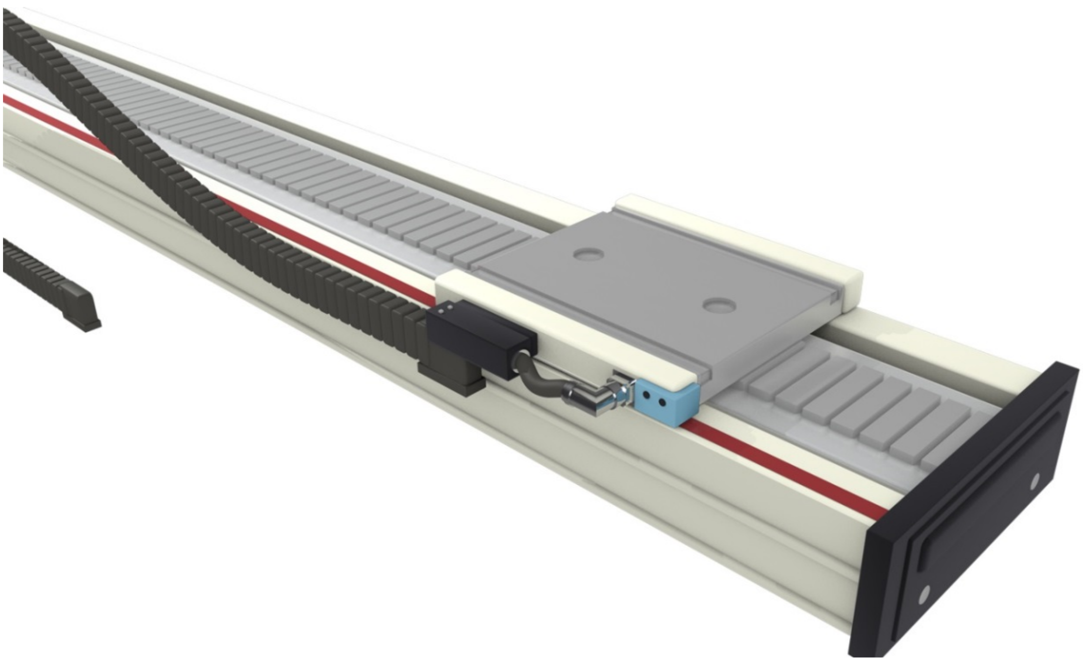
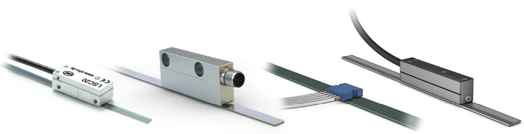
WHITE PAPER

High productivity with open motor feedback systems

Selection criteria for motor feedback solutions based on optical, magnetic, inductive, and capacitive measurement systems



Motor feedback solutions based on the optical, magnetic, capacitive or inductive measurement principle are offered for the exact control of linear and rotative direct drives. The decision to use a particular system is greatly application-dependent. Three main criteria determine the selection of a perfectly suited motor feedback solution: Precision, insensitivity to mechanical and external influences as well as the price. Based on the above criteria, this white paper will present the pros and cons of the four measurement principles. Examples, drawings, tables and figures facilitate the choice of the most suitable system for any conceivable application.



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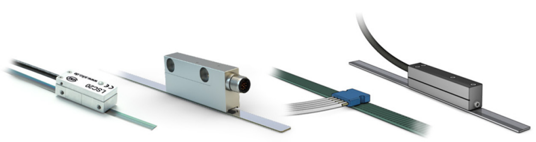
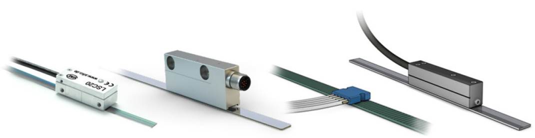


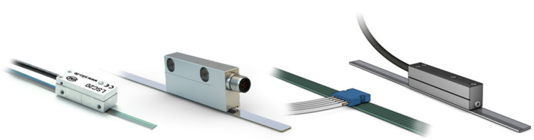


1 Introduction: Efficiency and economy

Efficient and reliable drives are an important precondition for high productivity in industrial automation. Machines and plants can work faster, safer and more resource-saving when drives are controlled and exactly governed. Encoder solutions which meet the specific requirements of the production environment regarding the measurement system and which gather precise values for length and position measurement are fundamental for this purpose. Rotative and linear motor feedback systems are built into electrical drives to measure velocity and detect motor positions. The specifications of these measurement systems are as diverse as are the areas of application where the sensors are used. Therefore, the choice of a suitable measurement system is based on the following principle: the combination of required precision with least possible interference by external impact in order to arrive at an economical solution. The performance of the measurement system even under severe conditions together with precision and economy of the system is one of the main arguments for the choice of the suitable measurement technology.

In the last years, a great variety of products for length measurement (sensors/measurement systems) was developed based on various customer requirements. The optical systems have been on the market for the longest time for this type of application. Since the early 2000 years, additional technologies based on the magnetic, inductive, and capacitive measurement principles became established. From a technological point of view, these systems do not yet reach the very high accuracy classes of the optical systems. On the other hand, compared with the three methods mentioned above, the optical systems are more sensitive to external influences such as dust or liquids as well as mechanical impact such as vibration or shock. If economic criteria additionally influence the choice of a suitable measurement system, the advantages of the magnetic systems may outweigh those of the optical, inductive of capacitive ones – always depending on the application in question.

In order to give end users assistance regarding their orientation in the area of motor feedback systems, the fundamental aspects of the optical, magnetic, inductive, and capacitive measurement principles will be explained and compared in the following sections.



This will result in a guideline for the selection of a customized position measurement system of linear and rotative direct drives which is suited for the particular application.

