HIGH SPEED
LSM DRIVE SYSTEM

Intrasys
Linear Synchron Motor
Drive System

for
Amusement Rides

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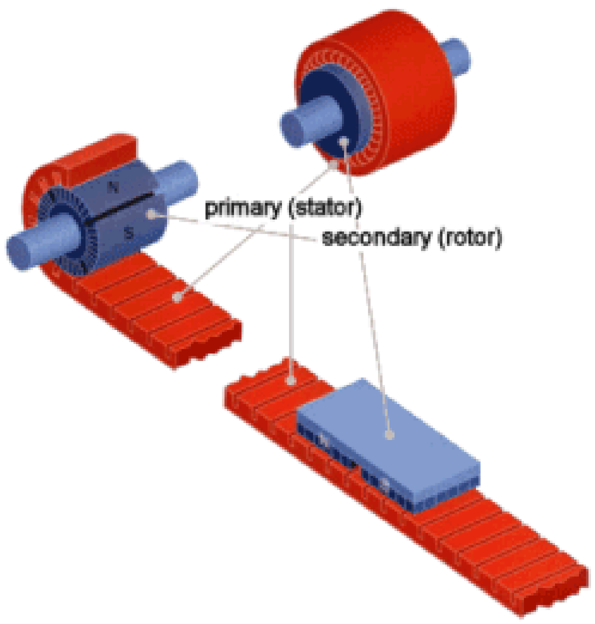
1. LSM Drive System

1.1 LSM Motor Principle

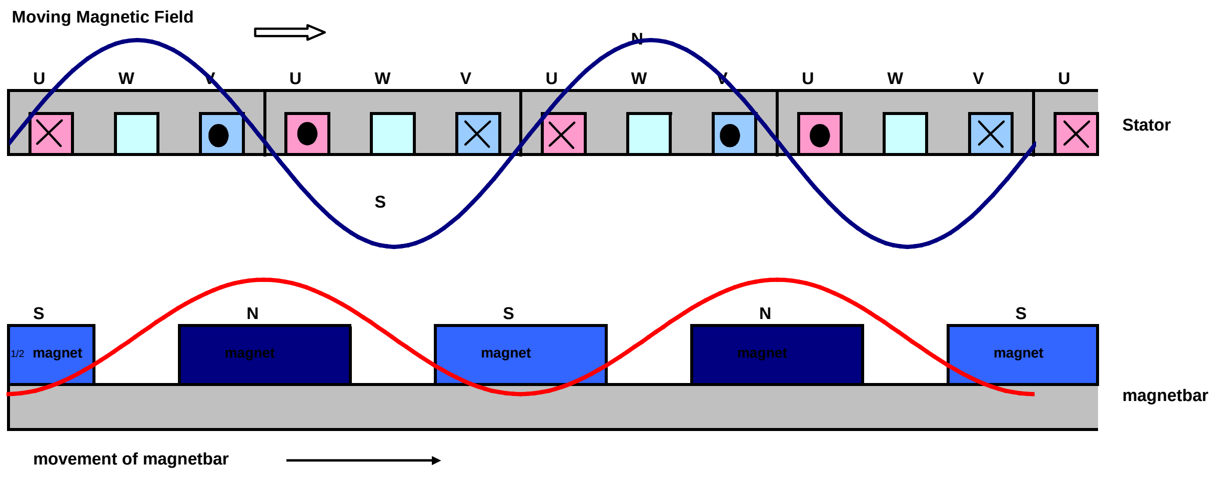
The following paper describes the function of a Linear Motor Drive system using a **Long-Stator Synchronous-Motor (LSM).**

A linear motor can be considered as an „unwinded“ coventional rotating motor consisting of a primary element or stator and a secondary element (rotor)



In a Synchroneous Linear Motor (LSM) the secondary element consists of permanent magnets mounted alternately with N and S pole on a reactance core. The resulting magnetic field in a certain distance has a sinusoidal shape.

The electronic control generates a moving electromagnetic field over the stator (Primärteil) which interacts with the field of the permanent magnets and pushes the Secondary Element forward.



Picture: Magnetic fields in the stator and secondary.

A LSM works comparably to a conventional rotating Synchronous Motor. The "moving" magnetic field accross the stator pushes the secondary magnet bar if both fields are synchroneous in a defined manner.

