Propulsion and Magnetics: Propulsion Basics

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February 2, 2022

1 Alternatives available.

All the designs that are going to be mentioned in this section come from the idea of taking a traditional rotary electric motor and making it suitable for linear application. One of the main considerations that must be made is the "end effects", that take place on the end side of the motor, because a certain amount of the magnetic field generated is leaked due to the ending of the motor, unlike rotary motors that do not have endings, so this problem must be taken into account during the design process.

1.1 Linear Asynchronous Motor (LIM)

This is the easiest approach both technical and economically speaking, as it does not need as complex systems as the other options. This design is based on developing linearly a rotary induction motor, so it is made from a stator and a rotor. These motors can appear in 2 configurations, short or long primary, being the primary the element that contains the windings that must be energized, so short primary means windings on board, and long primary means windings on the track. The first approach is more appealing for the Hyperloop (HL) because makes it suitable for any track. Another design option is the Single/Double-side configuration, meaning that when designing a short primary, the motor can be placed either on 1 side or on both sides of the track, acting as a clamp. This motor works by creating a traveling magnetic field $\vec{\mathbf{B}}$ parallel to the velocity vector, so the pod will move in the same direction. This $\vec{\mathbf{B}}$ is generated by the arrangement of the different coils on board of the POD, which creates an alternating field because the different set of coils receives out of phase AC currents, that induce a magnetic force on the stator (railway) that pushes the POD forward. The main constraint of this type of motor is that the rotor (POD) will never reach the $\vec{\mathbf{B}}$ displacement velocity, so a slip will exist.

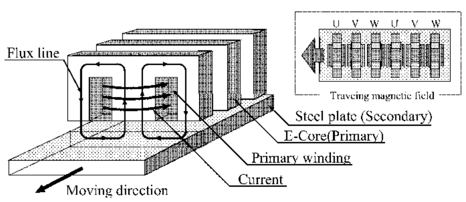

Figure 1: LIM typical layout.

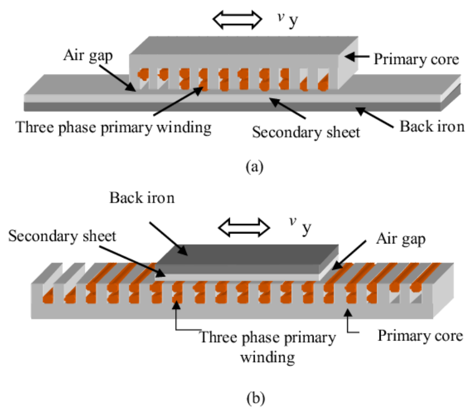

Figure 2: Different configurations for the LIM. a) Short primary. b) Long primary

1.2 Linear Synchronous Motor (LSM)

The nature of the LSM is very similar to the LIM, being the main difference in operation that there is no slip, so the rotor moves at the speed of the $\vec{\mathbf{B}}$, giving the "synchronous" part of the name. This makes this motor more precise, less need for control, and more stable. To operate at this constant speed, the rotor will need a permanent magnet arrangement, either by a normal magnet or by an electromagnet generated by a coil and a constant DC current. One of the principal problems of this motor is that is not self-starting, as it operates at a given speed (synchronous speed), it will need assistance to reach this speed until it starts operating in the synchronous mode, and the most interesting option is to operate the motor as a LIM until the speed is reached and then switch to LSM mode. LIM systems are less complex to control, require less feedback and power conditioning equipment, and can produce higher peak forces. LSM systems are significantly more efficient, smaller, and use less real power and current.

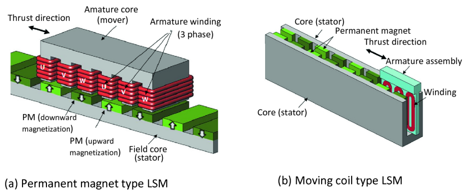

Figure 3: Permanent/Moving type LSM

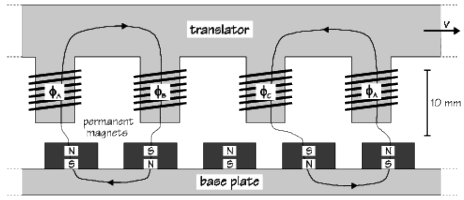

Figure 4: LSM in synchronous operation

1.3 Homopolar Linear Synchronous Motor (H-LSM)

These are characterized, in general, by a passive long (fixed) variable reluctance (segmented) ferromagnetic secondary and a short primary on board of the vehicle (mover) that contains an iron core, which hosts both dc coils as long as the core and a three-phase ac winding. The DC coils produces a homopolar, pulsating, air-gap magnetic field, which is used for con- trolled electromagnetic suspension of the vehicle; its 2p pole fundamental ac component interacts with the 2p pole three-phase ac winding to produce propulsion (braking) force. Can reach the best efficiencies of around 85 % at speeds of +100 m/s, but are the harder to develop because of the lack of work in this field, and so the lack of references.

