TK Series frameless motors installation and application manual

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Introduction

The present document detail the installation, integration and initial mechanical set-up of PHASE MOTION CONTROL series TK frameless torque motors (henceforth named TK motors). It provides the customer with the necessary information on how to integrate and operate with TK in his application.

Remark: The liability of PHASE MOTION CONTROL is in all events limited to the functionality of the motor alone and is limited to its repair or replacement according to the rules agreed in the documente Condizioni Generali di vendita Phase Motion Control , www.phase.eu, which are implicitly accepted when the motor is purchased.

Frameless motors are just components, however important, of complex systems of which Phase Motion Control is not aware and not responsible. The Customer or whoever owns or operates the system must take the responsibility to assess all safety or economical concerns relevant to the complete system, over and beyond motor replacement, which may stem from any type of motor failure, and of which Phase Motion Control is unaware and is not and cannot be responsible.

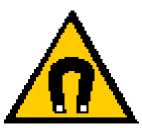
Safety

The user must have read and understood this documentation before carrying out any activity. In case of unclear information, please contact PHASE MOTION CONTROL.

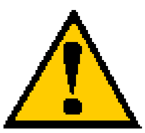
Handling, installation and maintenance must be done by competent and trained technical personnell according to IEC 364. Non-compliance with the safety instructions, statutory and technical regulations may lead to injuries to persons, damage to property and the environment.

General safety instructions

Anyone having active implants (pacemakers) or having any other ferromagnetic prosthesis is not qualified to work with these kinds of devices, or to approach them. Keep at safe distance from the motor!



Electronic devices and measuring equipment may be affected or destroyed by strong magnetic fields. Avoid placing devices with magnetic parts close to computers, monitors and all magnetic data carriers (e.g. disk, credit cards, audio and videotape, etc). Because of strong attraction forces, special caution is required in the direct proximity of the rotor (i.e. under 100 mm). Therefore heavy or wide objects made of steel of iron must never be brought close to the rotor by free hand. As magnetic forces are invisible, their effects are generally overlooked close to the rotor.



To cope with any event of an accident while handling the motor, always have at hand at least two wedges of solid, non-magnetic material (i.e. aluminium) as well as a non-magnetic hammer (approx. 2-3 Kg). In emergency cases, these tools are for separating parts magnetically attached to the rotor in order to free caught limbs (finger, hand, foot).

Electrical risk

Before installation verify the motor about any damage due transportation and handling, that may impair electrical safety.

Drive start-up may produce sudden uncontrolled movement. Keep away from all moving parts to avoid injury!

Do not connect motor to power supply other that specified by PHASE MOTION CONTROL.

A defective power supply may damage the TK assembly.

It is dangerous to interrupt earth or grounding connections. In no way must an earth wire be disconnected!

Before servicing, make sure that the TK is not powered.

TK motors may have hot surfaces also when the motor is not powered. Normal operating temperature could be over 100°C.

Slow turning motors have high back-EMF. For example, a TK-xxx-xxx-100 would develop 300 Vac at its terminals when manually rotated at 5 rpm. Beware of manual or gravitational rotation, dangerous voltage can be present at the motor terminals even if the machine is not connected.

WARNING: Deep deflux motors (constant power range > 1:2) may deploy higher than mains voltage between motor and series inductor. Verify maximum interconnection voltage while siziong the plant.

Transport and storage conditions

1. Transport and packaging

The PHASE MOTION CONTROL standard package is designed to avoid transport damage.

If any transport damage is observed upon reception of the goods, please inform immediately Phase Motion Control so that transport damages can be timely claimed or corrected.

2. Unpacking and mounting

To unpack the TK, please adopt all general safety instructions, reported on the paragraph 3.1.

After opening the package, never pull the motor cable, nor lift the motor by its cables.

Check for cable damage during transport or unpacking

For handling of heavy motors (i.e. >15Kg) the use of lifting tools is recommended, using threaded lifting bolts, when possible, or using a lift belt.

When storing the motor outside the original packaging put a non-magnetic spacer (i.e. wood) with 40-mm minimum thickness between stator and rotor.

After unpacking the rotor, keep the original rotor wrapping or wrap the magnetic part of the rotor with paper tape, to keep the magnetic surface clean. The tape must be removed just before mounting the rotor into the stator.

Take care with the rotors banded with carbon fibre ring: an accidental contact with metallic parts attracted by the magnetic field can cause damages to the carbon ring, if this happens please contact PHASE MOTION CONTROL.
Do not leave the rotor outside of its package longer than necessary for assembly to prevent pollution of the magnet surface and accidents
After mounting verify that the rotation of the rotor inside the stator is free, without contact for the whole revolution.