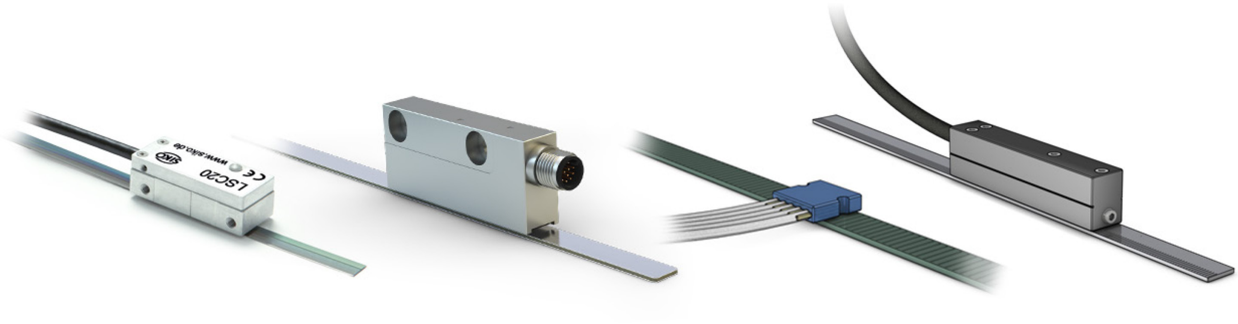
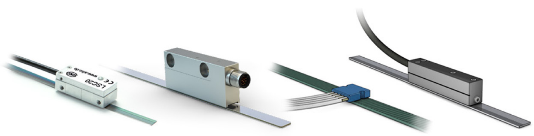


Figure 1: Physically different solutions of position detection (from left: optical, magnetic, capacitive, inductive)

2 Overview of linear and rotative direct drives

2.1 The difference between linear and torque motors

In case of direct drives, the electric motor and the machine driven are directly connected, no gear mechanism is employed. Linear and rotative direct drives are differentiated in a wide size and performance spectrum. With the rotative drives, the use of torque drives increasingly gains in importance. The translatory linear drives can often be found in the form of positioning drives in the area of machine tools. Linear motors are employed wherever it comes down to a very good force-to-mass relationship and optimum synchronization. They are best suited for tasks that require highest accuracy of path and constant velocity.



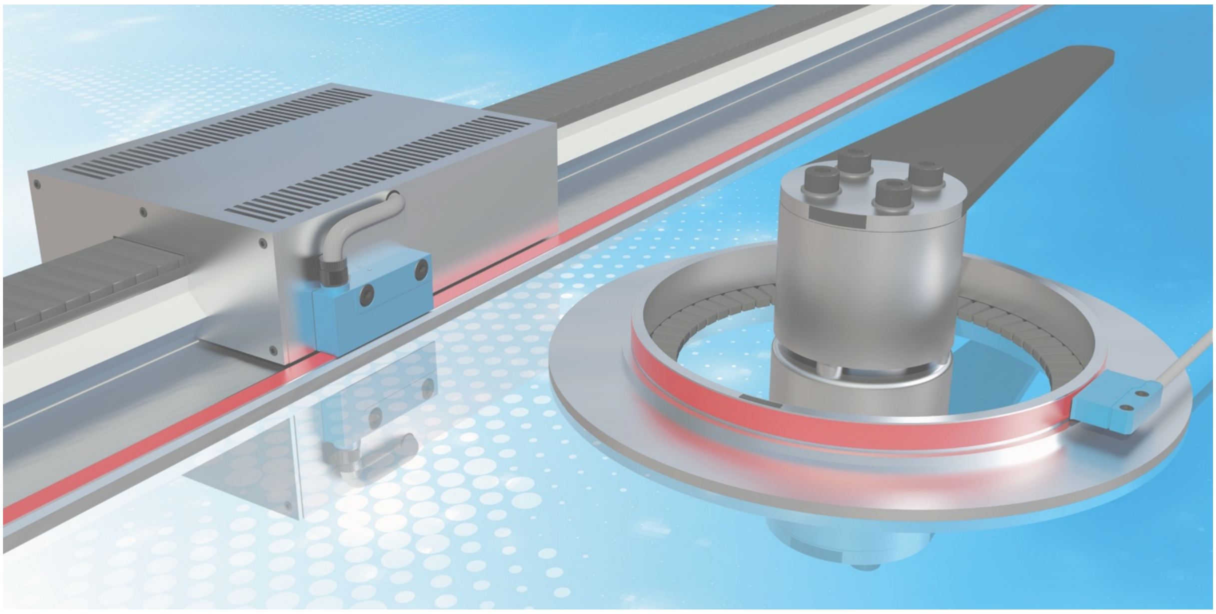
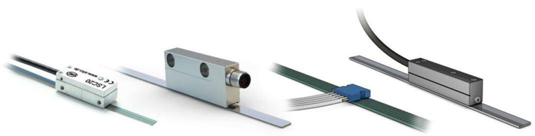


Figure 2: Motor feedback solutions on linear and torque motors (schematic view)

A linear direct drive can be compared with an opened motor. The AC motors used have magnets in the form of permanent magnets and a coil through which power is applied. The alternating field created ensures that the coil moves in this magnetic field – or also the magnetic strip depending on what is fixed mechanically. In this case, the coil is mounted on a slide, which moves along the magnet via a linear guide.

Torque motors are best suited for applications requiring high torque combined with ideal synchronization. Rotative drives function like the linear drives. However, the coil is turned in the magnetic circuit in case of rotative motors. As a rule, torque motor feature a through hollow shaft that permits the feed-through of cables or compressed air lines as required with robot applications for instance.

In both systems, the requirement is specified that motor feedback, i.e. position feedback, is needed since there is no mechanical coupling such as a gear mechanism as a rule.



2.2 Requirements of motor feedback solutions

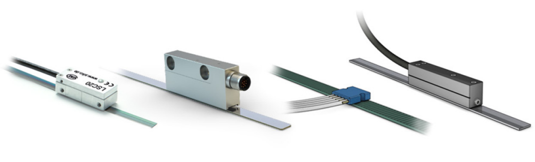
Motor feedback is the generic name for the position feedback of linear and rotative systems. Systems consisting of motor and control are concerned – an electrical drive controls the motor and the measurement system acts as the link to the downstream electronic system or controller, resp., which in turn transmits a signal to the motor indicating the direction, velocity and precision of travel. The measurement system is called motor feedback system in these applications.

Basically, three main criteria are set for motor feedback systems: Firstly, precision with regard to measurement accuracy and repeat accuracy play a decisive role. Generally it can be stated: The longer the measurement path, the less precision is required and the more suitable are magnetic systems.

Insensitivity to or protection from mechanical impact including shock, vibration and interfering ambient conditions originating from liquids, lubricants, dust, etc. are the second requirement of the overall system. Only specific systems can be used if these influences impact the measurement system. Much water is needed for cooling the tool in glass working for example. The optical and capacitive measurement systems are very sensitive to humidity. Therefore, they drop out for such areas of use and only inductive or magnetic solutions are qualified.