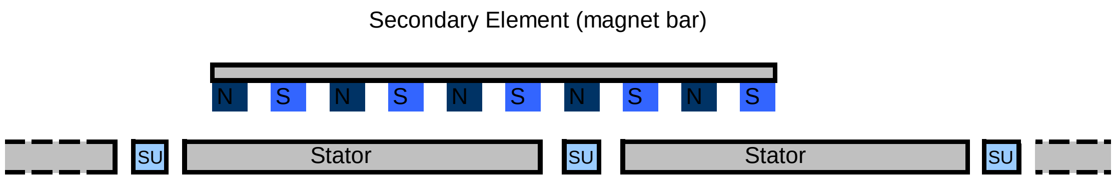
The repulsive force between the two magnetic fields is at its maximum, if the phase shift between the two sinusiodal curves is 90° (blue and red sinusoidal curves in the picture).
To reach this synchronized mode the postion of the secondary magnets has to be determined by postion sensors. Intrays method of determinating the postion is to measure the field accross the magnet bar (red curve) by means of the S-NET hall sensors. This sensor information is than processed by a real time control system (XPC) to gain the actual pole angle in a standardized sinus-cosinus signal. This signal is transferred to the inverter which controls the stator current and the phase in such a way that the pole angle remains ideal.

An arrangement is called long-stator-synchronous-motor (LSSM) if several stators (primary parts) are stationary and distributed over the whole track whereas the secondary part with it's permanent magnets is mounted on a vehicle and moving accross the track pushed by the motor elements.

1.2 LSM Drive System for Amusement Applications

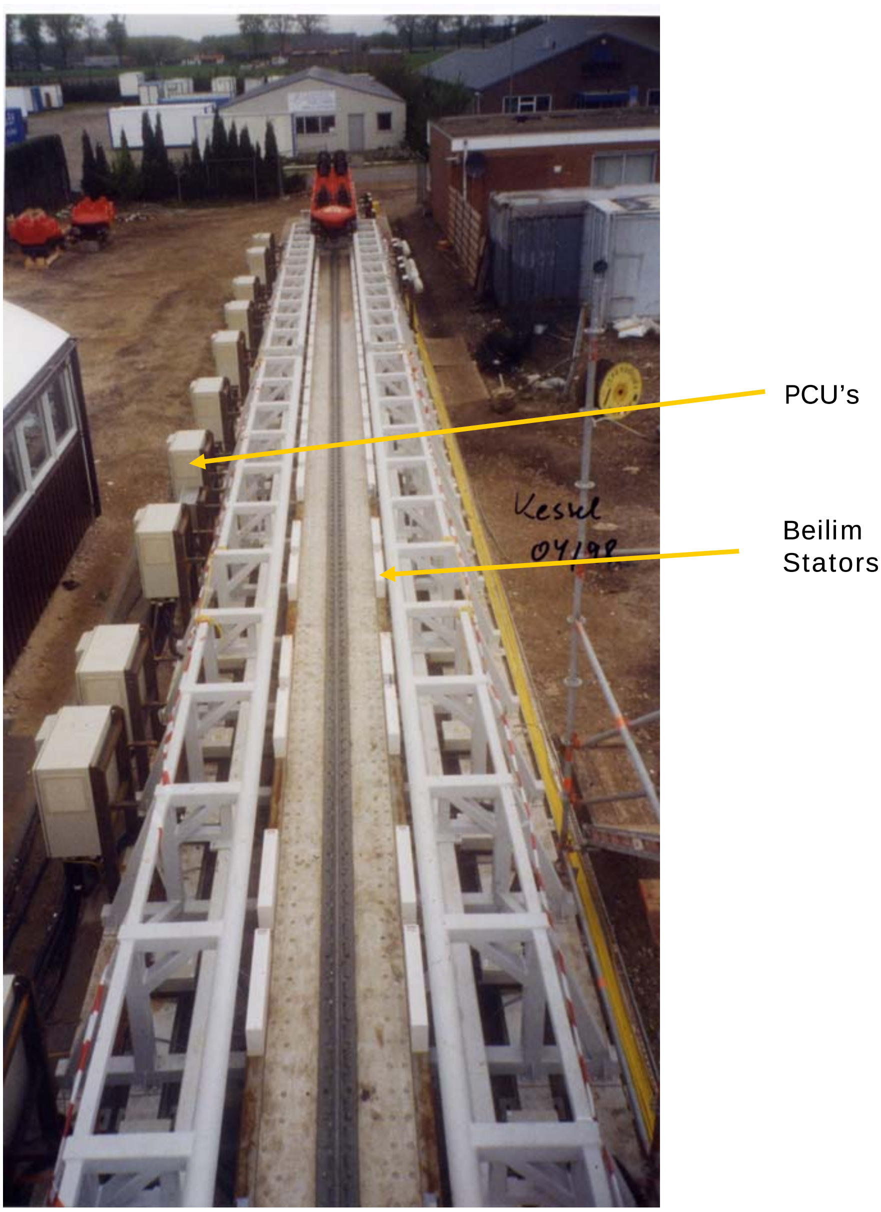
In Amusement Application typically a Long Stator Synchronous Linear Motor (LSSLM) is used. This type of linear motors has a short Secondary Element, attached to a vehicle and eqipped with permanent magnets alternating in a N and S pole orientation. The primary part (stators) is fixed and integrated in the track. Usually those stators are electrically connected in serie and powered by a central frequency inverter.

