Celera MOTION
A Novanta Company

Air Bearing Spindle Installation & Operation

REV210608

WHY IS PROPER SPINDLE INSTALLATION IMPORTANT?

Celera Motion's Westwind air bearing spindle technology is adopted in many specialized machine tools, robotic automation, and semiconductor processing applications, specifically to achieve higher productivity, greater accuracy, and longer product life. These air bearing spindles offer an oil-free bearing solution, with zero contamination to the environment.

To consistently deliver high performance, air bearing spindles must be correctly installed within the machine, particularly if being used in a dynamic application, such as being mounted in a robotic arm, or in a high speed multi-axis machine tool head. In addition to the mounting of the spindle, all the necessary services to the spindle must be given careful consideration, including the electric drive parameters when installing a motor driven version, and the interaction of the surrounding components on the performance of the spindle. Any deviation from the installation and operational instructions will result in inferior performance, and possible spindle damage.

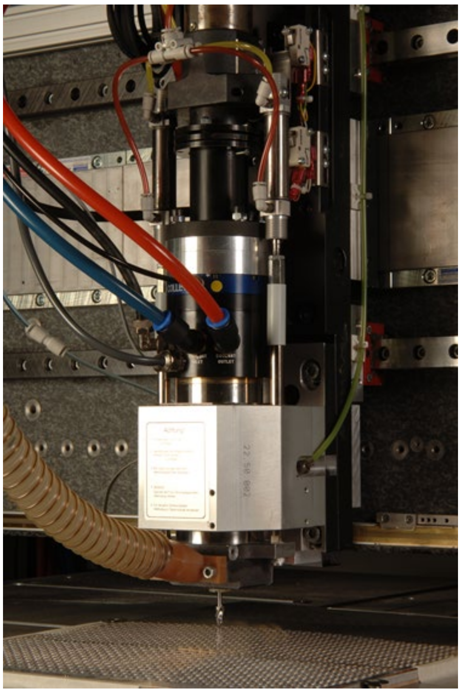

Figure 1: PCB Drilling & Routing Air Bearing Spindle Installation

SPINDLE INSTALLATION GUIDELINES

For many high technology industries, Celera Motion's Westwind air bearing spindle is the perfect solution – but apart from the more obvious activities of mounting and service connections, there are many design considerations that must be taken into account when incorporating air bearing spindles in the design or upgrade of a high speed or high precision machine. The following guidelines should act as an aid to machine design and problem solving, where some less obvious effects may be overlooked.

Installation

It should always be remembered that, although robust in operation, an air bearing spindle is a high precision device that requires a similar degree of precision in its attachment to the machine it is being used in. Care should be taken that the method of attaching the spindle to the machine does not create stresses within the structure of the spindle that could lead to imperfect operation.

A simple first-step method to checking that an installation is satisfactory would be to reduce the bearing air pressure to a low value (0.5 to 1 bar) and checking if the shaft still revolves, by hand, with minimum effort. If the shaft does not revolve freely, this will show there is a major problem. However, this will not show the dynamic problems, such as heat distortion, that could still be present.

Clamping

Air bearing spindles are manufactured with very fine bearing clearances, and serious damage can occur to the spindle if it is distorted during installation. The spindle body is suitable for location in a linear bearing sleeve or a clamp. Spindles must be rigidly mounted and free from distortion. To achieve this, the following steps should be taken:

- The spindle body should be lightly clamped over the maximum possible length of its location diameter (refer to Figure 2 below).
- It is essential that the spindle body and housing bore are cleaned and lightly greased prior to assembly.
- Housings must be checked for roundness, size, and straightness before clamping.

When spindles are clamped on a parallel body location, there are two basic forms of clamping that can be used: split clamping and saddle clamping (see Figure 2 and Figure 3 below).