3. Storage

The storage area of TK motors must be strictly restricted and indicated with “Caution, powerful magnets”.
Motors and motors parts, whenever possible, should be stored in the original packaging.
The storage air humidity should be between 5 and 80% and the temperature between 5 and 45°C.
Should components be stored outside their original packaging, wrapping with oiled paper to prevent corrosion is recommended.
Magnetic parts should be separated and wrapped in non-magnetic protection. These protections should be at least 40mm thick.

4. Transportation

By land
The motor must be shipped with original packaging; if it is not possible use IP54 protection packaging. The parts must be packaged firmly to avoid any movement in case of shocks.
By sea
Use only sea standard packaging (IP55).
By air
CAUTION: if the rotor must be shipped unassembled, i.e. not inside the stator, airline authorisation is required because of the stray field of the rotor. The use of the original iron box in which the rotor was supplied is recommended. As required, enquire with Phase Motion Control for the supply of a shielding box.

Type and manufacture of TK motors

PHASE MOTION CONTROL TK brushless motors are the technical solution with the highest torque density currently available and are designed for high performance motion control.
Tk motors are frameless and are supplied as separate stator and rotor units for integration into the final equipment.
The motors are all three phases brushless and rotors are based on rare earth, high energy FeNdB magnets
All the motors have Class H insulation; the stators include a triple PTC for thermal protection and KTY linear sensor for temperature monitoring.
All TK motors are designed for liquid cooling as well as conduction/convection cooling

For deflux operation liquid cooling.is necessary

PHASE MOTION CONTROL, together with the Customer, often achieve higher level of efficiency and performance by designing and supplying semi-custom variants of the TK motors with special winding, rotor and frame designs.

TK motors can be supplied in the following types:

Standard (microframe option)	Rotor	Tubular ring with magnets, with sleeve for magnets retaining: this sleeve can be of 3 types depending to the rotating speed of the motor: • Metallic glued and fixed by key for slow speed operation.. • Carbon fiober sleeve for peripheral rotation speed from 50 to 150m/s. Shaft assembly is performed on the internal tube diameter generally ground to H6 tolerance.
	Stator	Inserted on thin steel sleeve machined to h7 tolerance, suitable for hot assembly on the operating equipment.
Custom or SQUID design	Rotor	Completely designed on customer specification. Same type of magnet retention technology of stanard product.
	Stator	In this case the standard stator can be inserted on a frame, designed on customer specification, for liquid cooling using internal chambers or using the external surface. The frame carries fixing holes for interfacing with the driven machine.

All the stators windings of TK motors are three dip vacuum impregnatied to provide the best mechanical characteristics, insulation and thermal transfer.

The winding heads have a glass fibre tape protection to increase protection during handling.

Special motors (type S-Squid) may carry an additional vacuum encapsulation with high thermal conductivity epoxy to increase thermal performance and mechanical protection..

All standard TK motors are supplied with power and sensor wire length 500mm, different length on request.

With custom frames also power and signal.connectors can also be supplied.

TK motors are supplied without position sensors

TK motor rotors are always not pre balanced; final balancing, if necessary, must take place after rotor assembly on the shaft.

Precautions.

Ground connection

Rotor and stator must be connected to the ground. Do not energize before connecting the grounding terminals.

Insulation voltage

All TK PHASE MOTION CONTROL motors are tested with following parameters:

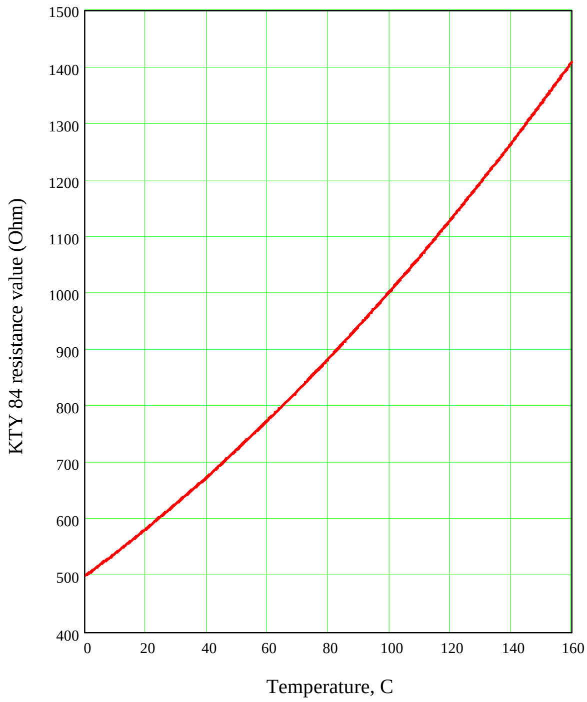
Insulation voltage between Phases-GND	4,5KV 60s
Insulation voltage between Phases-PTC/KTY	3,5KV 60s
Insulation voltage between PTC/KTY-GND	3,5KV 60s

Over temperature protection

All TK PHASE MOTION CONTROL motors are supplied with two types of sensors: one KTY 84-130 and three PTC 130.

