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Numerical modelling of processes that occur in the selective waste disassembly installation

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Abstract. This paper is the result of the attempts of quantitative approach of some of the processes that are occurring in the selective fragmentation with high voltage pulses installation. It has been formulated a methodology which customizes the general methods for the issue of transient electric field in mixed environments. The electromagnetic processes inside the fragmentation installation, the initiation and formation of the discharge channels, the thermodynamic and mechanical effects in the process vessel are complex, transient and very quick. One of the underlying principles of the fragmentation process consists in the differentiated reaction of materials in an electric field. Generally in the process vessel there can be found together three types of materials: dielectrics, metal, electrolytes. The conductivity of dielectric materials is virtually zero. Metallic materials conduct very well through electronic conductivity. Electrolytes have a more modest conductivity since they conduct through electro-chemical processes. The electrical current, in this case, is the movement of ions having sizes and the masses different from the electrons. Here, the electric current includes displacements of ions and molecules, collisions and chemical reactions. Part of the electrical field's energy is absorbed by the electrolyte in the form of mechanical and chemical energy.

1. Introduction

The selective electrodynamic disassembly is a process that is based on the high-voltage pulse discharge technique. In installations for electrodynamic disassembling occur electrical discharges at voltages of hundreds of kV with energies on the order kJ. By electrical discharging of high voltage in the dielectric materials are produced breakdown channels in that focus a large part of the available energy. Usually, the discharging channels seeks the ways of minimum dielectrically strength. At the forming of the breakdown channel, the substance is passed in gaseous state and in plasma state, in the first moments of the discharging. Status of transformation occurs within a very short time, being consuming of the electrically energy available for changing state parameters. In reference literature are specified very high values for pressure (10,000 MPa), temperature (10,000 K) and density. Basically, density, in the moment of forming discharge channel, takes the density value of the material in which occurs the breakdown. Depending on the amount of energy and duration of the discharging, the dimension of channel section may be as order, units and tens of microns. In the reference material is specified the fact that from electrically energy available, only 10 ... 20% is converted in to thermo-mechanical energy, in useful form. Most of the available energy is consumed for dissociation of molecules, for ionisation of atoms and for bringing them into the plasma state, for local melting, or it is lost by radiations and other forms of energy transfer. With the triggering of the discharge arc, in the material around the breakdown channel

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starts a compression shock wave generated by the action of the pressure that is forming on the walls of the channel. The pressure in front of the shock wave reach very high values, in accordance with the internal pressure of the discharge channel. As the shock wave departs, its intensity is reduced accordingly. There is an area in the vicinity of the breakdown channel in which the stressing pressure exceeds the capacity of materials resistance , even for some metals. If material is fibre composite , first breaks the matrix. Essentially, in electro-dynamic fragmentation process, two main forms of energy are involved: energy that produces the discharge arc in the breakdown channel and mechanical energy transferred to the adjacent environment as the shock wave. Only a part of the available electrical energy is converted into mechanical energy, stored in the shock wave. The destructive effect of the shock wave occurs in a field that, depending on the discharge intensity and mechanical characteristics of the material, may have dimensions in the scale of millimetres or more, in cracks situations. In this paper, attention is focused on the mechanical aspect of the process of electro-dynamic selective disassembling. The generation and propagation of shock waves, with the thermo-mechanical processes associated and the state of crossed material are the main directions to follow. Analysis of these processes can lead to fulfil the knowledge, to suggest constructive solutions for facilities fragmentation and optimization technologies. It is chosen an analytical method based on numerical simulations.

