a heat transfer from the outside environment, through convection and radiation from the air and the sun, through conduction in the shelter's walls and through convection from the walls to the inside air. The directions of the heat flows depend on the difference of temperature according to the second thermodynamics principle.

This heat exchange shall be globally approached with an exchange sent through convection directly between the temperature of the outside and the inside air, approximated with a relation in the form:

$$Q_{conv} = \sum h_i A_j (T_z - T_{ext}) \quad (2.2)$$

where A_j are the surfaces of the shelter's walls, and h_i are the global convection coefficients.

The reduction of the heat flow through the cover is realized by choosing a good thermal isolator material (Iancu and Vinatoru 2003).

4. MATHEMATICAL MODEL OF THE SHELTER

4.1. Mathematical model of the equipments rack

As it can be noticed from figure 2, inside the shelter is the Rack board, with the telecommunications equipments. This is the main source of heat from the inside of the shelter which shall be evacuated to the outside. That is why a first study will be realized on the Rack board.

A. Dynamic model of the Rack board. The Rack board measures 300x800x1700 mm and hosts the telecommunications equipments having a total mass (rack + equipments) m = 100 kg.

The air from the inside is returned through a system of two cooling fans (nominal voltage range 36 ... 60 V, 180mA).

The mathematical model corresponding to the thermal transfer is determined according to the thermal balance equation of the type:

$$mC_p \frac{dT_{ra}}{dt} = Q_{ec} - (h_a A_r (T_{ra} - T_z)) - F_{wr} \rho_a C_a (T_{ra} - T_z) \quad (2.3)$$

Where m is the mass of the board and of the equipments from the inside, m=100 kg;

C_p – is the specific heat of the board and of the equipment support equivalent with C_p = 890 J/kgK;

Q_{ec} – the heat generated by the telecommunications equipments. Q_{ec} = 7x200w = 1400 w;

h_a – the coefficient of heat transfer through convection through the walls of the board. h_a = 1,15w/m^2 k;

A_r – is the total surface of the board. A_r =4,22 m^2;

F_{vr} – is the air supply transferred by the cooling fans from the board and will be taken as a control input in order to ensure the temperature;

C_a – is the specific heat of the air. C_a = 1011 J/kg K

ρ_a – is the air density . ρ_a = 1,2047 kg/m^3;

T_z – is the temperature of the air from the shelter considered in accordance with the standards between 15ºC and 25ºC;

T_{ra} – is the air temperature from the inside of the Rack board which shall be kept lower 30 ºC.

The term $mC_p \frac{dTra}{dt}$ represents the quantity of the heat accumulated by the materials from the inside of the rack, where was neglected the heat accumulated by the air from the inside, this being lower in comparison with the heat accumulated in the board and equipments mass.

B. Stationary model of the Rack board.

According to the equation (2.1) in stationary regime (T_{ra} = ct.).

Is determined the temperature T_{ra} depending on F_{vr} and T_z.

$$(h_a A_r + F_{vr}\rho_a C_a)T_{ra} = Q_{ec} + (h_a A_r + F_{vr}\rho_a C_a)T_z \quad (2.4)$$

$$T_{ra} = T_z + Q_{ec}/(h_a A_r + F_{vr}\rho_a C_a) \quad (2.5)$$

$$T_{ra} = T_z + 1400/(4{,}22 \times 1{,}15 + 1{,}2047 \times 1011 \times F_v)$$

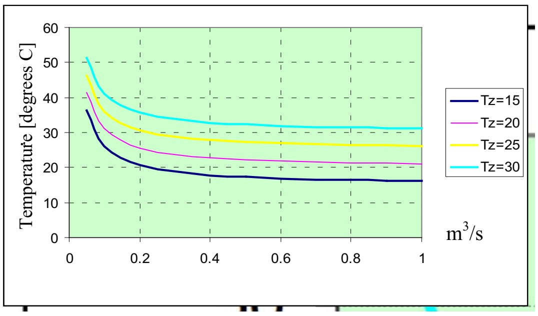

Figure 4. Temperature variation in Rack board

In figure 4 and in table 4.1 are presented the variations of the temperature T_{ra} in the rack of equipments, depending on the variation of the air input returned through the own cooling fans of the rack. It can be noticed that the temperature T_{ra} is higher than the temperature T_Z inside the shelter. As a conclusion, in order to keep the temperature in the rack board lower than 30^0 C, we shall keep the temperature from the inside of the shelter lower than de 29^0 C.

