ON A LINEAR FIRE DETECTION USING COAXIAL CABLES

by

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Alarm systems represent a combination of the various modern engineering solutions (electrical, mechanical, hydraulic, etc.) with the primary goal to protect human lives, living and working environment, and material properties. Detectors are basic and common components of these systems. There are many different kinds of detectors which usage depends on system solutions, prices, and other technical properties of system application. Different types of non-typical lines can be used as detectors in alarm systems, such as coaxial cables or special constructed electrical lines. The change of some parameters of cables, such as capacity, impedance, resistance or similar, according to temperature, pressure, torsion or other disturbances, can be used for detection of intruder or fire. This work presents experimental results obtained on three different types of coaxial cables: RF 75-3-1, RF 75-4-5, and RF 75-7-9 in order to show changes of capacity as a consequence of heating due to growth of surrounding temperature, and consequently, possible application of cables as fire detector. Before an experiment, a simulation of fire in laboratory 113 in the Electrotechnical school Nikola Tesla in Niš was made in fire dynamic simulator software to show the possible spreading of fire, and consequently, to find optimal location for coaxial cables as fire detectors.

Key words: *coaxial cable, fire, detector, simulation, fire dynamic simulator*

Introduction

The fire detection systems belong to the class of real time system that has a primary goal – detection fire at the early stage. The basic component of this type of the system is the detector of phenomena related to a fire – smoke, heat, flame or gaseous components of combustion. Today, there are many different solutions for this part of fire system and the most frequent are fire detectors based on smoke and fire detectors based on heat realized in fire. All types of fire detectors have some specifications as sensitivity, inertia, ranging zone, and disturbance protection. From the technology aspect, the fire detector should be appropriate according to some conditions as measuring range, selectivity, the type of exit value, environmental conditions, *etc*.

The special case of fire protection is the protection of large objects, where the important thing is, besides detection of fire and appropriate response in the sense of action to determinate the right distance where the fire has started. This is important for tunnels, hangars, and similar objects where the length or height of object can be considered. That means that the fire

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detectors should be distributed according to all of the length of object, on the appropriate place and appropriate altitude, easy to install and capable to have adequate reaction for adequate time.

In the case of heat detectors, it is important to say that they do not have the unique principle of realization because the energy of fire could be detected on different ways. For that purpose of large group of sensors elements based on expansion of metals, dependence electric resistance of temperature, dependence electric capacity of temperature, the speed of melt of alloy, the speed of propagation of fluids, coaxial and temperature cables, dependence of magnetic induction of temperature were used. Heat detectors are less sensitive than the other types of fire detectors; that means, that their activation depends on fire heat release rate, *i. e.* of fire height, and their application is limited by conditions where the usage of fire detectors based on smoke is not convenient or possible (for example, strong wind or air circulation). The different types of heat sensitive cables were the first and the oldest way for the linear detection of fire, especially in the tunnels. The main problems related to this type of linear fire detectors were the slow response without possibility to determine distance from fire centre.

Generally, a lot of electrical lines and cables have several temperature dependent parameters such as resistance, capacity and other, whose change could be used for fire detection. Of course, there is a possibility to produce a special, no typical electric cable appropriate for some conditions that could be use for fire detection. Coaxial cables have its own property in sense of changing the resistance and capacity according to temperature. Limited to appropriate length, they present the capacitors with defined capacity, which depends on the type of cable and their dielectric and isolation. This kind of capacitors are implementing in the appropriate electrical circuit where the change of capacity due to temperature can change some other values such as voltage or current and can make a resonance or a delay of signal through the coaxial line. All this changes could be noted on suitable way with reliable instruments [1].

The aim of this work was to show the possible appropriate application of coaxial cable as a detector. In this context, right location of the detector-cable is very important in order to detect fire in early stage. For this purpose the fire dynamic simulator (FDS) simulation was used. After the simulation was over, the experiment and the analysis of coaxial cables capabilities were realized.

Methodology and background

Measure bridges present electrical circuits which enable direct comparison of known and unknown dimensions by manual operated or automatic indicator brought to zero position. The appliance of these circuits is huge. The basic measure bridge is the famous Wheatstone bridge. Beside this bridge, there are lots of other bridges, such as Murray bridge, Varley bridge, De Sauty bridge, Schering bridge, *etc*. These circuits can be used as balanced and unbalanced. Balanced bridge implies the fact that the current and voltage in the measure line should be equal to zero. The main advantage at balanced bridge is the fact that the balance condition does not depend from voltage supply. Unbalanced bridge implies the fact that the current and voltage in the measure line should not equal to zero. The main advantages of these bridges are the big work speed and simple construction [2].

