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The Installation of Air Bearing Spindles

Introduction:

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 notes are produced as an aid to machine design and problem solving, where obvious, or sometimes more subtle, effects may have been overlooked.

Installation:

It should always be remembered that, although robust in operation, an air bearing spindle is a high precision device, which requires a similar degree of precision in its attachment to the machine, on which it is to be used.

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 of checking that an installation is satisfactory is to reduce the bearing air pressure to a low value (0.5-1 bar) and check that the shaft still revolves, by hand, with minimum effort. This will show if there is a major problem (shaft will not revolve freely) but will not however show the dynamic problems (such as heat distortion) that could still be present. Detailed advice on [clamping](#) is available from Westwind if required.

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, as 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 high load working condition.

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



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 to thermally sensitive materials or devices. It is also important to avoid restricting the exhaust flow and it is advisable to contact Westwind if exhaust will be piped or directed away from its normal outlets.

Where a spindle is fitted with a collet for tool holding, it is important that a tool or transit pin is always fitted, as 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 to the correct operation of the spindle.

Correct **air quality** is crucial, as the air must flow in a controlled predictable manner through very small clearances between the bearing and shaft. Specifications for general bearing air supply are available from Westwind.

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

Coolant (when specified for use) serves two purposes; firstly it removes heat generated by the motor stator and the shearing of the air film, in high-speed devices, and secondly 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 to flow specifications. Specifications for cooling water properties are available from Westwind.

Correct **coolant flow** and **temperature range** are important and 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 de-ionised water is not recommended as this promotes erosion of some of the materials used for internal components.



Electrical supply wires as well as internal transducer wiring, etc. 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.

The spindle body is designed to be of consistent potential and should normally be grounded. Most **motor stators** are fitted with integral thermistor protection, going high resistance (>1000Ω) at 100°C and it is recommended that these wires be connected to the appropriate inputs on the drive. 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.

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 overvolting or undervolting 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 the shafts have very little frictional resistance to rotational motion and sometimes fairly high polar inertia. 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.

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 for the spindle (e.g. 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 e.g. 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 (k_S) in the plane considered, where k_S is calculated from an equation

$$1/k_S = 1/k_B + 1/k_1 + \dots\dots\dots 1/k_N$$

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

$k_1\dots k_N$ being the stiffness's 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; i.e. 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).

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 gripping forces. Westwind can advise on this procedure.

On some spindles, replacement toolholders or collet cartridges may be used; the convenience of this feature should be balanced against the slight compromise on extreme accuracy.

Summary:

In general, if an air bearing spindle is used within the constraints specified, it should perform well throughout an extremely long service life.