Table 4.1. Model of Rack board

Tz	15	20	25	30
Fv	Tz=15	Tz=20	Tz=25	Tz=30
0.05	36.29258622	41.29258622	46.29258622	51.29258622
0.1	26.05424579	31.05424579	36.05424579	41.05424579
0.2	20.63508766	25.63508766	30.63508766	35.63508766
0.3	18.78134625	23.78134625	28.78134625	33.78134625
0.4	17.84533368	22.84533368	27.84533368	32.84533368
0.5	17.28076605	22.28076605	27.28076605	32.28076605
0.6	16.90314612	21.90314612	26.90314612	31.90314612
0.7	16.63280694	21.63280694	26.63280694	31.63280694
0.8	16.4297176	21.4297176	26.4297176	31.4297176
0.9	16.27156029	21.27156029	26.27156029	31.27156029
1	16.14490891	21.14490891	26.14490891	31.14490891

Herewith, from the chart results that the air input of the Rack board cooling fan shall be higher than 0,2 m^3/s (F_r > 0,2 m^3/s). (Vinatoru 1993).

4.2. Mathematical model of the shelter

Considering that the temperature in the Rack Board is stabilized very quickly to a normal operation of own cooling fans, the study of the temperature variation inside the shelter will be realized by considering the Rack Board as a constant heat source Q_{ec} = 1400 w, corresponding to seven telecommunications equipments installed and we'll take into account only the heat flows from the inside of the shelter's structure, as resulting from figure 2.

Dynamic model of the shelter:

The dynamic model of the shelter results from the thermal balance equation for the air volume "V" of the shelter according to the figure 3 and has the form:

$$V_s\rho_a C_a \frac{dTz}{dt} = \sum Q_{echip} + \alpha_v F_V C_a (T_z - T_{ex}) + \alpha_r F_r C_a (T_r - T_z) + \alpha_{ac} F_{ac} C_a (T_{ac} - T_z) + \sum_i h_P A_{pi} (T_{ex} - T_z) \quad (2.6)$$

where the following terms appear:

$\sum Q_{echip}$ - the amount of internal heat sources flows (lighting, electric equipments, people);

$h_P A_{pi}(T_{ex} - T_z)$ - the equivalent heat transfer through convection from the outside air with the temperature T_{ex} at the interior volume of the shelter with the temperature T_z through the surfaces A_i of the shelter;

$Q_v = \alpha_v F_V C_a (T_z - T_{ex})$ - the heat transfer through the air return cooling fans from the shelter;

$Q_{rad} = \alpha_r F_V C_a (T_z - T_{ex})$ - is the heat transfer from the heating radiator of the shelter used during the cold seasons, which introduces air with the

temperature $T_r > T_z$;

$Q_{ac} = F_{ac} C_a (T_{ac} - T_z)$ – is the heat transfer from the air conditioning which introduces air at the temperature $T_{ac} < T_z$. In the mathematical model, were introduced the coefficients for the use of the heat sources α_v, α_r, α_{ac}, which have values equal to 1 if the source is used and equal to zero if the source is not used.

According to the operational rules of the shelters, the values of these coefficients, depending on the outside temperature T_{ex} , are presented in table 4.2.

Table 4.2 Values of α coefficient

Temperatura exterioara	α_v	α_r	α_{ac}
$T_{ex} < 15^0C$	0	1	0
$15^0C < T_{ex} < 25^0C$	1	0	0
$T_{ex} < 25^0C$	0	0	1

In order to study the efficiency of heating or cooling sources of the shelter, from the equation (2.6) it results the variations of the temperature T_z inside the shelter, for various variation fields of the outside temperature T_{ex} . (Vinatoru 1993).

Stationary model for 15 ºC < T_{ex} < 35 ºC .

In this case, according to the operational instructions mentioned in table 4.2, the adjustment of the air temperature in the shelter's space is ensured only by the cooling fans which evacuate the air from the shelter, being replaced with an outside air with the temperature T_{ex}. In the equation (2.6.), appears also the term Q_{ec} = 1400 w and the term $h_P A_{pi} (T_{ex} - T_z)$ corresponding to the heat transfer through convection (shelter's walls).

