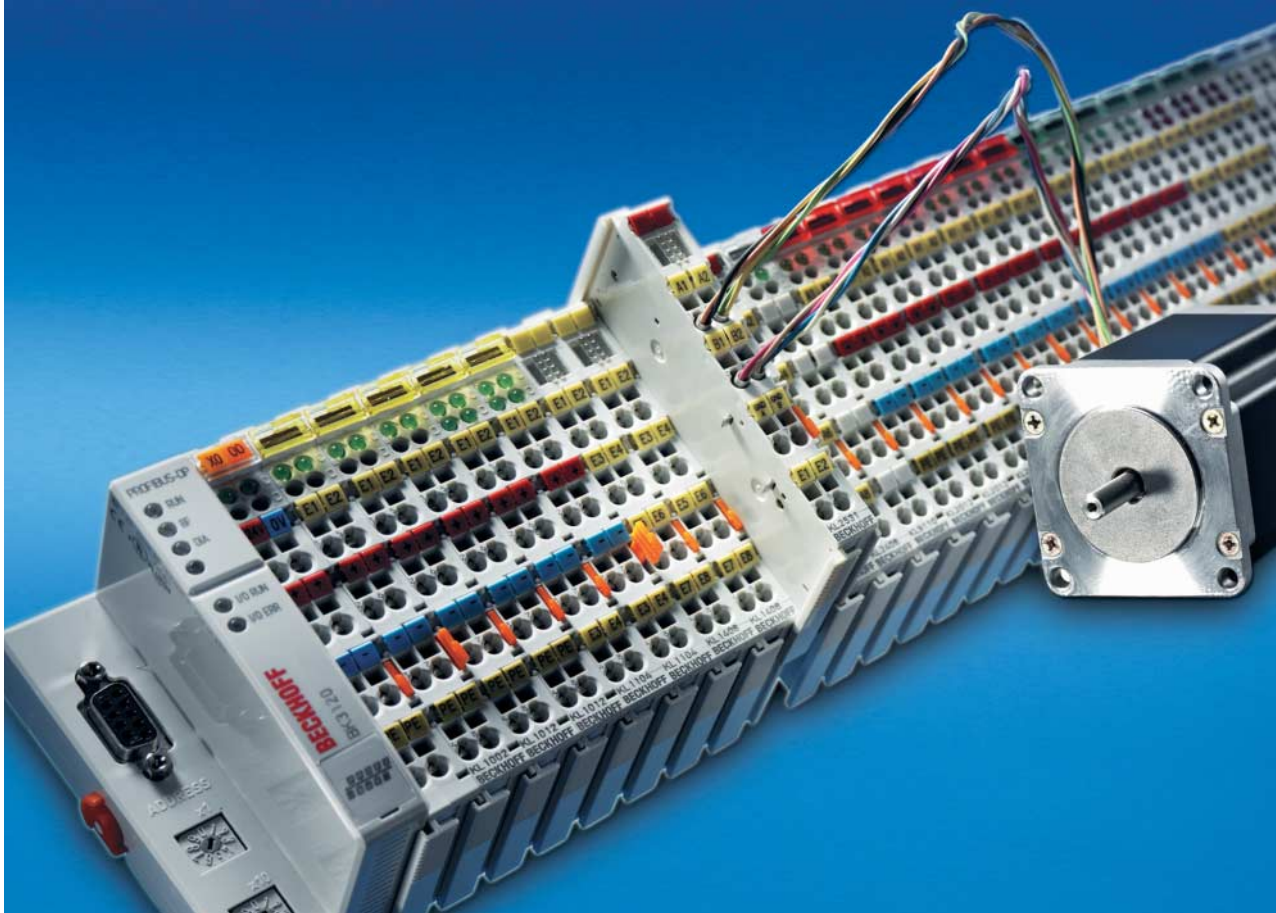


Integrated pacemaker



→ The new drive technology Bus Terminals integrate a compact motion control solution for small stepper motors up to 200 W. The KL2531 and KL2541 stepper motor terminals are a cost-effective alternative to traditional drives.

