Helium: Gas Filling and Extraction during the HDD Manufacturing Process

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The use of noble gases, notably Helium, is becoming mainstream as a vital component within the HDD manufacturing process. Helium provides a medium within the HDD for improving flow induced vibration characteristics during certain stages of the HDD test process, however the application of Helium in HDD production has physical limitations and demands process equipment requirements for the introduction and collection of the Helium gas whilst the technical challenges of hermetically sealed drives with Helium remains largely unaddressed. This paper reviews reasoning behind the use of using Helium in HDD manufacturing and examines the issues surrounding the continued use of it going forward both technically in terms of the specific requirements that need to be built into the HDD design, and managing the gas within the HDD manufacturing process equipment.

1. Background

The quest for increasing areal density in disk drives has driven the need for narrower data tracks on every successive generation. From RAMAC in 1956 with 20 Tracks Per Inch (TPI) to drives in 2011 approaching 400,000 TPI these gains have been achieved through the cunning and ingenuity of engineers who continue to push at physical boundaries.

One seemingly unavoidable consequence of rotating disks is the air which is dragged round as they spin. The air movement over the disk was harnessed early in disk drive development with the introduction of the hydrodynamic head bearing allowing for closer controlled spacing between the head and the disk and consequentially higher areal density. The air movement is also used to keep the drive clean; the pumping action of the disk rotation is used to force the air inside the enclosure through a scrubbing filter to remove any loose particles which might cause damage.

The air movement forces applied to the heads and actuator create vibration due to the flow and this is commonly known as windage. The linear speed of the air at the edge of a disk can exceed 90 miles (150 kilometers) per hour in some drives. At this speed the air flow is often turbulent and unpredictable increasing the effect.

The heads and actuator arm of the drive must work in constant buffeting while following tracks less than 4 micro inches (100nm) wide. Servo control systems cannot completely compensate for the random forces which windage exerts and there is an inevitable head/track misregistration associated with this. The wide band energy in turbulent flow also excites resonances in key components such as the head suspension and the disks.

2. Turbulence

Turbulence is a consequence of the speed of flow, the size of the channels or obstructions in the path of the flow and properties of the fluids flowing. A dimensionless value called Reynolds number is sometimes used to characterize fluid flow

Different physical systems with similar Reynolds number are likely to behave in a similar fashion. There is no exact physical link between the Reynolds Number of a system and whether flow is turbulent or laminar, but it is a good indicator. Higher Reynolds numbers indicate a higher likelihood of, or stronger, turbulence.

$$\text{Reynolds Number} = \frac{\text{Density} \times \text{Velocity} \times \text{Length}}{\text{Dynamic Viscosity}}$$

Turbulence is chaotic and unpredictable, it increases exchange of energy and momentum between the flow and the surroundings, which are all problematic when trying to hold a recording head on a precise trajectory. It is desirable to eliminate turbulence wherever possible within a disk drive. If we equate this to reducing Reynolds Number then reducing the density of the fluid, or the velocity or the size of the components, will all reduce the effects of turbulence in a disk drive.

Component sizes in disk drives have been getting smaller for a long time but there is a diminishing return. Reducing the diameter of the disk directly affects the maximum velocity of the air for any given RPM; this is one reason which 15000 RPM drives now tend to have the smallest disks while sacrificing the capacity which each disk can hold. Smaller components tend to have reduced structural stiffness and so are affected more by the air flow round them which limits the lengths to which miniaturization can help.

Referring back to the Reynolds Number, other factors which affect air flow are the Density and Dynamic

Viscosity of the fluid. To change these, the properties of the gas within the disk drive have to change.

3. Why Helium?

In 1980 the engineer Robert C Treseder filed a patent for a "Fermetically Sealed Disk File" [*sic*] which describes a disk drive filled with Helium. (Treseder, 1983) A colleague went further and proposed a vacuum, or a partial vacuum or a gas other than air (Tietge, 1981). Even at this point designers had been fighting the air flow problems for some time.

The clue to Helium being a good choice for disk drive engineers 30 years ago and why it is an important part of the modern process is in its physical properties. Helium has a low molecular weight, second only to Hydrogen and, unlike Hydrogen, it is completely unreactive.