Linear fire detection by line type heat detectors is well-known and important for temperature based detection, especially in aggressive environments characterized with high humidity, dust exposure, aggressive gases, and similar conditions. Typical applications are in traffic tunnels, hangars, cable channels, or conveyer belts. There are many principles which are used for realization of line type heat detectors. Optical linear fire detection is based on light scattering in optical cable as a consequence of temperature rising in cable (Raman diffraction or Raman scattering phenomenon). Semiconductor based line type heat detector uses discrete semiconductor temperature sensors along the line allowing localization of fire in these points. Both of mentioned line type heat detectors require relatively sophisticated accompanied hardware and software. The other solutions of linear heat detectors are based on the change in resistance of an electrical conductor of an electrical conductor and based on the physical law stating that the volume of a gas changes when a change in temperature occurs in a closed copper sensor tube. Well-known American NFPA 72 standard recognizes two types of line type heat detectors: electrical conductivity heat detector and pneumatic tubing heat detector, whereas, Europe is actually preparing the new EN54-22 standard for resettable line type heat detectors [3].

In the many applications, mostly from economic reasons, two prominent styles of line-type heat detectors are used: coaxial conductor and paired wire. Coaxial cable uses a semiconductor material inside a stainless steel capillary tube. The tube contains a coaxial center conductor separated from the tube wall by a temperature sensitive material. As the temperature rises, the electrical resistance of the temperature sensitive material decreases and alarm initiates. The paired wire line-type detector consists of a parallel pair of steel wires wrapped in a braided-sheath outer cable. The two wires are separated by thermally sensitive insulating material that is manufactured to melt at a specific temperature. The insulation between these wires melt because of a fire, wires come into contact with one another and the short circuit between them causes an alarm.

In this paper, the author's intent is to find another, simpler and cheaper method for effective heat detection using commercial coaxial cables made in Serbia. In this purpose, the experiments carried out with coaxial cables use change of capacity in cable and current in electrical bridge, rather than resistance, on elevated temperature in fire. The solution proposed in the paper give possibilities of the usage standard coaxial cables with balanced and unbalanced electrical bridge in area of fire protection. As a part of this approach, it should be noted that in this moment in frame of EN 54, that is a leading fire protection standard in Europe, there is only a draft in this area. Due to that, test conditions and proper location of cable during the experiment are checked by means of FDS [4].

FDS simulation of the laboratory 113

A very important fact related to the usage of coaxial cables as linear fire detectors is, according to the realized results, the place and position where they are installed. That means, according to the object or the room function, which the position of cables could be near the floor, in the middle of height or near the top of the room or object. The time response of cable, as well as response of the whole fire protection system, depends on that position. In some cases, the fire in the room or object could cause a lot of damage and endanger human lives until the reaction of the closest sensor-cable would be realized. In that purpose, the simulation model of the laboratory 113 of the Electrotechnical school Nikola Tesla in Niš was realized. This simulation model was realized in FDS software to show the possible distribution of fire products and heat release rate in the laboratory, and consequently, possible locations of cable [5].

The simulation model of the laboratory was realized with real measured dimensions, complete furniture, ambient temperature and humidity in laboratory. In the simulation model, the thermocouples were placed in purpose to detect temperature of fire on the heights from the floor as follows: 10 cm, 110 cm, 210 cm, and 310 cm. Since the cable was used as a detector, there was a question where the best place would be to install the cable in order to detect the change of temperature. It was decided that the cable is supposed to cover entire laboratory in size and to be at different heights from the floor, in order to be able to determinate where the fastest temperature detection was.

The dimensions of the laboratory are 8.9 m × 6.8 m × 3.2 m. The wall thickness is 27 cm, and the walls built from bricks with gypsum surface. The windows were modeled as three different glass parts with dimensions of 1.2 × 2 × 0.005 m, 3.12 × 2 × 0.005 m, and 2.34 × 2 × 0.005 m for the first, the second, and the third part, respectively. The complete contents of the laboratory 113 are shown in tab. 1. The pictures of the laboratory and its simulation model (view from above) with thermocouples are presented at figs.1 and 2.