The length of the Magnet Bar and the number of simultaneously covered stators determines the available thrust, in minimum one and a half stators should be covered by the Secondary Element to ensure a smooth movement.



SU are usually mounted between each stators to determine the exact postion of the Secondary Element by measuring the field accross the Magnet Bar

The picture shows a launch with two rows of Beilim stators and the PNET and SCU boxes ad the left side of the launch.



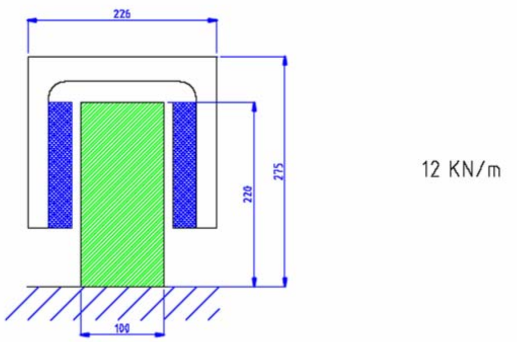
Picture: High Speed LSM Drive as realized at the Rock'Roller, Disney World or Seasame Street, Disney Paris

1.3 LSM STATOR TYPES AND DATA

Intrasys LSM Stators are available in both the conventional flat design or in the much more efficient upright Beilim arrangement.

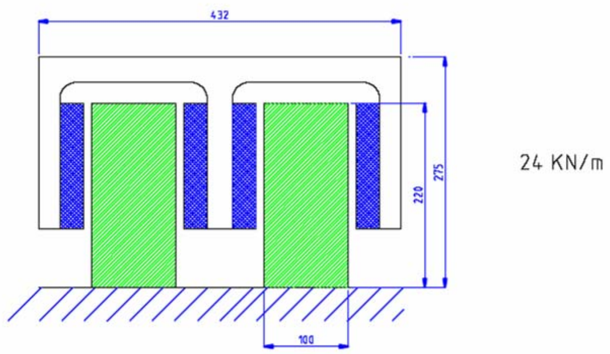
The Beilim Stator Line.

The Beilim Stator line is an High performance 3-phase stator design . It can be mounted at the track (Long Stator arrangement) or at the vehicle. It's special upright desing in combination with an magnet yoke as described in the sketch will produce double the thrust compared to conventional flat designs. Lateral attraction forces will appear in case of unsymmetrical air gaps.



The single row motor arrangement has total width of 226 mm and the standard height is 275mm. The typical stator length is 800mm.

The nominal thrust is 12KN per m magnet coverage.



Beilim Stators can be modulary combined also in a two or three row arrangement to double or tripple the nominal thrust per m.

The outline dimensions are given in the relevant drawings.

Typical Performance Data of the Beilim Stator and Motor arrangement

Height	220 mm
Width	100 mm
Length	800 mm
Weight	80 kg
Airgap (typ)	7 mm
Lateral forces at 3mm unsymmetrical yoke	8 kN/m
Typical thrust per m coverage	15 kN/m
Cooling	Natural convection Forced air cooling
Protection	IP 65
Outline Shape 1-row arrangement (width x heigth)	226mm x 275mm
Outline shape 2-row motor arrangement (width x heigth)	432mm x 275mm

1.4 ACTIVE AND PASSIVE BRAKING

1.4.1 Active Braking

Active braking can be achieved by operating the inverter in an reverse braking mode. In this case a braking chopper is required in the inverter to dissipate the energy generated in the stators. The system can be operated in a constant output velocity mode to adjust the speed differences due to different masses. Active braking can be used when braking is not safety relevant. As an additional option regenerative braking is available. This option is described in chapter 4.3.

