NUMERICAL SIMULATION OF THE OPERATION OF A PLASMA GUN IN MISSION TO MARS PLANET

Tudor Cherecheş[1], Paul Lixandru[1], Daniel Dragnea[1], Sergiu Mazuru[2]

[1]SC UPS PILOT ARM SRL, Dragomiresti, 137210, România
[2]UTM FIMCM, Str. Studenţilor, 9, Blocul de studii no. 6, MD-2045, Chişinău, Republic of Moldova

Corresponding author: Chereches Tudor, tudor.chereches@yahoo.com

Abstract: The authors present the results of the numerical simulations of the thermo mechanical processes taking place inside the coaxialplasmagun and at the interaction between high speed gas jet and the dust deposited on the surfaces of the space vehicles. The purpose of the study on the use of coaxialplasma gun to clean the dust from the surfaces space vehicles in spatial missions to Mars, was to elucidate some aspects of the system's energy efficiency, thermal and mechanical effects of high-speed jet upon intersecting bodies and efficiency of the dust cleaning operation on the surfaces of space vehicles under atmospheric conditions of Mars. Numerical simulation of mechanical and thermal processes at the forming of the jet in gun, the interaction of the jet with the rarefied atmosphere of Mars and during the dust cleaning operations was conducted on a 3D physical model with a symmetrical plan which schematize real processes. The most important schematization refers to the shape and position of the plasma layer and uniform distribution of Lorentz forces on the unloading layer. The analysis of the state and of the movement of gas launched by the coaxialplasma gun had in attention both, the status parameters p, q, T and ρ and the jet velocity v. The plasma gun launches very short pulse type jets, with the output speed of the order of thousands of meters per second at temperatures of about 10,000 K. The mechanical and thermal effects produced by the gas jet on the intersected surfaces, were analysed by numerical simulations. There were no observed negative effects, the stresses and the temperatures induced in the structure have very low values. In the case of an extended cleaning action it can be produced the erosion of the attacked areas due to the sand particles movement with high speed. Numerical simulations showed, besides satisfactory efficiency of the coaxialplasmagun in the operation of removing the dust on surfaces of the spatial vehicle in space mission to Mars, some disadvantages of using this system, in the head of the list being the complexity and very low energy efficiency.
Key words: coaxial plasma gun, thermomechanical processes, numerical simulations, space vehicles, dust cleaning operation, spatial mission to Mars planet.

1. INTRODUCTION

Full scientific research of complex phenomena occurring in guns with plasma (accelerators) involves, besides the theoretical and experimental approach, effective analyses using numerical simulation methods. Discharge of rarefied gases from gun with plasma are accelerated in the axial direction by the Lorentz forces produced by discharge currents in self-induced electromagnetic. Status moving of the gas inside the tube is analysed as a coupled problem of fluid mechanics and electromagnetism.
In case of magneto hydrodynamics the equations that governing the fluids motion in the electromagnetic fields include, besides the equations of fluid mechanics Navier–Stokes and the Maxwell equations. The two systems of equations are coupled by the electromagnetic forces developed in a conductive fluid, natural or by ionization, in electromagnetic field produced from external or self-induced. The coupled system of equations represents the equations of the magnetohydrodynamics and is one of the most complex sciences of the physics. Except for a few simple problems, magneto hydrodynamics equations do not lead to analytical solutions enough accurate for to be effectively used. Numerical computation was and still is a possibility to find satisfactory solutions in magneto hydrodynamics problems.

1.1 Numerical simulation of the working regimes of the coaxial plasma gun at low pressure

This paper aims to develop a systematic analysis regarding the constructive models and of the functionality of coaxial guns with plasma in conditions of missions to Mars.The study has as finality the justification of optimal constructive solutions and of the functional defining parameters. Investigation methods are mainly based on numerical simulations, but also on some approximate methods for preliminary assessments and for orientation toward the fields of the acceptable solutions.
The analysis concludes with a proposal of a constructive model with high performance in terms of minimum energy consumption.