Table 1. The complete contents of the laboratory 13 with dimensions and material

Number of objects	Object	Dimensions	Material
19	Chair	0.4 × 0.4 × 0.4 m (0.5 cm thickness)	Plywood
7	Desk	2 × 0.8 × 0.75 m (3.5 cm thickness)	Plywood
1	Bigger cupboard	1.8 × 1.0 × 2.0 m	Oak
1	Smaller cupboard	1.5 × 1.0 × 1.0 m	Oak
1	Floor	8.9 × 6.8 × 0.0 m (1.5 cm thickness)	Pine
1	Table	2.5 × 1.27 × 1.08 m (2.0 cm thickness)	Plywood

Figure 1. Laboratory 113 in the Electrotechnical school "Nikola Tesla" in Niš

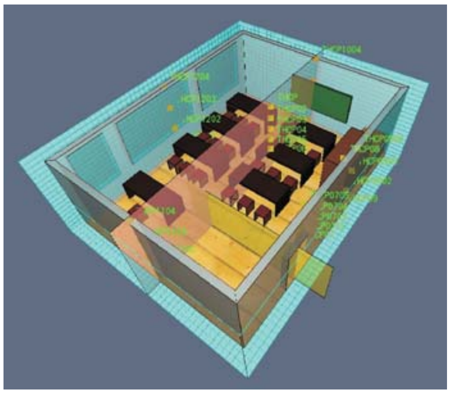

Figure 2. Simulation model of the laboratory 113 with example of thermocouples positions and slices for temperature determination

Generally, in the most technical laboratories, such as electro technical, chemistry or physic laboratories, the possibilities of appearance of fire are very real and often. The causes of ignition may be different: flammable chemicals (acids, magnesium materials, different gases, brimstone materials, phosphor materials ...) current, matches, spark, bad fuses ... For example, in the laboratory (fig. 1), every desk has plug with 220 V power supply, which may be potential source of fire. In that case, it is very important to predict the potential development of fire, and according to that, to place detectors, in this case, coaxial cables. The simulation was realized with a center of ignition set on the middle desk on the right side of laboratory, which was marked with red color (fig. 2). The heat release rate per area of fire source was set to 80 kW/m^2. Some data for used material were taken from library, until for some material data special handbooks, technical handbook, and chemistry handbook were used. The simulation was done for the fire propagation time of 3600 seconds [6, 7].

Simulation results

Duration of the whole simulation was 22 hours and 43 minutes. Figures 3 to 5 present spreading of fire and smoke distribution in laboratory FDS simulation model, during 3600 seconds. The fire spreads at first along the desk, and later covers chairs, cabinets and board. According to the fact that the desks were composed from plywood, it was recognized increase presence of smoke in the first several minutes. The biggest measured temperature value was 787.6 °C, right in the middle of the laboratory. The results from sensors which were positioned on the middle of each wall and in the middle of the laboratory, on the heights of 0.1 m, 1.1 m, 2.1 m, and 3.1 m are showing that the fire can be detected with cable positioned all around laboratory. Simulation temperature results on each wall in the laboratory 113 at the desk in the middle of the laboratory were presented from figs. 6 to 10.

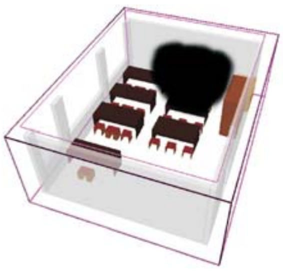

Figure 3. Simulation model in Smokeview at 500 s after ignition

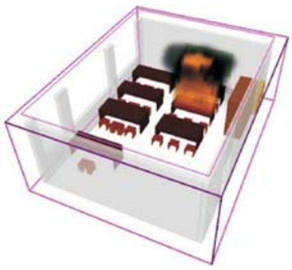

Figure 4. Simulation model in Smokeview at 1500 s after ignition

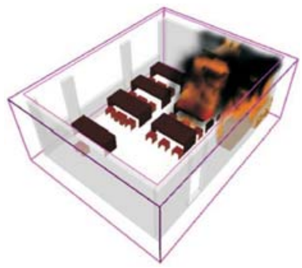

Figure 5. Simulation model in Smokeview at 3500 s after ignition

The important fact is that the temperature distribution inside of the laboratory was not uniform according to any direction from the fire source. That also implicates no uniform distribution on the walls of the laboratory, especially indicated on the wall which is positioned opposite to the table. The biggest temperature value did not exceed 38 °C (fig. 8) which is not enough temperature to cause significant change of potent ional sensor, and, according to that fact, any proper alarm action.