1.4.2 Passive Braking

Passive braking is used when safety-relevant or fail-safe braking is required. With LSM's two way's of braking is possible:

Braking by means of short circuited stators:

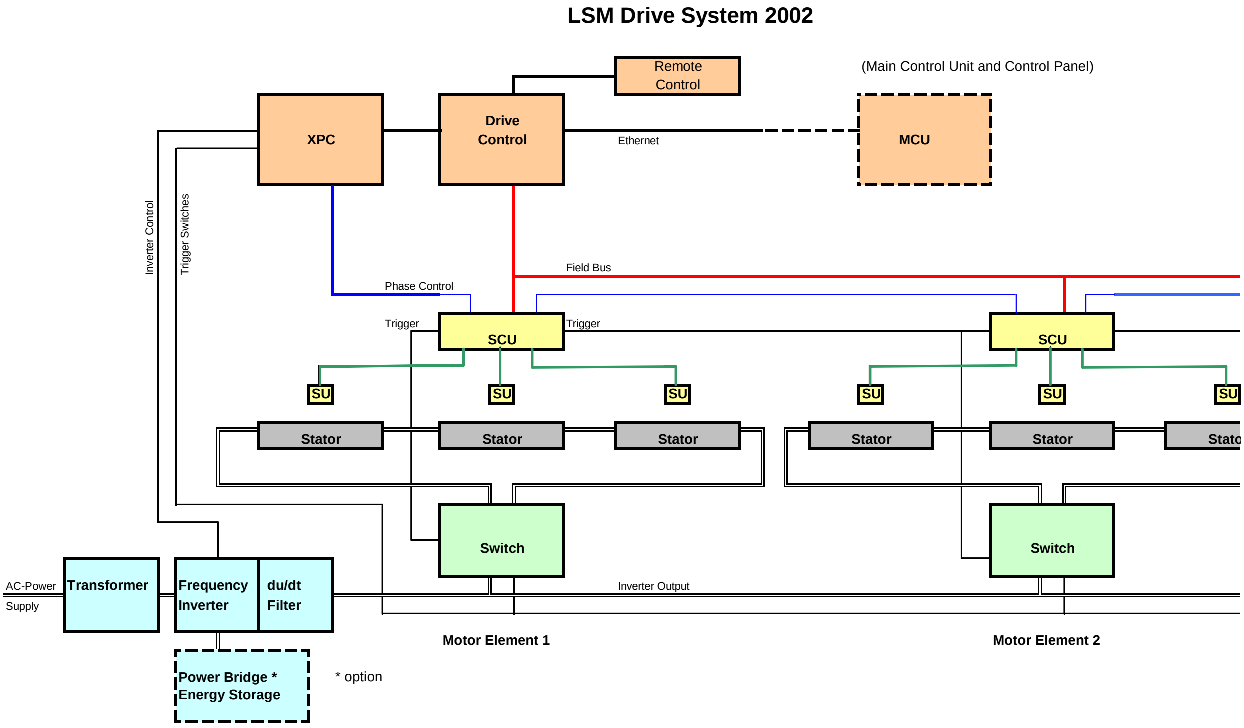
- A braking force can be generated by short circuiting all phases of the stator. By using a "normally-closed" type of contactor switch, a fail safe braking mode can be achieved. Typical braking forces are 4 kN/m

- Braking with a fin replacing the stator using the Eddy Current effect.
  This effect is achieved by replacing a stator in the track by a braking fin made of material with low resistance. The braking force in this case could even be adjusted moving the braking fin more or less into the air gap of the secondary for example using a hydraulic system. This arrangement can provide very high braking forces of up to 20 kN/m.

In both cases the braking forces is proportionally depending on the speed and will reduce whit the speed getting low. This means the brake can not stop the vehicle completely, typical minimum output speed of a passive brake is 0,5 to 1m/s.
An additional mechanical brake has to completely stop the vehicle.

2. DRIVE System OVERVIEW

The following principle shows a typical Intrasys LSM-drive system:



The main functional units of this system are:

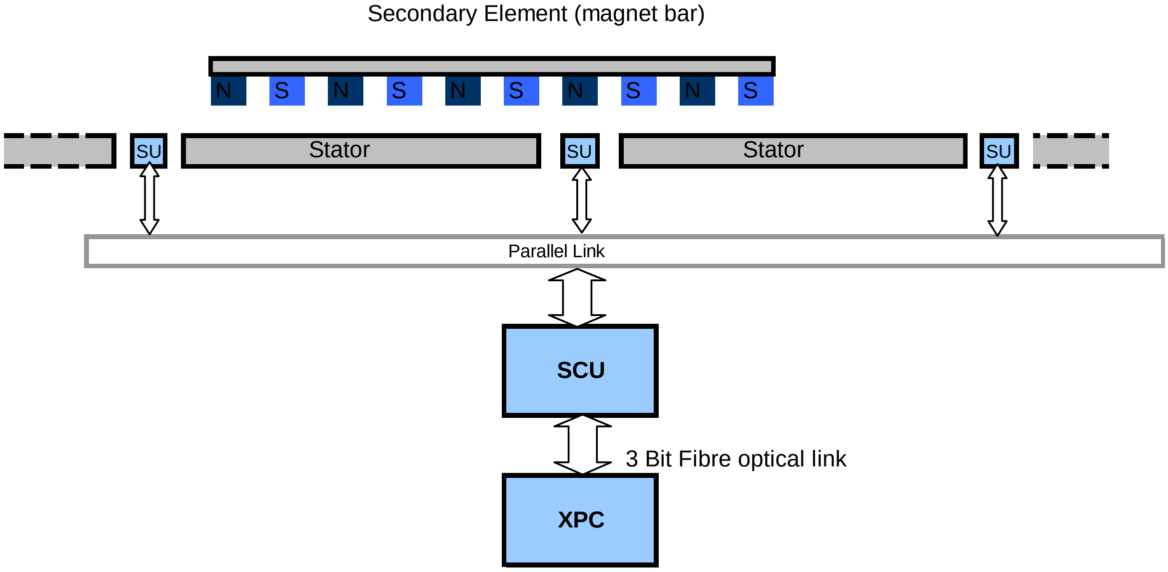
- Segmented Drives (motor elements) each consisting of a number of stators activated simulateously.
- PNET 2002 System and Thyristor Switches to supply the relevant Drive Segements
- SNET 2002 System in conjunction with the XPC to localize the phase angle and measure the speed .
- The power supply including the input transformer, the Inverter and an Output filter to power the drive segments and to control the speed.
- An optional “Power Bridge” energy storage system to buffer the peak energy.
- The low level drive control consisting of the Motor Control and the XPC for low level drive control purposes and a remote access for debug and service application
- The Main Control Unit with the Control Panel, Main Control Software, the Data Logger and a Remote access (usually provided by the system manufacturer)

The stators are distributed along the track and only the required motor elements are activated by the PNET 2002 switches. The actual postion and the phase angle of the moving Secondary Element is determined by the SNET 2002 sensors. The Motor Control samples the SNET values and controls the Inverter considering the actual sensor values, the nominal speed and postions requirements. The inverter than feeds the activate stators with an 3 phase AC. This generates the moving magnetic field whitch pushes the Secondary Element mounted at the trolleys. As an option an energy storage system is available which can buffer the energy necessary for the launches and can also store the braking energy if the option “regenerative braking” is available.

3. Control Principle

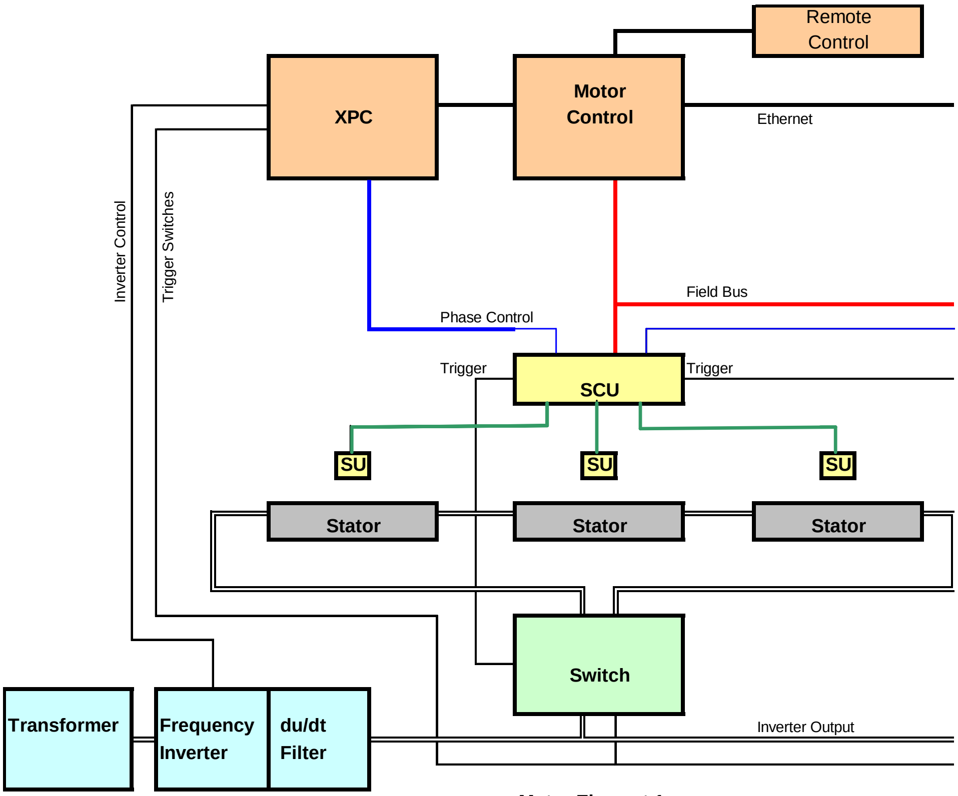
As already described, the technical principle of a synchronous motor is to keep the phase between the stator field (stator current) and the Secondary Element (magnet position relative to the stator coils) “synchroneous” with an optimimized phase shift of 90 degree.

