High-resolving encoder integrated in miniature drive

1. Introduction

The general push towards miniaturisation has not stopped, even for drive technology. The call is for the "highest possible performance in the increasingly smallest space", where performance means not only the mechanical output in watts but also performance in relation to precision, angular resolution, level of control and dynamics. It can be taken for granted that in addition to the increase in power, reduced cost is also demanded.

In order to fulfil these demands, methods and technologies such as micro-system technology, semiconductor technology, progress in sensors and increasingly efficient simulation and calculation methods are available.
Despite these possibilities there has so far been no success in the field of small drives to meet the demands for "small", "cost efficient" and "precise" in a feasible manner.

In particular, position sensing systems exhibit a typical drawback: even with quite modest characteristics they are most of the times even larger than the actual drive motor. This can be explained by the fact that an attempt has been made to reduce the size of the large components, which incorporate the basic building blocks. In the case of large drives, other targets are more important and thus this method failed. A new approach was avoided as long as possible as it would have meant leaving the traditional methods and a move into new, unknown territory, and this is also associated with a certain risk.

Minimotor has now taken this step and has worked out a completely new approach in which the progressive technologies are efficiently utilised.

The result is a dual-channel encoder with 512 pulses, which literally disappears into a motor of 15 mm diameter.

2. Basic considerations and development target

The objective was a new development of a very small and highly efficient drive with which it is possible to control lowest speeds very precisely. In addition, it should be possible to implement precise position control.

The magnetic material NdFeB now established in drive technology, 3D field calculation programs, Finite Elements Methods (FEM) as well as ingenious optimisation algorithms have led to motors with considerably better characteristics.

However, it very quickly turned out that there was still no sensing system on the market that jointly fulfilled the conditions of smallest installation space and high resolution. When it was required to achieve low speeds or precise position within the smallest dimensions, one inevitably hits fundamental limits. Either considerable sacrifice had to be accepted in drive quality or an increase in the installation space. This even applied when the costs only played a subordinate role.

From these considerations a general development target for a sensing system quickly crystallised:

- In order to fulfil the installation space preconditions, the device to be developed had to be integrated in to the motor.
- In order that speed and position could be determined simultaneously, an incremental encoder would be the ideal solution.
- The increasing digitalisation in control technology again speaks in favour of an encoder.
- The demand for high accuracy in speed and position sensing can only be fulfilled by a correspondingly high resolution.

These basic requirements then defined the physical implementation principle and the technologies used:

- The demand to integrate the encoder in to the motor means that an optical principle is unsuitable due to the risks of contamination and the high temperature requirements.
- As the sensor-transmitter wheel distance cannot be reduced in size to any great extent, in magnetic systems the distance depends basically on the pole geometry, a high resolution can only be achieved by interpolation.
- Highly complex systems with the smallest dimensions can only be produced with the aid of microsystem technology.

3. Structure of the system

In order to be able to fulfil the extreme space requirements, i.e. integration in to the motor, several possibilities had to be exhaustively examined. On the one hand the transmitter wheel is mounted directly on the commutator. Here, installation space so far unused was made available, or additional installation space created by means of technical refinements. By the use of high-performance plastics for the brush cover [Figure 1] success was achieved in gaining room for the sensor electronics. This contains the sensor, the ASIC (application-specific integrated circuit) and a few passive components and is designed as a hybrid circuit. Interface connection is made via ribbon cable, and a 10pin connector.

This simple structural principle brings some decisive advantages. As only a few components are required, the system is very reliable and cost effective. By means of the flexible interface to the outside the user can decide how to make connection. Additionally, motor supply and encoder signals are directed via a common cable.

4. The function of the encoder

The sensor principle

The encoder is based on a magnetic principle. Field differences, caused by a toothed magnetic ring, are converted into electrical voltages in a sensor specially developed for this application.
As only differential fields are evaluated, the sensor is insensitive to outside disturbance fields.
Directly on the magnetic wheel, the required field segments are rectangular. A Fourier breakdown of the rectangular signal produces the following proportional rations of the frequencies:

$$1 \cdot \sin(\omega t) + \frac{1}{3} \cdot \sin(3 \cdot \omega t) + \frac{1}{5} \cdot \sin(5 \cdot \omega t) + \ldots$$

As field strength of segments with small geometric size reduces very much more quickly with distance than those with large geometric size, the sensor almost only sees the base wave. For example, this can be shown by quadric reduction of the amplitudes. for the above formula, we then have:

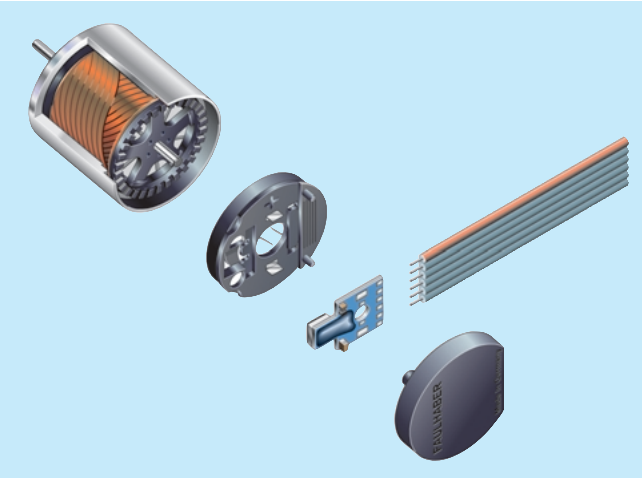

Figure 1: structure of the motor with integral encoder

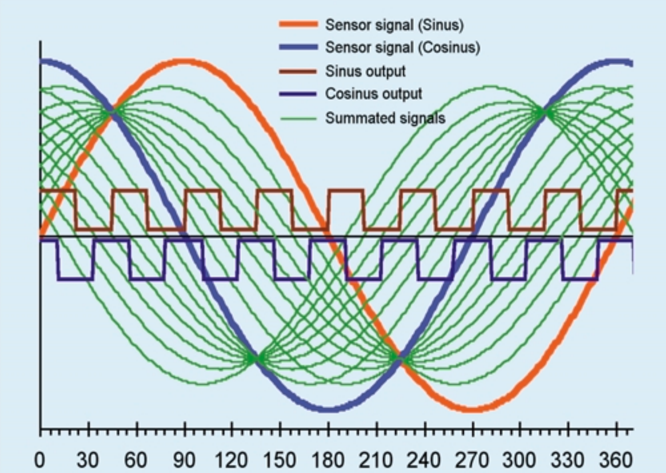

Figure 2: impulse multiplication

$$1^2 \cdot \sin(\omega t) + \left(\frac{1}{3}\right)^2 \cdot \sin(3 \cdot \omega t) + \left(\frac{1}{5}\right)^2 \cdot \sin(5 \cdot \omega t) + \ldots = 1 \cdot \sin(\omega t) + \frac{1}{9} \cdot \sin(3 \cdot \omega t) + \frac{1}{25} \cdot \sin(5 \cdot \omega t) + \ldots$$

The active sensor surfaces are not single point but reveal a certain spread so that the signal emerges as a folding of the magnetic field with the sensor surfaces. This fact again causes a reduction in the harmonic components in the signal.

There are several sensitive layers on a sensor; these are combined to form two output signals, a sine and a cosine signal. The production takes place using the methods of semiconductor technology so that the active zones are positioned with corresponding precision. This has an advantageous effect on the signal quality, on the one hand and on the other hand mass production is possible with low unit cost.

Signal processing in the ASIC

The sensor signals are very small and must therefore be amplified. Subsequently, the frequency multiplication with rectangular conversion and generation of the output level occurs. All of this occurs in a mixed-signal CMOS circuit [Figure 3], which was developed for this application but can also, be used generally.

The principle of multiplication is based on additive superimposition of the two input signals [Figure 2]. This occurs via a resistor network where a corresponding phase displacement of the output signal is achieved by differential resistor values. The solving of the fundamental networks leads to the following conditional equations for the individual resistances:

The formulae would partly require negative resistors. As this is not possible, the sinusoidal signal must be inverted and fed to the corresponding positive resistors. It is particularly advantageous that it is not the absolute values of the individual resistors but only their respective relationship that is important. This only makes integration in a chip possible as only resistor ratios can be implemented with a high degree of precision using semiconductor technology.

The 16 phase-shifted sinusoidal signals are then fed to comparators for rectangular conversion. Via a suitable logic system the conversion of the 16 pulses into two rectangular signals with eight-fold frequency occurs.

Via digital inputs on the ASIC it is still possible to switch over to the multiplication factor so that encoders are available with 64, 128 and 256 pulses. The encoder is supplied with 5 V and produces TTL- and CMOS-compatible rectangular signals.

From the point of view of information theory, this frequency multiplication corresponds to a conversion of amplitude information in to frequency information. The increase in the bandwidth results in a reduction of the amplitude resolution. At the same time, another distinction is made.

The whole evaluation circuit is housed in a chip of less than 5 mm². This was necessary on the one hand in order to guarantee minimal space requirement and on the other hand a small chip surface gives cost advantages for the user.

$$R_{k(\sin)} = \frac{R}{\left|\cos\left(k \cdot \frac{\pi}{16}\right)\right|} \qquad R_{k(\cos)} = \frac{R}{\sin\left(k \cdot \frac{\pi}{16}\right)} \qquad k = 0 \ldots 15$$

Application Specific Integrated Circuit (ASIC)