Generally, for all temperature sensors which are used as fire detector, is very important to detect pre-defined temperature threshold as soon as possible in order to generate alarm signal. It was considered that the whole damage from fire in some object could be decreased for more than 30%, if the alarming time is reduced twice. On fig. 11, the temperature distribution on the walls

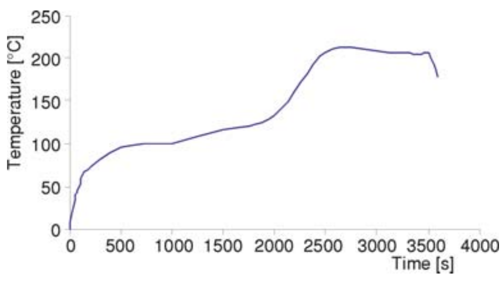

Figure 6. Simulation temperature results for sensor that was positioned on the wall with table on height of 1.1 m

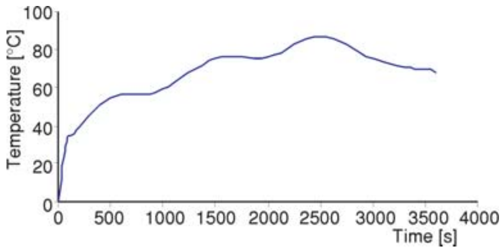

Figure 7. Simulation temperature results for sensor that was positioned on the wall with the door on height of 1.1 m

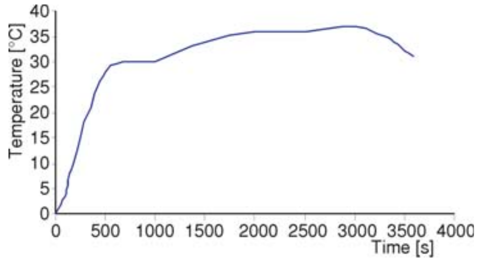

Figure 8. Simulation temperature results for sensor that was positioned on the wall opposite to the table on height of 1.1 m

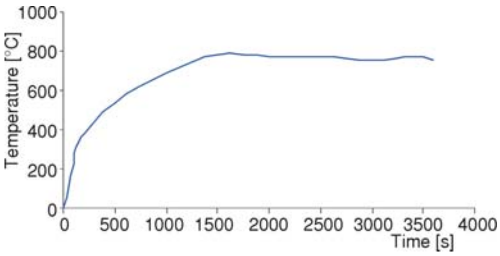

Figure 9. Simulation temperature results for sensor that was positioned on the wall with windows on height 1.1 m

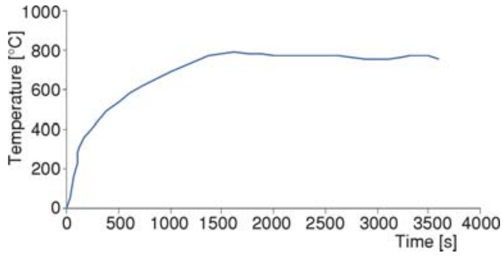

Figure 10. Simulation temperature results for sensor that was positioned right above the desk in the middle of the laboratory on height of 1.1 m

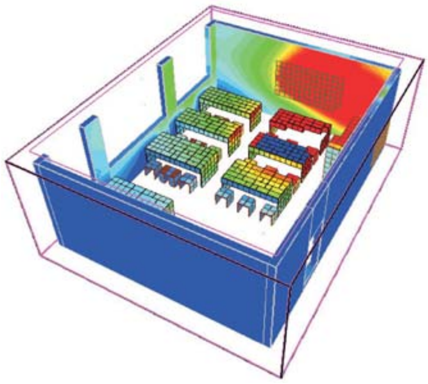

Figure 11. Simulation presentation of temperature distribution on the walls of the laboratory at 3500 s

at 3500 seconds was presented. On the basis of these and other data obtained from FDS simulation, the positions of cables for experiment are determined.