The Sensor Units determine the exact position of the magnets and so the resulting phase shift by measuring the field accross the alternating magnets of the Secondary part (in some applications an additional auxilliary sensor bar is used). Various of such SU are mounted at the track equidistanly using.



LSM S-NET arrangment

The SCU samples and combines the Hall sensor signals of up to 4 SU via a parallel bus and passes this information via an 3 bit optical bus to the XPC.



Motor Element 1

S-NET, XPC and Frequency Inverter

The XPC determines the postion and speed of the Magnet bar mounted on the vehicle by analysing the SCU signal. This information combined with the pole angle and the nominal speed are transmitted to the Drive Inverter via the “inverter control” line.

The Drive Inverter than controls the activiated stator by varying the frequency and the output current of the stators.

Only the actually covered SCU with the relevant Sensor Units (SU) is activated by the XPC. Via the Trigger Line the SCU also enables the required PNET 2002 switch. This switch connects the required motor element (various sators in serie) to the output of the inverter.
Only the motor element actually covered by the Secondary Part is active.The follow on motor element will be activated before transition to this motor.

The XPC together with the Motor Control handles all low level real time control tasks. and is controlled by the MCU via the Ethernet Line. The MCU handles the overall control, the data logging and provides the user interface.

4. Drive System Components Details

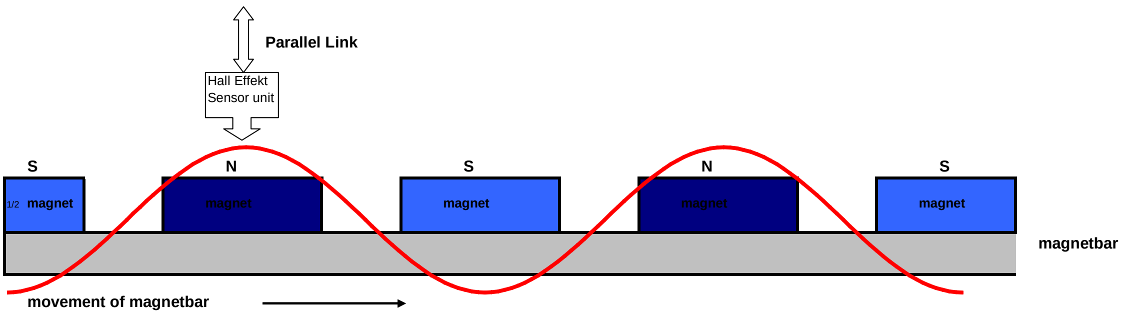
The main components of the LSM Drive System are:

- The motor elements (Stators)
- The Secondary Element (Magnet Yokes)
- An Auxilliary Magnet Bar (optional)
- The PNET 2002 Power Switches
- The Drive Control System (Motor Control plus XPC)
- The Master Control Unit (MCU)
- The SNET 2002 Sensor Components
- The Power Supply
- The Power Storage system

