UDC 621.3.031:629.3.06

Victor V. Nikitin, Vladimir M. Strepetov
Emperor Alexander I Petersburg State Transport University
(St. Petersburg, Russia)

VEHICLE ELECTROMAGNETS ENERGY SUPPLY OF A. C. COMBINED LEVITATION AND TRACTION SYSTEM

Date of receipt 24.07.2017
Decision to publish on 26.10.2017

Abstract:

Introduction. The combined levitation and traction system (CLTS) with alternating current represents a kind of electrodynamic suspension system in which the traction and levitation force are created by one set of onboard electromagnets, and the lifting force is provided at any speeds of the crew, including the zero speed. The disadvantages of the system are the low energy factor and the complexity of controlling the start-brake regimes. The scope of such a system can be passenger transportation within large cities and urban agglomerations for distances up to 100 km with speeds up to 150-200 km / h.

Goal. The aim of the work is the solution of the complex problem of providing CLTS onboard electromagnets with electric power with an increased energy factor and the ability to control all driving regimes.

Method (methodology). Mathematical modeling of electromagnetic and electromechanical processes with subsequent evaluation of technical and economic parameters of the CLTS were used.

Results. A practically realizable version of the power supply system for the on-board electromagnets CLTS is proposed.

Practical significance. The proposed version of the power supply system has significant advantages over previously considered ones: the ability to flexibly control all modes of CLTS traffic with an increased energy factor.

Conclusion. The system of power supply of the CLTS with alternating current from the traction network of constant voltage 3 ... 5 kV with placement of autonomous inverters onboard the crew allows to reduce the mass of the on-board electrical equipment by 10-20%, to minimize the consumption of inactive power and to flexibly control all modes of the crew's movement.

Key words: combined levitation and traction system, power supply system, starting and braking regimes, semiconductor converters.

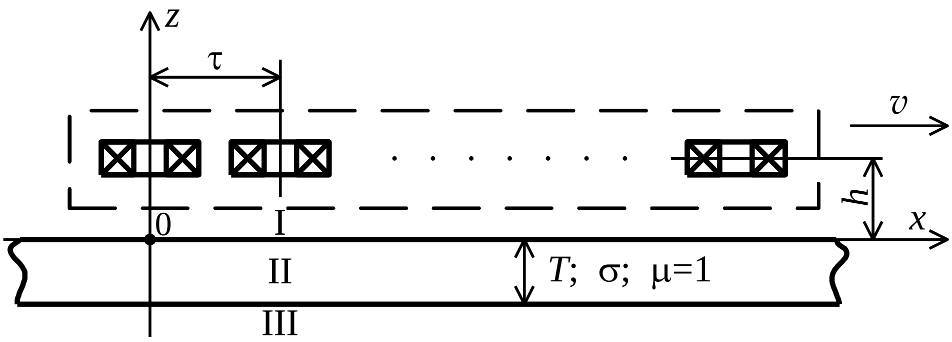
Introduction

At present, interest in development and creation of magnetic levitation transport systems of different functions [1 − 5] is being revived. This interest is caused by a tendency to increase technical and economic, ecological features of transport systems. One of the sustainable tendencies consists in design of combined systems in which electromagnetic forces in different coordinate axes directions are generated by one source of magnetic field.

The combined levitation and traction system (CLTS) with alternating current represents a type of electromagnetic suspension system in which traction and lifting forces are created by virtue of one set of onboard electromagnets, powered by alternating current (pic. 1). The crew car of CLTS is equipped with N single-type magnets, powered by single-phase alternating current, where magnetomotive force (MF) initially follows the condition:

$$wI_m(t) = \sqrt{2}\, wI_0 \cos[\Omega t + \pi(m-1)], \qquad m = 1, \dots, N.$$

where wI_0 – acting figure of MF of onboard electromagnet;
Ω – angular frequency of the power of electromagnets.



Pic. 1.
The combined levitation and traction system (CLTS) with alternating current.
I, III – non-conductive non-magnetic areas, II – area of non-magnetic conductive guidance, T – thickness of guidance, h – height of car suspension.