The third decisive criterion is the price. Equipping a very extended distance with the measuring sensor system can be expensive for specific linear systems. By way of comparison: magnetic scales are approx. 60% cheaper than optical scales.

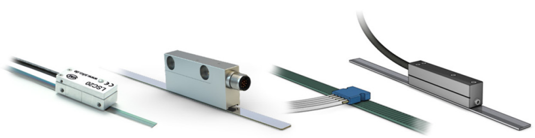
If motor feedback is concerned, the above-mentioned issues play a primary role. However, additional aspects should be clarified in advance, e.g. the choice of the suitable interface for the communication of motor and controller as well as the question whether the system should be incremental or absolute. For an incremental system it should be considered that a



reference position must be driven to when energizing the system in order to enable the targeted start of motor travel from a specified position. This reference travel is not required for absolute measurement systems. In case of systems for rotative applications it is important to note that the maximum shaft diameter influences the choice of the suitable measurement method.

On principle, the technological progress in the area of controller engineering has resulted in additional requirements e.g. regarding the precision of motor feedback solutions. Nowadays, modern controllers are able to work with cost-efficient systems in a way that enables motors to largely work in an absolute steady-state running condition. This was not the case some 15 years ago. Nevertheless, the decision to use a particular system is still application-dependent to a high degree.

Figure 3: Modern controller solutions: indispensable for efficient solutions in drive engineering



3 Technologies of open measurement systems for motor feedback

For the identification of motor feedback, open measurement systems without encapsulation or mechanical connection to the drives are mainly used because the design of the scale can be flexibly handled with open systems. With closed systems, scale and sensor unit form a unit which makes them less adaptable. However, great effort is required to keep dust or humidity away from open systems. For instance, lip seals are built in that prevent dirt from entering or dirt is sucked off by means of compressed air during operation. These measures influence the costs for the chosen method in turn.

However, they are indispensable for requirements of high precision, for example with high-performance machine tools.

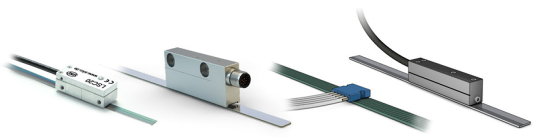
The four systems described in this white paper can all be designed as open systems. Moreover, the magnetic, capacitive and inductive systems are contactless systems which require no contact of scale and sensor unit, thus ensuring virtually wear-free use. The optical methods, too, function contactlessly on principle – with one exception: An optical sensor system based on glass scales features an indirect guide and a mechanical protective installation, which means that is not 100 per cent contactless.

Below, four measurement systems for motor feedback solutions are described with regard to their functionality and their pros and cons concerning possible applications highlighted.

3.1 Optical systems

3.1.1 Glass scale compared with epi-illumination and laser technology

In the realm of optical systems, systems based on glass scales are distinguished from epi-illumination or laser technology, resp. In case of laser-based technology, information is evaluated on an optical scale by means of the Talbot effect. Brightness distribution is arranged grid-type at defined distances. A grid structure is applied behind the sensor head as



well. This grating is then exposed to monochrome waves so that the light distribution behind the grating is wider. The position values are forwarded to the downstream electronic unit as digital counting impulses (A, B, R).

As a rule, the laser-based systems use a thin metal strip as the scale. As a special feature the scale is flexible enough to permit winding or coiling it up. This is an advantage compared to the glass scales where the glass support is rigid although it is mechanically fragile. It is applied in a profile in a protected manner and is not flexible for that reason. The sensor head is moved over the gradation on the glass scale and reads it.

By contrast, the glass scale’s advantage is that it can be designed very precisely. Measurement accuracies of at least 3 micrometers or significantly better can be achieved. The micrometer deviation per meter of measured distance is very low the the glass scales over the whole length. Therefore, they are predominantly used for shorter measuring ranges. For distances of many meters it would require much effort and be expensive to transport the long rods made of glass. Another disadvantageous aspect of the glass scales: They are less resistant to mechanical impact such as shock or vibration. There exists the danger of the glass rod breaking and of damage to the whole measurement system. Under such conditions, protective measures against shock or vibration are required for this measurement system.

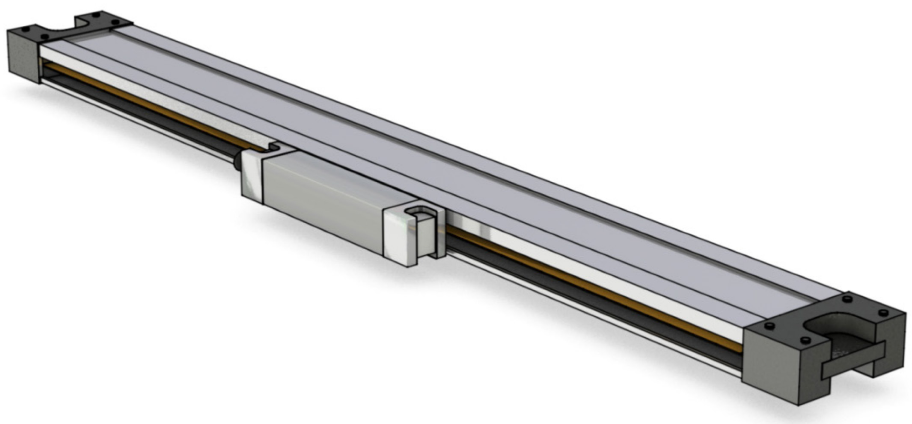
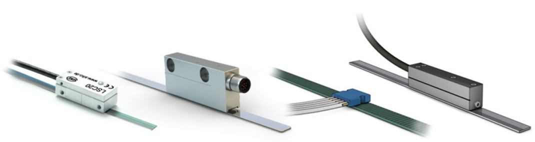


Figure 4: High-precision glass scale with guided sensor head



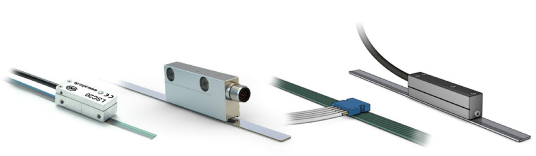
3.1.2 Pros and cons of optical systems

The most important benefit of optical scales is their high precision and fine resolution. The accuracy of an optical sensor is ± 5 micrometers, its resolution is 0.05 micrometers. The smallest grid or scale gradation, a relevant criterion of accuracy, is 20 micrometers with optical systems as a rule. This is the smallest measurement step applied on the scale. The values are then interpolated in the electronic unit and calculated down to a smaller division which will then be processed in the downstream controller. High dynamics, fast travel speed, paired with the requirement of high-precision specifications such as accuracy, repeat accuracy and high resolution can be achieved with the optical systems.