The KTY sensor (yellow wires) is a linear temperature sensor and provides a reading of actual stator winding temperature (see figure), which must be used for monitoring and verification of the motor temperature during the cycle. It is NOT a protection, because it is localized on only one point and cannot guarantee true information, when a localized overcurrent occurs on a zone far from the KTY.

The PTC 130 sensors (blue wires) are localized one each on every phase, so can react very fast when the temperature rise of the winding exceeds 130°C in any one phase. PTC sensors MUST be used for protection. The PTC sensors are highly non linear, so they are sensed via atreshold circuit. The sensors guarantee <750 Ohm resistance for Tw <125 C, and >4000 Ohm resistance for Tw>145 C.



KTY sensors have double insulation to the winding.

All TK stators have two KTY sensors. The customer can use either one of them indifferently. Should a KTY probe fail for any reason, the other one can be used without need for repair.

Anti-resonance filter (snubber)

In some conditions of the power supply chain, electrical resonance phenomena may occur in motor windings. These phenomena can multiply several times the instantaneous voltage of winding versus ground, leading to excessive stress of the motor insulation system resulting in quick degeneration and total insulation failure after a short time of operation.

Picture below shows the star point voltage versus ground waveform acquired in a system with significant resonance. The DC-Bus setting of the power amplifier is only 600 Vdc but the instantaneous voltage can reach a value as high as 1600 V. The insulation system cannot withstand this high voltage in long term operation.

To prevent such resonance, Phase supplies with each motor with such characteristics a tuned anti resonance filter (snubber) which must be assembled within 5 m of the motors, between the motor star terminal (white wire) and machine ground. Failure to connect the snubber may result in motor failure by insulator puncturing.

IMPORTANT NOTE: the values of snubber filter are calculated for a "typical" configuration. The actual configuration of the complete power supply chain (inverter PWM modulation method, type and length of the supply cables, type of series inductor and/or filter installed) can modify significantly the behaviour of the system. Consequently it is strongly recommended that for each first installation of a new motor type or significant modification of the power supply components (such as different power amplifier type or brand) the star point voltage potential to ground with supplied snubber connected is acquired. The peak value must be <= +/-1200 Vpk.

Motor integration

During mounting always refer to the assembly drawing in your hand.

Mounting and installation of TK motor are always operation strictly linked to the architecture of the machine where it must be installed, the following information are only general basic information for the coeewct handling of motor.

Stator

The stator installation does not have any particular critical item.

Checklist:

Wiring	Protect the wiring from being caught between metallic parts during assembly and bending in the conduits. Contact PHASE MOTION CONTROL if wiring appears damaged.
Winding heads	generally, if not covered by protection flanges, the winding heads are vulnerable during the motor integration. avoid all accidental impact with metallic parts to protect the insulation. Contact PHASE MOTION CONTROL if damaged.
Liquid cooling	When the liquid cooling circuit is assembled and sealed, pay attention to avoid any loss of liquid from input/output nipples and prevent the cooling liquid from wetting with the windings. Contact PHASE MOTION CONTROL in case if loss of liquid on the winding.
Safety distance	If there are flanges or metallic parts in proximity of the winding heads, check that the minimum safety distance between the unprotected winding head and any grounded metallic part is kept, A value >=6 mm must be ensured to guarantee correct dielectric rigidity Should a shorter distance be unavoidable, supplementary insulation may be necessary. In this case contact PHASE MOTION CONTROL to obtain detailed instructions

Special warnings for liquid cooling systems:

1) With SQUID type frames, or anyway whenever the cooling cavity is made with adjacent rings and cuts according to Phase Motion technique, carefully check that the inlet and outlet bores are placed exactly opposite with respect to the nearest cooling ring cut, and are centered on the first and last ring respectively. Frames with an even number of rings must have inlet and outlet on the same side; with an odd ring number, input and output are 180^o opposite.
2) Make sure that under no circumstance the static pressure in the cooling chamber could exceed 500,000 Pa to prevent motor deformation leading to O-Ring sealing failure (expecially for motor diameter > 400 mm)

3) Should a mix of water and glycole be used in the cooling circuit, be advised that glycole tends to dissolve most seals with the except of VITON rubber. All O-rings supplied by Phase are made of VITON,
4) It is anyway better to mix the water with an appropriate ion neutralizer (such as ELF Chip Supra, Total 60L, Eurotherm Eurocold 131) instead of Glycole with the additional benefit of limiting corrosion and clogging risk
5) Do not cool the motor or parts thereof below room temperature to prevent condensation on the motor, which would quickly degenerate the winding.
6) In as much as possible water must be prevented from leaku=ing on the winding even in case of O-Ring failure, by means of small drain holes and channels in the appropriate positions
7) Always make sure that all air bubbles and pockets are removed from the circuit before performing a full power test and commissioning.