2. General conditions of modeling and stages of numerical simulation

Comprehensive scientific research of complex phenomena that occur in dismantling facilities selective electro-dynamic, in addition to theoretical and experimental approach, requires analysis conducted using numerical simulations. Mathematical models for phenomena that occurs in the field of physics are already set, except for some simple problems. The equations that govern these phenomena lead to analytical solutions precise enough to be used effectively. Numerical calculation was and it is a possibility for finding satisfactory solutions to physics problem. The numerical simulations become the main tool for solving problems of continuum mechanics, solids, fluids, electromagnetism field and other areas of physics. Satisfactory numerical solutions are obtained in the magneto-hydro-dynamic, science that deals with the processes of electrical discharges. Methods mainly applied in the numerical simulations of physics problems, in solid environments, liquid or gaseous, are based on meshes discretisation and includes finite difference method (less used because of their stiffness), finite element method - used especially in mechanics of deformable solids and the finite volumes methods (cells) with particular applications in fluid mechanics. The success of the numerical simulations is assured only if the following conditions are respected:

- physical model is, in analysed terms, according to reality on the properties and the laws of physics;
- mathematical model correctly reflect, by the governing equations, boundary conditions and initial, the physical model;
- the meshing model approximates correctly the problem domain, and the finite elements of the mesh (volumes) and SPH is built optimal, for the achievement of nodes density in correlation with the gradients of field functions;
- preparation and introduction of input data on the properties of materials involved in the matter, shall be done using either data from certified reference materials either own experimental data;
- instructions for output files must be selective, watching the intended purpose of simulation;
- presentation of the solution in numerical form, especially graphics, must be suggestive and allow easy interpretation of analysis and the formulation of clear conclusions, useful to purpose in which the numerical simulation is achieved.

3. Numerical modelling of processes occurring in the selective disassembly facility of the waste

Next it shows the physical model of the fragmentation installation with high voltage pulse and the mathematical support of basic electromagnetic processes.

3.1. The physical model of the fragmentation installation with high voltage pulse and the mathematical support of basic electromagnetic processes.

3.1.1. The physical model

Under the procedure, the numerical simulation is applied to a physical model which highlights the facility subjected to research. The physical model of the fragmentation facility with voltage pulse is shown in Figure 1 under partial schematic form [1, 3].

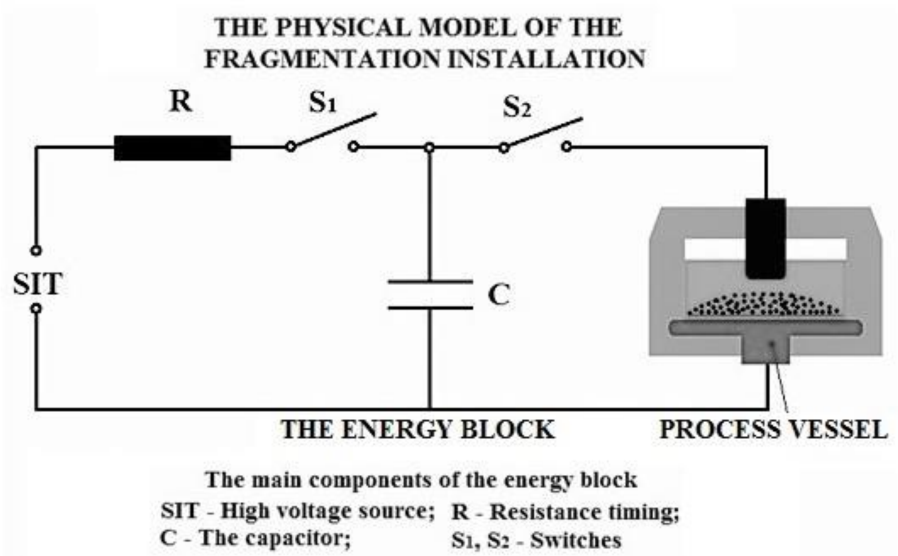

Figure 1. The physical model of the fragmentation facility.

The model can be separated in two main components:

- the energy block;
- process vessel.

The energy block is divided to "turn" in two parts:

- the circuit with high voltage power supply;
- the main circuit that brings the high voltage at electrodes of process vessel.