Depending on the sizes and the materials of which shelters are usually made of, it was considered:

$A_{pi} = 3 \times 10 \times 18 = 48 m^2$ and h_p = 1,15 W/K/m^2

(usually for the conditions from our country h_p = 0.28-1.4 W/K/m^2) .

Under these conditions from the equation (2.6) in stationary regime ($dT_z / dt = 0$) results:

$$Q_{ec} + h_p A_{pi} (T_{ex} - T_z) - F_v \rho_a C_a (T_z - T_{ex}) \quad (2.7)$$

or $$T_Z = T_{ex} + Q_{ec} / (h_p A_{pi} + F_a C_a \rho_a F_V) \quad (2.8)$$

$$T_Z = T_{ex} + 1400 / (1{,}15 \times 48 + 1011 \times 1{,}2047 \times F_V)$$

By the help of Excel program, using the formula (2.8) it was mapped out the chart of the variation of temperature T_z depending on the air input F_v of cooling fans presented in figure 5 for various values of temperature T_{ex} .

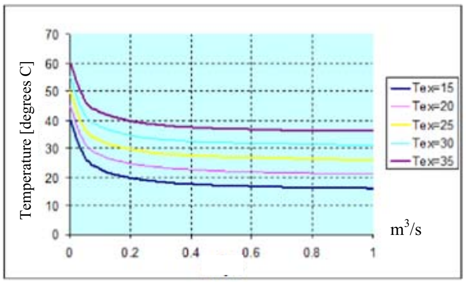

Figure 5. Variation of shelter's temperature for $15^0C < T_z < 35^0C$

From the relation (2.8) and from the charts from figure 5, it results that the inside temperature T_z is higher than the outside temperature T_{ex} .

Also, from the same chart, it results that in order to keep inside the shelter a temperature T_z < 40 ºC the minimum input of cooling fans shall be F_v > 0,2 m^3 / s.

Stationary model for -15 ºC < T_{ex} < 10 ºC

In this case, according to the operational rules, the adjustment of the temperature is realized through the heating radiator which transfers a heat flow: $Q_{rad} = F_v C_a \rho_a (T_r - T_z)$.

The balance equation becomes:

$$Q_{ec} - h_p 48 (T_z - T_{ex}) + F_v C_a \rho_a (T_r - T_z). \quad (2.9)$$

From (2.9) it results the variation of the temperature T_z depending on the input F_v for various values of the temperature T_{ex} :

$$T_z = (Q_{ec} + 48 \times 1{,}15 \times T_{ex} + 1011 \times 1{,}2047 \times F_v T_r) / (48 \times 1{,}15 + 1011 \times 1{,}2047 \times F_v). \quad (2.10)$$

From the fire prevention conditions is considered that the temperature T_r = 100 ºC of the air delivered by the forced convection air heater.

In figure 6 are presented the variations of the air temperature from the shelter for various values of the outside air temperature T_{ex}.

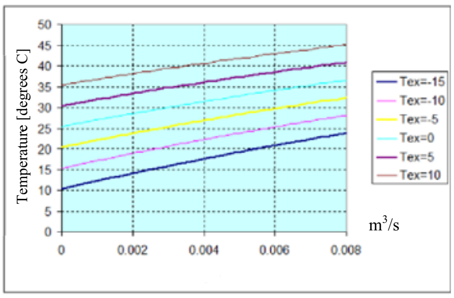

Figure 6. Variation of shelter's temperature for $-15^0C < T_z < 10^0C$

It results that for outside temperature higher than 0ºC to a zero air input of the forced convection air heater, the temperature from the inside of the shelter is higher than 25ºC. This thing comes from the fact that the thermal isolation of the shelter's walls is very good and the heat exchange through the shelter's walls is very low.

From this study, it results that the operational instructions of the shelter shall be changed, in the sense that the using field of cooling fans shall be also extended for outside temperatures under 15 ºC .

For temperatures between 0 ºC and 15 ºC, the study results are presented in figure 6.

From this figure, it can be noticed that, if it is accepted an inside temperature higher than 20ºC, the temperature adjustment through cooling fans can be kept even for values of the outside temperature up to -5ºC, and the heating system will operate only for temperatures under -5 ºC.

Stationary model for $T_{ex} \geq 35$ ºC.