Stepper motors are electric motors and are comparable with synchronous motors. The rotor is designed as a permanent magnet, while the stator consists of a coil package. In contrast to synchronous motors, stepper motors have a large number of pole pairs. In a minimum control configuration, the stepper motor is moved from pole to pole, or from step to step.

Stepper motors have been around for many years. They are robust, easy to control, and provide high torque. In many applications, the step counting facility can eliminate expensive feedback systems. Even with the increasingly widespread use of synchronous servomotors, stepper motors are by no means "getting long in the tooth." They are considered to represent mature technology and continue to be developed further in order to reduce costs and physical size, increase torque and improve reliability.

The development of the KL2531 and KL2541 Bus Terminals for the Beckhoff I/O system opens up new application areas. Microstepping and the latest semiconductor technology offer many advantages:

- | Smoother operation
- | Resonance avoidance
- | Reduced energy consumption
- | Lower thermal load on the motor
- | Minimum electromagnetic emissions
- | Long cable lengths
- | Simpler handling
- | Reduced size of the power electronics
- | Simple integration into higher-level systems
- | Integrated feedback system

Calculation and specification of the stepper motor

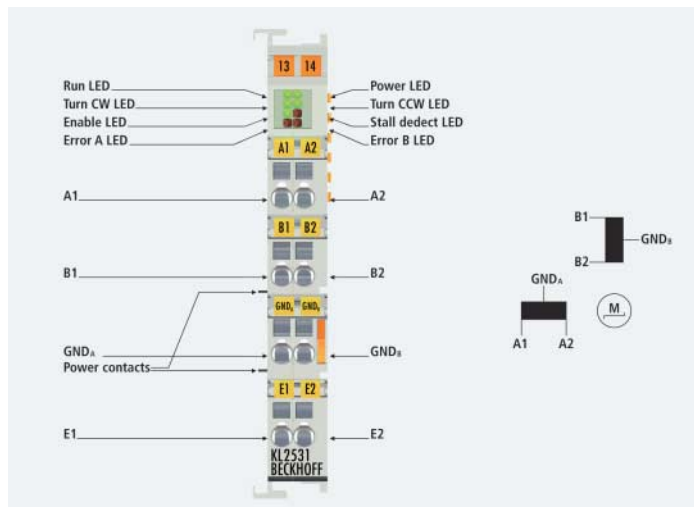
Selecting a stepper motor:

1. Determine the required positioning accuracy and the step resolution. The first task is to determine the maximum resolution that can be achieved. The resolution can be increased via mechanical gear reduction devices such as spindles, gearing or toothed racks. The 64-fold microstepping of the stepper motor terminals also has to be taken into account.
2. Determine mass m and moment of inertia J of all parts to be moved.
3. Calculate the acceleration resulting from the temporal requirements of the moved mass.
4. Calculate the forces from mass, moment of inertia, and the respective accelerations.
5. Convert the forces and velocities to the rotor axis, taking account of efficiencies, moments of friction and mechanical parameters such as gear ratio. It is often best to start the calculation from the last component, usually the load. Each additional element transfers a force and velocity and leads to further forces or torques due to friction. During positioning, the sum of all forces and torques acts on the motor shaft. The result is a velocity/torque curve that the motor has to provide.
6. Using the characteristic torque curve, select a motor that meets these minimum requirements. The moment of inertia of the motor has to be added to the complete drive. Verify your selection. In order to provide an adequate safety margin, the torque should be oversized by 20% to 30%. The optimization is different if the acceleration is mainly required for the rotor inertia. In this case, the motor should be as small as possible.
7. Test the motor under actual application conditions: Monitor the enclosure temperatures during continuous operation. If the test results do not confirm the calculations, check the assumed parameters and boundary conditions. It is important to also check side effects such as resonance, mechanical play, settings for the maximum operation frequency and the ramp slope.
8. Different measures are available for optimizing the performance of the drive: using lighter materials or a hollow instead of solid body, reducing mechanical mass. The control system can also have significant influence on the behavior of the drive. The Bus Terminal enables operation with different supply voltages. The characteristic torque curve can be extended by increasing the voltage. In this case, a current increase factor can supply a higher torque at the crucial moment, while a general reduction of the current can significantly reduce the motor temperature. For specific applications, it may be advisable to use a specialy adapted motor winding.

