THEORY BEHIND»AIR LINE« TANGENTIAL AIR BEARING TONEARM

KUZMA AIR LINE AIR BEARING TONEARM

1. **Basic Theory**
2. **Principles of air bearing**
3. **Practical solutions to problems of air bearings**
4. **Description of the »Air Line« air bearing tonearm**

1. BASIC THEORY

In principle, we all agree that a cartridge should follow the same line when playing an LP as the cutter head was travelling when cutting grooves on the master disc. This is tangential on any groove, in a straight line from the outer edge of an LP towards the centre of the record. Bearing this in mind it should not be forgotten that a cartridge can read very small levels of information from the groove of even a few molecules in size. This means the body of the cartridge must be still, if we are to retrieve this information accurately.

Let us first look at the most common factor involved in tonearm and cartridge assembly; its capacity to follow the grooves as they have been cut. Accuracy in this is not, in practice, easily achieved. The most common solution is the use of a pivoted arm with an offset angle for the cartridge. With this compromise we can obtain a remarkable approximation towards a theoretically ideal geometry of zero degree error in any groove. A pivoted arm, when optimally adjusted, can have a tangential error below 2 degrees with distortion levels below 1% which, of course, varies across the record. If a tangential tonearm is perfectly constructed and adjusted this figure would be zero.

Many factors, apart from optimum tracking geometry, affect faithful reproduction of the grooves and are inolved in tonearm design Both pivoted and tangential arms should have structural rigidity with minimum vibration of headshell, tube, bearing and all other parts. As the tonearm must move, bearings should show minimum friction and have minimal allowance for movement in those directions which will affect accurate tracking of the grooves. In addition, tonearms should be constructed in such a way that they are easy to adjust and hardwearing enough to be used for many years.

In most cases these goals are easily achieved with pivoted tonearms, but only up to a point. Structurally rigid and low noise bearings can be produced but the geometry and behaviour of the tonearms under dynamic conditions are not optimal. With tangential tonearms we achieve optimal geometry with a different approach in the use of various bearings but structural rigidity, under static and dynamic conditions, is compromised. Both types of tonearm can be adjusted to near perfection by making changes in VTA and azimuth.

In both types of tonearm the choice of headshell, tube shape and material have similar effects. The main structure can also be optimally designed in both cases. So what really are the main differences which affect reproduction, can they be heard and what makes some of the best tangential tonearms sound so different and so much better than the best pivoted arms?

Certainly if only perfect tracking geometry mattered, things would be very simple. In practice even some tangential tonearms compromise on optimal geometry.

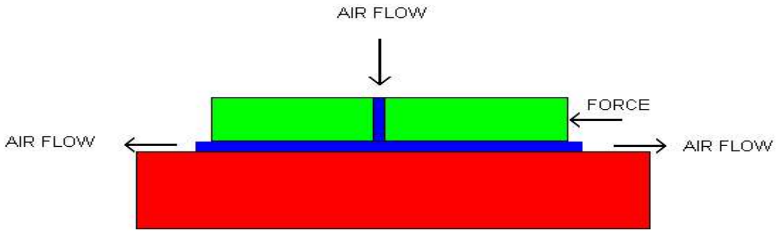
Some tangential tonearms use electronic controls with servo mechanisms to move a classic pivoted tonearm along a straight line. This compromises structural rigidity and introduces vibration and noise into the system. Due to the servo system there is a continuous mistake in tracking, when it notices a difference from optimal geometry and corrects the position of the tonearm. Another type of tangential tonearm uses very low friction bearings. The whole tonearm assembly is moved along via forces on the needle and cantilever with opposite forces of mass resistance and bearing friction. Such bearings have higher friction and noise than in the best pivoted tonearms. To achieve the lowest possible noise, small bearings are used which take a low load and are not stiff. To achieve minimum friction, there must be some play in the bearings which then resonate and allow non-tangential movements along the tube.

An airbearing is a natural choice as it allows movements in both vertical and horizontal planes with practically no friction. In practice we must solve a number of problems. There are different types of air bearings which have different properties. Most of them have zero friction but they do allow movement of the bearing and cartridge in directions which should not move at all.

