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Linear drive with expanded primary winding

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Abstract

Vehicle speed capacities are limited due to power supply construction. When using rotation type traction motors, their mechanical characteristics set the limits. Most common linear induction motor designs use pantographs, contact pads or wires that due to friction cannot run at extreme speeds. To override these limitations a new design of linear induction motor is proposed.

Keywords

Vehicle, electric traction, guidance, contact less, linear induction motor, safety

Introduction

le electric traction is under development, situations when regular rotation electric motors are not suitable are common. In high-speed transportation a linear induction motor is well known. I must admit, that due to material consumption, these drives are not widespread. Modern materials permit to design electric motors to be used in very hard conditions, but research in Japan figured out, that regular rotation drives do not permit train speed far above 500 km/h. Regulation scale of electric drive is insufficient and due to wide spectrum of obstacles, mechanical systems become unreliable. It is experimentally established that maximum linear speed for rotation electric motor is 80 m/s [2]. While running on limits, service costs increase dramatically. On trains with MAGLEV (magnetically levitated) suspension, linear induction motors without any rotating parts are common. Regular version of linear induction motor is passive track and active winding on bogie. Such approach is less material consuming but it has several limitations. Theoretically MAGLEV suspended trains can travel at the same speed as planes an even faster, but regular linear induction motor must have some sort of power supply for traction. A pantograph is involved. Modern technologies permit to design very precise mechanics, but these advantages do not cancel physics laws. Due to friction and aerodynamics, pantographs are reliable for speeds up to 600 km/h [1] so it is necessary to design the linear induction motor that can run without any mechanical contact between track and bogie.

Expanded primary winding solution

There is only one design of linear induction motor that permits contact-less traction – an asynchronous design. As in most other linear induction motors, this is designed from regular rotation motor with expanding it in plane. A two section primary winding is acquired that connected to source of electric current produces magnetic run-field. Those interact with secondary winding and create traction force. Speed regulation is achieved dually with commutation of primary winding and current limitation in secondary. In regulation process, secondary winding leaks several amount of energy that can be accumulated in batteries or supercapacitors. That accumulated energy can be used for regulation purposes or other technological processes. While building the track, such primary winding sections are placed in a row. Windings are commutated depending on vehicle position. A “Dead zone” – gap between traction windings, train pass by it’s inertia. It is also possible to design bogie where always at least one section will work for traction. So an instant traction is possible. Stylized view of primary winding on fig. 1 is shown.

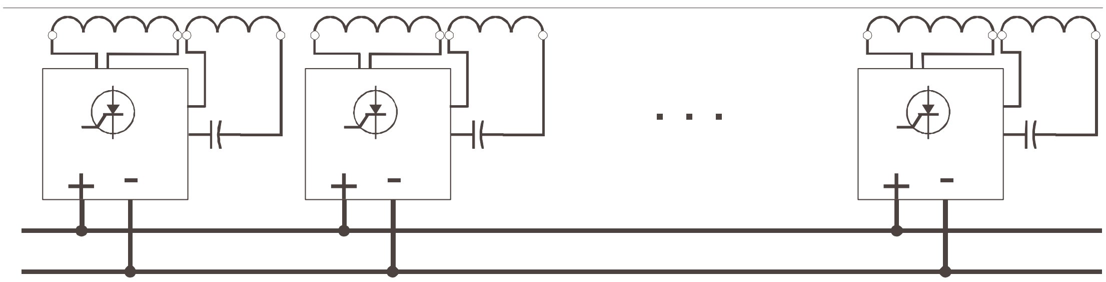

Fig. 1. Schematic view of primary winding.

Logic of linear induction motor

Up to day commutation in linear induction motors are designed to use contact pads for DC traction or pantograph for AC traction. In technologically simple solutions, where motor is running in asynchronous mode, speed of linear drive can be expressed with formula

$$v = 2\tau f, \tag{1}$$

where τ is distance between windings and f is current frequency. Contact pads and pantograph solution theoretically permit to work on high speed, but due to friction mechanical capacities are limited. Creation of electric arc between pantograph and contact pad is also serious problem. Alternating current suits not very well because of complex frequency regulation. Such consideration confirms, that a direct current supplied system with electronically commutated windings must be designed to achieve very high speeds.

Regular linear drive windings are permanently connected to power supply. That causes power losses due to border-effect. If motor poles are shifted to each other, interinductivity is decreasing that causes current increment and unneeded heating of the winding. In case, when traction windings are installed in the track, current is applied only when at least 1/6 of pole square is covered by secondary winding. This eliminates losses caused by border-effect. To provide commutation in exact moments, regulation schematic based on Hall-effect sensors must be designed. This schematics permanently controls pole square covered. In fig. 2 commutation time diagram is shown.

