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POSSIBILITIES TO SUPPLY THE RAILWAY ELECTRIC VEHICLES THROUGH THE ELECTRIC ARC

BY

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Abstract. The idea to use the electric arc for supplying the railway electric vehicles is attractive for the high speed train. The paper presents the aspects regarding the power transfer through the electric arc (ignition, stability, reignition, efficiency, electrodes material and geometry). There are also presented some experiments realized on a bench stand to test the energy transfer through the electric arc between a pantograph skate and a rotating disk.

Key words: electric arc power transfer; power supply; railway vehicle.

1. Introduction

The railway electric vehicles (electric trains, tramways) are supplied at present by sliding contact systems (Fig. 1). The electric energy is collected from a contact line or catenary (*1*) placed over the vehicle using a power collecting system (*2*), (a symmetrical or asymmetrical pantograph) through one or more skates (*3*). The skate acts with a certain pressure on the contact line, realizing an electrical contact through which is transmitted all the electric energy on the vehicle. In some situations it is used a rigid rail to supply the vehicles and the power collecting system is made of a skate pushing and froting on it. Using a sliding contact between the catenary and the pantograph it results some drawbacks which are more intense as the speed of the vehicle, v, is increasing:

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a) The contact line has a variable height over the vehicle because of the deflection (*f* – Fig. 1), and thus, during the vehicle movement, the pantograph has a vertical movement resulting in oscillations with variable amplitude.

b) The contact line, because of the fixed point on the pillars (*4*) along the rail, has a variable stiffness, which increases the oscillations of the pantograph;

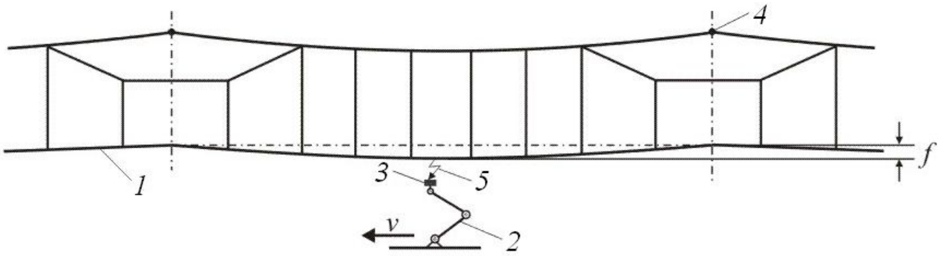

Fig. 1 – Sliding contact system used to supply the railway vehicles.

The pantograph has a vertical oscillation being into a permanent transient regime. Thus, it is difficult for the skate to follow the contact line, resulting detachments of the pantograph from the catenary. The detachments will generate electrical arcs (*5*), with variations for the current and with dangerous overvoltages, which can disturb the electrical motors, power converters, and other electric equipments. If the electric arc is important, it can deteriorate the contact line and the skate, with the effect in a rapid wear of them. In order to assure a good power supply of the vehicle, the pressure in the contact point has to be constant, a condition which is difficult to obtain, especially at higher speeds. Considering these aspects, there are some attempts to improve the railway vehicles power supply, including the attempts to use contactless methods, as the electric arc (Klapas, 1976). The transfer of power is achieved by conduction through an arc plasma which bridges the gap between a "collector" attached on the fast moving vehicle and a "distributor" supported from the ground, in the form of an overhead wire or a third rail positioned on the wayside.

2. Contactless Power Transfer Methods

There are basically four methods of contact-less power transfer: Capacitive, Electromagnetic, Inductive, and through Arc plasma.

2.1. Capacitive Power Transfer

Capacitive coupling operates through displacement currents in a capacitor which usually has parallel plates. For a 10 MVA power transfer at a frequency of 50 Hz the necessary plate area is very large, about 4 km^2 (Klapas *et al.*, 1976). This is an important drawback, and in order to reduce the plate area to accessible sizes, the frequency needs to be increased. Even so, the dimensions of the capacitor will be large and impossible to use on vehicle with limited space. A low efficiency, safety problems and electromagnetic interferences are others major disadvantages of this method. At present, low power capacitive transfer system are considered, but not suitable for the vehicle supply (Mitchell, 2011).