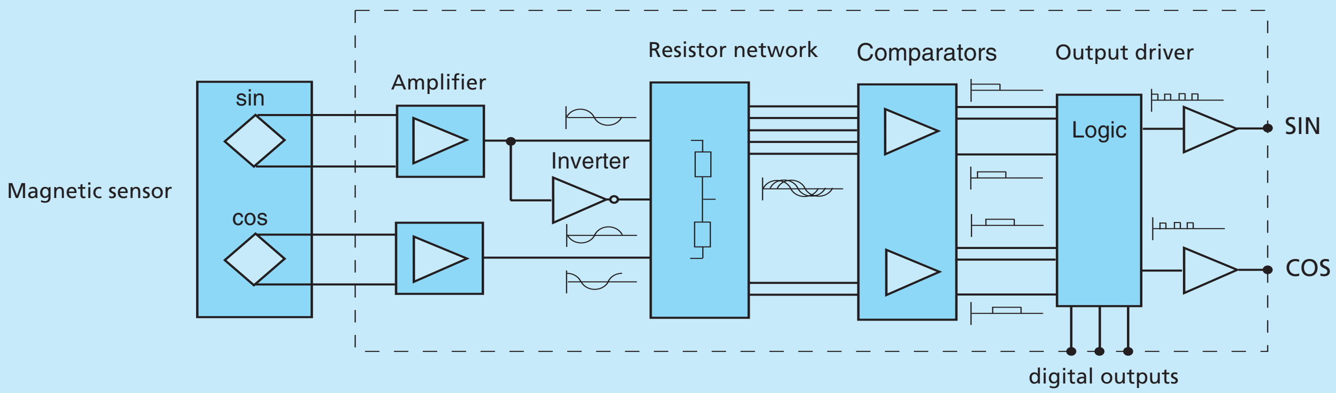

Figure 3: block diagram

5. Applications

If only a small space is available, or masses and weights play an important role, to date one had to accept enormous quality sacrifices for control drives. Essentially, three possibilities are available:

1. Control without a separate sensing device (I*R compensation)
   - very imprecise speed regulation with high parameter dependence (temperature and loading)
   - no position control possible
   - not suitable for low speeds
   - advantage: inexpensive
2. Control with tachogenerator
   - only speed control possible
   - increased installation size on account of flange-connected tachogenerator
3. Control with encoder
   - to date only low number of pulses per revolution, therefore only suitable for higher speeds
   - increased installation size on account of flange-connected encoder

The encoder listed in point 3. also offers the advantage that positioning is possible. If the connection between number of pulses and position resolution still seems easily comprehensible (in case of IE2-512 still < 0.2°), a rather more in-depth examination is necessary in the assessment of the level of control.

For example, the simulation of a digital speed control (scanning time 1 ms) with ideal value is shown [Figure 4]. For sensing systems, encoders with 16 and 512 pulses per revolution with a four-flank evaluation were simulated. The controlling parameters were selected in each case so that a compromise between speed ripple and rise time resulted. As can be seen in the curves, the encoder with 512 pulses at very low speeds still provides excellent behaviour in relation to the controlling properties.

6. Summary

With this encoder a sensing system is available for the first time for the user even for miniature drives which meets the current requirement for positioning accuracy and level of control. These properties first became possible due to a new approach and the massive application of modern methods and technologies. However, this principle has also led to a considerable reduction in price.

This encoder is definitely the start of a whole generation of new applications in miniature drive technology. The result once again shows that in miniature drive technology it is simply not enough to reduce the principles of large machines but that a different analysis and theoretical approach is necessary in order to successfully achieve significant progress.

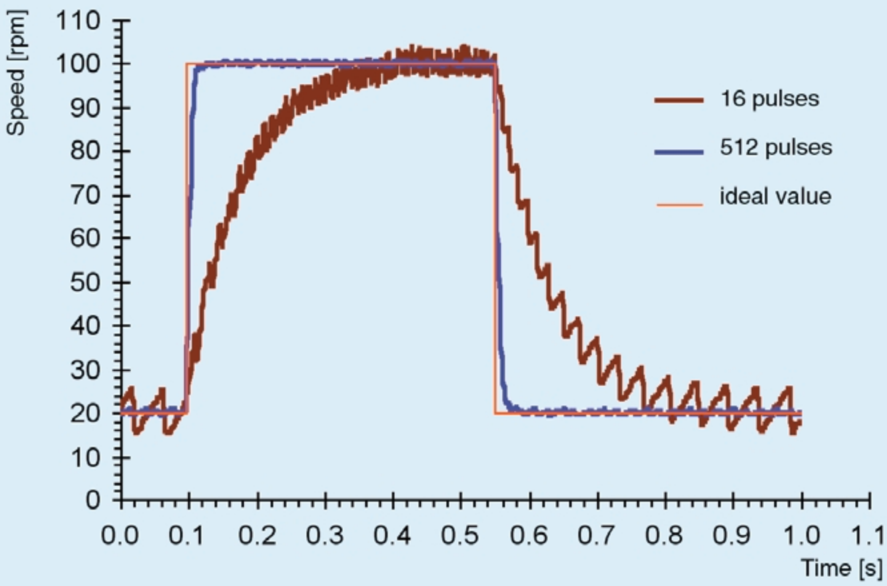

Figure 4: comparison of two encoders with speed control

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Encoders

Magnetic Encoders

Features:
64 to 512 Lines per revolution
2 Channels
Digital output

Series IE2 – 512

		IE2 – 64	IE2 – 128	IE2 – 256	IE2 – 512	
Lines per revolution	N	64	128	256	512	
Signal output, square wave		2				channels
Supply voltage	V_{DD}	+ 5 V + 5%				V DC
Current consumption, typical (V_{DD} = 5 V DC)	I_{DD}	typ. 6, max. 12				mA
Output current, max. [1]	I_{OUT}	5				mA
Pulse width	P	180 ± 45				°e
Phase shift, channel A to B	Φ	90 ± 45				°e
Signal rise/fall time, max. (C_{LOAD} = 50 pF)	tr/tf	0,1 / 0,1				µs
Frequency range [2], up to	f	20	40	80	160	kHz
Inertia of code disc	J	0,09				gcm^2
Operating temperature range		– 25 ... + 85				°C