Another advantage of optical systems is their insensitivity to magnetic disturbances. For instance, when linear motors are used, electromagnetic fields develop, which can influence the position values of magnetic sensors. But the magnetic impact of linear motors is critical only if sensor head and tape measure are installed too near to the motor. This problem can be remedied by a defined safety clearance between motor and sensor or by a shield, which is normally possible with sufficient space.

Moreover, the optical measurement systems are more sensitive to ambient influences including dust, oils or fats. Temperature fluctuations and high humidity resulting in condensation on the code strip can also affect the optical systems. The implementation of complex protective housings is required in order to prevent dirt and humidity from entering the sensor unit resulting in an increased price of the measurement system.

Generally speaking, optical sensors are more expensive than magnetic sensors for instance. The cost of an optical sensor is about double the cost of a magnetic sensor. The price of optical scales is two or two and a half times the price of magnetic tapes.



3.2 Magnetic systems

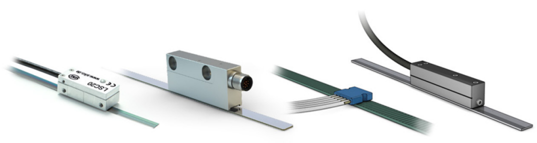
3.2.1 Technology of magnetic systems

With the magnetic measurement systems, the sensor travels contactlessly over a magnetic tape applied to a steely carrier layer of a few tenths of a millimeter thickness. The scale is magnetized with defined pole pitches. This means that a signal is created and converted into digital signals when the magnetic poles are scanned. The digital signals are processed by a downstream electronic unit. The sensor system recognizes the division of the tape and converts the information into high-resolution path information.

Figure 5: Solution for position detection of linear and rotative direct drives, tried and tested for years: High-resolution incremental magnetic sensor from SIKO MagLine

3.2.2 Special applications with gantry drives

Gantry drives for instance are realized with very long linear motors, with the requirement to travel very quickly from one point to another. The requirements of accuracy and precision are not very strict. Nevertheless, there is a special feature with gantry drives. SIKO is the only supplier of magnetic motor feedback solutions to offer the possibility of using the magnets of the motor lined up as the scale over a certain lengrh. With a custom-designed sensor



system, the motor strip can be used as the scale. The customer benefits from this arrangement insofar as no additional scale is required and costs are saved. The only restriction: There exists no solution off the rack. The system must always be adjusted explicitly.

3.2.3 Pros and cons of magnetic systems

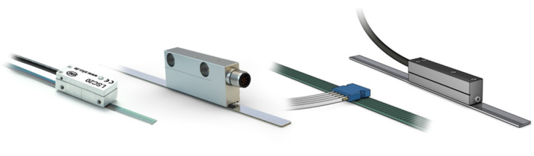
Magnetic systems are resistant to dirt, oils, and humidity. For instance, a magnetic scale is functional also in an oil bath. This spectrum of use would also be conceivable with the inductive systems.

Since the magnetic sensor system performs relatively stably also under mechanical influences such as shock and vibration, a wide field of application opens to the user, e.g. for outdoor units and systems or with machine tools. The robust magnetic measurement technology is even suited for extreme applications such as stone or glass working. The flexible handling of the magnetic tapes is an additional advantage. The user can stock the tapes as rolled goods and cut to size as needed.

The coding of the scale uses relatively rough structures with the magnetic scales, which partly allows for relatively large reading distances of up to several millimeters. This is not possible with other systems. With the optical systems for instance, the grid structure has a very small design and the distance between the scale an the sensor head must not exceed a few tenths of a millimeter.

The inductive technology in general allows for scale divisions of one millimeter resulting in reading distances of a few tenths of a millimeter also in this case. Here, relatively large-volume reading electronics is required due to the principle of measurement. By contrast, the reading heads of magnetic systems may be somewhat smaller.

Compared with optical systems, magnetic systems are characterized by lower absolute accuracy, resolution and repeat accuracy on principle. Moreover, a magnetic sensor can be



affected by external magnetic sources of interference – a disadvantage regarding measuring accuracy.

3.3 Capacitive systems

3.3.1 Technology of capacitive systems

The capacitive principle of measurement can be compared with a capacitor. The system is based on two mutually changeable plates. The change of the position generates an electric signal which again is used for position detection. The scale consists of a PCB.

The design of the capacitive systems predestines them for rotative use in torque motors, but linear applications can be realized as well with restrictions regarding the lengths of the scales because of the principle of measurement. They are mainly used in the handling area where constant conditions predominate.

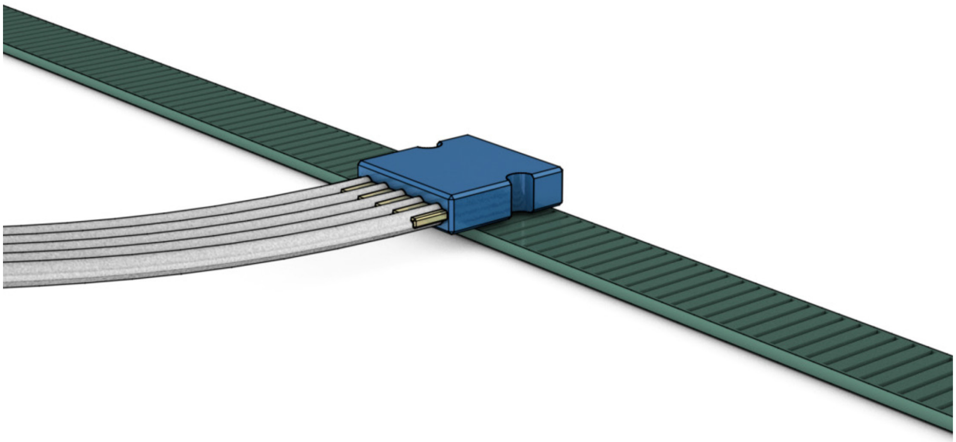
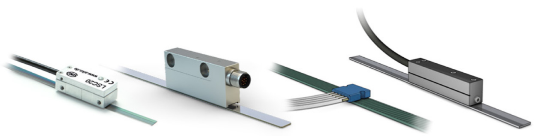