Rotor

The procedure for rotor assembly is determined by the type of coupling with the shaft
Checklist

Insertion of rotor to the shaft	All TK rotors have permanent magnets, so avoid mounting procedure using hot insertion, because there is a risk of rotor demagnetising if the temperature exceeds 80°C.Contact PHASE MOTION CONTROL in case of demagnetization
Shaft-Rotor coupling	Always respect interference value between shaft and rotor as indicated by PHASE MOTION CONTROL.
Carbon fiver sleeve	On this type of rotors check carefully the integrity of the sleeve. This preloaded unidirectional composite structure displays exceptional strength for high speed rotors, but can be damaged easily by shocks. Contact PHASE MOTION CONTROL if rotor is damaged.

On request, rotors can be supplied with dual diameter and connection hole for hydraulic disassembly

Mounting of the rotor inside the stator

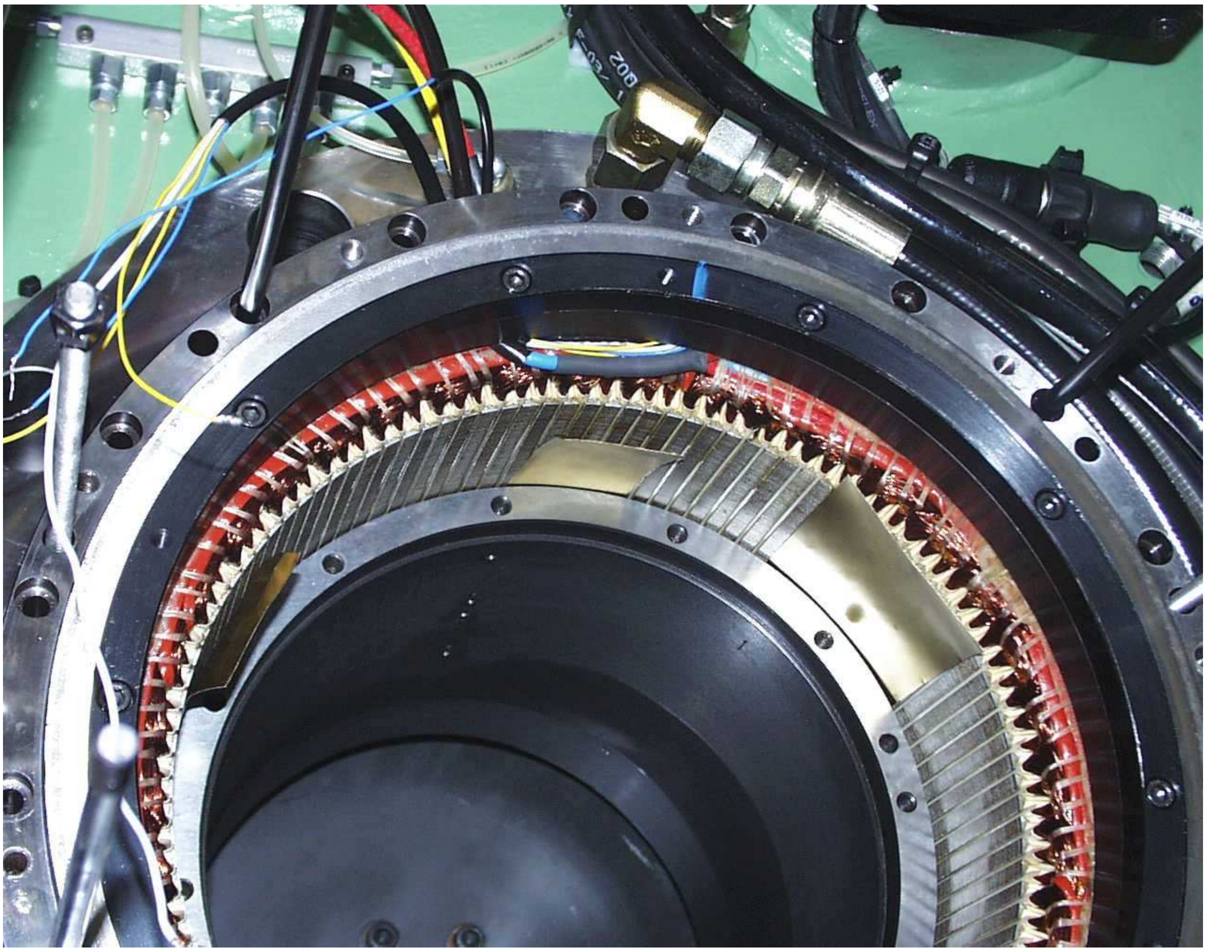
Important warning: Avoid contact or close proximity of the bearings or parts thereof with the rotor magnets. Magnetized bearings, or magnetized cages, wear rapidly and catastrophycally expecially at high speed.
If special assembly tools or jigs have not been designed with the application, (i.e. special long shafts on which the rotor may slide, or positioning pins), then the rotor introduction is performed according to the following routine