2. PRINCIPLES OF AIR BEARINGS

Let us first look at the main principle of the simplest air bearing. This is a flat bearing for moving loads on a flat surface. (Fig A)

Fig. A: Flat bearing



Imagine a flat surface. On top of this surface we have a block of metal. If we provide air flow between the flat surface and the bottom of the block, then the block will rise above the flat surface. With very little force we can push it along as if it were on a smooth ice surface. In our case, the thin film of air which is between the surfaces, has practically zero friction, so that the force required for movement to occur is really very small. To provide this airflow we need to bring air between the two surfaces. We can make a hole in the block and provide air there. Due to atmospheric pressure all around us we must provide pressurised air, above that of the atmosphere in order for air to flow from the hole. If this pressure is high enough it will lift the block above the flat surface and there will be a small gap between the flat surface and the block. This gap will be proportional to the mass of the block, air pressure and the size of the surface of the block and air will start flowing through the gap to the outside.

The same effect can be gained if we provide holes in the flat surface. Where the holes are covered with a block, there will be a lifting effect.

Imagine what will happen if you press the floating block down in the middle. The gap will be reduced and restored after release of pressure. Thus the block will move up and down. This system is unstable and sensitive to outside forces. Movement is possible in all directions along the flat surface. If we apply force to one corner of the block, that side of the block will be easily pushed down, the gap will close and friction might increase to such an extent that we are unable to push the block along the surface. Such a bearing is very unstable and, in practice, of very limited use. To make practical use of such a bearing, we must limit movements in certain directions while allowing frictionless movement in those desired.

The obvious choice is to replace a flat surface with a round one: a rod around which our block is captured like a sleeve (Fig. B, C).

Fig.B: Round Bearing-cross section

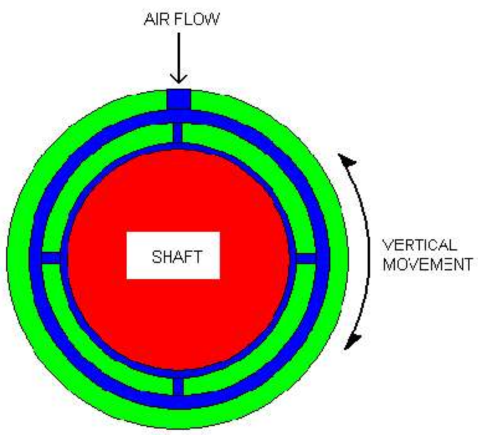
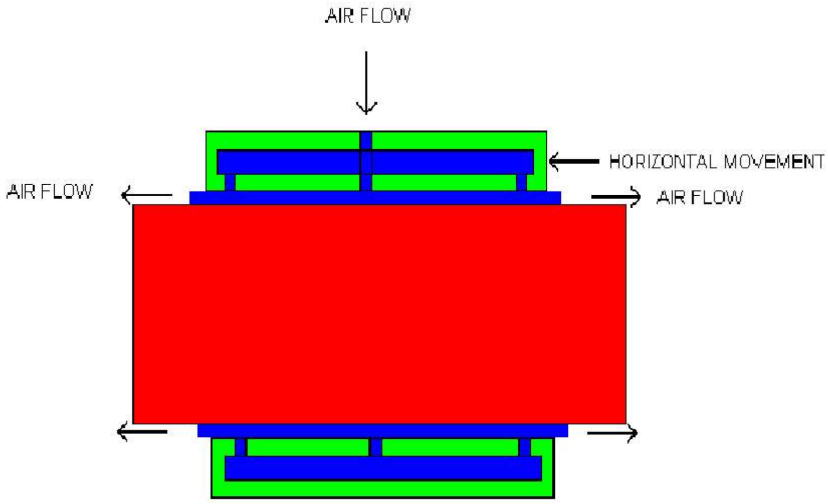


Fig. C: Round bearing-side view



If we bring pressurised air between the sleeve and the rod the compressed air will « lift the block«. Because the sleeve is surrounding the rod, however, forces are equal on all sides and we have a sleeve floating around the rod without touching any surface. We can move the sleeve along the rod and this movement can be used as horizontal movement of the tonearm. At the same time we can rotate the sleeve and we can use this movement as vertical movement of the tonearm. This is in theory. What happens if we apply outside forces. The sleeve and parts like tube, headshell, counterweight and cartridge all have a mass. There are forces moving the tonearm along and up and down and forces pulling the cartridge along the tube in the direction of disc rotation. If we remember what happened with the flat block when we pushed it down we have the same problem. Fixing the sleeve and moving the rod makes no difference regarding this unstable situation. We need to stabilise the situation so that the sleeve will not be moved in any direction other than along the rod axis (horizontal movement) and in rotation (vertical movement).