Figure 6: Capacitive scale in a small, compact design



3.3.2 Pros and cons of capacitive systems

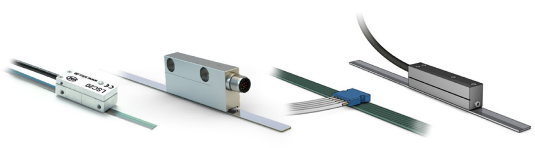
The question of cost has priority with the capacitive systems. They have the advantage that the material is very cheap. The fact that capacitive sensors are designed to fit on specific, especially rotative motor types is another ideal feature. However, this aspect also restricts the use of these systems, since they are fixed to only a few types of construction. Regarding the price, comparable solutions can easily be offered with the inductive as well as magnetic systems. With the optical systems, it is more difficult, however, to combine rotative motor shafts with optical scales. This effort would result in an unreasonably higher price.

The serious disadvantage of capacitive systems is their sensitivity to humidity. Therefore, capacitive sensors are excluded from certain areas of application, e.g. where water or coolant must be used for cooling tools.

3.4 Inductive systems

3.4.1 Technology of inductive systems

With the inductive systems, a structure is etched into the scales – comparable to the optical systems. Thus, fine structures are created, which are etched in a steel tape. The scales can be designed with similar lengths as with the magnetic ones. 30 to 70 meters of coiled scales are technically feasible. The electronic system functions so that the the sensor has multiple small coils. Current is applied to the coils and the characteristics of these coil currents changes by traveling over these fields or slots. This forms the basis for calculating the relative movement or position.



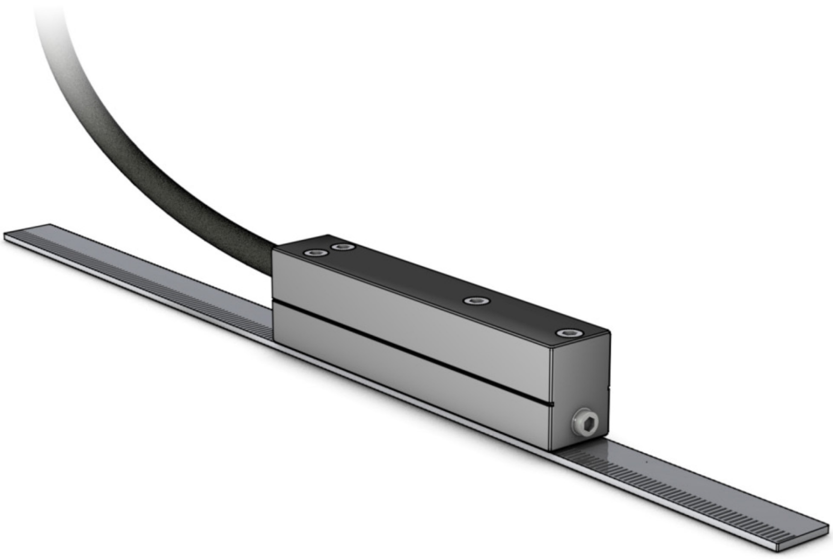


Figure 7: Inductive measurement systems combine precision, high resolution, and repeat accuracy

3.4.2 Pros and cons of inductive systems

The specification regarding accuracy and resolution is nearly comparable for magnetic and inductive measurement systems. The inductive systems have a decisive advantage: they are less sensitive to external magnetic fields. This is one of the main arguments in favor of inductive measurement systems.

Regarding the price one can say that the inductive system is more expensive than the magnetic one as a rule. The electronic design of the inductive solutions is more complex with regard to the hardware. The scales have comparable prices.

3.5 Tabular overview and comparison of the systems

Each one of the four above-named systems has its peculiar pros and cons related to the particular application. The criteria of precision, resilience, and price determine the decision of whether to choose an optical, magnetic, capacitive, or inductive system.

The table below gives an overview of the central criteria.

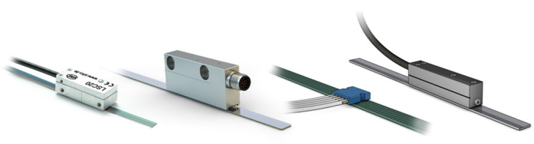
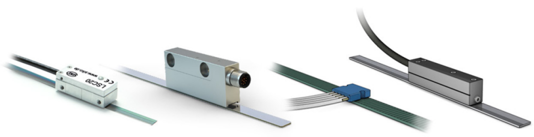


Table 1: Exemplary overview with selection criteria for motor feedback solutions based on flexible scales

		Optical measurement system	Magnetic measurement system	Capacitive measurement system	Inductive measurement system
Precision	*Absolute accuracy*	High system accuracy ± 2 µm and better	System accuracy ± 10 µm	System accuracy max. ± 25 µm	High system accuracy ± 3 µm
	Repeat accuracy	Very high repeat accuracy	Repeat accuracy max. ± -1 µm	Repeat accuracy 1 µm	Very high repeat accuracy
	Resolution	Very high resolution 0.2 µm and finer	Lower resolution max. 0.2 µm	Very high resolution 0.02 µm	Very high resolution 0.25 µm and finer
Resilience	*Mechanical impact such as shock and vibration*	Sensitive	Robust	Relatively robust	Robust
	Influences from the production environment	Sensitive to dust, shavings, oils or fats as well as temperature fluctuation and high humidity	Stable under external influences	Very sensitive to humidity	Stable under external influences
	Magnetic influences	Insensitive	Sensitive (keep a safe distance)	insensitive	insensitive
Economic efficiency		Relatively expensive, highly precise solution	Similar price level as capacitive measurement systems	Saving owing to lower material cost	More expensive than magnetic measurement systems regarding the electronic system



4 Areas of application

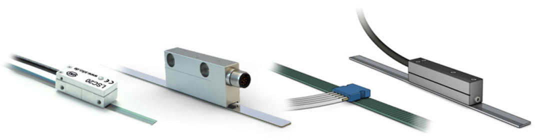
When choosing a suitable measurement system it is important to assess and bring in line the requirements of precision and the probability of external conditions influencing them. Furthermore, the decision for an optical, magnetic, inductive or capacitive system depends on economic factors. Examples of application based on these criteria will be presented below.