1) Make ready a few (at least four) "shims", (flexible spacers made of non magnetic, not scratching, material, e.g. brass, copper or mylar) to interpose between rotor and stator. The shims should be at least 4 and are placed in the stator hole, equispaced on the internal circumference of the stator. The shims are best made with thickness

approximately half of the theoretical mechanical air gap. This to guarantee a right cantering and to achieve the extraction after rotor mounting. (Remark: up to size TK 450, all TK motors are supplied with 4 mylar shims in the delivery package),

2) Immediately prior to rotor instertion in the stator, peel the protective tape from the surface of the sleeve, check for cleanliness of the rotor surface; if any metallic part is attracted by the rotor, clean the surface peeling with a adhesive tape.
3) Position the rotor in front of the stator, well centered, making sure that the "shims" are in the correct positions, and that they can be removed after rotor insertion.
4) Insert the rotor; pay attention to the attraction force of the magnets that tend to "suck" the rotor inside the stator. This force is about 15 N/mm of rotor diameter and starts to be felt when the rotor is at some centimeters from the stator
5) If a crane is used to move the rotor check for metallic parts in the rotor trajectory which could be attracted to the rotor causing damage
6) After rotor insertion the shaft/bearings can be locked, and te shims removed;
7) If the rotor interface is based on bearings on both sides of the rotor, the shims are extracted when only one bearing is in the correct position. Generally, assembly of the second bearing is possible and the rotor will be re-centered if the last bearing seat is machined with a **proper conical chamfer**..

The photograph shows a mounting example.



Check list after integration

1) After rotor installation, if possible, check that the rotation is free and there is no interference between rotor and stator;
2) Immediately perform a back-EMF testing and compare with the spec; if the back EMF is within +/- 8% of specified voltage and balance between the 3 phases is better than 5% the assembly is electricaly and magnetically correct. Note the measured EMF value and the temperature of the measurement for possible, future diagnostics and rotor temperature measurement.
3) Repeat the motor insulation test (according to table in paragraph 6.1) to verify the proper connection and integrity of cables and to be sure that no damage occurred to the windings during installation. <u>The "Spike Suppressor Unit" (if present) must be disconnected for this test</u>. It is recommended to execute the test with a DC voltage (AC insulation test may be disruptive and test results can be affected by errors due to motor and cables capacitance to ground). Max. leakage current acceptable is 100 uA stable or reducing in time..

4) Connect the the “Spike Suppressor Unit” between the star point terminal of the motor and ground.
5) Check the proper sealing of the water cooling circuit (if present) by applying a pressure of 1.5 bar and verify that the same pressure is maintained;
6) Proceed with the electrical installation.
7) After machine completion proceed with insulation voltage testing according to the relevant local regulation (CE or UL-CSA).

IMPORTANT NOTE: in case of first installation of a new motor type execute the measure of winding voltage to ground as reported in previous chapter “Precautions”.

General technical information on TK frameless motors

The TK series of frameless brushless motors provide the highest torque density available today for direct drive, high performance applications. Unlike traditional torque motors, TK units have both high torque and high speed capability and thus operate seamlessly both as spindle and table motors.

TK motors consist of separately supplied stator and rotor units suitable for direct assembly inside the structure of the machine. TK motors are three phase, rare earth (Iron Neodymium Boron) permanent magnet units and reach the highest continuous and peak torque density available today, together with high speed and flux control ability over a constant power range up to 10:1.

The rotors use special Phase manufactured magnets with minimized loss factor allowing high speed operation with a thin isotropic rotor. All rotors are rigid units with mechanical, glue free magnet retention, preloaded carbon fiber sleeve for safe operation even at very high speed.
Rotor are often semi custom units to allow direct coupling to bearings, encoders, brakes.

All TK motors are designed for fluid (water) cooling on the outside of the stator for maximum performance. Conduction/convection cooling is also possible. Constant power operation (flux control) always requires water cooling.

Customized frames with integral cooling or even partial machine subassemblies with bearings and encoders are manufactured on request based on the standard frameless magnetic designs available.
The torque range spans from 10 to 40,000 Nm with maximum diameter 1150mm; above that size, segmented semi custom units are available, currently up to 18 m diameter.

Applications:

Metal cutting	DD rotary tables with both contouring and turning ability; DD spindles for mills and lathes; Tubular spindle motors for multi spindle machines; Rotary table indexing for transfer machines;
Metal forming	DD flywheels for press; Cold rolling machines; DD Capstans for hot and cold rolling/drawing;
Plastic	DD extruders; Injection and mixing stages for plastic injection molding machines, replacing hydraulic motor; Gearbox suppression in mixer, grinders, shredders;
Energy	PM generators for small steam or gas turbine, cogeneration.

