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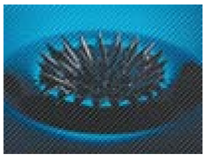

The Story Behind Ferrofluids
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Undoubtedly, you have seen the term "ferrofluid-cooled" or liquid-cooled", or "magnetic suspension" in speaker ads and read the cryptic descriptions of the benefits of ferrofluids in speaker manufacturer's literature. But after **twenty five years of ferrofluid being used by the audio industry???** and with over **400 million speakers treated???**, it seems about time for a more comprehensive discussion on the implications of magnetic fluids on audio quality in high definition loudspeakers. We will explain what are ferrofluids, why they are used in woofers, midranges and tweeters, and new developments in this technology will be discussed.

Ferrofluids are sub-microscopic magnetic particles suspended in a lubricating oil, and were first created in research for NASA. Ferrofluidics Corporation was founded in 1968 with a license from NASA to research the technical and market development of magnetic fluids technology. Magnetic fluid applications include high performance bearings and seals, such as used in computer hard disk drives and optical scanners. High performance hard drives use ferrofluids in their servo motors to improve settling time enabling faster data access and the latest generation of DVD players are using ferrofluids to damp their laser servo motors for more stable performance.

Speaker manufacturers have used ferrofluids mostly for expediency - to increase production yields and reduce customer warranty returns. This is due to ferrofluid's thermal conductivity which reduces voice coil burn out and the "magnetostatic force" of the ferrofluid within the magnetic gap which suppresses voice coil rocking. Ferrofluids, being magnetically responsive, are attracted to the voice coil gap's flux field and the fluid pushes back when the coil starts to become off center in the gap, acting as a restoring force to maintain concentricity, thereby preventing rubbing and buzzing. This is only partially due to the levitation effect of ferrofluid (magnetostatic force). Another factor in reduced voice coil scrapes is the reduction in voice coil operating temperature avoiding the voice coil expanding and reducing gap clearance leading to the coil scraping the speaker magnetic system's top plate. Even the simple lubrication effect of the fluid reduces the abrasiveness of coil/ top plate collisions. There are still other practical benefits, such as ferrofluid's deterrent to dirt or particles entering the gap and even inhibition of corrosion of the coil and gap. Speakers used for life safety and voice warning applications almost always use ferrofluids in order to pass UL tests.

Many speaker manufacturers have had positive results with ferrofluids in tweeters and mid ranges, but wanted a ferrofluid more appropriate for woofers. Low viscosity and high saturation magnetization (magnetization strength) was asked for, in order for the fluid to stay in the gap even at large excursions without requiring extensive changes to existing woofer designs. About seven years ago woofer-grade ferrofluids were commercialized. The first speaker companies to use ferrofluids in sub-woofers were in pro-sound, followed by autosound manufacturers. Quite a few high-end speaker manufacturers first begin evaluation of ferrofluid woofers about five years ago and today many there are many examples.

While ferrofluid's use and application for increasing power handling are common knowledge, its advantages in reducing harmonic distortion, intermodulation distortion, high power non-linearity anomalies as well as increasing overall clarity and definition, are not commonly known by the audio community and will be discussed in this article.

So how will ferrofluids optimize and stabilize woofer sound quality? Transient response settling time (the ability of the speaker to stop when the signal stops) is usually improved. The damping is effective since, in the case of ferrofluids, it is applied directly in the motor, rather than "after the fact damping treatments" on the cone or suspension. If a woofer has a top-end response peak, ferrofluids will tend to bring this under control with less side effects than a passive crossover network solution. Ferrofluids reduce certain mechanical noises that speakers make in and around the voice coil when the cone moves. The muck or noise floor of the speaker masks the natural inner voices of the music and ferrofluids usually clean this up a bit.

Perhaps the biggest difference is not what you will hear, but what you won't hear. Speakers change their sound quality as the voice coil heats up, which would normally result during playing music for an extended period of time at realistic (or beyond realistic) sound levels. Since ferrofluids avoid much of the power compression effects that would otherwise result under these conditions, the sound characteristic is more stable over time with ferrofluids. What are these unstable effects? We discuss these in more detail in this article, but briefly the speaker's impedance increases, which shifts the crossover point.

Some acoustical phenomena that are due to voice coil temperature changes are sometimes be attributed to other factors (such as in comparisons of speaker hookup wire, etc.) during a/b and double blind testing will be touched upon.

Heat Buildup and Power Compression In Speakers - A Missing Variable

The heat sinks in power amplifiers are a familiar sight, as most amplifiers are less than 75% efficient, with the wasted 25+% energy resulting in heat. An amplifier that consumes 100 watts will put out about 75 watts of audio power and 25 watts of heat. But when the 75 watts of audio signal is connected to a speaker, almost all of the power results in heat within the speaker, with only a tiny amount of signal actually being converted to sound. Only the most sensitive speakers achieve efficiencies of 5%, with most well-damped dome tweeters and medium density cone paper or poly cone woofers performing closer to 1 - 2%.