[1] V_{DD} = 5 V DC: Low logic level < 0,5 V, high logic level > 4,5 V: CMOS and TTL compatible
[2] Velocity (rpm) = f (Hz) x 60/N

Ordering information

Encoder	number of channels	lines per revolution	in combination with DC-Micromotors and Brushless DC-Servomotors
IE2 – 64	2	64	**series 1516 ... SR, 1336 ... C**
IE2 – 64	2	64	**series 1524 ... SR, 1727 ... C**
IE2 – 64	2	64	**series 2224 ... SR, 2342 ... CR**
IE2 – 128	2	128	**series 1516 ... SR, 1336 ... C**
IE2 – 128	2	128	**series 1524 ... SR, 1727 ... C**
IE2 – 128	2	128	**series 2224 ... SR, 2342 ... CR**
IE2 – 256	2	256	**series 1516 ... SR, 1336 ... C**
IE2 – 256	2	256	**series 1524 ... SR, 1727 ... C**
IE2 – 256	2	256	**series 2224 ... SR, 2342 ... CR**
IE2 – 512	2	512	**series 1516 ... SR, 1336 ... C, 1628 ... B**
IE2 – 512	2	512	**series 1524 ... SR, 1727 ... C, 2036 ... B**
IE2 – 512	2	512	**series 2224 ... SR, 2342 ... CR, 2444 ... B**

Features

These incremental shaft encoders in combination with the FAULHABER DC-Micromotors and brushless DC-Servomotors are used for indication and control of both, shaft velocity and direction of rotation as well as for positioning.

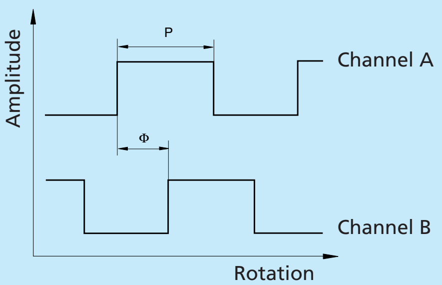
The encoder is integrated in the DC-Micromotors SR-Series and extends the overall length by only 1,4 mm and buildt-up option for DC-Micromotors and brushless DC-Servomotors.

Hybrid circuits with sensors and a low inertia magnetic disc provide two channels with 90° phase shift.

The supply voltage for the encoder and the DC-Micromotor as well as the two channel output signals are interfaced through a ribbon cable with connector.

Details for the DC-Micromotors and suitable reduction gearheads are on separate catalog pages.

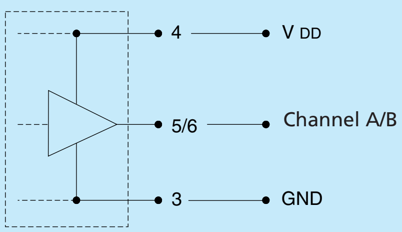
Output signals / Circuit diagram / Connector information



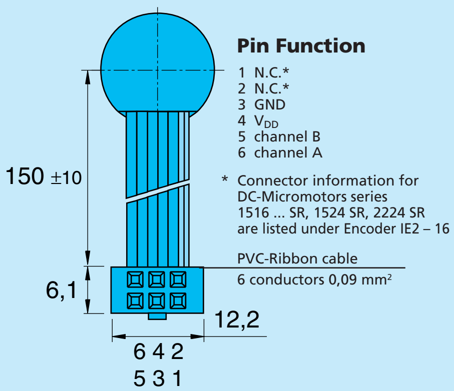
Admissible deviation of phase shift:

$$\Delta\Phi = \left| 90° - \frac{\Phi}{P} * 180° \right| \leq 45°$$

Output signals
with clockwise rotation as seen from the shaft end

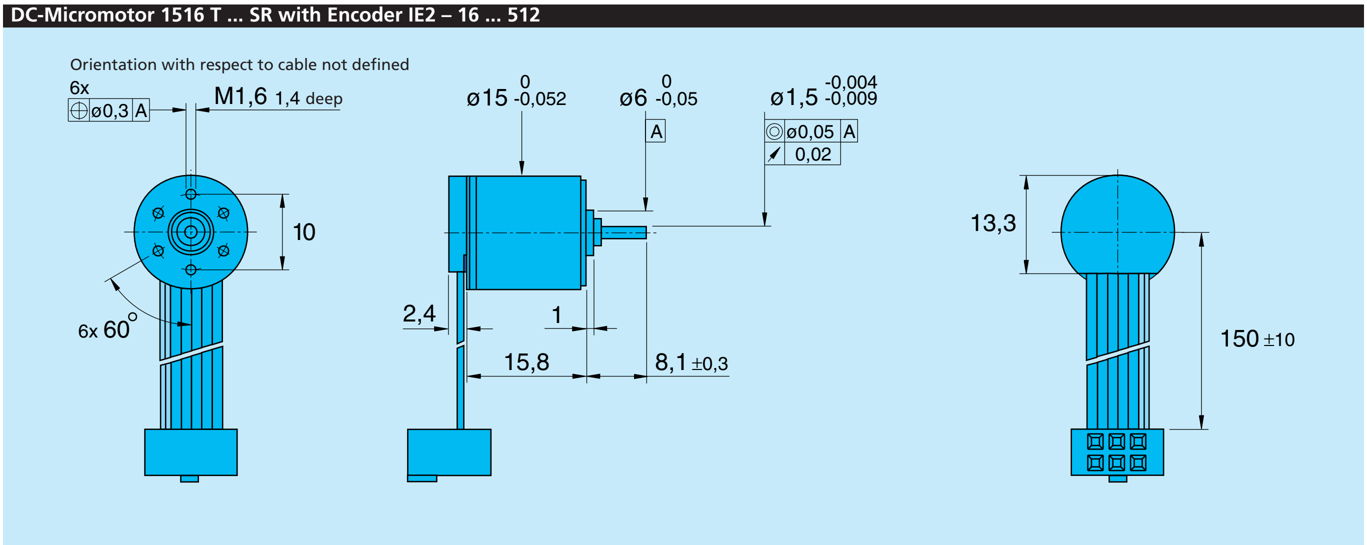


Output circuit
Note: Motor terminal resistance increases by approx. 0,4 Ω