The main problem is that the cushion of air in the gap behaves like a spring.
This means that, under dynamic conditions, the cartridge and tube assembly will move in various directions and the cartridge will not stay in the position of the cutter head but will be pulled along the groove and twisted due to the forces

moving the cartridge in the grooves. Of course this also happens in pivoted arms, but due to differences in construction ie. loose bearings, vibration of bearings and other parts.

To practically avoid this effect we must use a stiff bearing, which automatically reacts to these external forces. Construction of a stiff airbearing is dependent on the air gap, air pressure and bearing surface. Higher air pressure means a stiffer bearing which can carry a heavier load. The same effect can be achieved by a small air gap between the moving parts of the bearing. In the best bearings the gap is limited to a construction of 10 microns. This is actually less than in most pivoted tonearms which have air slack in their bearings to move!!

A stiff bearing will not in itself stop the tonearm bearing from moving closer to one side of the bearing shaft when force is applied to one side. The bearing must be constructed in such a way that it is self-centering. That means, in practice, if force is applied to one end, the gap will decrease but a properly constructed bearing will respond to this by increasing airflow to the smaller gap, restoring the equilibrium.

In practice the gap stays the same if forces are not overloading the bearing and the cartridge position under dynamic conditions remains stable. If we apply force to one end of the bearing sleeve, we have the same problem. To have a self-centering effect along the axis as well as along the diameter of the rod, the airbearing must be properly designed.

An airbearing has few holes through which air is forced but most such bearings behave poorly under dynamic conditions. If the bearing were to have only a few holes then the bearing would twist, moving the cartridge away from a tangential line.

The best solution is an almost infinitessimal number of holes which can be obtained by use of porous material with holes of 10-20 microns in size. This makes the most stable bearing and, in our case forces, equivalent to a few kilos applied to the tonearm, will maintain the gap as a stiff bearing with practically zero friction.

Another positive aspect of the tangential tonearm is its lack of bias forces. Close inspection shows that the forces pulling the cartridge along the groove are dependent on the modulation of the groove, the flatness of the record and the eccentricity of the grooves. In a tangential tonearm all these forces are pulling straight forward along the tube and the cartridge can not move along the axis of the tube when a proper airbearing is used in the construction of the tonearm. In pivoted tonearms, due to construction of an offset angle of the headshell, forces are pulling the cartridge along the tube and pushing the cartridge towards the inner groove. To compensate for this we use antiskating forces or bias. As these forces change all the time due to rotation and the modulation of music, they vary in size and direction and cause the cartridge to behave in a very unstable manner. The needle travels along the tangent in the groove back and forth and directly affects the signal by modulating it with the vibration of the cartridge and headshell combo. This increases wow and flutter and makes the whole sound unstable and unfocused. In a tangential tonearm this force tries to pull along the tube but these and other movements are negated by a properly designed airbearing itself. Thus the cartridge is kept in a position as close as possible to that of the cutter head.

3. PRACTICAL SOLUTIONS TO PROBLEMS OF AIR BEARINGS

For an airbearing tonearm to function properly certain criteria must be fulfilled. One is to have an airbearing constructed in such a way that it behaves as a stiff bearing in all unwanted directions and have zero friction in desired ones. An airbearing with a high load capacity and with self-centering properties is mandatory. This means, among other things, that there must be only a small gap between the shaft and the bearing and as many small holes as possible as air outlets. Since we are talking about a few thousandths of a mm we must supply clean air at high pressure.

Air supply:

Clean air means air that is free of moisture, small particles of dust and other contaminants such as oil, which may come from air compressors.

Air pressure:

There are different types of compressors. Their basic function is to compress air to the level necessary for optimal airbearing funtion which is about 3-4 bars or 50-80 psi. Air compressors are, unfortunately, very noisy machines. In small compressors an electric motor is usually used to rotate a piston which, in return, compresses the air. This air flows out of the compressor in pulses. To achieve steady airflow, we need to store air in a reservoir. On the outlet of the reservoir is a pressure valve, which regulates output pressure. The reservoir smooths pressure pulses like a capacitor in electricity and the pressure valve smooths it further to a working pressure of about 4 bars.