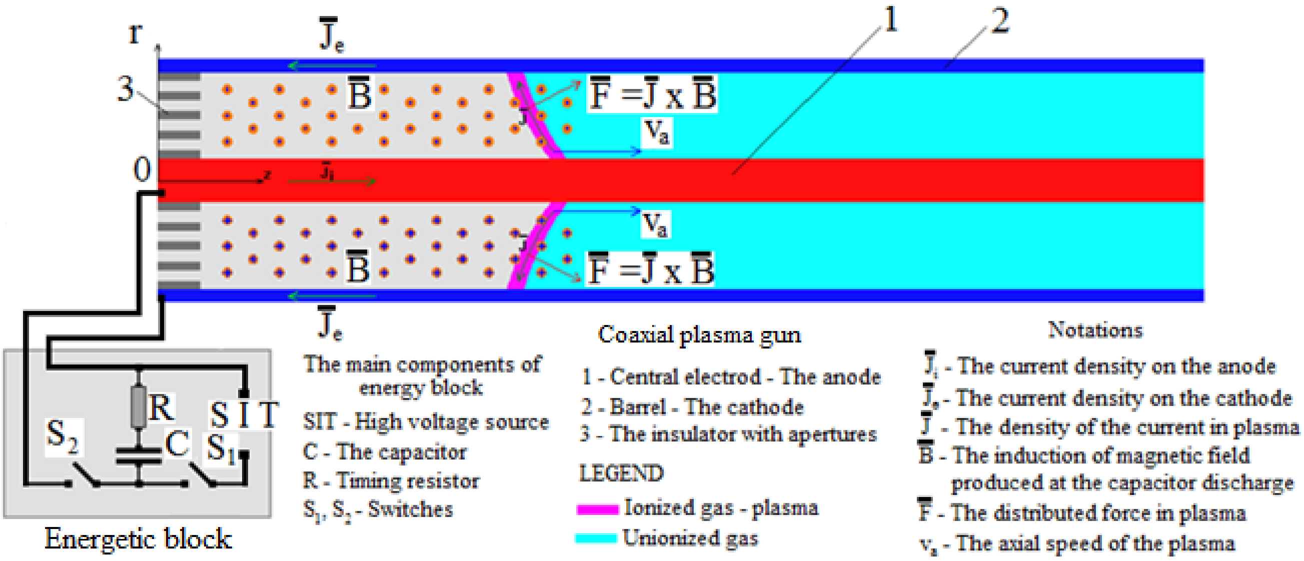

Fig. 1. The physical model of the coaxialplasma gun

1.2. The physical model of the coaxial plasma gun

This model is defined by the general operation conditions [4], without specifying some constructive elements and characteristic parameters imposed by the missions to be performed in the specific environment of Mars planet (figure 1).

The atmosphere of Mars planet is essentially different from that of the Earth through composition, temperature, pressure and density. Atmosphere of Mars planet contains in majority, carbon dioxide (95%) the balance being nitrogen (3%), argon (1.6%), traces of oxygen and water vapour. Depending on weather conditions the pressure varies between 700Pa and 900Pa (5.25 ... 6.75)torr and the temperature within the limits 133 and 293 K (-140° ... 20 °)C. To simplify the characterization of the Martian atmosphere, in composition is admitted only carbon dioxide, for which we know the following data in normal terrestrialconditions,p_{ref} = 101325Pa and T_{ref}=288K: density: ρ_{ref} =1.7878Kg/m^3; molar mass: Mol=44.01g; specific heat at constant pressure: c_p=840.37J/Kg K; thermal conductivity: K=0.0145W/mK; adiabatic coefficientc_p/c_v =1.31.

1.3. The motion equation of the plasma layer in coaxial gun with plasma, alternately

The motion equation of the plasma layer in the gun is established on the simplified model shown in figure 2, where the thickness of the plasma, δ, is considered small compared to the length of the ionization chamber, z_0. With z letter, it's identified abscissa of the mean plane of the plasma layer.

Because the driven mass is in variable motion, for the motion analysis it's using the impulse theorem, is put in the form:

$$\frac{d}{dt}(mv) = F \qquad (1)$$

where: v is the velocity of the plasma in the median plane, and F is the resultant force of Lorentz. The force F can be inferred in many equivalent ways, [5].