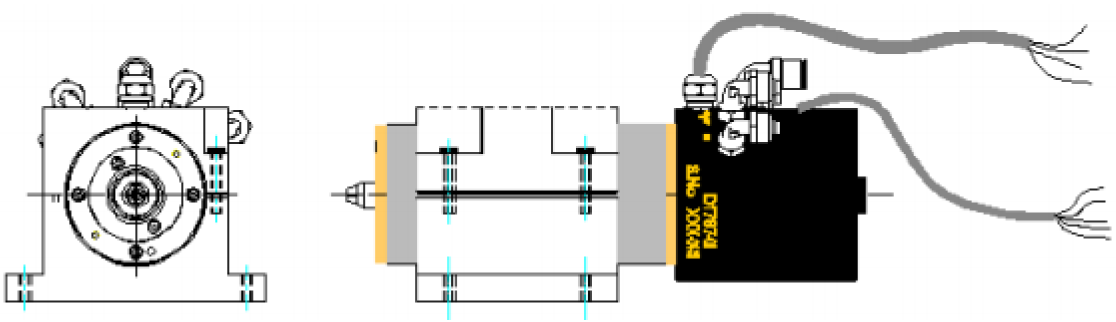

Figure 2 – Split Clamping

Split clamping is the more common form, as shown in Figure 2, where the clamping takes place due to a minor deflection of the spindle housing on one side only. If this type of clamping is adopted, then it is recommended that a suitable piece of gauge plate is fitted accurately into the slot and clamped down prior to finishing the bore of the housing. On completion of the housing bore, the gauge plate may be removed and ground down by 0.001 inches (0.0254 mm) before replacement.

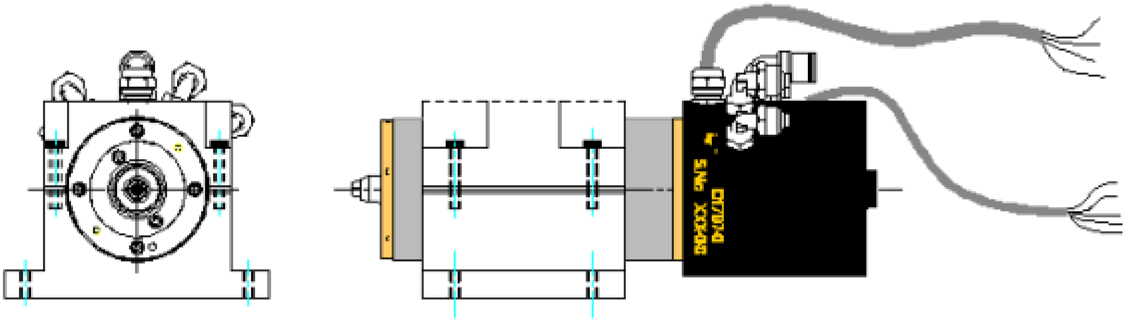

Figure 3 – Saddle Clamping

A similar approach may be adopted if the saddle clamp is employed, as shown in Figure 2. Care should be taken to ensure that the clamping force is spread as uniformly as possible over a relatively large area.

Note: Only light clamping is necessary. The maximum clamping force should be 10ft/lbs (13Nm). Excessive force will damage the spindle.

Positioning

Air bearings operate on a principle of air flow, and it is very important that the constant exhausting of this air should not be impeded. It is normal for the spindle to exhaust air from any number of specific ports, usually through an integral filter, as well as from the front shaft/bearing interface, the shaft bore, or any other component joint that is not specifically sealed (it is normal to use metal to metal contact on joints that are only subject to exhaust air pressure). The exhaust air may also be warm (up to 70° C) and care should be taken to avoid impingement of this on thermally sensitive materials or devices. It is also important to avoid restricting the exhaust flow, and it is advisable to contact Celera Motion's Westwind team if exhaust will be piped or directed away from its normal outlets.

Handling

It should also be remembered that, until supplied with air, the bearing has no stiffness and subsequently the shaft is free to move within the spindle. The component materials used within the spindle are selected to provide some degree of protection against any 'transport' damage, but care should be taken when handling or connecting a drive device, because even small amounts of shaft rotation can cause damage to the bearings in this state that may not become apparent until the spindle is run at speed or has obtained a high load working condition.

Figure 4

Where a spindle is fitted with a collet for tool holding, it is important that a tool or transit pin is always fitted. Failure to do so could produce relaxing of internal components and subsequent imbalance problems at a later time. A spindle should never be run without a tool or transit pin fitted in the collet.

Services

The correct connection of all services is of paramount importance.

Figure 5

Correct air quality is crucial, as the air must flow in a controlled predictable manner through very small clearances between the bearing and shaft.