Two performance classes for optimum usage

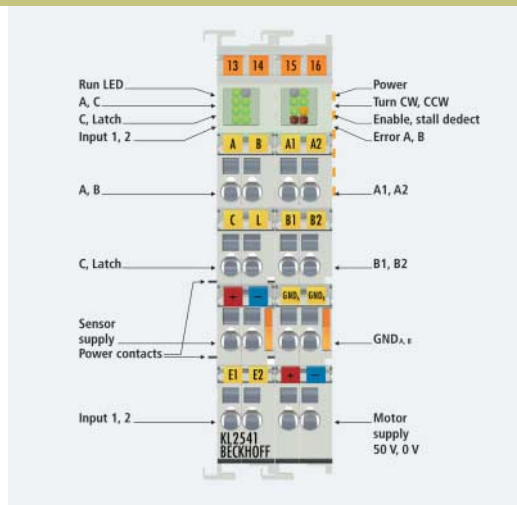
The KL2531 and KL2541 stepper motor terminals differ in terms of performance. With a size of only 12 mm, the KL2531 Bus Terminal covers the lower performance range. The device is designed for simple integration into a 24 V DC control voltage system. With a peak current of 1.5 A per phase, a large number of small drives and axes can be supplied.

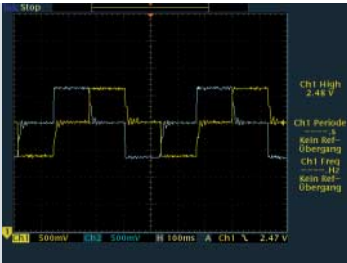
The KL2541 offers higher performance comparable to that of small servo drives, because with a peak current of 5 A, the KL2541 can generate an impressive torque of 5 Nm in conjunction with a standard stepper motor. The supply voltage



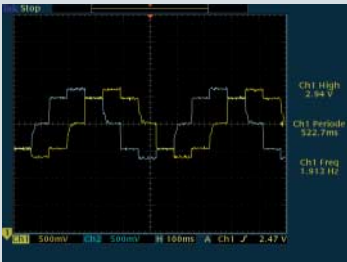
KL2531: Stepper motor terminal, 24 V DC, 1.5 A

KL2541: Stepper motor terminal with incremental encoder, 50 V DC, 5 A

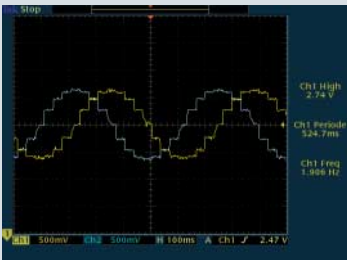




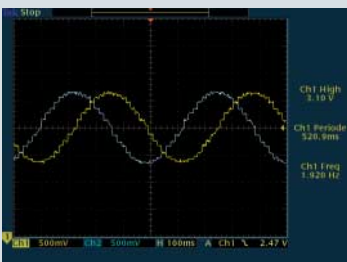
Current curve:
| full step



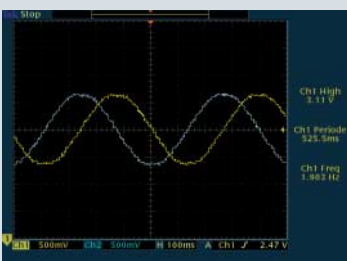
| half step



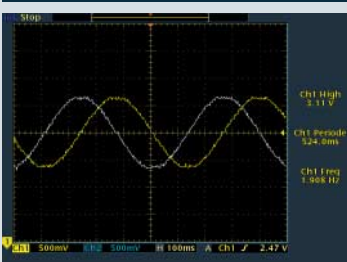
| 1/4-step microstepping



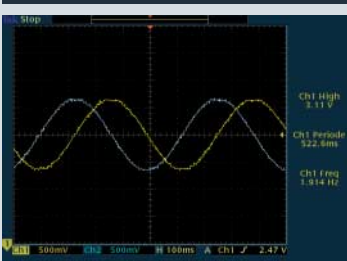
| 1/8-step microstepping



| 1/16-step microstepping



| 1/32-step microstepping



| 1/64-step microstepping

of up to 50 V DC enables high speeds with good torque and, therefore, high mechanical output (up to about 200 W). The KL2541 has an integrated incremental encoder interface, although it is still only 24 mm wide.