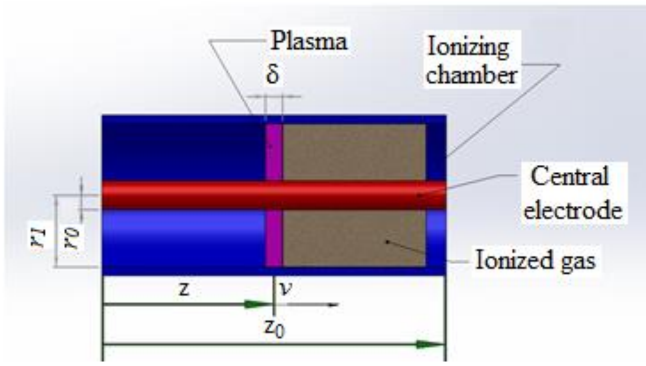

Fig. 2. The simplified model of the coaxial plasma gun

The simplest way uses elementary mechanical work given by relation (3) in which is introduced $L_t$with the expression $L_t = \lambda z$, where $\lambda = 0.3708\ \mu H/m$ thus:

$$F = \frac{dL}{dz} = \frac{1}{2}\lambda i^2 \qquad (2)$$

The equation of motion receives final form:

$$\frac{d}{dt}(mv) = \frac{1}{2}\lambda i^2 \qquad (3)$$

There is a very strong dependence of the movement of discharge process in plasma, as opposed of the reverse effect, of the movement on the electromagnetic process that is much lower. The fact that the two equations are coupled involves a simultaneously integration.

1.3. Coupling. Solutions

The equations governing the two processes, electromagnetically and mechanical, forms the coupled system of equations:

$$\frac{d^2q}{dt^2}+2\alpha\frac{dq}{dt}+p_0q=0\,;\frac{d}{dt}(mv)=\frac{1}{2}\lambda i^2$$
$$i=-\frac{dq}{dt} \qquad (4)$$

The complete solution of the equation of the free electromagnetic oscillations is written as:

$$q=e^{-\alpha t}(A\sin pt+B\cos pt) \qquad (5)$$

where in A and B are constants of integration and $p=\sqrt{p^2-\alpha^2}$ represent the amortized pulsation that is very slightly different from the one unamortized,p_0. The constants A and B are customized for the initial conditions of the problem. Harmonic function of the current enables easy integration of the equation of motion to obtain the impulse in the form:

$$mv=\frac{1}{2}\lambda I^2\left(\frac{t}{2}-\frac{1}{4p}\sin 2pt\right) \qquad (6)$$

The velocity at the end of the discharge, at$T/2$, is:

$$v_0=\frac{1}{2}\frac{\lambda}{m_0}I^2\frac{T}{4}. \qquad (7)$$

Finally the movement has the expression:

$$z=\sqrt{\frac{\lambda}{\beta}\frac{It}{2}}\sqrt{1-\frac{1}{2p^2t^2}(1-\cos 2pt)}. \qquad (8)$$

The two motion parameters can be put in the dimensionless form, substituting the time *t*with dimensionless variable, $\tau=\frac{t}{T/2}$, figure 3.

1.4. Monoblock coaxial plasma gun

Monoblock coaxial plasma gun is a constructive variant in which the main power supply circuit (RLC) is arranged together with the gun in a compact block.