The effect of Helium circulating in a disk drive when compared to air is dramatic, almost entirely due to the change in density. An example of this is that the flow over a 70mm disk may well be turbulent for speeds much over 2000RPM in Air but needs to exceed 15000RPM in Helium before turbulence takes hold. (Aruga & Suwa, 2006)
The effect Helium has on flow can yield a significant improvement in disk drive performance with some papers claiming track density capability doubling. It may be that it is an essential part of future disk drive if track density is to be significantly improved.

Power consumption in disk drives is also a major design consideration. Spinning the disk pack in a heavy viscous medium such as Air takes considerably more energy than spinning the same disk pack in a lighter fluid such as Helium. The net benefit of reducing the drag can be several watts in a high performance drive. The graph below shows the effect on current when Helium is introduced and then leaks out of a 7200rpm drive

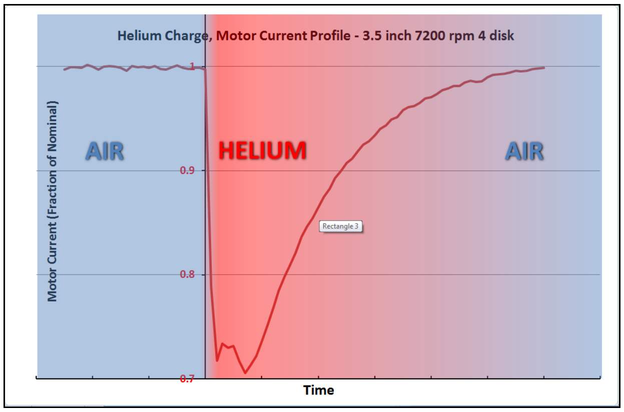

Figure 1: Effect of Helium on spindle running current

There are other advantages too.

Helium is a significantly better conductor of heat than Air so a drive filled with the gas will have a more uniform temperature, another advantage when designing for higher track densities.

The magnetic spacing and indirectly the bit density of drives is in part limited by the thickness of the protective coatings on the head and disk. Introducing Helium and expelling Oxygen from the drive will help protect the delicate materials of the head and disk as the protective overcoats on these components are reduced.

4. HDD Engineering

A patent for a sealed disk drive was filed in 1970 (Buslik, 1973) but experience showed that sealing the drive was both difficult and counterproductive. Some components such as the bearings could not be made entirely impermeable and others such as screw threads and connectors provided pathways for air to leak in and out unless great care was taken. Changes in pressure, particularly when shipping by air freight, force air in and out and can be so large as to cause the sealed housing to collapse, damaging the internal components.

Methods were proposed to prevent a pressure difference from developing. Early designs to compensate for imperfect seals used internal positive pressure and filtered air (Walsh, 1973); the incorporation of a bladder (Wheeler, 1977) was also proposed. The solution used almost universally today is an unsealed enclosure design incorporating a "breather filter" allowing air to bleed in and out of the disk drive through a small hole in the top cover or casting.

The catalogue of difficulties in sealing drives for Air suggests filling drives with Helium and maintaining that atmosphere is not a trivial task.

1) A leaky drive filled with Air in an Air environment will remain filled with Air whatever happens, in the entire life of the disk drive it may never be noticed; if it is filled with an exotic gas then the gas will be lost to the environment through the leak; if the drive performance depends on the gas being present then drive failure may be the consequence.
2) Helium with its small atomic radius is a great gas for detecting leaks and is used in many industries to do just that. If there is a flaw in a drive seal Helium will find it and escape.
3) One slightly obscure consequence of filling a disk drive with Helium is that a leak may itself cause a pressure difference between the inside and outside of the drive. This effect is a consequence of the higher rate at which Helium can escape compared with Air entering the enclosure (Bernstein, 1949), this causes a transient pressure change as the gas inside and outside the enclosure reach equilibrium. Fortunately under normal conditions the pressure drop in not likely to be significant.

5. Temporary fill for SSW/Servo Fill

Despite the difficulties of keeping Helium in a disk drive the benefits are attractive and most drive manufacturers in recent years have looked at engineering for Helium filled drives and processes using Helium. While filling a drive for its life is some way off, using Helium as an assist during the manufacturing process is useful and can be worth the added complication.