2.2. Electromagnetic Power Transfer

The electromagnetic power transfer is made through the air or waveguides. The principle is to transform the energy into microwaves, to transmit this energy between two antennas and, finally, to convert the microwaves into electric energy at the receiver. Large antennas are necessary, the density of the beam is small, and the electromagnetic power density of more than 0.01 W/cm^2 can be dangerous for life (Klapas *et al.*, 1976) which limits the method at high power.

2.3. Inductive Power Transfer

A primary conductor loop and a secondary pick-up (located on the moving vehicle) are magnetically coupled, acting as a single phase transformer but at high frequency (10…100 kHz). The system is complex and has a medium efficiency, but it has no wear, no pollution, it is safe due to the complete isolation of primary and secondary, and it is less exposed to the environment influence. One example is The Inductive Power Supply, IPS® (Bauer *et al.*, 2006) used on the Transrapid Magnetic Levitated Vehicle for the auxiliary system supply at low speeds. It uses an induction loop along the guideway (as primary) and pick-up coils on the vehicle (the secondary) and operates at a frequency of 20 kHz.

2.4. Power Transfer through an Electric Arc

Contact-less power transfer can be achieved by conduction through arc plasma which bridges the gap between two electrodes. The electric arcs are known especially for their destructive effect on the electrodes. In some situations the electric arc is used as a useful phenomenon, as in electric welding, in electric arc furnaces, and arc lamps for lighting.

3. Problems Related to the Power Transfer through Electric Arc

There are intensive studies on the electric arc, both experimental and theoretical, for applications as welding, arc furnaces or circuit breakers and regarding the mathematical models, computer simulations and experimental aspects. The stability of the electric arc and the damage effects over the electrodes are also largely studied. The electric arc is usually associated with the opening of the contact from the apparatus in commutation during the disconnection of the circuits. It is also associated with a “burning” of the contact areas, even with their melting and destruction.

The electric arc discharge has to be differentiate from the “spark” and it is defined as “a discharge which exists normally above one or more amps and un to the highest current, which has a low cathode potential and supports a quasi neutral conducting gas column” (Klapas *et al.*, 1976).

There are three main parts to study on the electric arc: the cathode region, the anode region and the plasma column. The currents into the arc implies both electrons and positive ions current; in general, the electrons current is sustained by electrons production into the cathode region and the positive ions current is maintained by ions production in the anode region. Assuming that the plasma in the arc is in local thermodynamic equilibrium and the temperature of electrons, ions and neutral particles are the same in any point, it is possible to estimate the electrical and thermal conductivity of the plasma, density or specific heat as a function of temperature, but this is a simple model since it ignores the space-charge region (Lowke *et al*., 1992). More realistic models assume different electronic and ionic temperatures (in the ionization zone), (Hsu, 1982; Schmitz *et al*., 2002). These models allow the prediction of the transport properties (or the voltage–current characteristics) or the current densities at the cathode (when it is not used as an input parameter of the model) as well as the energy losses through radiation. The cathode temperature can be as high as 4,000 to 5,000 K to provide the very high current densities required for stabilizing the plasma column (air ionization). The physical conditions imposed to the electrodes as well as the conditions for arc sustainment depends strongly on the geometry and size of the air gap, the electrodes surface state and the atmospheric conditions.

The plasma column reacts to outside mechanical and magnetic forces as a solid conductor capable of deformation and thus it can be achieved the arc extension by transverse magnetic fields and radial gas flow or it can be achieved an arc stabilization by longitudinal magnetic fields and axial or vortex gas flow (Klapas *et al*., 1976).

The problems regarding a power transfer through the electric arc are related to the ignition, reignition, arc maintenance, electrode materials and geometry, current level, electromagnetic interference and power losses.

3.1. Arc Ignition, Reignition and Stability

Arc stability change with arc current level and it may be difficult to maintain the arc for all current levels, being necessary a power control to realize the reignition of the arc. Arc ignition may be achieved by a mechanism which will slowly move the collector towards the distributor until breakdown and removed quickly at its normal position as soon as the current flow is sensed in the arc circuit. This technique requires a high voltage power supply, even 25 kV (Klapas *et al.*, 1976). A better solution is by using an auxiliary low current which is first ignited by high frequency/high voltage breakdown of a gap between the collector and the third electrode and after that an application of low voltage can ignite the main arc. The arc instabilities is a well known phenomenon and causes the arc roots to move irregularly around the electrode surfaces or to make the arc channel to bend or to twist in sub-channels with individual electrode spots. This problem is more important in free burning arcs than with nozzle-stabilized transferred arcs and AC arcs tend to be less stable than DC arcs (Bakken, 1997).