In this case, according to the operational rules from table 4.1, the adjustment of the temperature is realized by the help of the air conditioning equipment which provides the cold air flow $Q_{ac} = C_a \rho_a (T_{ac} - T_z)$, where F_{ac} is the cold air flow input considered variable, with the temperature T_{ac} = 10 ºC.

The thermal balance equation in stationary regime becomes:

$$Q_{ec} = h_p 48(T_z - T_{ex}) + F_{ac} C_a \rho_a (T_{ac} - T_z) \quad (2.11)$$

From (2.11) it results the variation of the temperature T_z depending on the input T_{ac} for various temperatures T_{ex} = [35, 40, 45]

$$T_z = (Q_{ec} + F_{ac} C_a \rho_a T_{ac} + h_p 48 T_{ex}) / (h_p 48 + F_{ac} C_a \rho_a) \quad (2.12)$$

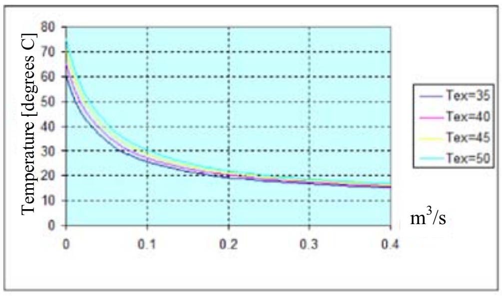

Figure 7. Temperature variation of the shelter for $T_{ex} > 35^0$C.

In figure 7 are presented the variations of the air temperature from the shelter for various temperatures of the outside air.

From figure 7 it can be noticed that the temperature from the inside of the shelter can be kept under 40ºC for an air input of the air conditioning system $F_{ac} \geq 0{,}05$ m^3/s.

Emergency operation study

In the operational instructions of the shelter is mentioned the fact that if the cooling system gets out of order for temperatures higher than 35 ºC, than the temperature control automatic machine shall keep the ventilation system with the maximum debit at cooling fans.

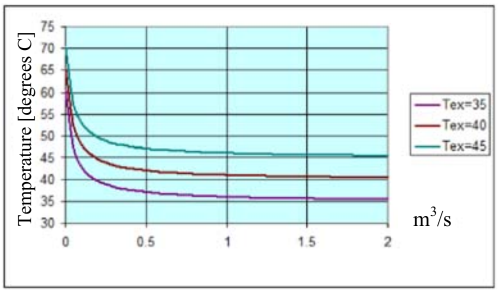

Figure 8. Emergency operation study

For the analysis of this case, the study is restarted, but for T_{ex} = [35, 40, 45] ºC, with T_z given by the relation (2.8).

The results of the study are presented in figure 8.

It can be noticed that the temperature inside the shelter is closer to the outside temperature for a debit of cooling fans $F_v > 1$m^3/s, but it cannot get down.

5. CONCLUSION

The most important thing is the operation of telecommunications equipments in the environment parameters recommended by the manufacturer, fact which leads to their operation in safety, the life extension and the decrease of maintenance costs.

A coherent management of the energy gives the greatest opportunity from the present for the energetic efficiency. From the point of use, the well managed systems will be a significant factor, allowing to the network to make real savings of energy.

The implementation of the sensors network, distributed and managed by microcontroller, leads to the use of the outside temperature of the air (through ventilation) for a better management of the heat flows from the shelter. This working way leads to important improvements of the energetic efficiency in terms of use, costs, security and impact on the environment, to an extension of the life of telecommunications equipments, but also of the ventilation equipments.

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An Overview of the Hiper-Redundant Robot HIPROB-I

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Abstract: In these days can be observed a grown in interest regarding the robots with high mobility degree, wanted for their capability to avoid obstacles and reach difficult positions in their working space. One particular class of these robots consists in tentacle robots, biologically inspired by cephalopods. This paper present the steps followed for building a hyper-redundant robotic structure called HIPROB-I. It is shown how the CAD model was made, the preparation and built of the physical robotic structure and the finite-element analysis.

Keywords: hyper-redundant; CAD; finite-element; actuation; flexible.

1. INTRODUCTION

A tentacle manipulator is a hyper-redundant or hyper degree of freedom manipulator. The control of these systems is very complex and a great number of researchers have tried to offer solutions for this difficult problem. Various solution have been tried in order to obtain a fast and accurate control algorithm (Cieslak, 1999), (Hirose, 1993), (Immega, 1995).