One approach to filling the drive seen in several early patents is to have a single hole, possibly with a valve or some method of sealing, through which the air is first drawn out and then Helium is introduced (Bernett, 2003). This has the somewhat terminal problem of the drive potentially collapsing under the enormous pressure differential created by the vacuum. Fortunately this particular problem was solved (Arasteh, 1992). By placing the whole device in a chamber; the inside of the disk drive can be evacuated and refilled without any pressure differential occurring.

A clever corollary to chamber filling for long term Helium retention in disk drives within a subsystem is to place the Helium filled drive in a Helium atmosphere (Bernett, Anderson, & Wong, 2004). Leaks within the drive don't matter as long as the outside container, such as a storage drawer or rack, has a maintained Helium atmosphere. The reasonable assumption is that it would be easier to replenish the Helium in a storage drawer size product than an individual drive.

Drawing the pressure down and then refilling the drive with Helium takes time. The necessity of putting the drive into a chamber would demand a batch process which may not be the preferred solution. Hitachi (Fukushima, 2007) describes a method using 2 ports in the drive enclosure, one to inject Helium and a second to exhaust Air. As many drives are designed with 2 ports (one a breather hole with filter and a second for pressure/leak/particle testing during manufacture) this method is claimed to be a logical and cost effective solution.

It is easy to see that filling a drive should be a simple process which only takes a few seconds, so the capital cost of equipping a manufacturing line should be low. There is also the cost of adding extra process steps with additional points of failure which cannot be ignored (Fukushima, 2007b).

Once the Helium is in the drive it has to be kept there. Permanent solutions are not yet in production but even having a Helium environment just for Servo track writing is an advantage. The servo track write process may take from 1 to 12 hours depending on manufacturer and for this length of time a simple metalized tape over the hole(s) through which the gas was introduced is sufficient (Fukushima, 2007a).

If the servo track writing takes place outside the drive a containment box must be built to retain the Helium. Seagate (Fioravanti, Sheeran, Oxley, & Pasi, 2004) describe a servo track writer for a single disk drive or a multi disk write enclosed in a box containing a replenished supply of Helium with purge and gas recovery.

As the enclosure being filled becomes larger the volume of gas used per drive increases and recovery becomes more important. The multi disk servo writer in particular is relatively large and complicated and Helium recovery is important to the economy of the process. Fortunately

Helium recovery and reuse is not that uncommon in other industries and the technology is mature. A micro-porous membrane is one approach relying on the faster effusion of Helium than other gases to achieve more than 95% purity in the recovered gas with very little energy use.

Where Helium is introduced into the drive temporarily for servo filling it is important to remove it before tuning drive parameters such as servo and fly height control which will be altered by the gas environment. This can be achieved using a reversal of the Helium fill process but adds yet another step to the test process. In the worst case a 1 step test process has now become 4 steps.

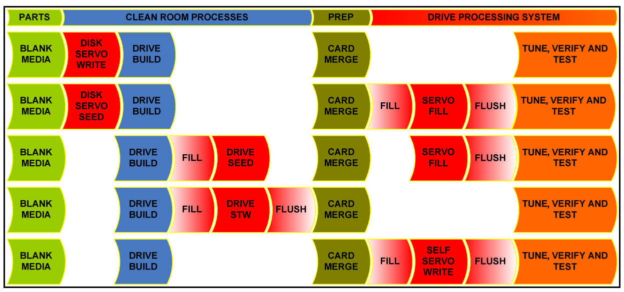

Figure 2: Manufacturing process options - Helium use in red

6. Permanent Fill

The ultimate goal of manufacturers is to introduce Helium early in the manufacturing process and to retain it throughout the useful life of the drive, typically 3-5 years. There is a lot to be done before permanent Helium fill is practical.

First the designed in porosity of the drive such as the breather hole needs to be removed and to do this design changes must also be made to meet the mechanical effects of atmospheric pressure changes.