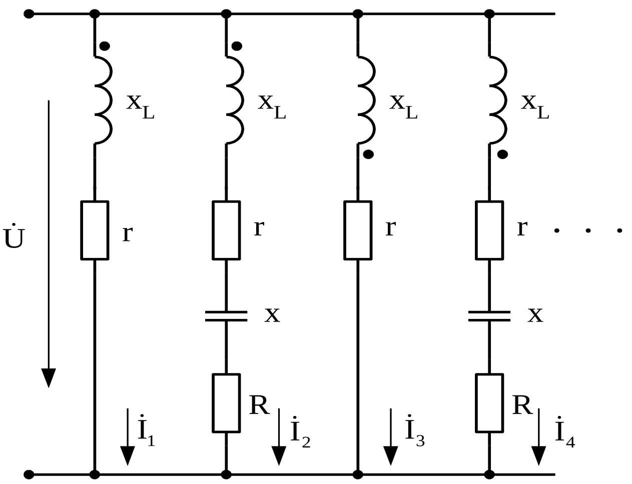
Under this condition, the onboard electromagnetic system is an alternating-pole magnetic system, which makes it possible for the lifting force Fz to be generated at any speed V, including zero speed. This favourably distinguishes this system from the conventional electrodynamic suspension with the permanent MF, in which, as it is known [6], lifting force occurs at minimum speeds of v=80...100 km/h. Furthermore, CLTS preserves such important advantages of electrodynamic suspension systems as a large suspension height (100 - 150 mm), which is crucial in harsh climate conditions, and the natural vertical stability of the crew. Researches have shown that it would be most advisable to apply CLTS in urban passenger transportation and within urban agglomerations for relatively short distances of 70-100 km, with speeds of 150-200 km/h.

The disadvantages of CLTS, which is powered by single-phase alternating current, are the lack of starting force $F_x|_{v=0} = 0$, low power coefficient, as well as the necessity of deep cooling of onboard electromagnets [7, 8].

Ways of Producing Starting Force in CLTS

In order to produce starting (or braking) force of CLTS, it is necessary to ensure a space-time shift of MF of onboard electromagnets, which will enable creating a direct (reverse) travelling wave of magnetic field for the period of acceleration (or braking). One of the options of technical solution of this problem is a capacitor start of CLTS [9, 10]. The option is based upon onboard electromagnet windings' connecting to one of alternating-pole systems of active-capacitive elements (pic. 2) in a way that their MF is determined by correlation

$$wI_m(t) = \sqrt{2}\, wI_0 \cos\left[\Omega t + \frac{\pi}{2}(m-1)\right], \qquad m = 1, \dots, N.$$



Pic. 2.
Connection of starting active-capacitive elements in capacitor start of CLTS option.

Yet studies have shown insufficient energy efficiency of the proposed option: starting active-capacitive elements will face significant loss of power. Besides, there will also be increase of weight and dimension parameters of onboard equipment.

A more profitable technical solution is application of onboard semiconductor converter [11, 12], which enables not only to minimise loss of power in start-and-brake modes, but also to minimise or totally exclude the consumption of reactive power in electric traction network.

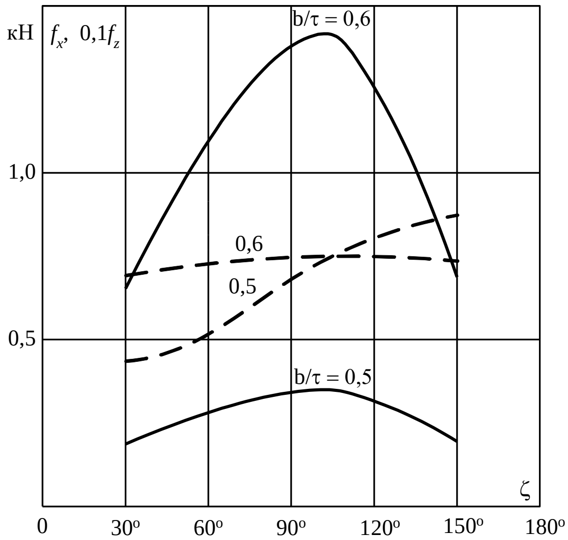
Besides, in case onboard electromagnets are powered by semiconductor converter, the possibility of ensuring a travelling magnetic wave arises, making it feasible to improve properties of transport with CLTS.

In this case, the alteration of MF of onboard electromagnets in time follows the condition:

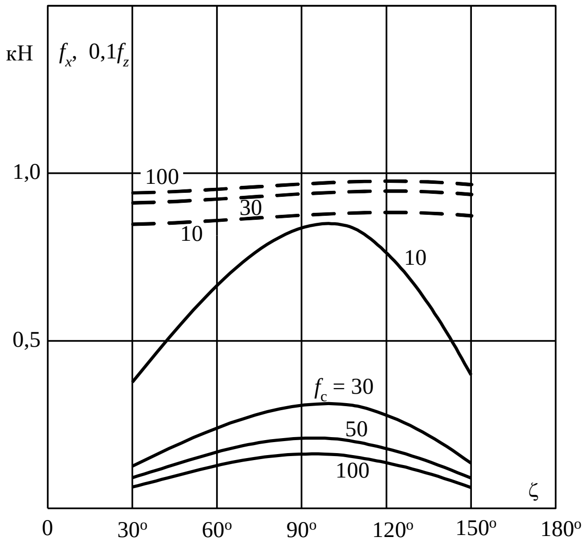
$$wI_m(t) = \sqrt{2}\, wI_0 \cos[\Omega t + \varsigma(m-1)], \qquad m = 1, \dots, N.$$

where ς – phase shift between MF neigbouring electromagnets.