For analysis is retained only the main circuit, that includes the battery of capacitors C, the switch and the electrodes of process vessel. In the initial state, the battery of capacitors is charged to the maximum voltage.

The main elements of the process vessel (Figure 2) are:

- the two electrodes: the cathode with adjustable position and the anode grounded;
- insulating housing;
- the electrolyte - deionized water;
- material subjected to fragmentation.

The process vessel is sized for an inside diameter of 80 mm and a distance between electrodes of max. 30 mm. The anode, expanded in the available space, forms the hearth on which is placed the processed material.

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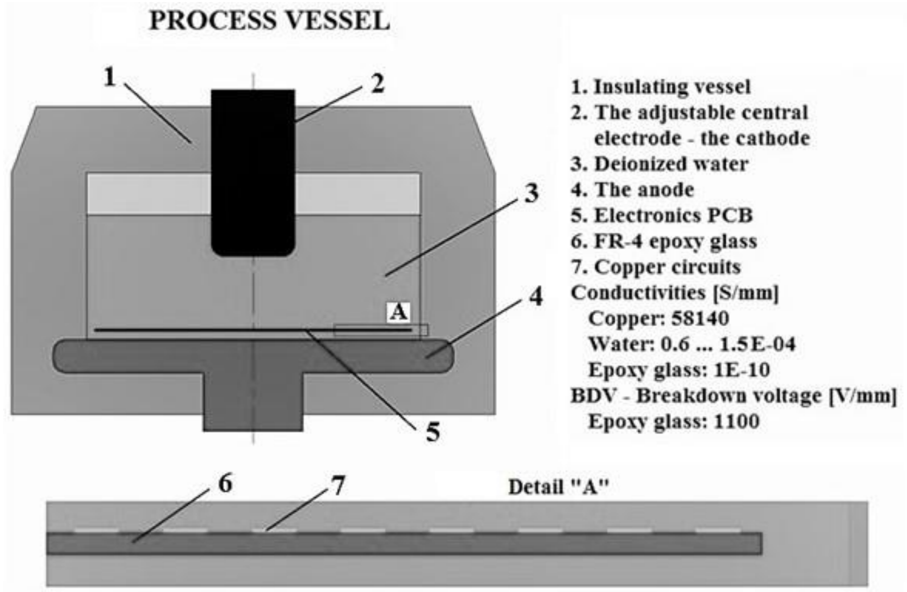

Figure 2. Process vessel.

3.1.2. Main power circuit

Principle scheme of the main power circuit is given in Figure 3. On the scheme were figurate, as individual elements, the variable total resistance of the entire circuit noted with R, that the sum of the electrical resistance of the feed path and the internal resistance of the process vessel, and the total inductance, L.

The circuit thus formed is of electrical loop, RLC type. The switch (the spark gap) is not presented in the drawing, but its effects are incorporated in the R and L sizes.

The intensity of the current i (t) flowing in the circuit satisfies the differential equation:

$$\frac{d^2i}{dt^2} + 2(\frac{R}{2L})\frac{di}{dt} + \frac{1}{LC}i = 0 \tag{1}$$

Between current and the voltage drops on the three components of the circuit there are the following relations:

$$\frac{dU_C}{dt} = \frac{1}{C}i; \quad U_L = \quad L\frac{di}{dt}; \quad U_R = Ri \tag{2}$$

The characteristic equation associated to the differential equation (1), has the form:

$$s^2 + 2(\frac{L}{2L})s + \frac{1}{LC} = 0 \tag{3}$$

and has the roots:

$$s_{1,2} = -\frac{R}{2L} \pm \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC}} \tag{4}$$

When the roots are real, operating mode of the loop is aperiodic. For imaginary roots the loop becomes oscillating circuit.

