

LINEAR MOTORS

Typ
Type
Typ

L1S

L1SK

L2S

L2SK

L3S

L3SK

LTSK

LNS

LA

1. General

1.1. Introduction

An intensive development of the production and the practical application of linear motors and drives has only begun in the last 10 years, although their design principles are well-known for such a long time as those of rotating machines. Before that only patents were applied for, prototypes or technical specialities were built. The reasons are partly economical – a linear motor, especially that with a longer travel is more expensive than a rotating one of a comparable power output, partly technical:

- retaining of a relatively big attraction force between the primary and secondary parts;
- arrangement of mechanical guide ;
- power supply into the moving part .

One of the reasons of this development is looking for a drive with the following characteristics :

- better dynamical properties and wider control range;
- higher speed;
- higher accuracy of positioning.

The possibilities of standard rotating motors with a mechanic transmission of the rotating movement to the linear one are utilized in a number of industrial branches on the limit of dynamical properties given by inertial masses and on the limit of precision given by mechanical clearances and gradual wear. Further reasons of the boom of linear motor production are as follows: technical development, reasonable prices of power electronics (frequency converters, digital controllers), of feedback sensors and first of all of permanent magnets, especially of the type Nd-Fe-B.

1.2. Design of the motor

A linear motor is substantially a standard synchronous or induction motor developed into the plane as can be seen in the figure below .

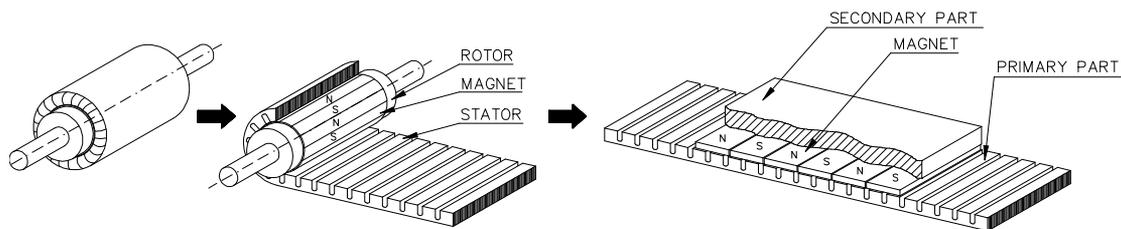


Fig.1.

The stator of linear motors is usually called a primary part and the rotor a secondary part. The primary part is formed, like in the case of standard machines, by ferromagnetic stack composed of laminations and by three-phase winding inserted in its slots. Synchronous motors are designed in such a way that the secondary part, formed by rare-earth permanent magnets (e.g. Nd-Fe-B) being glued on a steel base, is arranged against the primary part. In induction motors the secondary part is formed by the squirrel cage located either in the slots of the ferromagnetic stack, or at least fixed on the steel base of the driven device. The secondary part is usually the longer part of the machine. Which part of the linear motor will be moving depends on the design of the driven device. Most often the primary part is moving along a travel being formed by an arbitrary number of secondary parts. This arrangement requires, however, a movable supply cable, a position sensor cable, and, provided that water cooling is used, also movable supply and outlet of cooling water.

The basic principle of a linear motor has a number of modifications. Some of them are included in our manufacturing programme and are described below.

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1.3. Accessories of linear motors

Basic elements of a linear drive are the motor itself and the power supply. These basic parts are supplemented with mechanical guide, additional coolers and protecting elements. As most of the drives are controlled ones, a control system consisting at least of controllers and of a position sensor is also a part of the drive.

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Some of the mentioned parts belong directly to the driven device and fulfil several functions at the same time – e.g. those of mechanical guide, encoder system (a position sensor) and protecting elements like mechanical stops, terminal switches intended both for the normal operation and for the case of a failure, mechanical covers. Linear motors are usually delivered as built-in parts and form a modular system together with drive accessories.