It should be noted that $\varsigma=\pi$ determines the initial stationary mode of CLTS motion, and $\varsigma=\pi/2$ corresponds to the capacitor start mode of CLTS. Practical interest is represented by dependence of specific (those falling on one electromagnet) forces of traction f_x and levitation f_z on the angle ς at different frequencies f_c of supply voltage. Such dependences may be seen in pictures 3 and 4 for the following basic parameters of transport with CLTS: MF of onboard electromagnet $wI_0=5\cdot10^4$ A; specific resistance of the guidance $1/\sigma=3{,}2\cdot10^{-8}$ Ом·м; thickness of the guidance is T=0,02 м; the ratio of half a thickness of electromagnet to the distance between the centres of neighbouring electromagnets a/τ=0,6. The ratio of half of the thickness of electromagnet to the distance between the centres of neighbouring electromagnets is marked by b/τ.



Pic.3.
Dependence of specific forces of traction (solid lines) and levitation (dashed lines) on control angle ς at frequency of f_c=5 Hz of different figures of parameter *b*/τ.

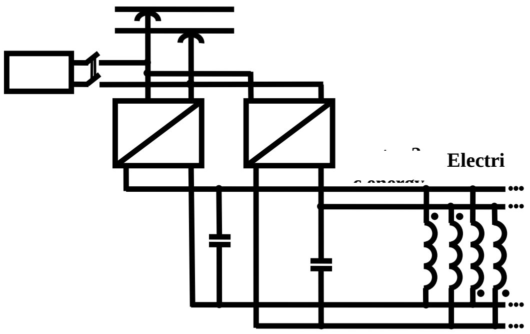


Pic. 4.
Dependence of specific forces of traction (solid lines) and levitation (dashed lines) on control angle ς at different frequencies of supply f_c and *b*/τ=0,6.

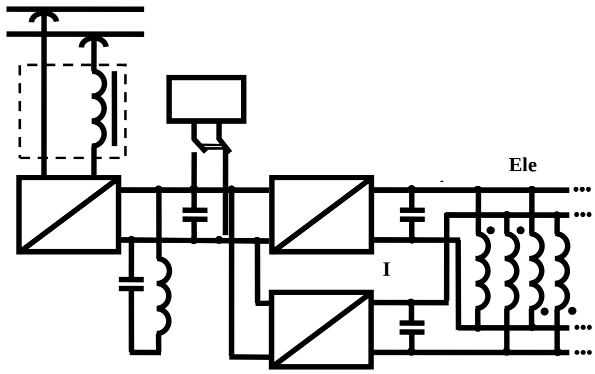
Systems of Supply of Onboard Electromagnets of CLTS

In order to provide security and satisfying operation properties of transport with CLTS, the system of supply of onboard electromagnets should meet a number of common requirements: uninterrupted power supply, smoothness of speed control, traction and braking force, minimum deviation of current waveform of onboard electromagnets, minimum harmonic motion content in the traction network current, high energy efficiency.

Deployment of static converters of energy on the crew car of CLTS is characterised by a range of advantages in comparison with a stationary deployment of converters: it ensures flexible and independent operation of crew cars, making it easier to control traffic volume during changes of passenger traffic, it results in converter aggregates of traction substation becoming more simplified and cheaper, onboard converters ensure the possibility of operation of all modes of traffic – start, movement and braking. The two options of power supply of onboard electromagnets are considered: power supply from a direct current network Uc = 3-5 kV and an alternating current network of the same level. Since the speeds being realised are relatively low (up to 150-200 km/h), there is an intention to use a movable current collector from a third rail. The schemes of the both options are represented in the pictures 5 and 6.