Motor morphology and application guidelines

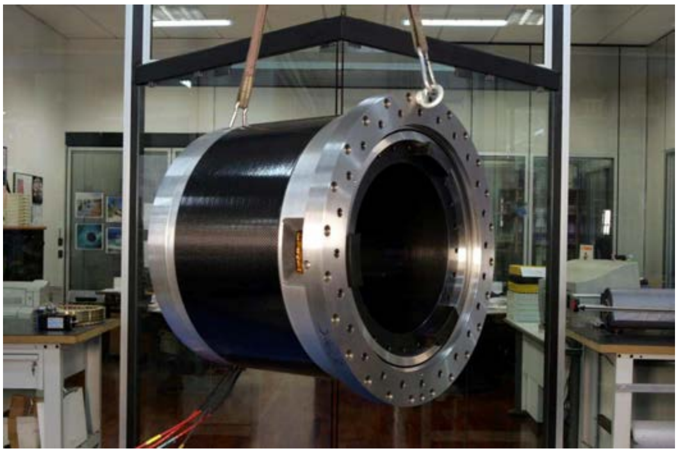
TK motors consist of:

A three phase stator, wound and impregnated (3 dips, preferred solution for high thermal cycling), or vacuum encapsulated in super high thermal conductivity compound (for low surface temperature operation), which is either built into a thin steel microframe, cylindrical, or into a metallic frame carrying the cooling chambers and coupling O-Rings on the outside and a set of tapped holes on one side (Squid type).
The microframe units are ground to h7 tolerance on the outside diameter and are machined parallel on the two stack sides. This construction is intended for interference fit or axial pressure locking.

The microframe technology maximizes the usage of space in the assembly and requires the machine body to carry the cooling cavities on the inside. It requires some care in the design of the application but results in the highest space and power density today possible.

Alternately, the SQUID frame is much simpler to use and only requires a cylindrical cavity, while motor assembly and fastening s just through a set of screws. The achieved torque density is slightly inferior to the microframe due to the radial size of the frame.

The insulation system of the motors is rated Class H (magnet wire: Class C) with reinforced insulation specifically designed for the high DV/dt typical of 600 Vdc servo drive application; the windings are equipped with three PTC sensors for protection and a KTY 84 linear temperature probe for process monitoring. The star point of the winding is also generally available for filtering purposes. All windings are factory tested for insulation 4.5 kVdc to ground and 3.5 kVdc phase to phase, far in excess of regulation requirements.



A Permanent Magnet Rotor, with tubular, isotropic base shape, which carries the magnets on the outside periphery, protected by a preloaded carbon fiber (up to 150 m/sec) ring.

The magnets are generally high temperature, high energy FeNdB sintered magnets, Phase Motion Control manufactured with a special patented technology. They are designed for the maximum class temperature and are virtually impossible to demagnetise except in case of drive failure or improper operation. If continuous exposure to oil is forecast, special oil resistant magnets can be specified.

The rotor may be fastened on the shaft either by interference fit or by an array of axial bolts. The latter construction is preferred for high torque, low speed applications such as rotary tables. In general, the rotor inside profile is customised to fit with the needs of the machine provided the required profile is compatible with the maximum hole required by the magnetic field, and specified in the accompanying technical sheets. For proper operation, the motors need a position sensor on the shaft (not supplied) both for field orientation and for position/speed control. The rotor is permanent magnet type and has no primary losses, so that no rotor cooling is needed in principle. However, the inverter chopper frequency must be set high enough to ensure that the ripple current, pk-pk is less than 20% of the nominal rms current to avoid the insurgency of unacceptable, and dangerous, stray rotor loss.

Customized frames with integral cooling or even partial machine subassemblies with bearings and encoders are manufactured on request based on the standard frameless magnetic designs available.
The rotors are supplied not balanced; high speed operation requires dynamic balancing when assembled on the application shaft.

Depending on their geometry and magnetic circuit, TK motors can be divided into three main branches:

Thin ring, large diameter motors for high torque, low speed (torque motors)

Typical applications:

- Rotary tables for NC machine tools, often with turning capacity
- Indexers for transfer machines
- NC machine head orientation
- Large rotary tables (glass, packaging, assembly)
- Carbon fiber deposition machinery
- Direct drive of mills (concrete, ceramics, rubber
- Large low speed generators (mini hydro, wind power)
- Metal forming: electric press and bending
- Direct drive plastic injection machines

In all these applications, direct drive eliminates play and removes the need of an accurate mechanical gearbox, which in turn would limit the accuracy and the dynamic performance of the system. Mechanical brakes-dividers are unnecessary. The table accuracy is the accuracy of the encoder system. The system is thus extremely simple, flexible and reprogrammable. The removal of the transmission system and of its backlash and elasticity results in control bandwidth up to 250 Hz, so that a positioning cycle can be completed with great accuracy within a few msec with advantage on the machine cycle time.
To ensure adequate servo performance in direct drive high accuracy, high stiffness applications such as indexing and rotary tables in NC machine tools, the sensor must be sinusoidal so that the drive may interpolate the actual position with a resolution at least ten times greater than the required accuracy. Additionally, the sensor fastening or spring mount must have intrinsic resonance frequency above 2000 Hz not to limit the overall system performance.