An important study is realized by Cantemir *et al*., (2011), regarding the sliding electric arc and power transfer in static and dynamic regime with an electric arc controlled by a coaxial gas.

3.2. Power Losses and the Efficiency

The efficiency of the power collection by arc is generally high, but there can be important power losses if the power supply is low and the arc voltage is high (Klapas, 1976). A large gap will also influence the power losses, until 30% of the total power, which imposes a good control of the arc length. The parameters necessary to control act on many interrelated processes of different natures (electric, magnetic, gas, thermal, and optical) being difficult to estimate the dominant processes over the phenomena (Yas'ko, 1997).

It is to mention that in most cases of arcs with one electrode moving it is required a magnetic control for the arc maintenance. Some experiments (Klapas *et al*., 1976) with a stationary electrode and a moving annular one shown that arcs can be maintained at different speeds depending on the arc current level, but the anode materials and anode surface conditions may reduce the minimum current level necessary to maintain the arc stability.

3.3. Electrode Materials and Geometry

The arc stability depends on the electrode materials and on the current. For low currents the difference regarding the average arc lifetime could be of three orders of magnitude and for higher currents the differences tend to minimize, but the stability of the arc depends especially on the cathode material. The graphite-cathode is better than the steel-cathode but in some situations it is used a tungsten cathode and a copper anode (Urusov *et al*., 2003). Arcing makes important erosion for the electrodes and it depends on the arc current level, the speed of the mobile electrode, the materials and on the gap (Klapas *et al*., 1976). The shape of the current–voltage characteristics is sensitive to electrode geometry, temperature and the gap and thus the arc stability and the interruption criteria are sensitive to them (Klapas *et al*., 1980).

3.4. Environmental Impact

An important type of environmental impact is related to electromagnetic radiation by arc plasmas. The electromagnetic spectrum radiated by such plasmas is enriched with UV radiation and above, dangerous for human bodies and not suitable for electrical devices. Arc noise is another environmental impact and some results (Klapas *et al.*, 1976) show that the arc noise is reduced with increasing of the arc current, the source of noise being associated with the cathode. Another environmental aspect is related to the electromagnetic interference (EMI) and this require investigation at high current moving arcs and regarding the frequency and voltage of the spark breakdown systems for arc initiation. The EMI is low if reignition is not required frequently.

4. Tests and Results

A test bench was realized in order to study the electric arc power collecting (Fig. 2). The stand uses an asymmetrical pantograph and the contact line is simulated with a disc from copper. The disc has an eccentric on the center which simulates the deflection of the real line along the span.

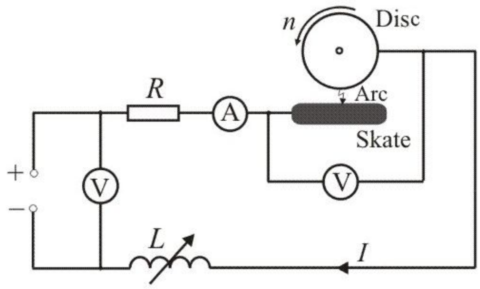

Fig. 2 – The test bench schema for the electric arc study.

Fig. 3 – The electric arc between the rotating disc and the skates of a pantograph.

The contact pressure is assured by a resort and to compensate the inertia, the friction and the mass related to the slipper the asymmetrical pantograph is drived by a linear induction motor. The contact between the copper disc and the pantograph can be realized through one or two graphite skates. The pantograph can be displaced on vertical in order to modify the space between the disc and the skates. The stand also uses a gas flow (argon) in order to help the maintaining of the electric arc. When the necessary current is established through the main circuit, an electric arc occurs between the copper disc and the graphite skates of the pantograph, as shown in detail in the Fig. 3 and recorded in Fig. 4, where the contact disc/skate is opening (disc is stationary), the electric arc is on, and the system is in a transient regime for the disc/skate detachment.