Recommended Westwind air bearing spindle air supply specifications are:

- Particulate carryover filter <1µm
- Oil vapor carry over <0.01 mg/m3 at 20°C
- Dew point at running pressure <7.5°C , using a freeze dryer
- Temperature similar to the surrounding atmosphere, to avoid condensation forming on the spindle surfaces

Air Pressure

The air pressure must be set by measurement as close as possible to the inlet of the spindle (with air flowing, not a dead leg). If this is not possible, the air supply pipe diameter should be as large as possible (6 mm bore is advisable as a minimum, in most cases). It is strongly recommended that individual pressure switch protection be used on all spindles.

Coolant

Coolant, when specified for use, serves two purposes:

1. It removes heat generated by the motor stator and the shearing of the air film, in high-speed devices.
2. It stabilises the interface temperature between the spindle and the mounting device.

Both of these principles assist in providing extremely consistent positional accuracy of the tool. Water is the cooling medium normally used, although other fluids are often acceptable after discussion with Westwind and subsequent adjustment is made to flow specifications.

Recommended Westwind air bearing spindle cooling specification are:

- Clean (preferably distilled) water in a closed loop cooling system. Water should be inspected regularly for fungal and bacterial growth
- De-ionized water should not be used
- Inlet temperature 16°C – 20°C Typ (refer to outline drawing)
- Temperature rise across the spindle < 10°C (unless otherwise stated by Westwind product information)
- Use of a commercial heating system additive such as "Fernox" to minimize any corrosive and calcification effects
- 25µm particle filter
- Electrical ground on chiller should be at the same potential as the main machine

Correct coolant flow and temperature range are important. It is recommended that each spindle should be monitored for flow at the outlet or return port. A temperature rise in excess of 10° C differential across the spindle denotes a problem. The use of deionised water is not acceptable as this can promote erosion of some of the materials used for internal components.

Electrical Supply Wires

Electrical supply wires as well as internal transducer wiring may or may not be attached to plugs when supplied (depending on the spindle type). Whatever the type, it is essential that all connections outside of the spindle or plug are carried out to the relevant machinery safety standards.

Motor Protection

Incorrect use of a spindle, including operation with an unsuitable drive type, inappropriate drive parameters, or improper cooling flow, can result in excessive heating of the spindle motor. To help reduce the risks of this causing permanent damage to the spindle, most Westwind air bearing spindles are fitted with a thermistor.

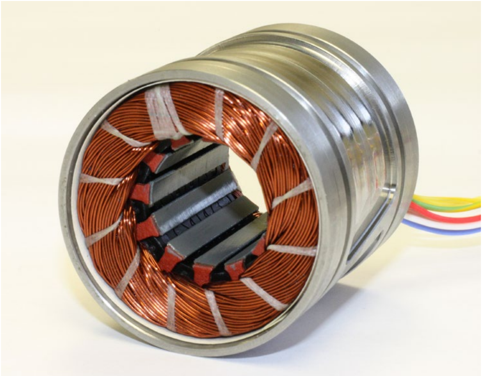

Figure 6

The thermistor provides an electrical connection which will switch from a closed connection to an open circuit condition (resistance greater than 1,000 Ohms) when the internal motor temperature rises above 95° C to 105° C. Monitoring of this connection as a gate to allow spindle operation only in the closed condition will protect the spindle from a number of potential problems, though there will be some circumstances where its effectiveness is limited. There is no substitute for ensuring that the spindle is setup and used correctly, and the Westwind product line technical support team will aid with this.

Many types of spindle drives have suitable thermistor monitoring connections, but it is recommended that the thermistor is directly monitored by the machine control system. Failure to monitor the thermistor exposes the spindle to an unnecessary risk of damage, for which we cannot take responsibility. The Westwind product line and authorized repair houses will therefore refuse claims for warranty where the failure is due to overheating of the motor (example: stator burn out), and where it cannot be proven that the thermistor has been correctly connected and utilized within the machine operation.

Spindle Grounding

The spindle body is designed to be of consistent potential and should normally be grounded. However, as part of the Westwind product line continual observation procedures, it has become apparent that some OEM's are not using the spindle earth wire or wires correctly. The earth wire is fitted as a safety precaution and inappropriate use may place the end user at risk, which could result in a condition where the spindle body or cable screening could be at an elevated electrical potential while accessed by the operator.