4.1 Handling automation

The requirements of handling automation vary considerably in some cases. When small components are placed on a circuit board with high repeat accuracy in the hundredth millimeter range over thousands of pads, the requirements are significantly higher than in robot technology where movements are carried out from one position to another, which are intended to surmount distances of several meters.

An example of automation in the electronic area is mass assembly of smart phones. A high number of components has to be assembled very quickly and cost-efficiently. The PCB circuit boards are already populated but the individual components must still be brought together. Here, automatic machines can be used, which fulfill the requirements of positioning in the tenth millimeter range. The assembly feed with repeat accuracy and precision of a decimillimeter are fully acceptable. Consequently there is a high probability that inductive or magnetic systems will be used because extremely high precision as with the optical systems is not required.

Using the example of handling automation in filling technology it is important that humidity is present for instance when mineral water is filled into PET bottles. It is unlikely that optical or capacitive systems that are prone to be adversely affected will be employed for such



purposes. Great quantities of dust which may settle on the scales develop in the packaging technology. Unlike the capacitive or magnetic systems, the optical systems would have to be cleaned.

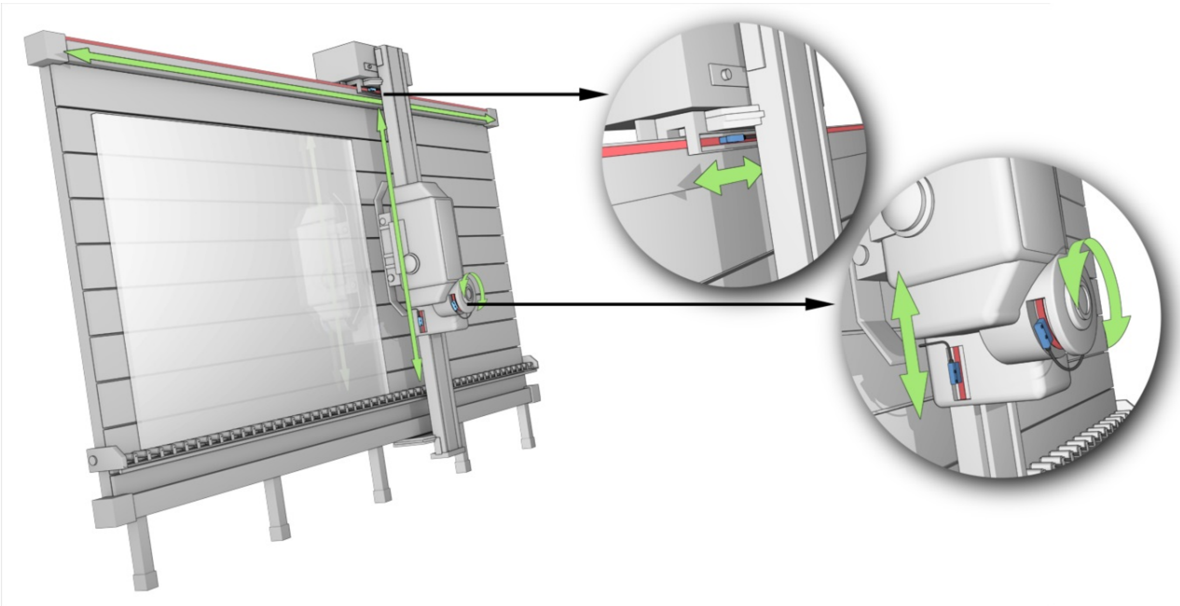
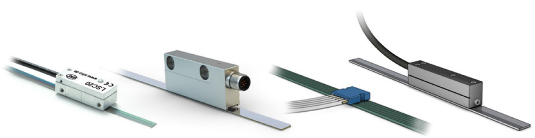


Figure 8: Linear direct drives with magnetic motor feedback solutions on duty in glass working centers

4.2 Machining systems

CNC-operated wood working is an example of machining systems which involves the milling of contours to get structures in a door or piece of furniture. The working of materials made of wood or composite wooden materials generates dust the inductive or magnetic systems are better able to cope with.

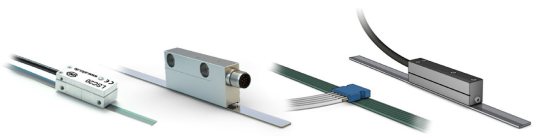
By analogy, this scenario applies also to stone or glass working. In the manufacture of windows, relatively long linear motors are employed which enable fast transport of tools between the machining stations.



High dynamics and fast adjustment of axes is required there, predestining the magnetic system under these conditions of use.

So-called depaneling machines are another example where a relatively large PCB panel populated with many small circuit boards is milled down to smaller units. As a rule, some dozens of smaller PCBs are concerned, which are held on the mainboard by means of crosspieces. Much dust is produced here, too. Therefore, the systems of magnetic measurement technology are used for such purposes as a rule because they are very insensitive to these influences: Moreover, the magnetic systems are very compact and, therefore, ideally suited for this type of smaller plants. Inductive systems would require more space and are, therefore, less suitable.

Figure 9: Magnetic motor feedback solutions can even be used without problems for applications producing great quantities of dirt



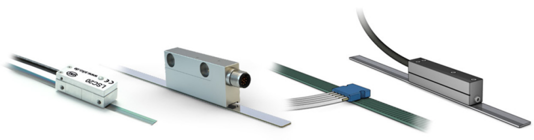
4.3 Robot technology

Virtually all systems can be used in robot technology. As a rule, the robot arms are encapsulated and contain torque motors of small to medium size. Their selection depends on the user specification.

Figure 10: The customer-specific, miniature and compact design of magnetic systems facilitates integration, e.g. in robot systems

4.4 Pick-and-Place

High precision is important for automated populating of printed circuit boards. The components including resistors, condensers, and microchips have to be positioned exactly on the PCB before soldering. Optical and inductive systems are predominantly used for this purpose.



However, other measurement systems including magnetic measurement technology can also be used if there is no high packing density and economic aspects play a role. Although the components used for populating printed circuit boards are very small and require precise guidance and positioning in the pick-and-place machine, a magnetic sensor may be sufficient depending on the requirement of precision.