In the constructive diagram of the monoblock gun, the circuit elements - the battery of capacitors and switching device - are positioned at the minimum distance from the gun. This arrangement minimizes the length of the supply conductor of the electrodes, leading to a number of advantages that will be analysed later. To maintain the high performance of the plasma gun is advisable to select variants of maxim speed, placed at the top of the velocity strips,

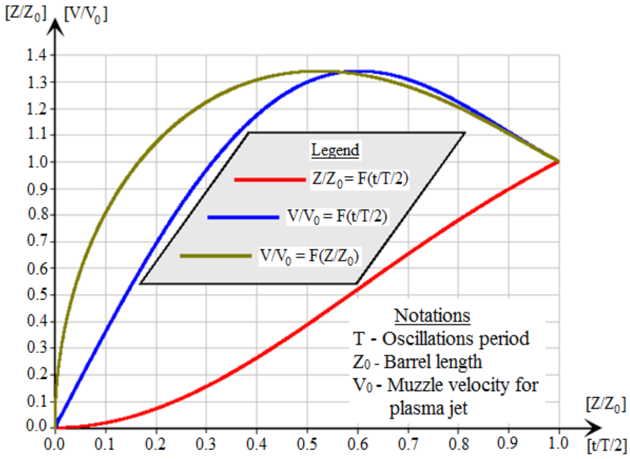

Fig. 3. Internal ballistics of the coaxial plasma gun alternately

where the value of the necessary capacitance of capacitors is minimum. The characteristical data for these conditions [6] are shown in Table 1. The supply voltage of the condenser is maintained at 10kV. For the solutions of the monoblock coaxial plasma gun is reserved figure 4. Here are represented the solutions obtained on the circuits with approximate adjustment and fine adjustment for two functional situations.

Table 1.The characteristics of the monoblock coaxial plasma gun

Discharge duration	2 T	4 T
Muzzle velocity [km/s]	4.91	3.47
Capacitance of the capacitor [μF]	12.6	6.32
Oscillations period [μs]	12.2	8.65
Current amplitude [kA]	64.8	45.8

In the A graph, the curves functions of time, are given. I, v, z, U_t for the 2T adjusted circuit, while in Graph B is given ones of the 4T adjusted circuit. And here, the dotted curves overlapping over the ones continuous (meaning representation is maintained) appear to be satisfactory.

1.5. Numerical evaluation of the functioning efficiency of the plasma gun

In figure 5, taken over from the previous numerical simulations, is shown the shape of the jet at the exit of the coaxial plasmagun for the two types of nozzle. In both representations, the jet with the form of short pulse has braking tendency and cross development. The convergent nozzle concentrates better the jet of gas, and accordingly the energy, on the axis of the gun. The conclusions of analysis of the two representations from figure 5 help to finalizing of the coaxial plasma gun model used in the cleaning action of the dust and other particles, of the surfaces, in space missions on the Mars planet.