Some major components are described in the following

4.1 SNET-2002 Sensor System

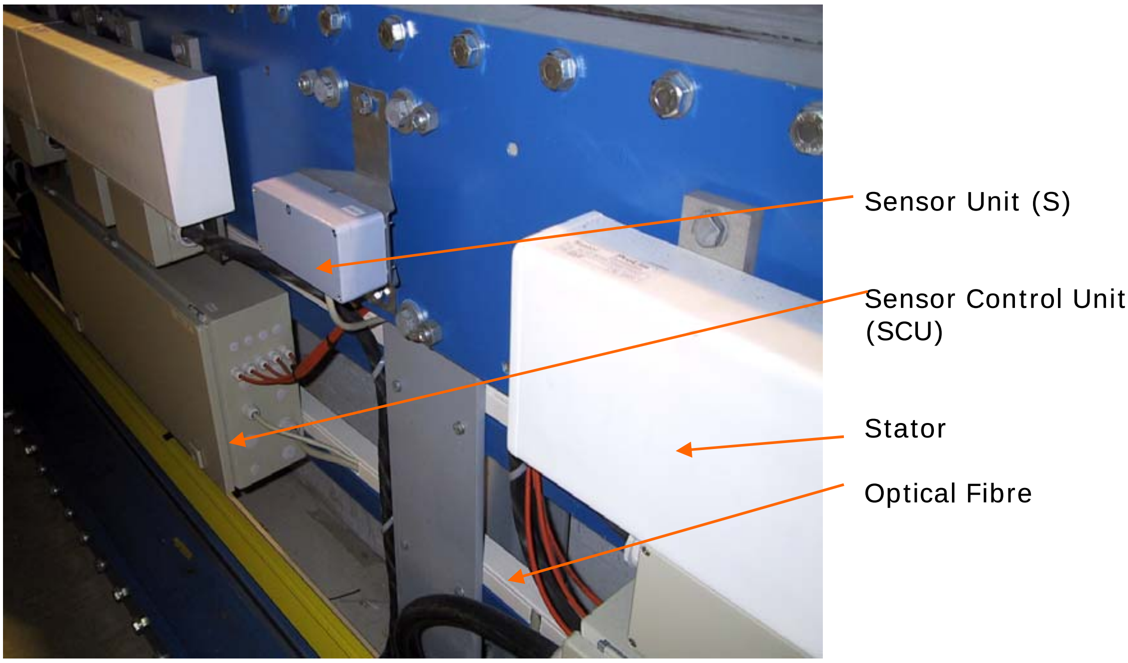
The SNET-2002 consists of the Sensor Units (SU) and the SCU.



Picture: Sensor Units (SU)

The Sensor Units (SU) measure the field accross the Secondary magnets with several Hall sensors. Due to the alternating arangement of a North and South pole magnets the resulting field is sinusiodal when moving the magnet bar relative to the sensor. One cycle (360 degree) of the Sinus Signal refers to the distance between to North Pole magnetswhich corresponds with two pole pitches of the stator. By using several hall sensors the exact angle of the SU relative to one field cycle can be determined by one degree accurancy. Counting the number of cycles leads to an absolute postion of the secondary (trolley) in the track.

The SCU combines the signal of 4 hall-sensors to provide a single 3-bit-signal over a distance of 4 x magnet bar lenght (4 SU'S) . This signal is transmitted via an optical link to the XPC.
This fibre optic are plastic cables, which can easily be mounted at site, without special instrumentation. In each SCU, the signals are inforced (and the local signals fed in) by a one-bit coupler.



Additionally the SCU also includes the following diagnostic features:

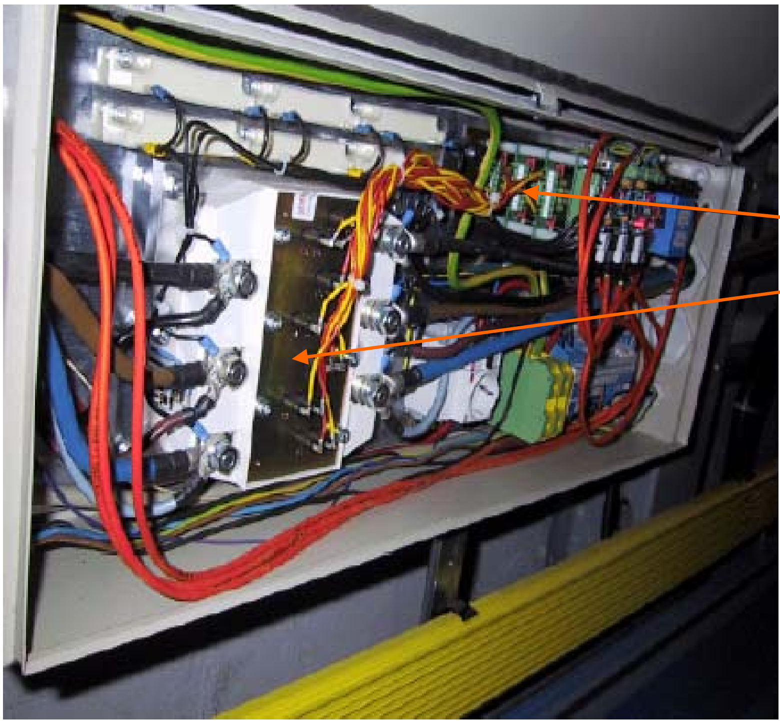
- Interrupted wire to a sensor unit
- Over temperature and status of the Power Switch
- Over temperature of the corresponding motor stators.

Diagnostic informations as well as control commands are transmitted from and to the Motor Control Unit via an independant interface using a standard commercial bus system (Beckhof bus) also with fibre optical link.