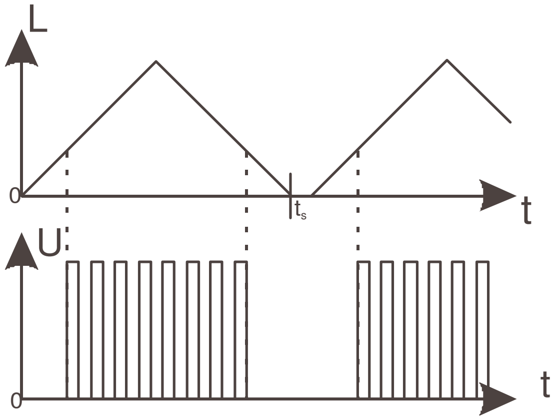

Fig. 2. Pole coverage and tension diagrams depending on time

Taking in account, that size of previous sections and vehicle speed are known, we can precisely calculate coverage square L. Values are g – length and p - width.

$$dL = dg * p; dL = f(t_s); dL = \begin{cases} 0;0 \\ g * p; \frac{t_s}{2} \\ 0; t_s \end{cases} \tag{2}$$

Regulation principles

As listed earlier, winding to power source is connected only in predefined moments so avoiding border effects (Fig.3). Due to direct current usage, at slow speed conditions it is possible only winding resistance causing unacceptable current ratio sets that current rate. Because it is possible to determine the working type of the winding – acceleration, deceleration, speed upkeep, so in sections with slow motion, windings are supplied with pulse current avoiding overload.

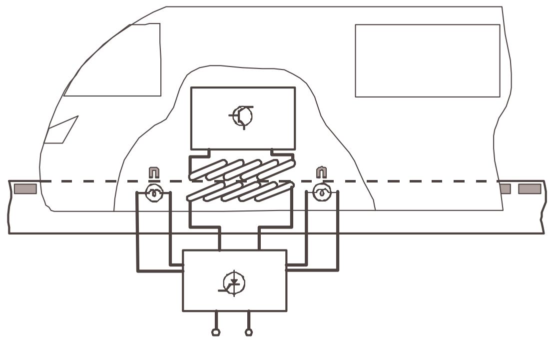

Fig. 3. Visualization of primary and secondary winding conjunction.

Most important characteristics of electric motor is traction force [3],

$$F = \frac{2F_k(1+\rho)}{\frac{S}{S_k} + \frac{S_k}{S} + 2\rho} \tag{3}$$

$$F_k = \frac{mU^2 x_i^2 r_i}{2\tau f} * \frac{S_k}{\{r_i r_{i+1} - S_k(x_i + x_{i+1})\}^2 + \{r_i x_{i+1} + S_k r_{i+1} x_i\}} \tag{4}$$

where F_k and S_k are critical slip coefficient and force.

This force is affected by count of windings, current and magnetic characteristics of motor core. Contact-less linear drive is superb at this point because permit to select necessary winding parameters and somehow automatically adjust according to conditions. Traditional regulation methods are also available. Traction force moment define motion parameters of the drive. In traffic it is a common case, when motor must be run at partial power to keep the speed constant. In this case, to overcome atmosphere resistance (remember – no mechanical contact between track and vehicle). As a result, a very energoeffective drive can be acquired because regulation is achieved changing its power consumption minimizing any sort of losses. Technically it come so, that changing the time when winding is connected to power supply, it is possible to run drive at optimum and/or maximum of traction moment in full speed range. Also important moment is thermal conditions of the drive. While primary winding is connected only a short period, it is possible to run them on much harder mode than regular rotation motors permit. A heat dissipation factor is also practically unlimited.

Possibility to adapt dynamic parameters of the drive to provide necessary traction and speed permit creation of fully automated transport systems where motion is regulated from track and not from driver in vehicle.

Regulation design permit significally change not only electro mechanical parameters of the drive but also efficiency factor. Meaning conversion of electrical energy to mechanical and also losses appearing in regulation process. Usage of electronic circuits permits to transform excess energy from regulation to saloon lightning and conditioning. Newest technologies of supercapacitors and LED based sources of light permit to design vehicle with unbeatable reliability and efficiency.

Conclusion

Asynchronous linear induction motor with expanded primary winding is not affected by mechanical limitations. Thus allowing designing vehicles with significally higher motion speeds than are common today. Material consumption is also bigger than in traditional motors but close to no running expenses are expected. Linear induction motors similar to proposed, are not well researched so exact mathematical description does not exist and it must be synthesized from common physical and mathematical facts.

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