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1.3.1. Mechanical guide

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The mechanical guide must comply with two basic conditions –static and dynamic loading capacity and required speed. The mechanical guide can be selected on the basis of the following recommendation:

- sliding metal surfaces with sliding friction are suitable for the speed up to $0,5 \text{ m}\cdot\text{s}^{-1}$;
- ball bushes with sliding friction are suitable for the speed up to $1 \text{ m}\cdot\text{s}^{-1}$;
- linear ball or roller bearings with rolling friction enable speed up to $10 \text{ m}\cdot\text{s}^{-1}$;
- ceramic sliding surfaces saturated e.g. with Teflon enable the speed up to $20 \text{ m}\cdot\text{s}^{-1}$;
- air-space bearings and levitation systems are intended for the speed up to $100 \text{ m}\cdot\text{s}^{-1}$;
- latest speed values given in the published papers up to $140 \text{ m}\cdot\text{s}^{-1}$;

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1.3.2. Encoder system

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Encoder systems are mostly incremental and work on a magnetic or photoelectric principle.

A magnetic sensor is formed by magnetic read-head and carrier tape of the required length with a thin recording layer carrying information about the position (magnetic grid). On the carrier metal tape of optical sensors of the up-to-date design there is an etched scale with $20 \mu\text{m}$ pitch. The read-head consists of light (laser) source, sensing optical system directed at the signal reflected from the tape, and electronic shaping circuit.

1.3.3. Control system – controllers

Digital controllers are used almost exclusively. The arrangement of three feedbacks – internal current feedback, middle high-speed feedback and external position feedback – is prevailing. In some cases the acceleration control is inserted into the circuit and band-pass filters are added for improving mechanical stability of the drive. A processor with a high operation speed (up to 10^7 instructions/sec) and an interpolator are basic elements of the control system. There is a two-way communication between the control system and the linear motor – the motor does not receive the control system instructions only passively, but by means of different sensors informs it about its state. Besides the position that has been already mentioned and the given current, also sensing voltage and temperature, signalling overload, falling out of synchronism, loss of control stability, etc. are possible. The drives being controlled in this way are called “intelligent drives”.

2. Manufacturing programme of linear motors in VUES Brno a.s.

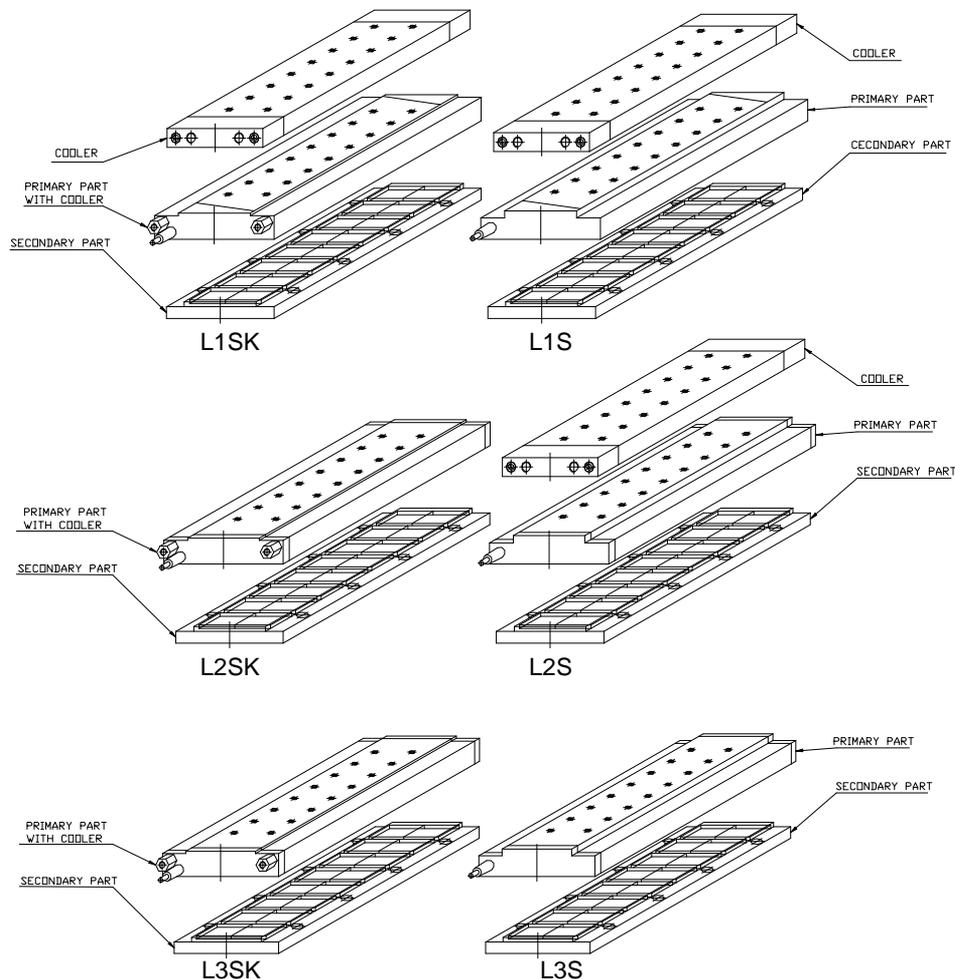
The manufacturing programme of linear motors in VUES Brno a.s. is directed mainly at production of three versions of synchronous linear motors. VUES Brno a.s. has been dealing, of course, also with production of induction linear motors or special synchronous tubular motors (see below).