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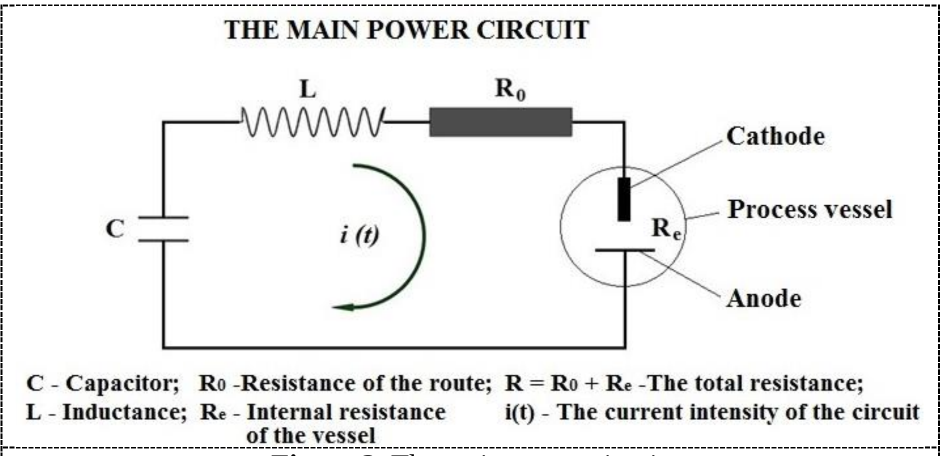

Figure 3. The main power circuit.

With the notations:

$$\alpha = -\frac{R}{2L}$$

$$\text{and } p = \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC}} \;\; if \;\; (\frac{R}{2L})^2 - \frac{1}{LC} > 0 \tag{5}$$

$$\text{or } p = \sqrt{\frac{1}{LC} - (\frac{R}{2L})^2} \;\; if \;\; (\frac{R}{2L})^2 - \frac{1}{LC} < 0$$

the solutions are obtained:

a) hyperbolic shape

$$i = e^{-\alpha t}\left(A\,ch\;pt + B\,sh\;pt\right); \tag{6}$$

b) trigonometric shape

$$i = e^{-\alpha t}\left(A\cos\;pt + B\sin\;pt\right). \tag{7}$$

The constants of integration A and B customizes the initial conditions in that may be involved and the relations (2).

3.1.3. The electric field in the process vessel

The electric field in a given field, without electric charges distributed inside, is governed by Laplace equation.

$$\Delta V = 0\,, \tag{8}$$

under the conditions specified on the borders.
The potential V is a function of space and time:

$$V = V(x, y, z, t) \tag{9}$$

From function of potential derive the intensity of electric field

$$\overline{E} = \quad gradV\,, \tag{10}$$

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as a vector size.
The current (current density) in the conductor environment, of conductivity σ, is given by relation

$$\bar{j} = \sigma \bar{E} . \tag{11}$$

Equations (8), (10) and (11) associated with the boundary conditions, form a complete system of differential equations describing the state of conduction from a field.
If the materials are dielectrics, for which $\sigma \rightarrow 0$ practically does not exist conduction.
A domain, like the one studied in this paper, may be busy both of dielectric materials and conductive materials. Generally, the system of equations of the electric field, has analytical solutions in very few cases. If in the problem occurs the time, the solution for the transitional regime becomes unreachable on analytical ways. In practice, the useful solutions are obtained by numerical simulations or on experimental ways. In this paper the solving of electric field equations, stationary or transitory, is looking for and is obtain on numerical way, by simulations of the physical processes using methods based on finite element.

4. The process simulation of selective discharge

This paper aims to establish the characteristics of the installation of selective fragmentation necessary to design and implement an experimental model. As a working method, was appealed the method of numerical simulation in which a limited amount of experimental data was used. In the paper, firstly it makes an analysis of the fragmentation selectivity and then analyses few functional situations. The selective electrodynamic fragmentation is a process for the separation of components of composite structures, especially, those which include metal. The process is used for the recovering of materials from waste products out of use, but can also be applied in manufacturing of ores, to separate the useful components. The process uses for the separation of the components the energy developed by the electrical discharges pulsing, by high voltage, selectively products in the composite structures [1].