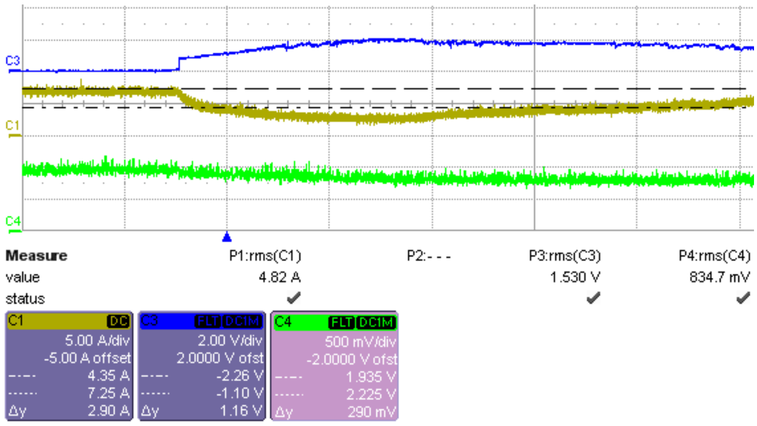

Fig. 4 – The contact disc/skate in opening, with electric arc; transient regime for the disc/skate detachment.

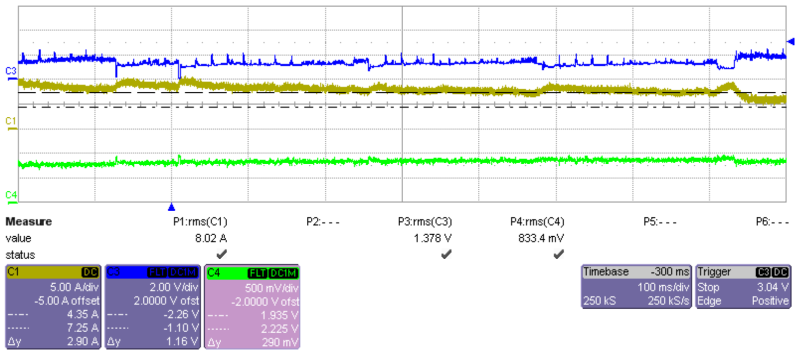

Fig. 5 – Electric arc current and voltage current with the disc rotating.

The electric arc maintains when the disc rotates with a certain speed. The gap between the disc and the graphite skates is an average of 3 to 5 mm, because of mechanical imperfections. Fig. 5 presents the electric arc current and voltage current with the disc rotating at 500 rpm and a 0.2 barr gas.

5. Conclusions

The electric arc is large studied for the applications as welding, lighting, circuit breakers, and less for the power transfer. On the electric vehicles supplied from a catenary system the electric arc occurs between the contact line and the pantograph, having serious disturbances over the line and the vehicles too.

The idea to use the electric arc as helpful in supplying the vehicles is attractive for the high speed train which could be supplied for the entire section or for short section of catenary. The tests realized in our bench shows the possibility to transfer the energy through the electric arc for a gap of about 3…5 mm. For the electric trains the gap could be larger and the power is, of course, much higher.

The technical barriers to be considered for the power supply by a sliding electric arc are: a very complex mathematical model for the sliding electric arc; the time to maintain the stability of the sliding electric arc; the wear of the electrodes due to high temperatures; complex methods to control the electric arc (by magnetic field, by artificial gas medium), and control of a third electrode to reignite the arc.

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POSIBILITĂŢI DE ALIMENTARE A VEHICULELOR DE TRACŢIUNE ELECTRICĂ PRIN INTERMEDIUL ARCULUI ELECTRIC

(Rezumat)

Utilizarea arcului electric pentru alimentarea vehiculelor de tracţiune electrică este atractivă pentru trenuri de mare viteză. Se prezintă o analiză a problemelor care apar la transferul energiei prin arc (amorsare, stabilitate, randament, materialul şi forma electrozilor). De asemenea se prezintă o serie de teste realizate pe un stand pentru transferul energiei prin arc între un pantograf asimetric şi un disc în rotaţie care simulează sistemul de alimentare catenară–pantograf.