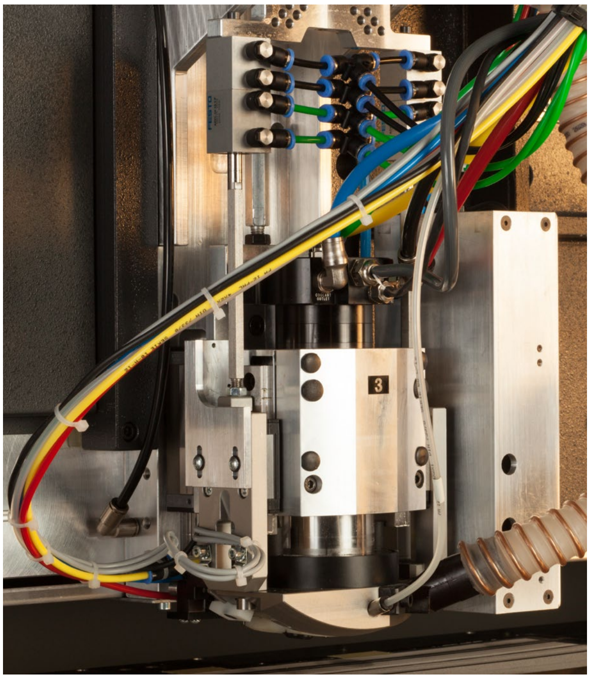

Figure 7

Many PCB drilling machine OEM's use a contact drilling interface and use the earth wire as a method to supply the spindle with the signal. If this system is not designed correctly, any internal short within the spindle will not trigger the appropriate safety cut-out on the drive. Westwind product line representatives recommend that all OEM's should carry out a risk analysis on their contact drilling interface circuitry as a precaution.

The main OEM drive suppliers have issued the following advice on this issue:
When a contact drilling interface causes the earth to have a high resistance, the degree of electrical protection is reduced and subsequently may allow degradation of the spindle or wiring to the point where a major machine alarm or failure occurs. It is only when the current level is higher than the limits set in the drive that the drive will raise an alarm condition.

Note that signal wires and cable screens will not normally be grounded at the spindle. Where integral speed probes are used, the output signal type and pulse count per revolution should be checked prior to connection.

Electric Drives

Motor voltage/frequency characteristics, or relevant voltage constants, in the case of DC motors, should be checked and set on the drive prior to connecting to the spindle, as over-volting or under-volting can cause specific motor problems and possible failures. It is a fact that some electrical drives experience problems with the correct control of air bearing spindles, because the motors used are often high frequency devices with minimal low speed impedance and are effectively very sensitive to 'dirty' or 'spikey' waveforms. This is coupled with the fact that shafts have very little frictional resistance to rotational motion, and sometimes fairly high polar inertia.

In addition, voltage figures quoted on Westwind specifications are True RMS values, and should be taken as a guide to the parameter settings of individual drives. Actual figures indicated on specific drives may differ from the values measured as 'True RMS' and must not be assumed to be correct.

Note: Under certain operating conditions, the use of Pulse Width Modulated (PWM) frequency converters with high speed spindles can cause an electrical heating effect, leading to an increase of the shaft rotor temperature to an unacceptable degree. This phenomenon particularly affects spindles used in conjunction with multi-head PCB drilling machines. The electrical heating effect is a result of increased current losses within the shaft rotor. Test results indicate the cause is due to the presence of electromagnetic harmonics (normally due to the high frequency switching of the PWM converter).
Westwind air bearing spindles advises the use of high frequency filter units, in conjunction with PWM converters, as normal operational policy. These units can be obtained from the drive supplier or via the machine manufacturer.

Operation

The first consideration is that the spindle (unless specifically designed with aerodynamic bearing capability) should never be run without an air supply connected. Similarly, if an ATC (automatic tool change) system is incorporated, the spindle must not be run without a tool fitted. Operation outside of the specification parameters, even for a fraction of a second, could cause damage that may render the spindle unfit for the intended application.

Correct balance of any associated tooling is critical, as is the method of connecting the tool to the spindle. It should be remembered that tool holder geometry and location might alter with increasing rotational speed, due to centrifugal, thermal or windage effects.