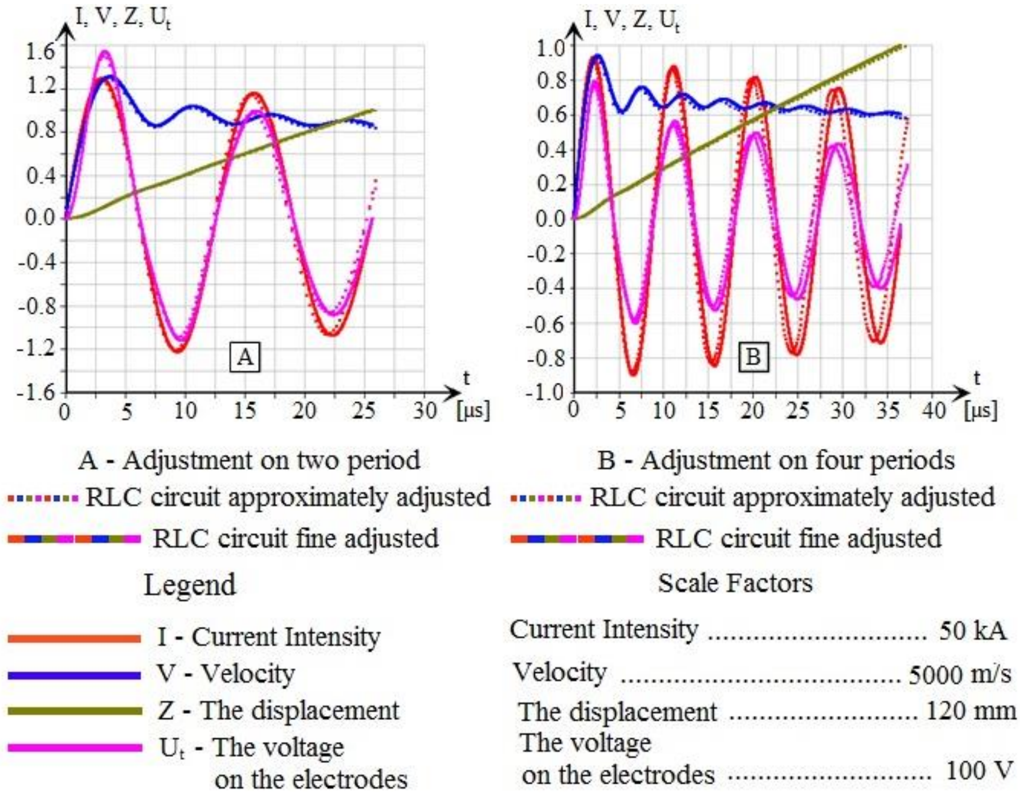

Fig. 4. Monoblock coaxial plasma gun. The solutions of the coupled differential equations

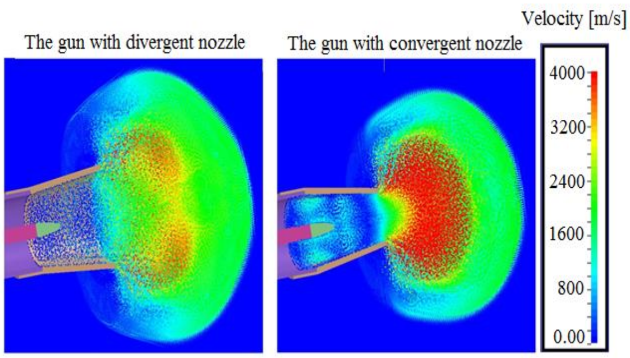

Fig. 5. Jet <PULSE> shape at the exit of the nozzle. Comparativ reprezentation of velocities fields

1.6. The physical model of the cleaning process of the dust

This model is shown in figure 6. Was opted for use a convergent nozzle that concentrates better gas jet. On the other hand, has the disadvantage of reducing the aria of action.

The reason judicious use of computing resources has limited the domain of the atmosphere at a minimum functional.

In the first part of the analysis has been followed the functionality of the coaxial plasma gun, the formation of the jet and its interaction with the plate and the dust particles. Figure 7 gives a sequential representation of the process in this step.The first three sequences, up to t = 0.045ms shows how the jet is forming. The following three represent the interaction of the jet with the support plate.

More eloquent representations are the ones from Fig. 8, where the motion is associated with velocity vectors. From figure 8 it can be seen that almost all dust particles enter into motion, even if some are moving slowly.

Duration of analysis being limited to 1ms, their displacements cannot be highlighted (these being the ones with highest weight or the ones marginal disposed).

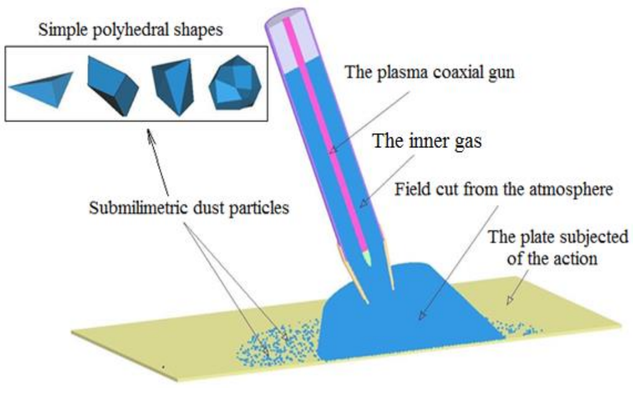

Fig. 6. The physical model of the coaxial plasma gun in action to remove dust on some surfaces of the spacecraft in the atmospheric conditions of Mars