Second the unintentional leaks need to be plugged. Helium will find any path which is not completely sealed. Design rules such as having no screw holes between the inside and outside of the drive are relatively simple to set. Material choice for gaskets may also seem simple until you take into account the need to retain an essentially pure atmosphere for 5 years, in this time frame diffusion through most materials can be significant, and has to be done at very low cost, ruling out many techniques used in other industries (Albrecht, Stipe, & Strand, 2006). Designing the connector which bridges between the external and internal electronics also needs a lot of care as any material interface such as between the pins and the housing or the connector and the casting can leave a pathway for Helium to follow. Even undetected defects in the aluminium base casting can be a source of terminal leaks over the life of the drive.

Several methods have been proposed to replace the gasket seal used today with a more permanent soldered (Hatchett & Price, 2010), welded (Macleod & Lee, 2006) or epoxy (Hearn & Kumaraswamy, 2002) seal. Unfortunately the reality of manufacturing is that some percentage of the product will fail during the production process and to manage costs needs to be reworked. A permanent seal makes rework somewhere between unreasonably difficult and impossible so methods have been proposed to temporarily seal the drive until it has passed test and quality steps at which point the seal is made permanent (Bernett, Brent, & Sorrell, 2007) (Hatchett & Price, 2010).

7. Economics and the future

Any book on Chemistry will tell you that Helium is the second most abundant element in the universe; unfortunately this abundance occurs mainly in stars and nebulae and not on earth. Helium makes up less than 0.0005% of the earth's atmosphere and is being continuously lost to space. Helium is being produced within the earth's crust as a result of radioactive decay (the Helium atom is sometimes described as a retired Alpha particle). Helium filters from the crust until it is captured by impermeable rock and sits as a reservoir often with oil and natural gas. Today the viable sources of Helium are natural gas fields in the USA, Qatar, Algeria, Russia, Poland, Canada and China (USGS 2011) where it makes up between 1% and 7% of the gas recovered from some fields.

A long term plan of the US government, dating back to its use in blimps in the First World War, has caused "raw" Helium to be stockpiled. A bill in 1996 put in place a policy to run down this reserve at Cliffside Field, Texas by 2015 and retain only a strategic reserve. While the excess is being sold off the price of Helium will remain relatively low. What happens after this is open to speculation; at one extreme it has been suggested that once the reserve has depleted the price will increase up to 50 times the current market rate to reflect the true scarcity of this element (Witchalls, 2010).

Like oil, Helium is a finite resource and is being used faster than it can be replenished from natural sources. Unlike oil it is very difficult to find a replacement for Helium in many of its uses. In disk drives it has been chosen for being light and un-reactive, what are the possible alternatives?

1) Hydrogen is lighter and could provide the an even better improvement in dynamics to Helium; it also has the advantage of being widely available; There are even methods for building in a reserve should the drive leak during its life (Eldridge & Farrar, 2005); It can hardly be described as un-reactive though and would pose a significant problem of safety in the manufacturing process.

2) Neon is still lighter than Air but heavier than Helium so gives a partial benefit; it is un-reactive but is also an expensive gas.

3) Nitrogen is slightly lighter than Air, and is abundant (79% of Air is Nitrogen); although it does not have a significant effect on disk drive dynamics it is a controlled and relatively unreactive atmosphere which is useful when the life of components due to oxidation is a concern.

4) That leaves the old favorite the partial vacuum, abundant but difficult to design for. Designers might still contemplate this solution in disk drives if the Helium cost goes too high (Hirano & Satoh, 2000).

8. Conclusions

Using Helium in the disk drive industry has been 40 years or more in coming. With Helium in unconstrained supply its special properties are too attractive to the industry to give up. As a process gas it is simple to gain benefit in the HDD manufacturing process for manufacturers who perform servo track writing in the closed drive. Where large volumes of gas are required it may still be a viable process as long as provisions are made for effective recycling of used gas. Adding Helium to drives is not a major capital outlay but complicates a cost sensitive process with extra steps.

A permanently gas filled drive with a sealed enclosure of reasonable cost which retains gas for 5 years still represents some significant challenges. There is also a horizon now only 4 years away where the Helium supply industry may undergo significant changes as the US gas reserve runs down. This would be a less significant threat if the permanent fill problem were solved by then.

It looks probable that the industry will become dependent on the performance improvements that Helium offers. Can we design a reliable permanent seal, could we ever go back or find an alternative if Helium becomes too expensive? The HDD industry has faced many challenges in its past and this may just be one more to prove that ingenuity overcomes the impossible.

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