4.1. The simulation on a reduced model

To highlight the selectivity of electrical arc discharging process has been used a simplified model in 2D. Figure 4 shows this model that comprising a part of a hypothetical fragmentation process vessel, in which there are a piece of insulated metallic conductor, an electrolyte and the electrodes. Layout of the objects is such made, that the direct distance between the electrodes to be shorter than the detour route by conductors. The conductivity of materials which come in the structure of the model is shown in figure 4 [4]. For the support of the demonstration it was admitted that the used electrolyte - water - has the degree of wear to which the breakdown voltage reached 15 kV/mm, lower compared from to the insulator one (20 kV/mm). If it would ignore the presence of metal, for this commitment, the electrical discharge should occur through the electrolyte less rigid on the shortest path. Numerical simulation of the electric discharge on this model It has the aim to highlight the importance of the presence of metal in the process of electric field distribution in process vessel.
To simplify the numerical simulation, but without losing the quality, a step function for the law of the conduction it was adopted, different to some extent by the law of real. The graph of figure 4 shows this hypothesis, which can be simple formulated, as follows: the material is dielectric up to the achievement of breakdown voltage, after which it becomes conductor. Also in the electrolyte the conduction makes a corresponding jump at the crossing over breakdown voltage (BDV).
Since there are no experimental data available, in the paper was admitted for the conduction state a greater conductivity than 0.1 S/mm. In Figure 4 the electric field at the moment of dielectric breakdown initiation is presented, which corresponds to a supply voltage on electrodes of 54 kV. One can notice easy the effect of concentrator of the metal on the electric field. In the electrolyte was not yet reached the breakdown voltage of 15 kV/mm.

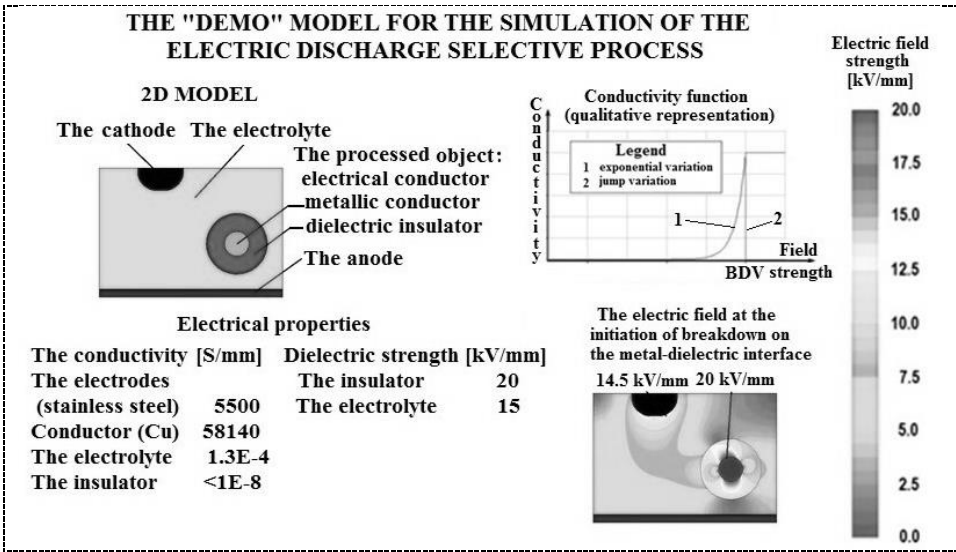

Figure 4. The "DEMO" model for the simulation of the electric discharge selective process.

After the initiation of breakdown process, the electric field has very rapid developments triggered in avalanche figure 5.