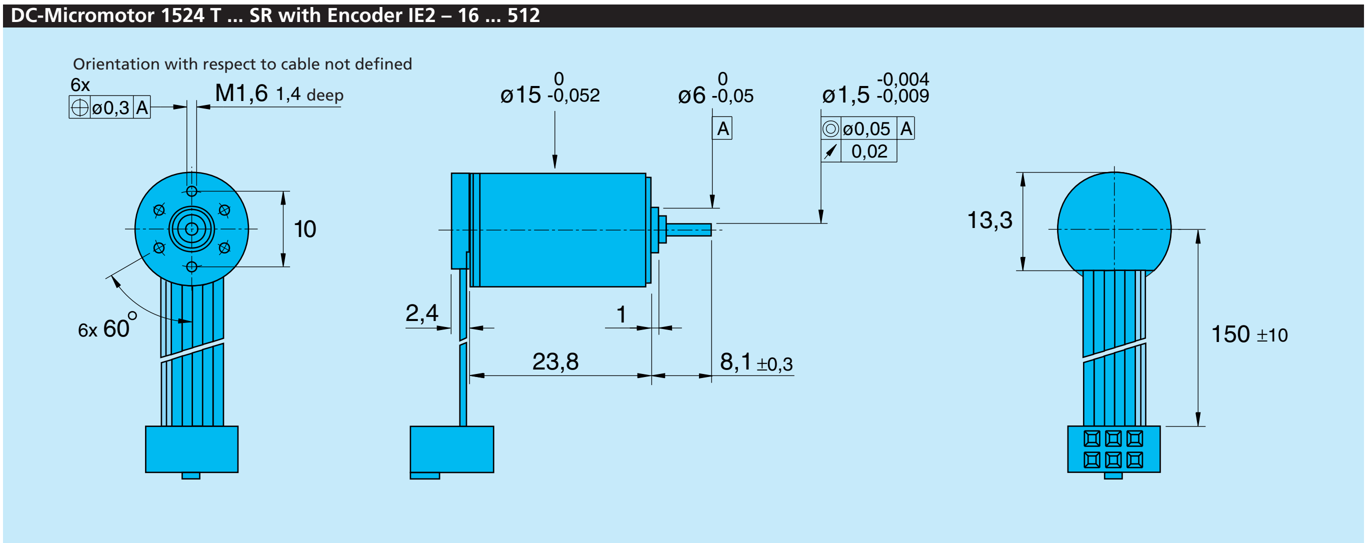


Connector
DIN-41651
grid 2,54 mm

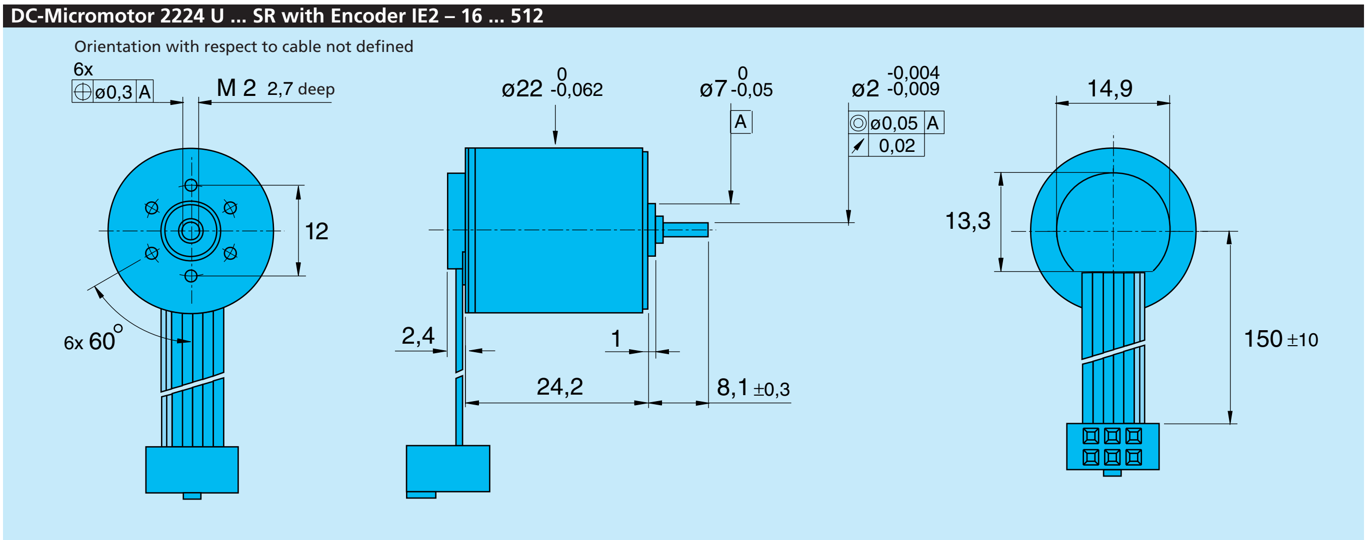
DC-Micromotor 1516 T ... SR with Encoder IE2 – 16 ... 512



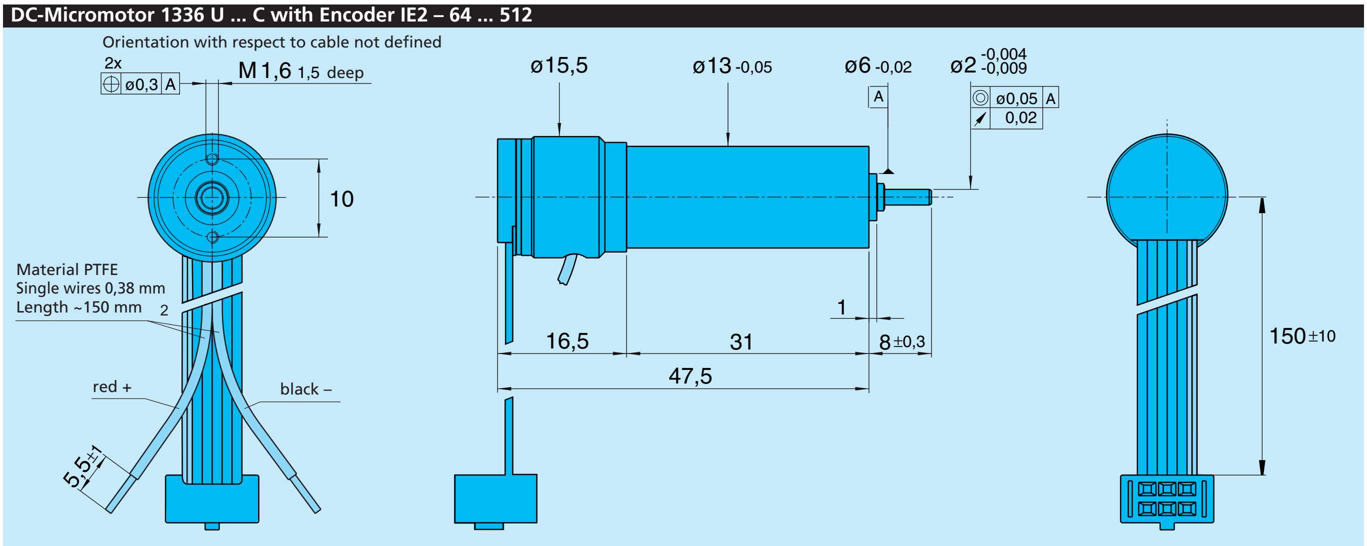
DC-Micromotor 1524 T ... SR with Encoder IE2 – 16 ... 512