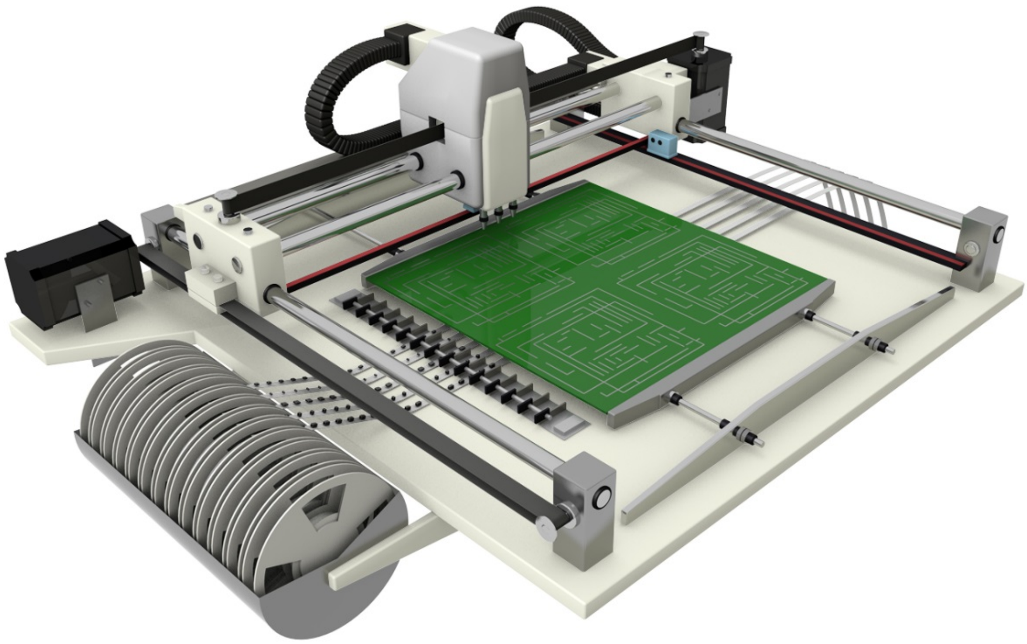
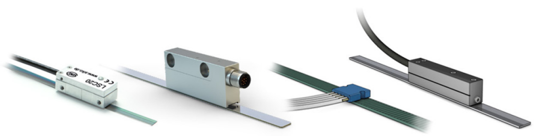


Figure 11: Pick-and-place unit assembled with linear drives and magnetic scales for position detection

4.5 PCB working

The optical sensors are also used in production machines and inspection machines in the semiconductor industry. For instance, chips are bonded here with gold or aluminum wires under clean room conditions. With integrated circuits, the function of the electronic components is integrated approx. 1 micrometer deep near the surface, a process requiring absolute precision and, therefore, involving the use of optical sensors, which are 100 per cent free from hysteresis.



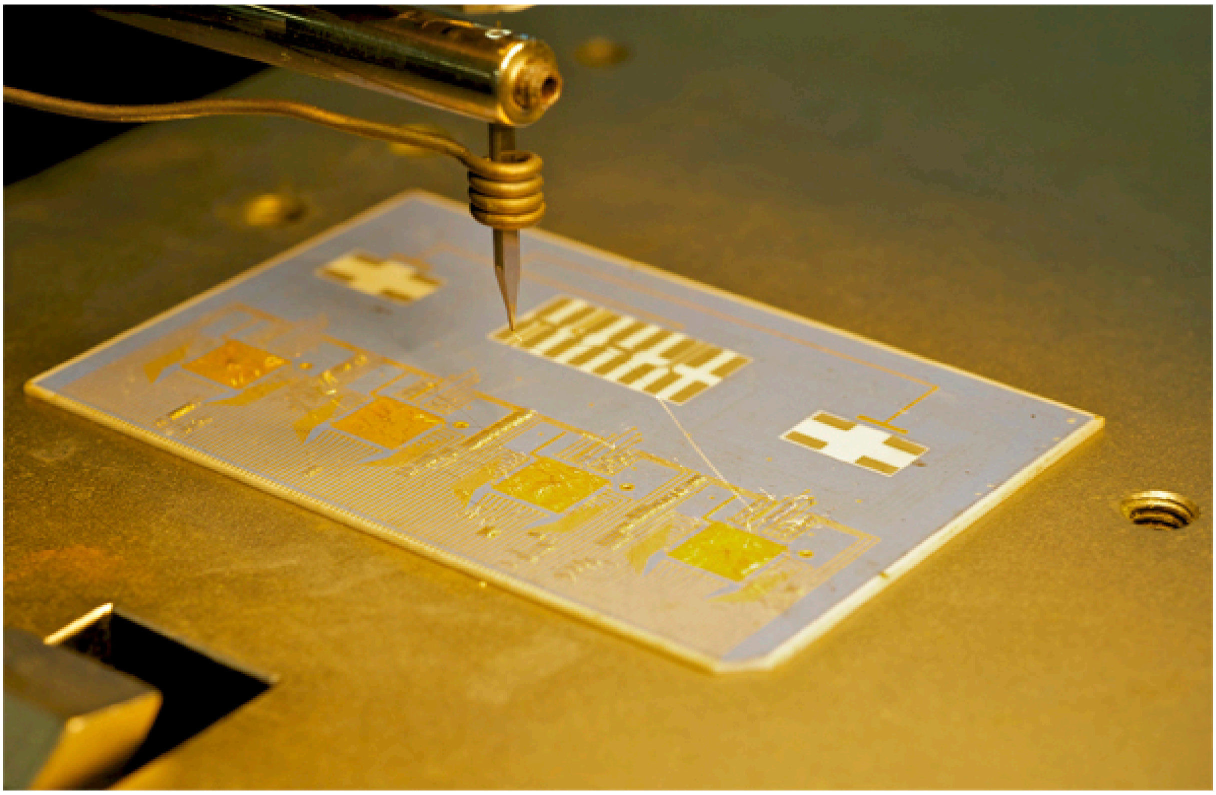
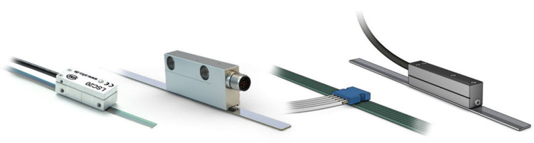


Figure 11: High-precision positioning tasks, e.g. on wire bonders are solved by means of optical measurement systems as a rule.