2.1. Synchronous linear motors

These motors are three-phase synchronous motors with the winding distributed on the primary part excited by permanent magnets of the type Nd-Fe-B with peak magnetic parameters, which are included in the secondary part (see the figure).

The motors are adapted for being supplied from field-oriented controlled frequency converters. The motors supplied from converters with the intermediate circuit voltages of 120, 330, 560 V_{DC} are considered to be

standard ones. The winding of linear motors can be made to order also for the supply from converters with other intermediate circuit voltages.



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Fig.2.

As it is shown in Fig. 2, we can distinguish two basic designs in three versions of linear synchronous motors: a simple one called L1S (version 1), L2S (version 2), L3S (version 3), and a design with an integrated cooler called L1SK (version 1), L2SK (version 2), L3SK (version 3).

Note: For convenience's sake we will designate individual designs of all three versions LXS and LXSK, where X is the version number.

The primary part is a compact unit with the winding and the magnetic circuit cast in plastic. In the case of the design LXSK, the special structure of the water cooler is also sealed together with the winding and the magnetic circuit. The secondary parts can be set up to the necessary length of travel. Magnets are protected against mechanical damage and environmental influences by being cast in plastic. Linear motors in the basic design are offered as built-in ones with a range of accessories (additional water coolers, thermal insulation plates).

- **L1S, L1SK** - compact design in sizes with the force of 50 N to 16000 N, speed from 0,01 mm/s up to 15 m/s and module of the active surface width 25 mm;
- **L2S, L2SK** - compact design in sizes with the force of 50 N to 16000 N, speed from 0,01 mm/s up to 15 m/s and module of the active surface width 25 mm;

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- **L3S, L3SK** - compact design in sizes with the force of 50 N to 16000 N, speed from 0,01 mm/s up to 15 m/s and module of the active surface width 25 mm.

2.2. Induction linear motors

Linear motors of the series LA are operating on the principle of an induction machine. In comparison with synchronous linear motors they have a simpler and cheaper secondary part being formed by a squirrel cage. The squirrel cage consists either of the winding located in slots, or by the aluminium (copper) bar fixed to a steel base. The latter type of the secondary part can be used advantageously in conveyers, industrial manipulators, feeders, drives of sliding gates, doors, barriers, etc. Another advantage of these undemanding drives is the possibility of being directly supplied from the standard distribution network 3 x 400 V/50 Hz, without a necessity of using frequency converters.

- **LA** - are produced in sizes with the force of 100 N to 300 N.