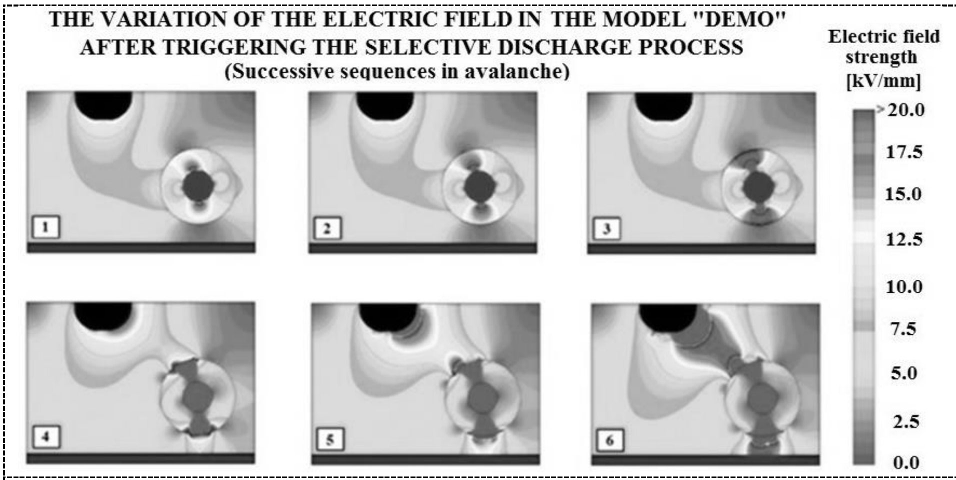

Figure 5. The variation of the electric field in the model "DEMO" after triggering the selective discharge process (Successive sequences in avalanche).

The numerical simulation of the electrical discharge process on the analysed model highlighted the powerful effect of concentration of the electric field on the metal-dielectric interfaces.

These concentrations of the electric field become, to the achievement of the breakdown voltage, the nuclei of conduction, which in turn, develops in areas of conduction with fast-growing. At one point by the union of conduction areas is formed the conduction bridge which is the support of electric arc [1, 2]. In conclusion, we can say that the selectivity consists in the focusing of electrical discharging at the interfaces between the metal and dielectric components.

4.2. The numerical simulations of the selective fragmentation process applied to the rubber armed with steel wire

In Figure 6 the arrangement model of the material in the process vessel with the electrodes adjust at the distance of 16 mm.

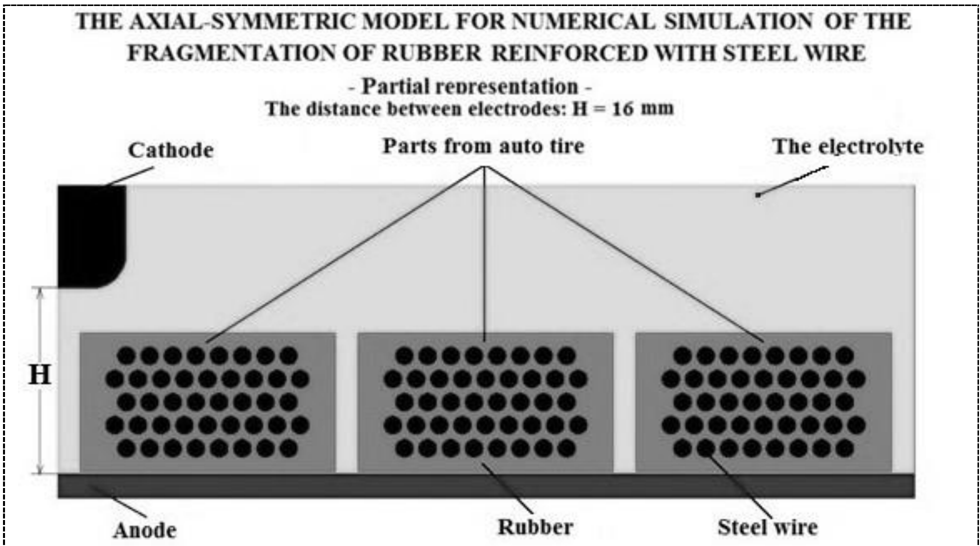

Figure 6. The axial-symmetric model for numerical simulation of the fragmentation of rubber reinforced with steel wire.