Pic. 5.
System of power supply of onboard electromagnets from a direct current network



Pic. 6.
System of power supply of onboard electromagnets of CLTS from an alternating current network

Pre-estimates made by the authors [12] have shown that for traffic routes up to 100 km with speeds up to 150-200 km/h, these requirements are most closely (given the minimum weight and dimensions of the onboard equipment) met by the system of power of transport with CLTS as a traction network of direct current and two onboard autonomous inverters in crew car. One of the inverters powers onboard electromagnets with odd numbers, forming an alternating pole system, the other – that with even numbers. This allows providing a required angle of shift ς between waves of MF of onboard electromagnets in starting, moving (action) and electric braking modes. Such type of power supply of onboard electromagnets of CLTS ensures flexible, independent control of crew cars and, if needed, facilitates control of traffic volume. Having a DC link (traction network) in the electric power supply system minimises consumption of inactive power and reduces loss of power in traction network. Moreover, lower energy conversion rates are provided, as well as smaller weight and dimension properties of onboard equipment. The conditions of application of onboard uninterruptible power supply (UPS) are simplified, which ensures uninterruptible power supply of traction and levitation electromagnets in case of failure of current collector of stationary traction network.

Conclusion

Implementation of static converters into the structure of onboard electromagnets power supply system of CLTS will allow to flexibly operate traffic of crew car on the set route in starting, action and braking modes. System of power supply with static converters will ensure reduce of onboard equipment weight by 10-20 per cent compared to the system with a capacitor start. It is most expeditious to use power supply of electromagnets of direct current network of 3-5 kV with two onboard autonomous inverters with a controlled value, frequency and starting phase of basic harmonic output voltage.

References

1. Antonov Yu. F. & Zaitsev A. A. Magnitolevitatsionnaya transportnaya tehnologia [Magnetic Levitation Transport Technology]. Moscow, 2014. 476 p.
2. Antonov Yu. F. & Zaitsev A. A. Magnitolevitatsionnyi transport: nauchnye problemy i technicheskie reshenia [Magnetic Levitation Transport: scientific problems and technical decisions]. Moscow, 2015. 612 p.
3. Zaitsev A. A., Talashkin G. N. & Sokolova Ya. V. Transport na magnitnom podvese [Transport on magnetic suspension]. St. Petersburg, 2010. 160 p.
4. Zaitsev A. A. Zheleznodorozhny Transport – Railway Transport, 2014, No5, pp. 69–73.
5. Antonov Yu. F., Zaitsev A. A., Korchagin A. D. & Yudkin V. F. Magnitolevitatsionnaya tehnologia kak transportnaya strategia gruzovykh i passaghirskikh perevozok (Magnetic levitation technology as transport strategy for freight and passenger transportation) *Magnitolevitatsionnye transportnye systemy i tehnologii: trudy II mezhdunarodnoi nauchnoi konferentsii* [Proc. 2nd Int. Scientific Conf. "Magnetic Levitation Transport Systems and Technologies"]. St. Petersburg, 2014, pp. 22-49.
6. Sika Z. K., Kurkalov I. I. & Petrov B. A. Electrodinamicheskaya levitatsia i lineinye sinchronnye dvigateli transportnykh sistem [Electrodynamic levitation and linear synchronous motors of transport systems]. Riga, 1988. 258 p.
7. Baiko A. V. & Kochetkov V. M. Izvestia vysshikh uchebnykh zavedenii. Electromekhanika – News of higher educational institutions. Electromechanics, 1985, No 11, pp. 24-31.
8. Baiko A. V. & Strepetov V. M. *Elektrichestvo – Electricity*, 2006, no. 10, pp. 42-46.
9. Baiko A. V. & Khozhainov A. I. *Elektrichestvo – Electricity*, 1991, no. 4, pp. 30-41.
10. Khozhainov A. I., Sereda G. E., Milutin V. A. & Strepetov V. M. Traction Unit with Alternating Current for Transport System. Certificate of utility model No. 11513. Declared 07.04.1999, published in Bulletin of inventions, no. 10, 16.10.1999.
11. Bayko A. V. & Strepetov V. M. Estimation of influence of entrance converter of the A.C. levitation and traction combined system of system power supply. Proc. of the 6-th international conference on unconventional electromechanical and electrical system «UEES-04», 24-29 September 2004. Alushta. Ukraine. pp. 805-810.

12. Nikitin V. V., Strepetov V. M. & Voluvach A. S. *Izvestia vysshikh uchebnykh zavedenii. Problemy energetiki – News of higher educational institutions. The problems of Power Engineering*, 2010, no. 3-4, pp. 54-62.

Information about authors:
Victor V. NIKITIN, Dr. Sc. (Tech), associate professor, professor of Theoretical fundamentals of electrical engineering department of Emperor Alexander I Petersburg State Transport University
E-mail: victor-nikitin@nm.ru

Vladimir M. STREPETOV, Cand. Sc. (Tech), associate professor, associate professor of Theoretical fundamentals of electrical engineering department of Emperor Alexander I Petersburg State Transport University
E-mail: strepetov.vm@mail.ru