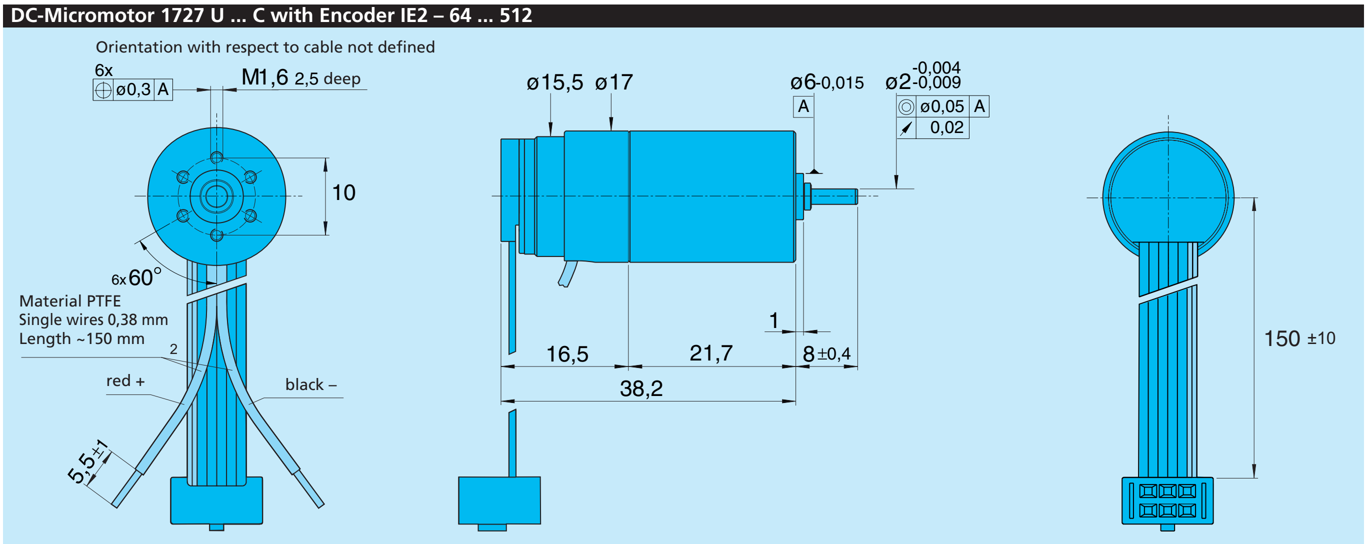
DC-Micromotor 2224 U ... SR with Encoder IE2 – 16 ... 512



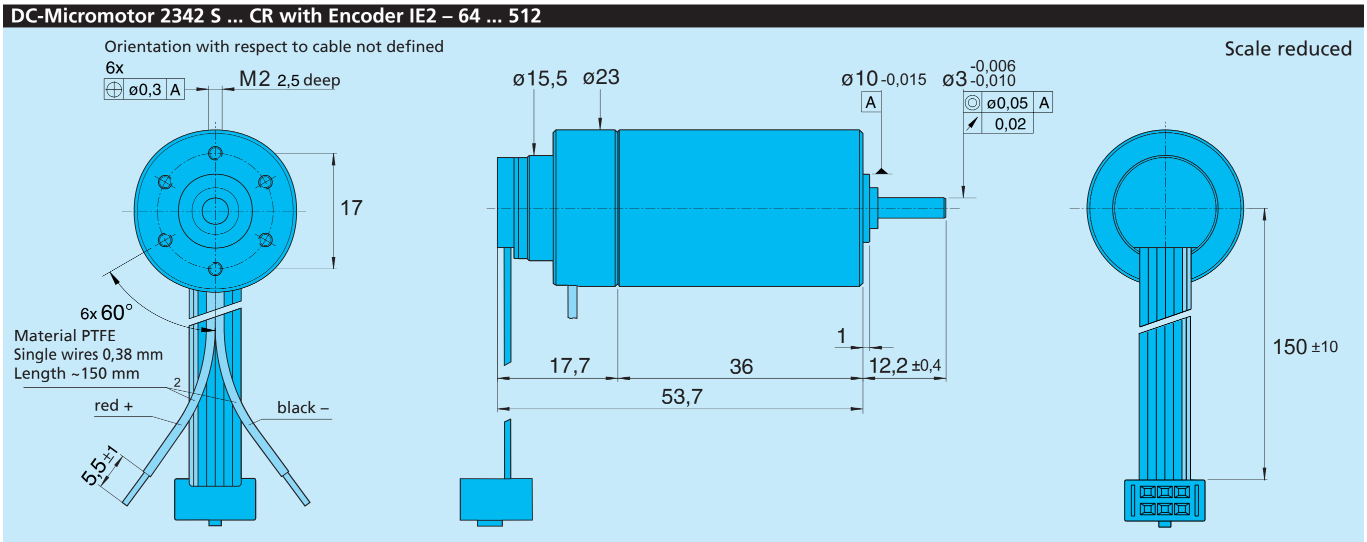
DC-Micromotor 1336 U ... C with Encoder IE2 – 64 ... 512



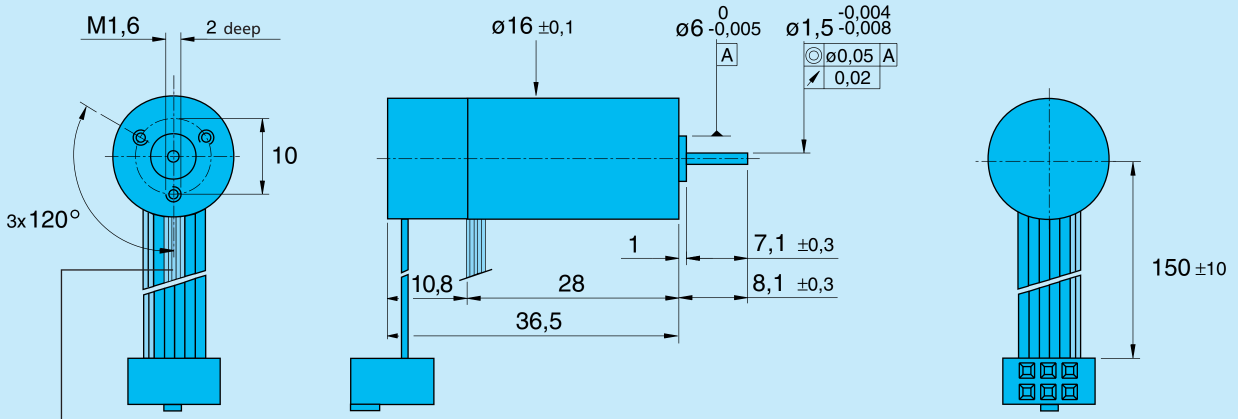
DC-Micromotor 1727 U ... C with Encoder IE2 – 64 ... 512