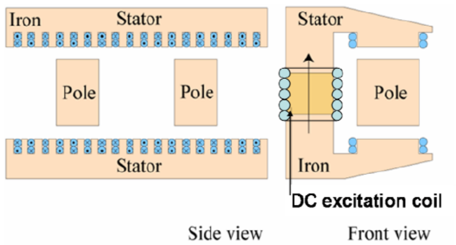

Figure 5: HSLM typical layout.

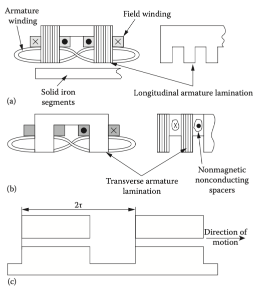

Figure 6: H-LSM layout (a) with longitudinal laminations primary core, (b) with transverse laminations, and (c) segmented and standard secondary solid care.

2 Main Design Constraints

In this section a brief introduction to all the parameters that govern this kind of propulsion is made. The most important ones are:

- Stator Slots: The magnetic field generated is not a perfect sine wave but a square approximation.Increasing the number of slots in the stator core improves the approximation because additional opportunities exist for the windings to interact and help "smooth" the stator field to make it more sine-like and gradual. But too many slots makes the peaks of the sine start to look triangular. To combat this, a left or right shift of a single slot winding for each phase can be performed. This technique adds unbalanced resistances that result in an imbalance of the magnetic field at the ends of the motor. So, adding slots helps improve the approximation of the sine wave distribution for the stator magnetic travelling field, which in turn helps decrease other harmonics and improves the motor's overall efficiency and ability to obtain a higher driving thrust.

- Power factor (PF): The currents and voltages are shifted apart from each other by some angle because in AC inductive systems, the voltage is not in phase with the current. The cosine of this angle is called the power factor and is a measure of the system's efficiency, as it describes the ratio of the active power to the reactive power. Asynchronous motors tend to have a power factor around 0.8.

- Slip: Is a relation of the difference of velocity of the stator and the rotor. The stator creates a magnetic field that sweeps across the rotor, which creates the opposite filed that produces the movement. So we have 2 fields with 2 field velocities, here is where the slip appears. When the slip is equal to 0, the rotor has reached the sync speed (i.e., the speed towards which it drives during operation) and no difference, or a small slip, between stator field velocity and rotor velocity is observed. In this case, the rotor moves at exactly the same speed as the synchronous field from the stator and there is no observable relative difference between the two. The rotor can never move faster than the synchronous speed of the stator field. Once v_s is reached, the rotor stops accelerating.

- Number of poles: This is the number of poles the different coils will generate, as no monopoles exist we will consider them as pairs (N and S The fewer pole pairs a motor has, the less drag the motor experiences and therefore the more thrust it generates so it is desirable for motors to be designed with the minimum number of pole pairs.

- Pole pitch: Geometrical length for a single pole in a motor: it is the pole's "pitch" or length. If the length of the motor is known, the pole pitch can be determined if the pole number is also known. : The motors can work with both AC and DC currents with a wide range of voltages from 1V to 300V, depending on the purpose. This will be crucial for the energy part and also a safety concern because of the heat dissipation.

3 Propulsion route.

In this section, a first approach to what we will be done is described. The first and fundamental step is a review of electromagnetism fundamentals and electrodynamics, to be comfortable to work with EM concepts or equations, so many papers will be given for self literature review. Then, a discussion must be made regarding which type of motor is the most suitable for the prototype, so a concrete study about these 3 options must be made (this is currently happening but your help will be very useful). Once all the information is collected a decision will be made and after that, the team must study in-depth the concrete motor configuration, and when this is ready the design process will start. First, we will estimate the thrust required for the POD and then find which magnetic fields and components that generate them are required. Once we know this we can start designing the components themselves and solving them with software. Once a design is selected, another round of simulations will come, know is the testing phase and evaluate if the selected design is suitable with the POD structure, power or safety requirements, etc. If all this testing phase is satisfactory, we will start manufacturing the motor itself (a company will manufacture it, we have to prepare the designs) and once it is in our hands we can perform real-life tests. All this process may be accompanied by the same steps for the railway if the configuration selected required a special railway.

4 Softwares.

For the design of the motors, many computer soft wares will be used. As many magnetic fields must be solved we will take profit of the ANSYS MAXWELL solver, which for a given geometry and characteristics will solve for the different magnetic phenomena (just like Fluent for fluids). This program has some tutorials online but the main source of information will be the different papers that already propose the usage of this software. Regarding the CAD, a geometry must be given as input to solve the $\vec{\mathbf{B}}$ and we have chosen CATIA V5 as it is very used in the aerospace field, the implementation of CATIA parts to ANSYS is easy and it can represent very soft surfaces. We may also use another ANSYS program related to electric motors but it is still under consideration. The use of MATLAB for the control implementation will also be present in this work, related to the work of Electronics Software. We will try to use Python for all the performance control and the daily work, as models or figures for reports.

5 Resources

In order to make this job easier we are sharing a google drive directory so everyone can access all the references, If you want to add something don't hesitate, just specify in the name of the .pdf the content of the document.