4.2 PNET 2002 Power Switches

Various Power Switches are distributed accross the track, Each switch connects a motor element (with up to four stators in serie) to the Drive Inverter. The switch-box consists of a three phase Thyristor Bridge, a gate drive unit (GDU) a power supply and some connection terminals.

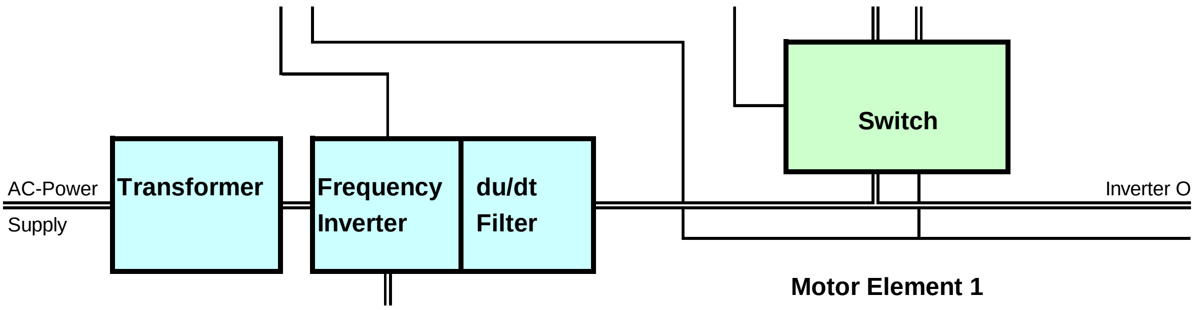
Only the required switches are enabled by a trigger signal sent from the SCU. The Sync Pulses to fire the phases are sent via optical cables from the XPC individually for each phase.



Depending on the installation one or two switches are included in one box.

4.3 The Power Supply

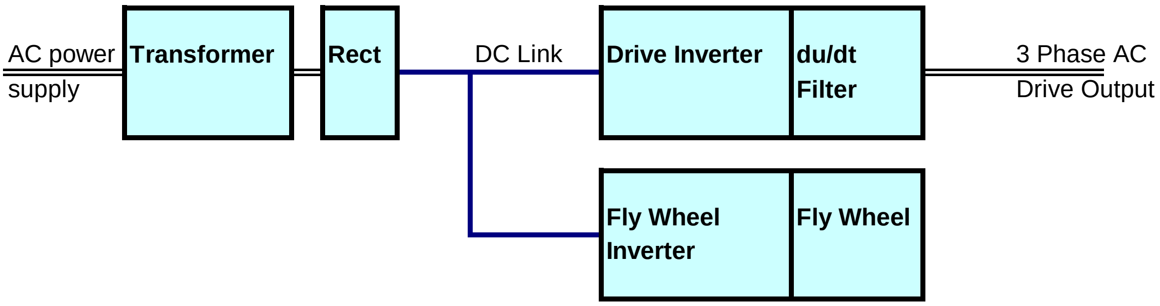
The standard Power Supply consists of an transformer, the Inverter and an du/dt filter to limit the voltage and current rise of the Inverter Output and to reduces the EMC disturbances. This is necessary to protect the PNET 2002 Thyristor Switches.



The Motor can be operated in an acceleration and brake mode. In the brake mode the energy fed back into the system has to be dissipated by means of a braking resistor.

LSM Drives in Amusement rides are typically operated in repeating cycles with relatively short shots to accelerate the vehicle.

This means that the Inverter is designed in a way that it can properly handly the peak currents required for the shots. A typical load cycle is a 3sec shot every 60sec.
During this shots a very high peak current of sometimes more than 3000A is required to feed the motor. Intrasys optional can provide an buffer element using a fly wheel to buffer the energy and to avoid an expensive peak demand on the power line. If the Power Bridge is used also regenerative braking is available as an option.



Option: Energy buffer with Fly Wheel

The input stage of the inverter in combination with the Input transformer and a 3 phase input inductance is designed in a way to optimize the THD and the Power Factor (cos φ) of the system. Typically a power factor of > 0,95 is reached in amusement applications.

4.4 The Drive Control System

The Drive Control System is the overall control system to move the vehicle along the track. It consists of the Motor Control Unit and the XPC. The Motor Control unit in combination with the low level XPC controls the position, velocity, and acceleration in communication with the Inverter and the S-Net and P-Net system. It provides a built-in data logger function and supports trouble shouting and service. A special interface provides remote access for service purposes.
The complete system uses a modular optical communication system for high data rates and high immunity against electromagnetic interference.