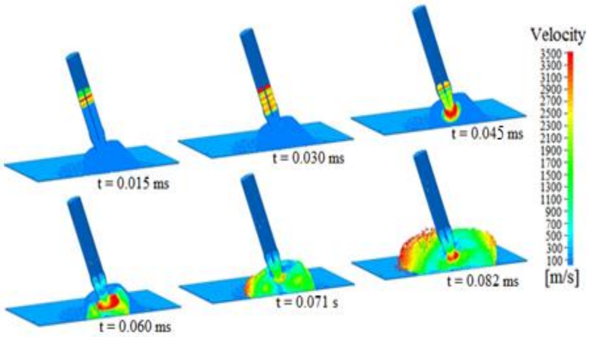

Fig. 7 The coaxialplasma gun in action. Sequential representation of the velocities field

2. CONCLUSIONS

The completion of the structure of the coaxial gun with plasma was realised based on research results main physical processes accompanying gun operation.Coaxial plasma gun is a complex aggregate in which the electrical concentrated energy, it turns into kinetic energy of gas.Use of this aggregate of cleaning of some surfaces of the spacecraft in missions to Mars planet was established by research theme.It was found, following the complete study of the electrical system of the gun, that its structure should be more compact, for the purpose of the thermal reductions and electromagnetic energy losses in the main power circuit.The length of the main circuit of the RLC type, should be minimized. Even in these circumstances, the ohmic resistance of the conductors and the inherent inductances reduce the energy that reaches at the two electrodes of the gun. For the coaxial plasma gun, defined as monoblock, in the operating version with v_0 = 3km/s, to a kinetic energy of 8.75J of the jet corresponds an energy loss of 18.1J, which results in a yield of 32%.Taking into account energy losses in the magnetic field, it is found a sentient decrease in yield. Numerical simulations have shown that the actions of the plasma gun is used are carried out effectively.Coaxial plasma gun has the ability to remove off the surfaces the spacecraft, solid bodies with dimensions less than 1 mm (average radius up to 0.3mm and higher).

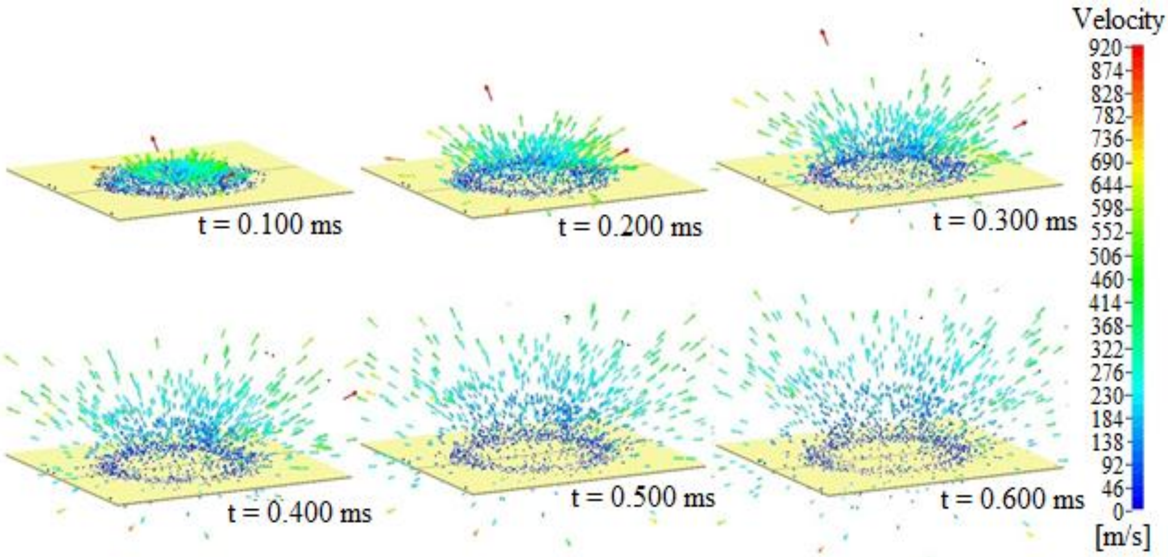

Fig. 8. Removing dust from the surface, with the puls jet generated by the coaxialplasma gun. Vectorial representation of the dust grains velocity

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