The research group from the University of Craiova, Romania started working in the field of hyper redundant robots over 20 years ago. Starting since 2008, the research group designed a new experimental platform for tentacle manipulators.

This new robot, called HIPROB–I, is actuated by stepper motors. The rotation of these motors rotates the cables which, by correlated screwing and unscrewing of their ends, determines their shortening or prolonging, and by consequence, the tentacle curvature. The backbone of the tentacle is an elastic cable made out of steel, which sustains the entire structure and allows the bending. Depending on which cable shortens or prolongs, the tentacle bends in different planes, each one making different angles (rotations) respective to the initial coordinates frame attached to the manipulator segment – i.e. allowing the movement in 3D (Blessing, 2004).

2. CAD MODEL

Taking into consideration the latest research results in the area of hyper-redundant robotic structures, a virtual model of such a robotic unit was elaborated. The robotic system is composed from two units, one with a flexible structure with kinematic possibilities similar with the snake's locomotion and another one for driving.

The poly-articulated unit is composed from three modules with independent driving, that confers a complex 3D configuration, with multiple kinematic possibilities for the working space.

The flexible structure as an integrate system, or as independent modules, is conceived to allow driving in two modes, respectively:

- one with wires and a flexible central column;
- one with flexible vertebrates and a flexible central column;

For the case in which the driving is made by wires, a module has two degrees of freedom and in the case of driving with flexible columns each module has three degrees of freedom.

The mechanical structure for each module is based upon thread transmissions with self decelerations possibilities and adjust of the axial-radial clearances.

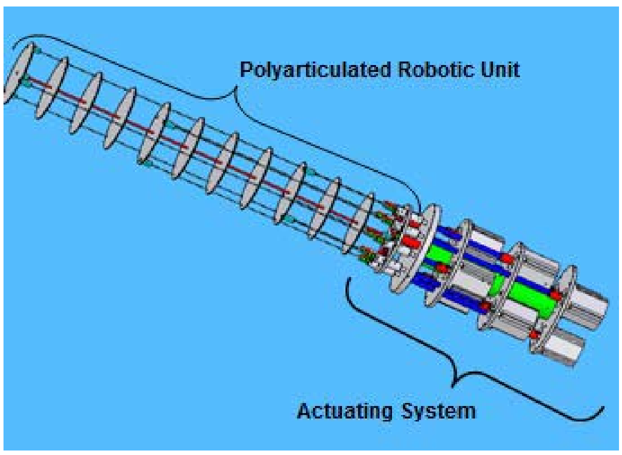

Fig. 1. Virtual model of the polyarticulated robotic unit.

The flexible unit with the snake-like design is composed from a base flange, some intermediary flanges, and four flexible shafts, with high elasticity which will be called vertebral spines. The central shaft is mounted rigidly to all the intermediary flanges, Figure 1. The three super elastic spines are mounted equidistantly upon the central spine.

The vertebrates are connected only to the end flange. The intermediary flanges maintain constant the radial distance between the secondary tubes and the central vertebrate.

By modifying in an active way the length of two of the vertebrate spines, the final flange can be manipulated with two degrees of freedom in any direction.

The actuating spines are rigidly joined only to the end flange; the joint between them and the intermediary flanges is like one translational joint.

In Figure 2 is presented the flexible unit that has a cylindrical form.

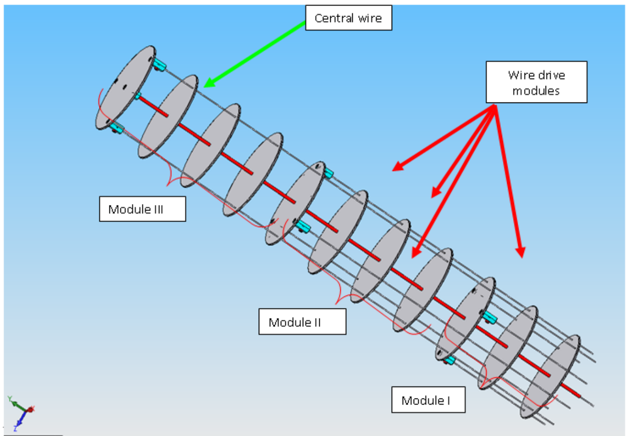

Fig. 2. Flexible robotic unit.