Experiment and analysis of coaxial cables behavior on elevated temperature

One of the most important properties of coaxial cable is its own capacity. The change of cable capacity due to the temperature is one of the most frequently used principles for using coaxial cable as detector. According to that, the basis of the experiment was to measure changes in capacity between inner and outer conductor of several coaxial cables because of heating, under the stable voltage with determinate amplitude and frequency. In order to detect and measure these changes, appropriate electrical circuits have used – balanced frequency independent electrical bridge, and unbalanced electrical bridge. In this work, the changes of capacity due to temperature on three different types of coaxial cables: RF 75-3-1, RF 75-4-5, and RF 75-7-9 have been considered. These cables have been produced in cable factory in Jagodina, Serbia, and their basic characteristics are shown in tab. 2 [8].

Table 2. The basic characteristics of tested cables

Cable type	r_1 [mm]	r_2 [mm]	C [pFm^{-1}]	Zc [Ω]	m [kgkm^{-1}]
RF 75-3-1	0.5	3.8	67	75 ± 5	38
RF 75-4-5	0.813	4.3	56	75 ± 5	50
RF 75-7-9	1.6	8.15	53	75 ± 5	120

The first hand-made model has been presented by simple balanced electrical bridge, frequency independent, with appropriate resistance and capacity elements. The coaxial cable consists of a capacitor that was connected and which capacity depends on the length of the cable. The connection realized at the end of the cable, the electrodes of capacitor-coaxial cable were connected, and, on the other way, there is an open cable, because the effect of capacitor should be achieved. The resonance circuit was supplied with alternate voltage amplitude of U = 10 V at frequency of f = 1 kHz, and as the generator, the function generator with square signals was used. The production price of model was negligible. The change of the cables temperature has been realized as follows: cables with lengths of 0.1 m, 1 m, 2 m, 5 m, and 10 m have been exposed on fire that has provided with several gas torches. The initial assumption was that the fire in the object like a tunnel would overtake wide range of space. The initial temperature of cables was T_c = 20 °C and the heating stopped when the temperature of cables reached T_c = 100 °C, because the change could be detected and cable remain undamaged. The height of cables from the fire source was 0.1 m. The temperature measured with infrared thermometer TM 959 according to the next length: 0.1 m, 1 m, 2 m, 5 m, and 10 m. The total length of each tested cable was 50 m, so the whole capacity of cable could be measure by instrument or calculated using the data from tab. 2. The fire exposed cables parts for lengths 0.1 m, 1 m, 2 m, 5 m, and 10 m were located on different distances from hand-made model according to the total cables length. The measuring instrument was the instrument MASTECH, MS8221C model. All of elements in the electrical circuit have been accommodated. The values for elements in circuit on fig. 16 are shown in tab. 3. The principle of measuring was that reliable change of temperature (in this case its maximum was for 80 °C) caused the reliable change of current and broke the balance of electrical bridge which was indicated with appropriate instrument. The part of the laboratory-measuring equipment with hand made model and the appropriate electrical circuit of balanced electrical bridge is shown on fig. 12 and 13.

Table 3. Values for elements in electrical circuit on fig. 13

Cable type	R [Ω]	R_1 [Ω]	C [μF]	C_1 [pF]	C_2 [pF]
RF 75-3-1	1000	5000	10	3350	3350
RF 75-4-5	1000	5000	10	2800	2800
RF 75-7-9	1000	5000	10	2650	2650

Figure 12. The part of laboratory-measuring equipment and hand made model

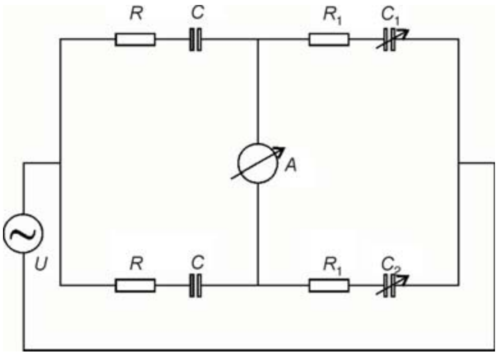

Figure 13. Electrical circuit of frequency independent bridge

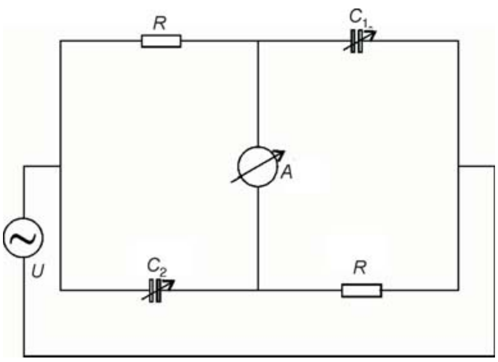

Figure 14. Electrical circuit of unbalanced bridge

Table 4. Values for elements in electrical circuit on fig. 14

Cable	R [Ω]	C_1 [pF]	C_2 [pF]
RF 75-3-1	950,66	3350	3350
RF 75-4-5	1136,8	2800	2800
RF 75-7-9	1201	2650	2650