At this distance between the electrodes the triggering of the discharge process has started at a voltage of 71.5 kV applied to the electrodes. The sequences of the discharging process are summarized in figure 7 and represents the variation in avalanche of the electric field in the process vessel after the start of discharging. The most important finding from the analysis of these distributions is the fact that the presence of the metal attract the electric field and it focuses in the adjacent dielectric.

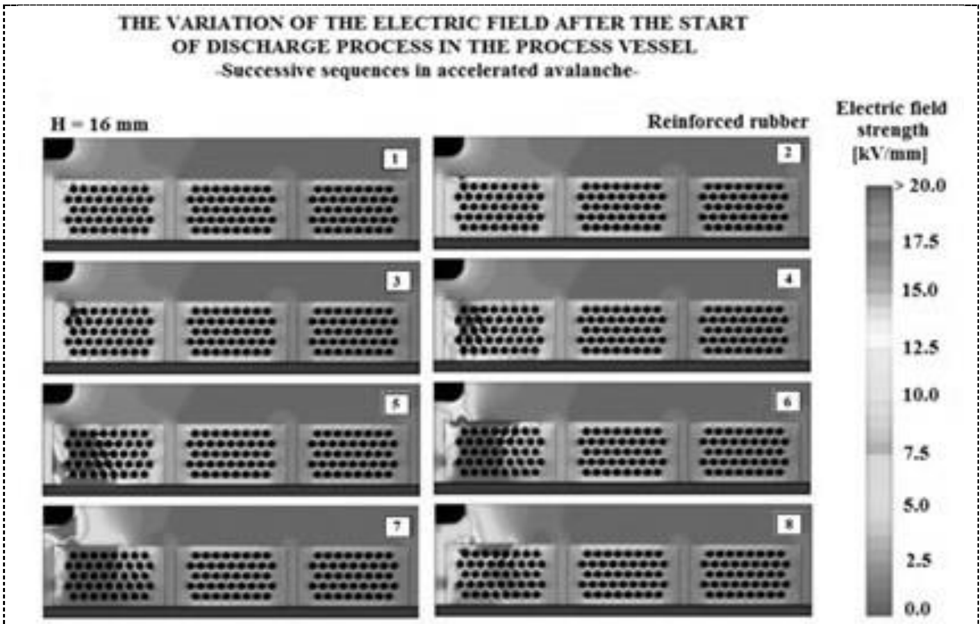

Figure 7. The variation of the electric field after the start of discharge process in the process vessel – Successive sequences in accelerated avalanche.

Following, some results are presented selectively. First, in figure 8 is shown the evolution of electric field and then in figure 9 the situation in the moment of forming of discharge bridge.