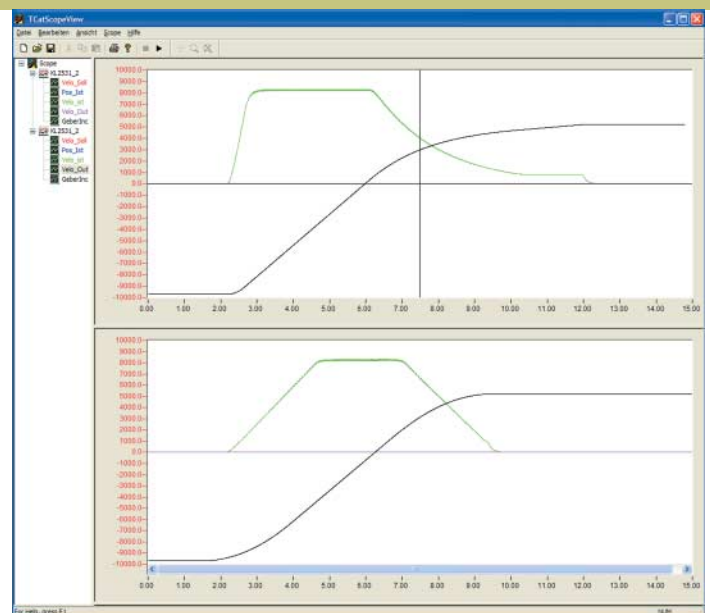
Both stepper motor terminals provide two controlled sine/cosine currents. 25 kHz current control enables smooth current output without resonance. Highly dynamic, low-inductance motors run just as well as stepper motors with small rotor mass. The current resolution is 64 steps per period: 64-fold microstepping. A standard motor with a 1.8° step angle runs very smoothly and can be set up to 12,800 electronic positions per turn. Experience shows that including approximately 5,000 positions is realistic.

Typical stepper motor problems such as pronounced resonance are a thing of the past. Microstepping and associated set values ensure that rotor jerk is avoided. Also, the rotor no longer tends to oscillate around each indexing position. Mechanical measures such as vibration dampers against resonance or gear reduction for increasing precision are no longer required. This allows the burden from costs and development effort to be lower.

The new stepper motor terminals also reduce engineering development time. Both Bus Terminals can be used just like standard Bus Terminals in all common fieldbuses. Interface programming is no longer required. Start, stop or resonance frequencies are no longer an issue. For simple positioning tasks, both Bus Terminals can automatically position the drive, taking account of an acceleration ramp and the maximum frequency.

The option of detecting the rotor position via the voltage returned by the stepper motor is not widely used yet. The KL2531 and KL2541 Bus Terminals offer status feedback that reflects the motor load with a resolution of 3 bits. This type of feedback is not suitable for "real" position control. However, since the stepper motor basically follows its control and simply stops in the event of overload, the technique is acceptable in practice: The motor will reach the specified position, as long as it is not overloaded. The position value counted in the Bus Terminal is "O.K."

Ramps are used for acceleration and deceleration. For Bus Terminals with internal positioning an exponential ramp can be used, leading to a noticeable reduction in positioning time.



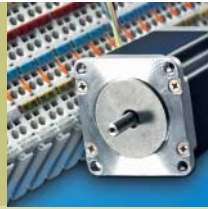
Solid handling of more demanding positioning tasks

More demanding positioning tasks can be addressed via the Beckhoff TwinCAT automation software. Like other axes, both Bus Terminals are integrated via the TwinCAT System Manager and the stepper motors can be used like "normal" servo axes. Special stepper motor features, such as speed reduction in the event of large following errors, are automatically taken into account via the "stepper motor axis" option. The effort for changing from a servomotor to a stepper motor – and back – is no greater than changing from one fieldbus to another one using TwinCAT.