The second hand made model presents almost the same electrical bridge but without capacitors from the first two branches and without resistors in the last two branches. This kind of electrical bridge presents unbalanced electrical bridge where reliable change of temperature (in this case its maximum was for 80 °C) caused the reliable change of measure instrument current but with the different sensitivity according to the first model. The principle of measuring was almost the same as in the first model, except that the resonance circuit was supplied with alternate voltage amplitude of U = 10 V at frequency of f = 50 kHz with square signals, and, the fixed values for circuit is elements shown in tab. 4, where the appropriate electrical circuit is shown on fig. 14 [9-11].

Experimental results obtained by balanced electrical bridge

The temperature of 20 °C and normal humidity were the ambient conditions in the laboratory during the experiment. Measurements were repeated in the same laboratory conditions several times in several days for, as much as possible, corrects results. On previous pictures, the experimental results that present dependence capacity/temperature (figs. 15, 17, 19), and dependence current/temperature through the measure instrument (figs. 16, 18, 20) were shown, for specified length of every tested coaxial cable.

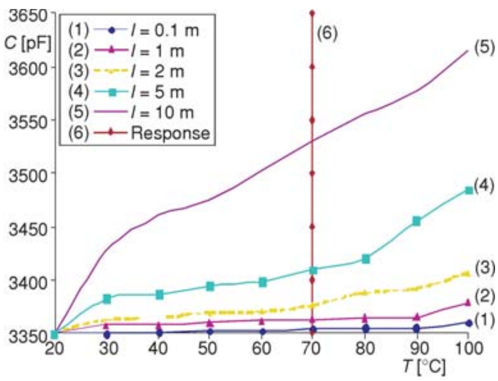

Figure 15. The dependence of capacity from temperature for cable RF 75-3-1

The experimental results which show the biggest growth of capacity has reached for lengths of 10 m for all of three coaxial cables exposed to the fire. The biggest change of capacity for the RF 75-3-1 coaxial cable is about 290 pF and the smallest change of capacity for the RF 75-7-9 coaxial cable is about 15 pF. The vertical line shown in figs. 15, 17, and 19 de-

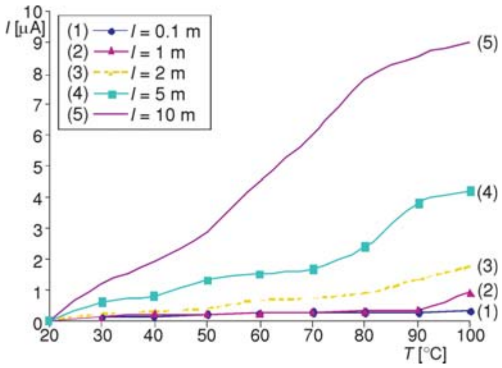

Figure 16. The dependence of current from temperature for cable RF 75-3-1

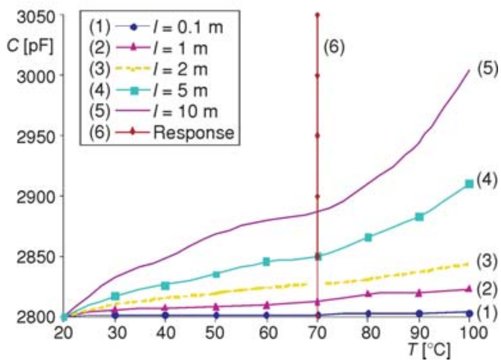

Figure 17. The dependence of capacity from temperature for cable RF 75-4-5

notes the value of temperature threshold from which there is enough change of coaxial cable capacity in order to generate the possible alarm signal.

Experimental results obtained by unbalanced electrical bridge

The results for unbalanced electrical bridge have been obtained also in the same laboratory and same laboratory conditions. Experimental results for capacity dependence from temperature for all of the three cables are presented in figs. 16, 18, and 20. The experimental results that present dependence of current through the measure instrument from capacity, for specified length for each coaxial cable in the unbalanced electrical bridge are presented in figs. 21, 22, and 23. The experimental results realized for unbalanced electrical bridge showing that the current change through the measure instrument is much bigger according to the change of current through measure instrument for balanced electrical bridge.