DC-Micromotor 2342 S ... CR with Encoder IE2 – 64 ... 512

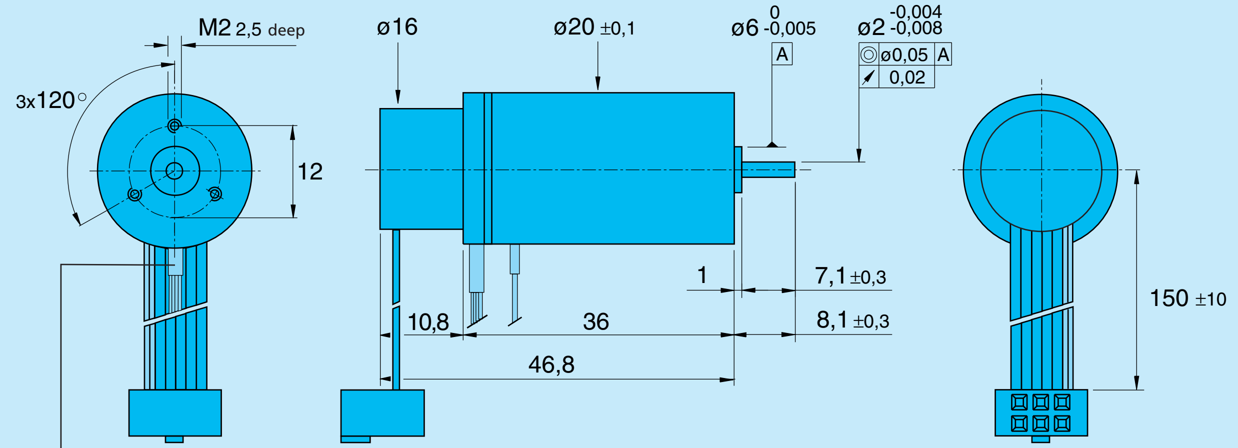


Brushless DC-Servomotor 1628 T ... B with Encoder IE2 – 512



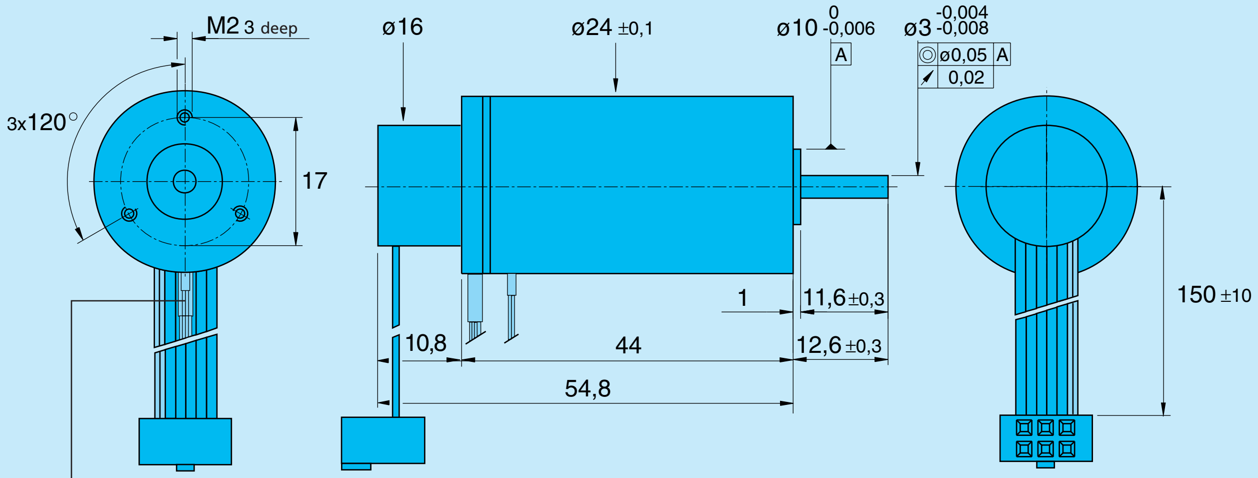
For details on the cable connection see the motor data sheet

Brushless DC-Servomotor 2036 U ... B with Encoder IE2 – 512



For details on the cable connection see the motor data sheet

Brushless DC-Servomotor 2444 S ... B with Encoder IE2 – 512



For details on the cable connection see the motor data sheet

For notes on technical data refer to "Technical Information"

Specifications subject to change without notice