Spindle motors for mills and lathes

long and thin motors, brushless with flux control ability, medium to high speed, high power density, suitable for heavy machining or control of large inertia loads for spool winding/unwinding. The TK motors have currently the highest power density and allow the manufacture of electrospindles with torque rating hiterto unattainable, in the range of several thousand Nm while reaching high speeds in the thousands of rpm. Spindle type motors are anyway high performance servo motors so another emerging application area is very short cycle actuation. Recent application are in direct drive of the ram of high speed turret punching press with stroke rates in excess of 300 strokes/min, or fast, heavy indexing in wire frame welding machines.

Typical applications:

- Power lathes for automotive,
- Spindle motors for mills and high speed machining centers
- Wire grid manufacturing

Tube motors, small diameter, for multiple spindle units

Typical applications:

- High speed/power motors where lateral (pitch) space is limited
- Multiple drilling heads
- Swiss type lathes

Standar size of terminal cables vs nominal motor current

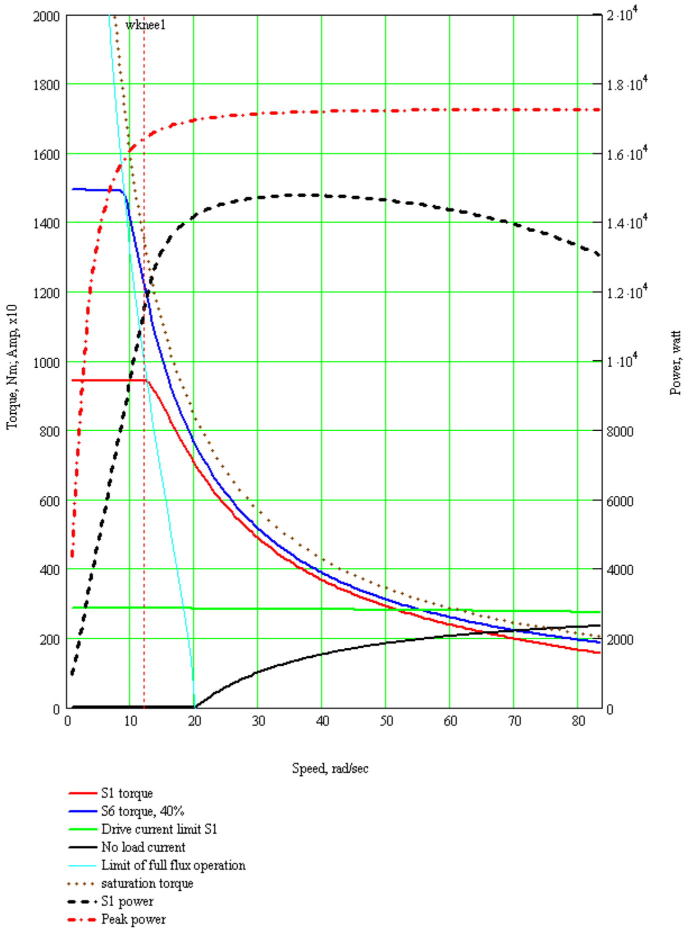
PTFE insulation, 2500 Vac, L=500 mm

Nominal current	Wire size
In < 15 Arms	1.22 mmq = AWG 16
15 Arms <= In< 25 Arms	2.97 mmq = AWG 12
25 Arms <= In< 45 Arms	8.6 mmq = AWG 8
45 Arms <= In< 82 Arms	15 mmq
82 Arms <= In< 110 Arms	25 mmq
110 Arms<=In<200 Arms	50 mmq

How to choose the optimal TK motor?

First, define the technical feasibility of the application. In general, all motors share the same physical limitation, that is, the ability to generate "airgap thrust", i.e. a sideways thrust between stator and rotor which is linear thrust in linear motor, and becomes a torque when the motor is round. The amount of thrust per unit area depends on motor technology but is fundamentally limited by the properties of the materials (magnets, copper, steel) used in the motors. PM technology offers the highest specific thrust available today, and this value is gradually increased as the technology improves. Many factors (cooling conditions, size, airgap thickness, linear speed etc.) affect this value which should only be used as a rough guideline. Tk rotary motors and Wave linear motors are characterised by a peak thrust around 80000 N/m^2, continuous thrust with water cooling ~ 55000 N/m^2.