The obtained results show that the change of capacity of different coaxial cables could be used as simple and cheep fire detector, in the combination with appropriate electrical circuit according to its temperature capacity change. The biggest change of capacity is at the RF 75-3-1

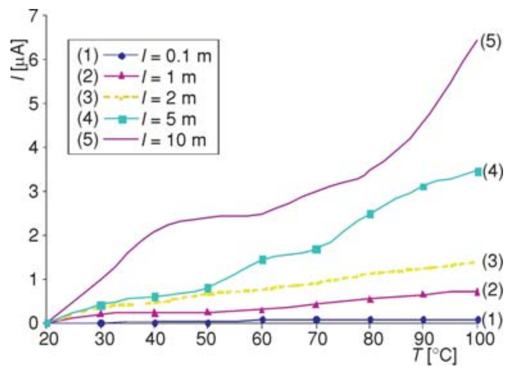

Figure 18. The dependence of current from temperature for cable RF 75-4-5

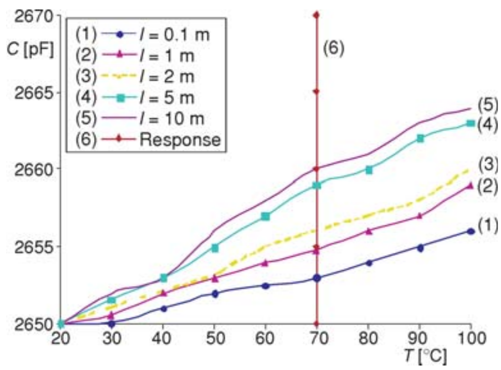

Figure 19. The dependence of capacity from temperature for cable RF 75-7-9

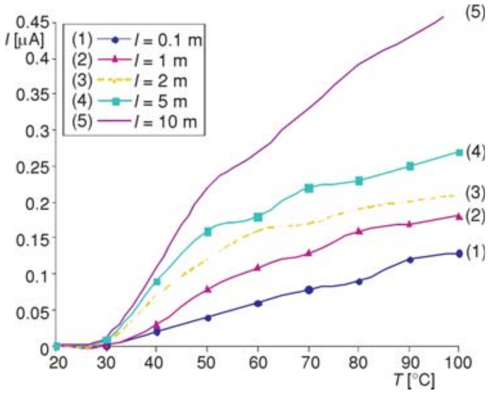

Figure 20. The dependence of current from temperature for cable RF 75-7-9

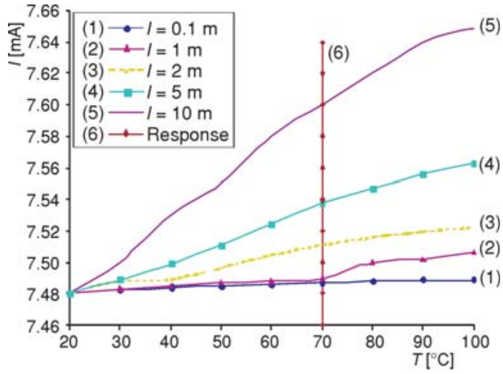

Figure 21. The dependence of current from temperature for cable RF 75-3-1

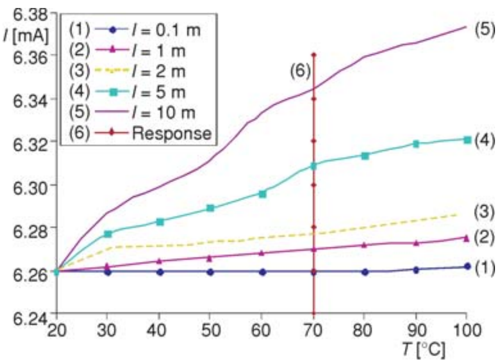

Figure 22. The dependence of current from temperature for cable RF 75-4-5

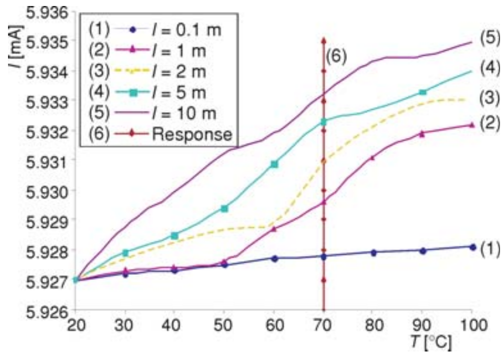

Figure 23. The dependence of current from temperature for cable RF 75-7-9

coaxial cable about 290 pF and the smallest change of capacity is at the RF 75-7-9 coaxial cable about 15 pF. The compared results show that the changes of currents for unbalanced electrical bridge are much bigger and easier for measuring and identification than the changes of current for balanced electrical bridge. The biggest current change for unbalanced electrical bridge is about 170 μA and the smallest current change is about 2 μA against to 7 μA as the biggest current change and 0.2 μA as the smallest current change for balanced electrical bridge. For example, the current changes from 2 μA for RF 75-7-9 coaxial cable to 17 μA for RF 75-3-1 coaxial cable were quite enough for the alarm reaction for temperature of 70 °C, which was presented on previous figures. Of course, the more precise alarm action requires construction of the more precise and better hardware. This conclusion is also supported by experimental results for cable temperature change in time when the fire source was distanced on 0.1 m, 0.3 m, and 0.5 m, for example, on fig. 24 the experimental results for the cable RF 75-3-1 were presented.

The usage of electrical bridges, balanced and unbalanced is just one method that this kind of coaxial cables could use as fire detectors according to changes of its own capacities. There are a lot of other possibilities that can be used in some future works according to the change of the coaxial cables capacity due to temperature, change coaxial cables capacity due to electric or magnetic field between cables or some other coaxial cables parameters. There are also other applications which use of coaxial cables in some other systems, with some other devices, such as burglary protection systems [12].

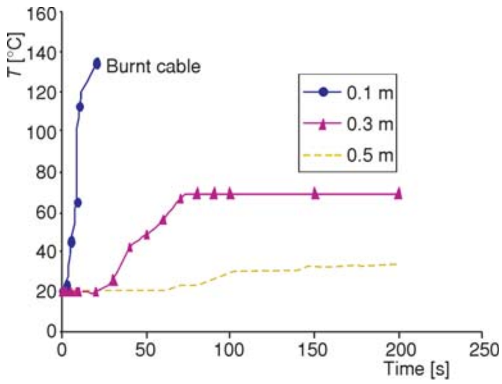

Figure 24. Experimental results for RF 75-3-1 cable temperature change related to the time for different fire source distance