If installing a high speed spindle, especially as a retrofit or upgrade of an existing machine, care should be taken that the resultant vibrational frequencies, induced by cutting material (number of cutting edges multiplied by speed) or by the drive mechanism or the spindle (example: six step inverter output multiplied by number of pairs of motor poles multiplied by speed; number of turbine buckets multiplied by speed, etc.) does not correspond with a modal frequency for any part of the machine construction or operation.

Vibrational levels produced by a rotating, unloaded, spindle are very small and, unless very high positional accuracy is required for the specific application (example: optical, etc.), these vibrations should not induce noticeable problems in other machine components. Individual components and gas films within the spindle will however have their own resonant frequencies and forced vibrations coinciding with these frequencies (or sometimes harmonics of these frequencies) can conceivably cause 'softened' bearing performance.

It should be remembered that the spindle shaft is 'floating' on a gas film and can therefore be considered as being suspended, axially and radially, on a compound spring system. This means that the action of the shaft, in space, will be affected by the 'system' stiffness (kS) in the plane considered, where kS is calculated from an equation:

$$1/kS = 1/kB + 1/k1 + \ldots\ldots\ldots\ldots 1/kN$$

kB being the bearing stiffness, itself variable with speed and temperature.

k1… kN being the stiffness of all individual components, joints, mechanisms, etc. between the bearing a rigid ground.

The result of this may be seen as an effect on system dynamic performance (whirl speeds), or on resonance frequencies or harmonics. The shaft will also experience machine induced spindle movements (intentional or otherwise) through the bearing 'spring' system. This further complicates the calculation of dynamic effects.

In an application where it is known that the spindle will be subject to controlled, externally produced, movements (e.g. drilling, spraying, etc.), it is necessary to estimate the bearing loading produced by shaft gyroscopic or inertia effects, resulting from this action. Most spindle outline specifications, as well as theoretical and test performances, consider the spindle in isolation (example: unaffected by external stimuli). It is therefore necessary to establish the angular and linear accelerations acting on the system before calculating the forces involved.

As the distances between shaft and bearing are so small, and the time requirements to move these distances are very short, it is necessary to consider all changes in acceleration (jerk) experienced by the spindle. It is best to measure the effects of such actions at the shaft with the spindle mounted in the machine to be used, as calculation can be very difficult. Typical control movement accelerations are in the order of 1G to 5G, but system clearances, backlash, bounce and resonance can create two to ten times this value at the spindle. A major problem associated with excessive acceleration, or applied vibration, is that it is one of the very few mechanisms that can cause minor damage to a bearing, and hence cause a degradation of performance over a period of time.

Although of very small frictional resistance, gas film shearing will produce some heat at high rotational speeds. This will be dissipated by the cooling system but some minor performance changes may occur in the first few seconds after start-up (all theoretical design and practical testing is based on stable dynamic conditions).

On machines with multiple spindles it should be noted that 'Brinelling' (localised bearing damage caused by sympathetic vibration of the static shaft) could result from long term isolation of one or more spindles.

Maintenance

One of the advantages of the air-bearing spindle is the small amount of maintenance required. This usually consists of maintaining the quality of the services; inspecting clamping to the machine and checking the spindle for ease of shaft rotation, as in most cases the spindles are not customer serviceable.

On spindles incorporating collets, it may be necessary to maintain taper lubrication, to ensure correct tool griping forces. Westwind can advise on this procedure. On some spindles, replacement tool-holders or collet cartridges may be used; the convenience of this feature should be balanced against the slight compromise on extreme accuracy.

THE BENEFITS OF CORRECT SPINDLE INSTALLATION

The key benefits of using Westwind air bearing spindles can only be realized by correct installation and operation. These benefits include:

- High spindle speed
- Low shaft dynamic runout (DRO)
- Ultra-low spindle vibration
- Extremely long service life
- Minimal maintenance
- Rapid spindle thermal stability
- High bearing stiffness
- Zero contamination to the environment

The Westwind Support Team will be happy to discuss in detail how the selected Westwind air bearing spindle can be integrated into a specific customer's machine to achieve optimum performance.

Westwind Air Bearing Spindle Technology Products Include:

- PCB Drilling and Routing Spindles
- Coating Atomizer Spindles
- Light Industrial – Precision Machining Spindles