As it was presented above, the actuation of the robotic unit is based upon thread transmissions. The motion of rotation developed by the actuators is transformed into a translation motion due to thread transmission (Figure 3).

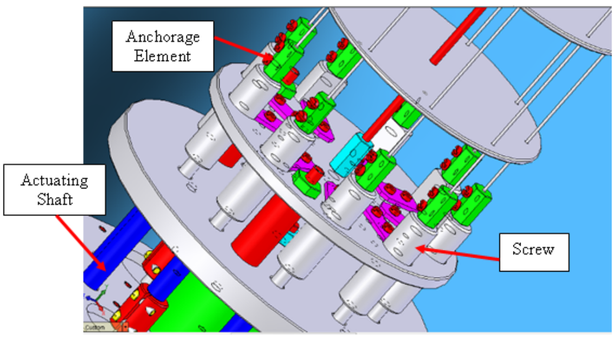

Fig. 3. Virtual model of the actuating shafts.

The shafts that are delivering the motion, unitive with the actuators shafts and using the command unit, are realizing a motion of rotation that encloses the characteristics of the actuators(rotative speed, torque, etc). Moreover, the shafts have at the opposite part a threaded sector that on which is mounted the screw joint that is realizing the motion of translation. Each screw joint is unitive with one actuating cable of the poly-articulated unit.

The stepper-motors are disposed on three superposed levels (three actuators on each level) for the individual actuating of the three modules. In Figure 4 is presented the virtual model of the actuating system together with the identification of it's main elements.

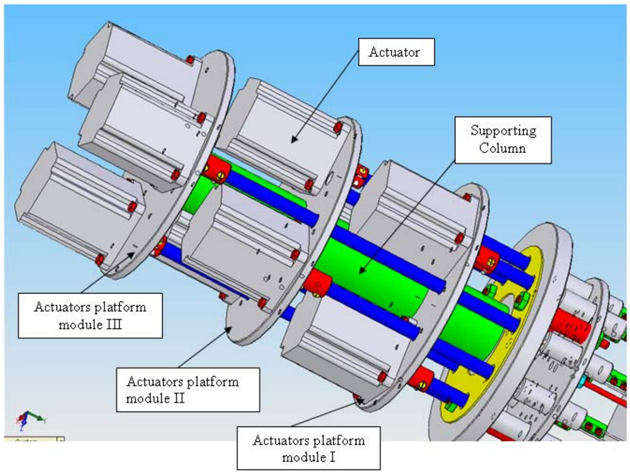

Fig. 4. Virtual model of the actuating system

3. THE VALIDATION OF THE ACTUATING PRINCIPLE OF THE ROBOTIC UNIT

The working principle was verified by importing the vitual model (respectively of the poly-articulated robotic unit) in the virtual simulation environment of the software Visual Nastran 2001. Therefore, it was applied an actuating force of 500N on the 9 actuating cables, on different directions (Figure 5).

The first simulation was realized for one module, some aspects being presented on the following figure. Observing that the simulation produces the bending of one module, it was realized the simulation for the entire robotic structure(some aspects are presented in Figure 6).

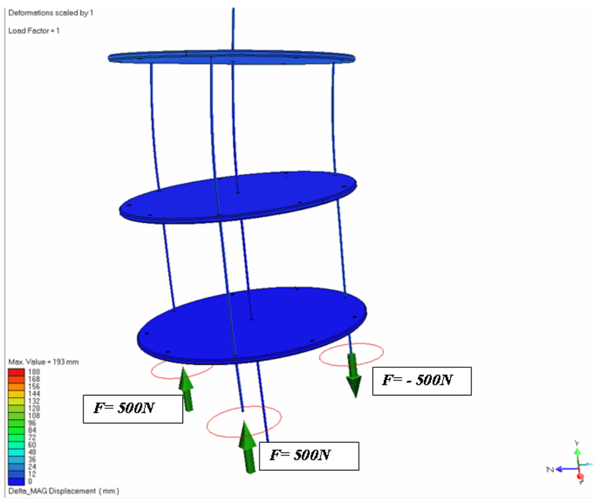

Fig. 5. Virtual simulation for one module (displacements in mm).