Conclusion and future investigation

The simulation results by FDS represent the possible propagation of fire, while experiment on coaxial cables proves that some coaxial cables could be used as linear fire detector. According to the simulation in FDS, it could be concluded that the cable should be positioned around the room (in this case laboratory) on the heights from 1.1 m to 1.5 m. From the point of view of fire protection, very important factor is the response time of the cable which implies the time which is necessary for changing of some parameters (in this case capacity) which depends on temperature.

Fire detection is very important at early stage; otherwise fire can cause much damage on material properties and destruction of the detector itself. From fig. 6, which presents simulation temperature results for sensor that was positioned on the wall with the table on height of 1.1 m, it can be seen that the temperature for time from 50 s to 100 s grows from 48.8 °C to 70 °C which is enough to cause the proper change of cable capacity and cause the proper current in the electrical circuit (electrical bridge, balanced or unbalanced). Only on the wall to the left side from the laboratory door, the maximal temperature was not enough to cause the proper capacity change of cable (the biggest measured value was 37.23 °C). But, according to the fact that the cable would be positioned all around the laboratory, on each wall, it can be concluded that the proper action would be realized on time. Also, the figs. 4 and 5 showed that the fire propagation was enough to realize the determinate temperatures on the walls of the laboratory and not enough to damage the cable [13].

The achieved results present just a small part of a possible research based on the usage of coaxial cables as non-typical electric lines in fire and burglary protection system. Our future investigations will be focused on several different tasks, as follows. The first task will be the construction of mathematical functions for more precise fire distance determination, using some other types of non-typical electrical lines such as optical cables. The second step will be the examination of the same parameters used in this work in order to detect pressure in burglary protection systems and realization of special non-typical electrical line that combines fire and burglary protection purposes. That also includes the usage of some other simulation programs for results checking, beside FDS. The last step in this investigation will be the construction of proper hardware and software for complete automatic management of fire and burglary protection system with non-typical electrical lines as fire or burglary detectors [14, 15].

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