2.3. Tubular linear motors

The drives with tubular linear motors are intended especially for precise in-feeds of automatic boring machines for printed circuit boards, where the motors carry high-speed boring spindles, in-feeds of machine-tools, in-feeds of heads of populating automatic machines, controlled valve drives, slide valves, etc. They consist of the solid cylindrical primary part with the winding cooled intensively by water, and of the external moving part formed by a steel sleeve with permanent magnets. The rotating symmetric arrangement of the machine compensates attraction magnetic forces between the primary part and the secondary part in such a way that they are not transmitted to the driven device. The advantage of this motor is the absence of thrust force pulsations.

- **LTSK** - are produced in sizes with the force of 300 N to 1200 N, stroke 25 mm to 265 mm and are made either in the built-in version or with the frame of drawn aluminium profile.

2.4. Synchronous linear motors with primary part without ferromagnetic materials

Primary parts of these motors do not contain any ferromagnetic materials. They are characterized first of all by low mass, absence of thrust force pulsations, practically zero attraction forces between the primary part and the secondary part and high efficiency. Thanks to these qualities, they can be used with advantage in applications with great demands on speed, acceleration, precision and low mass of the drive.

- **LNS** - are produced in sizes with the force of 10 N to 50 N.

3. General technical and operating conditions of the motors

3.1. Cooling of linear motors

Primary parts:

- | | | |
|--------------------------|----------------|---|
| □ series LXS* : | IC40 | i.e. natural cooling by motor surface |
| □ series LAS : | IC40 | i.e. natural cooling by motor surface |
| □ series LNS : | IC40 | i.e. natural cooling by motor surface |
| □ series LXSK* : | IC3W7 | i.e. water cooling by integrated cooler |
| □ series LTSK : | IC3W7 | i.e. water cooling by integrated cooler |
| □ series LXS* + cooler : | IC3W7 | i.e. water cooling by additional cooler |
| □ series L1SK + cooler: | IC3W7 | i.e. water cooling by both types of coolers |
| □ Secondary parts: | are not cooled | |

3.2. Operating conditions

Linear motors are designed for being used in the environment protected against weather influences defined in ČSN EN 60721-3-3:

- ambient temperature +5 °C to +25 °C;
- relative humidity of air 5 % to 95 %;
- altitude above sea level up to 1000 m;
- For water cooling, there is necessary to use treated water without mechanical impurities. The recommended water hardness is max. 0,7 nmol/l. If necessary, water softeners are to be used. The recommended cooling water acidity is 6,5 pH to 7,5 pH. The inlet water temperature is +5 °C to +25 °C. The maximum quantity of cooling water is 5 l/min at the pressure drop of 2 hPa. The cooling system is tested at the maximum pressure of 1 MPa.

3.3. Other technical data

- Degree of protection of the motor:
A high degree of protection against contact with live parts is reached by embedding the whole winding and the primary motor circuit into protective sealing compound. As the motors are usually delivered as built-in ones, protection against contact with moving parts cannot be ensured.
- Thermal insulation class "F" according to ČSN 35 0000, Part 1, maximum temperature rise of the winding is 105.
- The winding of the standard motor design is three-phase one, star-connected, without neutral point led out.
- Thermal protection:
The winding of the standard motor design is protected by a thermal sensor (break contact) being located in end windings and reacting at the temperature of 125 °C. By request of the customer also PTC or resistance thermometers can be used as thermal sensors.
- Connection of the motor to the converter:
The winding outlet is made as a standard by flexible cable enabling also supply of the moving primary part. By request the motor winding can be led out to a connector determined by the customer.
- Surface protection:
Surface protection is made by black varnish paint. By request of the customer also a paint for food industry or another shade can be used.

3.4. Labour protection

Because of permanent magnets ($Br \approx 1,2 \text{ T}$) on the secondary part, both parts of the linear motor must be handled very carefully.

High-energy magnetic fields and associated high magnetic attraction forces can result both in direct life endangering (e.g. people with pacemakers) and indirect one (high speed of moving parts of the machine).