Air contains moisture. The level of water contained in air is called the relative humidity. At higher temperatures the same volume of air can hold a higher amount of water. Relative humidity, therefore, depends on air temperature. For example, one litre of air contains a certain amount of water. When we compress air to 8 bars (1 bar is normal air pressure) we must compress 8 litres of air into the volume normally occupied by one litre. Unfortunately, we now have 8 times more water vapour. As, during compression, the air temperature is raised, the air can hold more water but as the air cools down in the reservoir and along the pipes it can no longer hold such an amount of water and condensation occurs, blocking airflow in pipes and bearing. This moisture must be removed from the system and this done using air dryers. There are different types of drying processes and different dryers.

The quietest compressors on the market are oil lubricated. Their noise level is like those used in fridges and could be used in a living area. Unfortunately, due to oil lubrication, small amounts of oil mist leaks into the air flow and has to be removed with oil filters.

We have chosen an air compression system with filters and dryers which consists of a compressor, which automatically fills the reservoir, drains out moisture and filters for dust particles and oil mist. Air is dried through a filtering system. The working pressure is fine adjusted and held constant with a pressure regulator.

The compressor is best situated in a separate room, permanently plugged into the mains and left switched on. A 4 mm PVC hose which can be anything up to 40 m long runs to the tonearm. On the tonearm is a valve which regulates airflow. When the valve is open the air is consumed from the reservoir and the tonearm moves without friction. When the pressure in the reservoir drops beyond a certain point, the compressor automatically switches on to refill the reservoir and then automatically switches off. So when the valve on the tonearm is closed, the bearing does not function, there is no consumption of air and the compressor stays switched off. Due to the automatic drainage system on the compressor, occasional leakage of air is heard when liquid drains from the reservoir into the drainage bottle.

Maintenance of the compressor consists of an occasional oil level check and emptying of the drainage bottle about every 6 months. In the summer, or in areas with higher humidity the bottle may need emptying more often.

4. DESCRIPTION OF THE » AIR LINE « AIR BEARING TONEARM

The tonearm base has a VTA adjustment which holds the stainless steel shaft of the main bearing. In the main carrier are fixed the airbearing, tonearm tube and counterweight holder. The airbearing is capable of carrying a load of 3 – 4 kg. with a 4 bar working pressure.

The main tube is machined from three solid blocks of aluminium and made into a stiff hollow conical tube. Azimuth adjustment is controlled by a zero play, non-resonant locking mechanism, which allows for fine repeatable adjustments.

The solid aluminium headshell is shaped to minimise resonance and further damped by the use of four ribs. The tube is internally damped. The shape of the counterweight minimises its own resonance as well as resonance of the carrier beam.

One carrier tube leads wires in a loop to the sliding bearing while the second has a flexible tube which supplies air into the bearing. At one end of the tonearm is the valve for regulating the air flow, while there is a small air pressure guage at the other.

The cueing mechanism can be adjusted according to the height of the tonearm. The VTA mechanism is locked with a lever and allows fine adjustments over a 10 mm range to a precision of 0.05 mm. The basic height of the tonearm is adjusted by a specially designed collar which can also hold the whole assembly at a certain height while adjustment of tonearm geometry is made. While changing height or VTA there is practically no change in azimuth due to precision in construction.

The tonearm has a mass of 2 kg and fits into the same mounting hole as Stogi tonearms. The wiring is from high quality copper or silver wires, unbroken in one length from headshell to RCA or XLR connectors.

Air is supplied via a 4 mm plastic tube, which can be fitted anywhere. Connection is via a Quick fit 4 mm connectors which are standard in compressed air supply. The air hose should not run outside in temperatures below freezing point. Tube length can be simply adjusted by cutting with a knife. An adequate number of connectors are supplied to enable various connections to be made as well as ample 4 mm tubing. The main drying filter with its stand is best located near to the tonearm.

Maintenance of the air bearing consists of occasional cleaning of the bearing shaft with a clean cloth (supplied) and alcohol.

The tonearm is supplied as a package consisting of tonearm and complete air supply with very quiet compressor, reservoir, all filters, dryers and tubes etc.

The system of air supply seems to be complicated at first but is actually simple to use and certainly worth the effort in view of the improvement in sound quality obtained.

Franc Kuzma