The output stages of the stepper motor terminals have an overload protection in the form of an over-temperature warning and switch-off. Together with short cir-

cuit detection, diagnostic data are accessible in the process image of the controller. In addition, this status is displayed by the Bus Terminal LEDs, along with other information. The output stage is switched on via an "EnableBit". The motor current can be set and reduced via a parameter value.

Optimum adaptation to the motor and the implementation of energy-saving features require minimum programming effort. During the test phase, the KS2000 parameterization software enables quick and efficient optimization. Since all data are set via software parameters, Bus Terminals can easily be exchanged and parameters stored or transferred to the next project. The need to transfer certain potentiometer settings and to document whole DIP switch configurations is finally a thing of the past.



What are the parameters that characterize a stepper motor?

Torque: Refers to the maximum motor torque at different speeds. This parameter is usually represented by a characteristic curve. Stepper motors have comparatively high torque in the lower speed range. In many applications, this enables them to be used directly without gearing. Compared with other motors, stepper motors can quite easily provide a holding moment of the same order of magnitude as the torque.

Speed: Stepper motors have low maximum speed, which is usually specified as a maximum step frequency.

Number of phases: Motors with 2 to 5 phases are common. The KL2531 and KL2541 Bus Terminals support 2-phase motors. 4-phase motors are basically 2-phase motors with separate winding ends. They can be connected directly to the Bus Terminal.

Rated voltage, supply voltage and winding resistance: Under steady-state conditions, the rated current at the rated voltage depends on the winding resistance. This voltage should not be confused with the supply voltage of the power output stage in the Bus Terminal. The KL2531 and KL2541 apply a controlled current to the motor winding. If the supply voltage falls below the rated voltage, the power output stage can no longer apply the full current, resulting in a loss of torque. It is desirable to aim for systems with small winding resistance and high supply voltage in order to limit warming and achieve high torque at high speeds.

Resonance frequency: At certain speeds, stepper motors run less smoothly. This phenomenon is particularly pronounced if the motor runs without load. Under certain circumstances, it may even stop. This is caused by resonance. A distinction can be made between resonances in the lower frequency range (up to approx. 250 Hz) and the medium to upper frequency range. In addition to their impact on smooth running, resonances in the lower range may lead to (in some cases significant) loss of torque, or even loss of step. If the characteristic motor curves are

not too "enhanced," this will become apparent as a loss of torque. While this type of resonance is mainly motor-specific and can only be influenced to a certain extent via simple stepper motor control measures, the type and design of the stepper motor control is quite significant for resonances in the medium and higher speed range.

Resonances in the lower speed range: They are easy to explain and particularly disruptive for the application. In principle, the stepper motor represents an oscillatory system (comparable to a mass/spring system), consisting of the moving rotor with a moment of inertia and a magnetic field that creates a restoring force that acts on the rotor. Moving and releasing the rotor creates a dampened oscillation. If the control frequency corresponds to the resonance frequency, the oscillation is amplified, so that, in the worst case, the rotor will no longer follow the steps, but oscillate between two positions. Due to their "sine/cosine current profile," KL2531 and KL2541 Bus Terminals are able to prevent this effect in almost all standard motors. The rotor is not moved from step to step and no longer jumps to the next position, but it moves through 64 intermediate steps, i.e. the rotor is gently moved from one step to the next. Any unexpected loss of torque at certain speeds is avoided, and operation can be optimized for the particular application. This means that the lower speed range, where particularly high torque is available, can be fully utilized.

Step angle: The step angle indicates the angle travelled during each step. Typical values are 3.6°, 1.8° or 0.9°, equivalent to 100, 200 or 400 steps per motor revolution. Together with the downstream transmission ratio, this value is a measure for the positioning accuracy. For technical reasons, the step angle cannot be reduced below a certain value. Positioning accuracy can only be improved further by mechanical means (transmission). An elegant solution for improving positioning accuracy is the microstepping function offered by the KL2531 and KL2541. It enables up to 64 intermediate steps. The smaller "artificial" step angle has a further positive effect: The drive can be operated at higher speed, yet with the same precision. The maximum speed is unchanged, despite the fact that the drive operates at the limit of mechanical resolution.