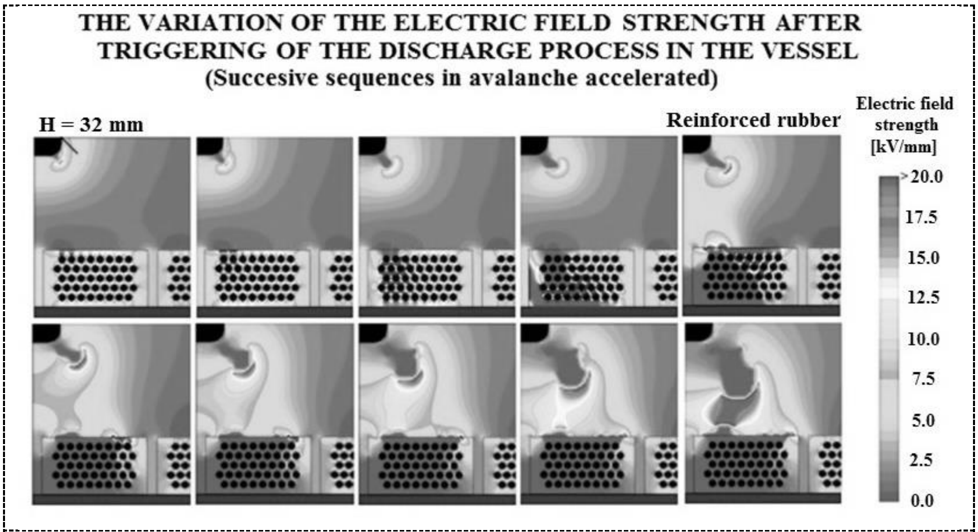

Figure 8. The variation of the electric field strength after triggering of the discharge process in the vessel – Successive sequences in avalanche accelerated.

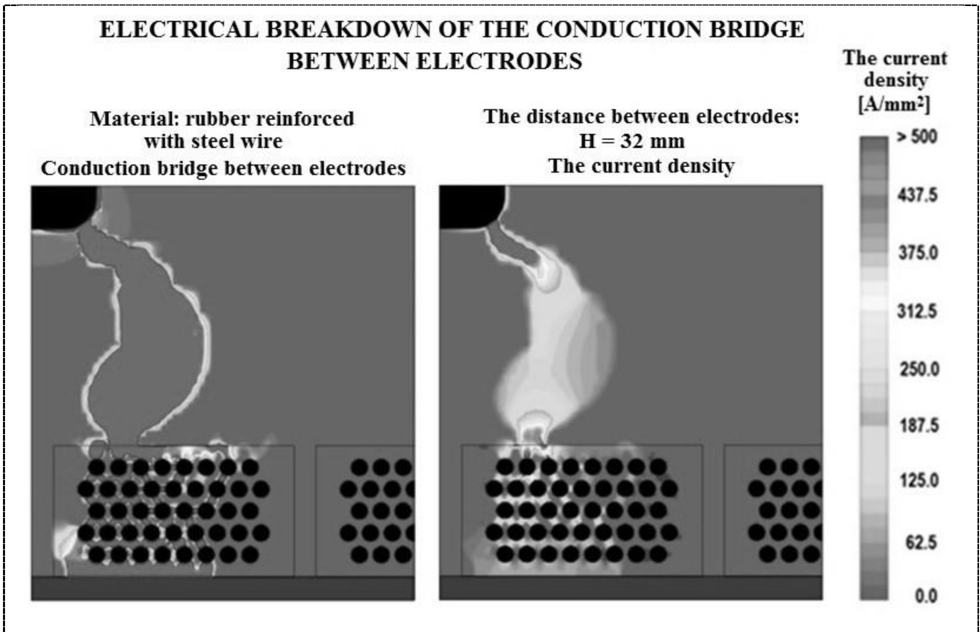

Figure 9. Electrical breakdown of the conduction bridge between electrodes.

5. Conclusions

The analysis of the process vessel with electrodynamic selective fragmentation, made on the basis of numerical simulations, has highlighted a number of very important conclusions at this stage of the research program, even if sometimes were used simple models and input data hypothetical but realistic. The designed process vessel possibly with some improvements, is functional and can be used in research of electrodynamic selective fragmentation, although the supply voltage was temporarily limited to 200 kV.

In all the analysed cases the selectivity of the process was found.

For efficient use of energy it is necessary that the central electrode to be as close as to the material.

An optimized solution would involve the use of a side isolated cathode.

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In the process vessel with the electrode centrally disposed, in the marginal areas the density of energy is very low and, consequently, there cannot be achieved conduction bridges. For remedial is necessary that the central electrode, in addition to the movement of axial advance, must do a transversal movement to ensure an larger area of interaction or may be adopted a flat section of the electrode expanded to the entire section of process vessel.
Block of voltage supply of the process vessel must support the process during maintaining of the arc.

6. Acknowledgments
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