4.6 Analytical and medical technology

The requirements of precision are decisive for the use of a suitable measurement system in the medical and analytical technologies. For positioning patient benches in the computer tomograph (CT), the magnetic measurement technology can be used for adjusting height, inclination, and position. The tube of the CT – a large torque motor with a hollow shaft diameter of 800 millimeters or more – can also be equipped with a magnetic sensor. Absolute accuracy plays a minor role here; fast reproducibility and high repeat accuracy matter due to the high dynamics when scanning the patient.



By contrast, high requirements are put on repeat accuracy of the measurement system in analytical technology. For example, magnetic systems are implemented in the area of liquid handling. Here, pipetting robots take up, transport and dispense liquids from sample storage vessels in very accurate and small quantities with high speed. The position once left must be traveled to only with minor deviation because the individual samples are in close vicinity to each other.

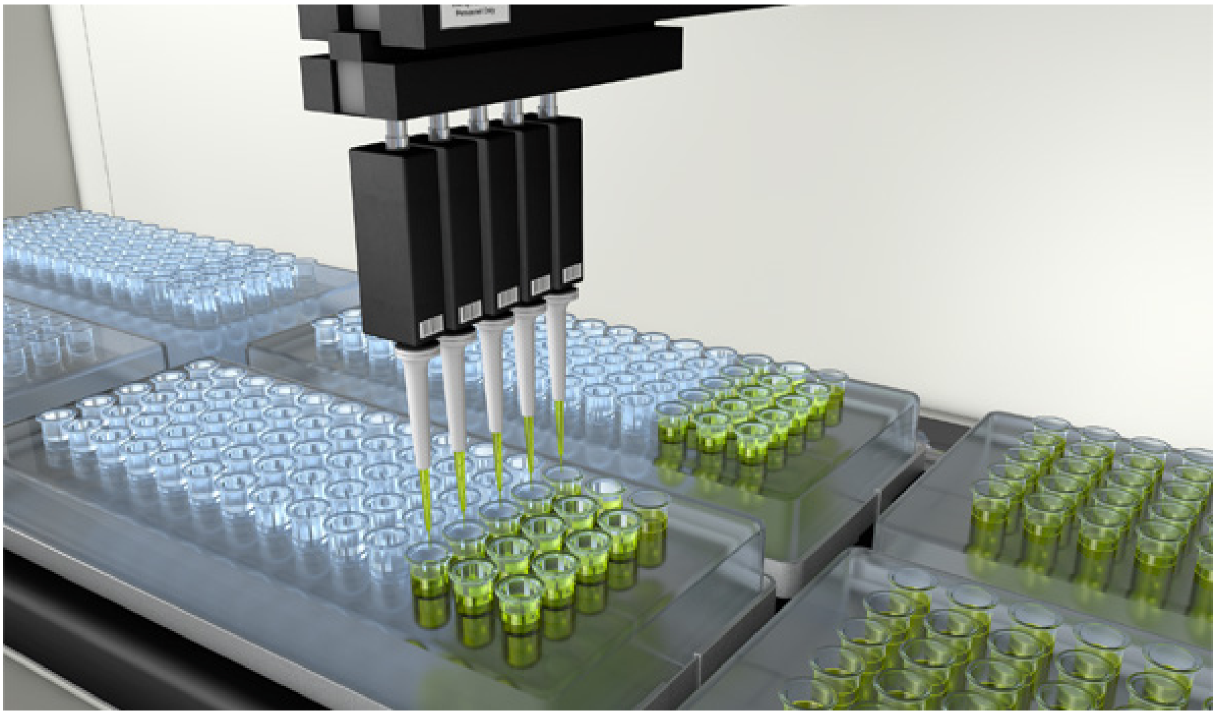
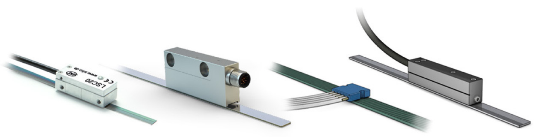


Figure 13: High-speed pipetting plants populated with absolutely measuring motor feedback solutions

5 Conclusion

Compared with the magnetic systems as well as the inductive and capacitive systems, the optical systems have been on the market for the longest time and are the method of choice for determining motor feedback in many applications. Furthermore, when selecting the suitable length measurement method, the optical measurement method must always have



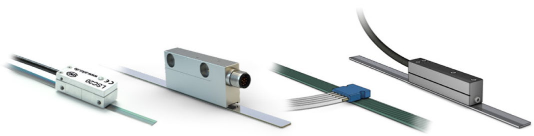
priority the more accuracy of measurement is demanded.

The newer systems are a real alternative above all in applications requiring a lesser degree of precision – mainly for reasons of economy. When comparing the optical systems with the magnetic ones with regard to the costs, the following can be stated: The longer the overall length of the unit to be measured the stronger is the price advantage of the magnetic compared with the optical solution. When comparing the newer technologies, the advantages of the magnetic measurement technology compared with the capacitive or inductive ones take effect with regard to economic aspects. The prices of the capacitive systems are somewhat more attractive than those of the magnetic ones due to lower material costs; they do not measure up to the magnetic ones regarding robustness, however. In areas of application where a certain degree of humidity is to be considered, the implementation of capacitive systems requires complex and expensive protective housings.

If there are many influences from the production environment and where exposure to shock, vibration, dirt or lubricants is to be considered, the optical systems will not be used in most cases because of their mechanical fragility and sensitivity. The magnetic systems' low susceptibility to dirt originating from shavings or lubricants is significantly more advantageous compared with the optical glass scales previously nearly exclusively used. A fundamental benefit of the optical system lies in its magnetic insensitivity often predestining it for applications in the area of linear technology.

Several factors determine the decision for a motor feedback solution based on optical, magnetic, capacitive or inductive measurement technology: The requirements of precision (resolution, absolute and repeat accuracy), sensitivity to interfering magnetic fields and to influences from environmental conditions as well as economic aspects. The particular measurement technology solution is concretely oriented towards the application and the specific requirements of the measurement task.

Since1963, the SIKO company has established itself as a supplier of measurement technology for different tasks including length, angle, and rotary speed measurement



technology as well as the measurement of inclination or velocity. The optical and magnetic motor feedback solutions from SIKO cover areas of application with harsh environmental and production influences as well as demanding measurement tasks requiring high precision.

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