As to the influence of magnetic field to human body, the latest medical reports confirmed that magnetic field with induction lower than 5 mT does not influence it in any way. In the distance of about 100 mm magnetic field induction is already lower than 5mT. Intensity of magnetic field induced by the poles of the secondary part of the linear motors is constant and independent of the operating conditions of the machine.

Because of a high attraction force, there is necessary to pay an increased attention in the vicinity of the secondary part. That is why heavy ($> 1 \text{ kg}$) or big ($> 1 \text{ dm}^3$) parts made of steel or iron must not be handled by naked hands close to secondary parts. As magnetic forces are invisible, they are often underestimated. Attraction forces act suddenly and can reach values higher than 500 N (50 kg) very quickly because of ferromagnetic objects being in the vicinity. Injuries caused by attracting of individual parts due to magnetic forces are very painful and unpleasant, treatment and healing of the wounds is very difficult. It is necessary to comply with particular rules in handling them. The most important ones are given below.

Main precautions :

- Warning plates must be located on visible places ("ATTENTION: STRONG MAGNETS IN LINEAR DRIVES OF THIS MACHINE!", "STRONG MAGNETIC FIELD!", "HIGH MAGNETIC ATTRACTION FORCES!").

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- Watches and electronic data media being sensitive to magnetic field must not be put near secondary parts.
- Assembly or maintenance must be carried out always in gloves.
- Persons with pacemakers should not handle secondary parts.
- Heavy metal objects must not be placed near secondary parts of the linear motor.
- Assembly and maintenance must be carried out by trained operators.
- For the case of an accident that could occur when working with linear motor at least two solid wedges made of non-magnetic material, e.g. of stainless steel (with the angle of 10° to 15°) and a hammer (approx. 3 kg) must be always at hand. It is necessary for the separation of ferromagnetic parts attracted by magnetic field to the secondary part, and possibly also for subsequent releasing of fingers, hands or feet.

Rules for transport and storage:

- Products in store rooms must be designated with a warning plate ("ATTENTION! STRONG MAGNETS!").
- Products must never be stored without a cover, always a special non-magnetic packing with the electromagnetic gap of 25 mm must be used.
- Warning plates must be read and complied with.
- Store rooms must be kept dry.
- Products must not be stored at high temperatures.
- In the course of transporting the machines or their parts with built-in primary and secondary parts their mutual moving must be prevented.

Assembly rules:

- The secondary part package must be removed just before it is mounted into the equipment.
- The assembly must be always done by two workers.
- For the case of an accident at least two solid wedges made of non-magnetic material, e.g. of stainless steel (with the angle of 10° to 15°) and a hammer (approx. 3 kg) must be always at hand. It is necessary for the separation of ferromagnetic parts attracted by magnetic field to the secondary part, and possibly also for subsequent releasing of fingers, hands or feet.
- The secondary part of the linear motor must never be placed with its magnetically active surface directed at the ferromagnetic parts of the equipment.
- The primary part of the linear motor must never be placed directly against the secondary part.
- Before starting the assembly work on the equipment where the secondary part have been already installed this part must be provided with a non-magnetic cover with the electromagnetic gap of the width approx. 25 mm (e.g. a wooden plate of the thickness 25 mm).
- Any spontaneous movement (due to magnetic forces) of the primary and secondary parts of the linear motor that have not yet be built in must be prevented.
- Any spontaneous movement of the secondary part or primary part of the linear motor along its assembled track must be prevented.
- Special assembly facilities can be used, if necessary.

4. Power characteristic of the linear motor

Linear motors are generally designed in the same way as servomotors rather for dynamic processes with a wide range of speed and with a variable load than for the continuous running duty S1 with constant load and constant speed. That is why these motors can be loaded with substantially higher forces (currents) than the rated ones, provided that their average r.m.s. value does not exceed the rated values for the continuous running duty S1. The utilizable working area from the point of view of the linear motor can be seen from the power characteristic.

Blank