The thrust limitation explains why it is



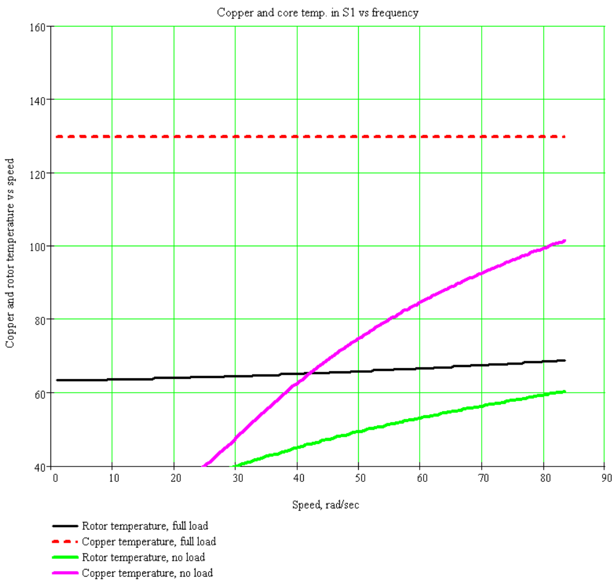
always appropriate to use the maximum diameter available to maximize output torque. In general if a motor is scaled in diameter, torque is scaled with the square of diameter, while it scales only linearly in length. Consequently, to verify whether a new application is feasible at all, if the torque availability is expected to be a limitation, the maximum diameter available should be determined compatibly with physical limitation and maximum peripheral speed (values below 150 m/sec pose no problem) and the airgap surface can then be evaluated. This would give a rough estimate of motor length and therefore indicate whether the application is feasible or not.

Large rings with very limited axial length are the most efficient solution for ***high torque low speed applications***, and they have the additional advantage of not needing separate bearings as they can be generally carried by the same bearings of the load. However, inertia scales with the cube of diameter, so ***where the inertia is the dominant load, long and thin motors are more appropriate.*** A typical example is the direct drive of the ram of high speed punch presses, in which motion is reversed over 300 times/min, or in high speed flying shears; in this case, tubular, water cooled TK motors provide the highest performance solution.

Spindle drives generally demand both high torque and high speed but the diameter is generally restricted, so they tend to be long and thin. Airgap hole diameter to length ratios up to 1:3 are routinely manufactured. In this case, the Phase PM magnet technology allows the manufacture of extremely ***thin stators and rotors*** which are particularly useful in ***multispindle*** applications.

Spindle PM motors manufactured with the high frequency Phase magnetic technology can operate both in constant torque and constant power mode. The constant power range, depending on the type, can exceed 10:1 although this is generally limited by the ability of the drive selected to control a deep deflux range. When compared to AC Induction spindle motors, the PM motor design offers:

- Rated torque approximately double in the same size
- Larger shaft compared to the outer diameter
- Loss only limited to stator, rotor is "cool" so that bearings can operate more accurately and reliably
- Solid, "mechanical" rotor (non laminated) which guarantees balancing stability
- Wide constant power control range (up to 10:1) without tap change
- Free from radial flux which may generate currents in the bearings



In the Phase TK technology, there is no fundamental physical difference between torque motors and spindle motors; they have the same smoothness and high bandwidth necessary for direct drive indexing and contouring operation, so that ***milling and turning operations on the same motor are now possible***.

There is, however, a fundamental difference between PM and induction spindle drives. In the induction technology, power is used to magnetize the motor (at low speed, high torque) thus resulting in limited output torque available; flux reduction is easily obtained by just reducing the magnetizing current. Thus the motor is "hot" at max load, and "cool" at no load. PM motors, conversely, derive the field from high energy permanent magnets, so that no power is required to build the motor field and more power can be devoted to torque generation. When the flux must be reduced, however, power must be applied just to lower the field so that PM motors at high speed need some current even at no load.

A typical power and torque curve versus speed is shown in Fig. 1 for a combined torque/spindle motor with 570 mm diameter, 100 mm axial length; in Fig. 2, the motor temperature at no load and full loads are displayed. It can be observed that above the "knee speed" i.e. the speed of transition between constant torque and constant power operation, the motor temperature becomes progressively independent of motor load.

Mechanical Assembly, airgap control and magnetic attraction

Another useful feature of PM technology is the ability to operate with a wide airgap, up to several millimetres in the larger motors. This feature can be useful in machines with important deformations, such as plastic injection press or impact hammers. As a standard the airgap is in the order of 1 mm, radial, and this generally enables designs in which the motor rides on the machine supports without need of separate bearings.

The magnetic flux in the rotor generates radial attraction forces. These are perfectly balanced only if the rotor sits in the center of the stator, and increase with eccentricity. In practice, this is equivalent to a "negative stiffness" which must be compensated by a much higher positive stiffness in the bearing system. The attraction data can be supplied on demand, the order of magnitude is shown in the graph in Fig. 3, for a 1000 Nm, 370 mm diameter, 105 mm long torque motor with a 1 mm radial airgap.