Lets say we have a speaker which is connected to an amplifier and tested at a 1 watt level for impedance and frequency response. Next the power is cranked up. After the CD plays for an hour, the speaker is retested and the impedance will be found to be significantly higher. The crossover network turnover points will have shifted significantly. Not only has the characteristics of the speaker system's crossover changed, but the frequency response has changed, typically with a falloff in the upper range of the woofer. All of these anomalies are caused by voice coil heating. The heat generated by the amplifier power passing through the voice coil is partially transferred to the steel top plate of the speaker's magnetic system, and eventually carried throughout the speaker. Unfortunately, air is not an adequate conductor of this heat and it builds up on the voice coil faster than the air can carry it away. Changes in impedance are not the only problem with hot voice coils, as the heat causes the coil to expand, resulting in the likelihood of buzzing by scraping the top plate.

Ferrofluid immerses the voice coil in a thermally conductive fluid and transfers the heat off the coil, reducing reliability problems and changes in performance that occur due to heat buildup. Ferrofluid stays in the gap due to the strong magnetic field of the gap.

A look at the two response plots (fig. 1 & 2) shows a 4" midrange speaker driven at 35 watts. The first graph is the speaker without ferrofluid, one plot taken immediately, the second after 45 minutes. There is a loss of over 3 - 8 dB over most of the response range, with a strong loss of output at the top-end. The second graph is the 4" midrange treated with ferrofluid, under the identical conditions. Note that the loss of output is only 1 - 3 dB, with only a slight shift in top end response.

Loss of Clarity and Definition due to Spectral Contamination

Aside from frequency response and other basic measurements typically used to judge the "quality" of a speaker's reproduction, complex multi-tone techniques have also been devised. Using Spectral Contamination testing, the "self-noise" of the speaker can be revealed. Spectral contamination is a measure of intermodulation distortion, but "IM" is typically comprised of only two test tones, while music consists of many more tones. All speakers have subtle (or not so subtle) buzzes, rattles, noise modulations, and other anomalies. Spectral Contamination uses multi-test tones (as many as 50 or more) that are generated simultaneously and are sent to the speaker. Each tone is about 1 Hz wide and spaced some number of Hertz apart. This test signal approximates the complexity of music. Deane Jensen devised one variation of this technique and wrote an AES paper describing the procedure. The Bell Labs SYSid acoustic analysis test system offers the Spectral Contamination test, while the Audio Precision One uses a similar procedure which they call FASTEST. Interestingly, Audio Precision only talks about FASTEST as a QC procedure for automatic testing for buzz and rubs of speakers coming off a production line. If high enough dynamic range is available (which is achieved with the SYSid using a technique known as synchronous averaging), then different speaker designs that are operating correctly can be evaluated for their relative freedom from spurious resonances. In this test the intrinsic self-noise of the speaker tends to fill the space between the tones, abet quite a bit down from the tones. For example, a shallow and relatively undamped metal dome tweeter will usually be noisy. When the tweeter is excited by the multi-tone test signal, all the resonances are excited and contribute to the output. Perhaps the "acoustical dirt" will be only 30 or 35 dB down on a fairly large midrange metal dome tweeter. A very high quality soft treated fabric dome tweeter may contribute negligible "noise" and mostly pass just the discrete test tones, with the self-noise of the speaker being maybe 40 dB to 50 dB down or more.

Why is this important and what does this have to do with ferrofluids? Actually, spectral contamination may just be the most important single test of a speaker's quality. If a speaker has low spectral contamination, then ambience and the inter-voices of the music will not be masked by the speaker's muck. A poor speaker will fill-in the space between the tones with junk.

While ferrofluids cannot help damp cone diaphragm breakup directly, the voice coil bobbin's torsional resonances are dramatically reduced. **(see figures 3 & 4, measurements of spectral contamination, with and without ferrofluid).** In fact, ferrofluids are primarily used in seals and precision spindle motors for computer disc drivers in order to damp these torsional resonances. A bobbin is the former that the speaker's voice coil wire is wound on. The bobbin is a critical element in sound reproduction as the vibration from the voice coil must travel through the bobbin in order to reach the cone or dome diaphragm. Any resonances within the bobbin will contaminate the sound quality before it reaches the diaphragm and therefore this spurious energy will be radiated into the room. With ferrofluid in the gap, the bobbin is damped and its "noisiness" is attenuated. Are these resonances a real problem and do ferrofluids really help? One way this can be evaluated is to build up a speaker without the cone, only the voice coil, spider, and dust cap. The self-noise of the bobbin will be clearly audible without ferrofluid, while the fluid-damped version will be significantly quieter. Pioneer measured similar phenomena almost ten years ago when they first began using ferrofluids in dome tweeters. In a dome tweeter the diaphragm is very tightly coupled to the bobbin, and the bobbin's distortion (and the distortion reducing effect of ferrofluid) is most dramatic. But in the case of speakers with large cone areas, what goes on in the bobbin has less of a direct effect on the "flapping of the cone" far away, and performance will be more dependent on the speaker engineer choosing a quality cone rather than ferrofluid damping.

Still another aspect of ferrofluids in woofers is proper cavity venting. The techniques used to prevent the ferrofluid splashing due to pressure buildup behind the voice coil (from trapped air within the magnetic structure) also dramatically reduces the speaker's modulation noise. Reducing the modulation noise of the speaker is critical to maintaining clarity and definition. **Fig. 5 shows various woofer venting schemes.**

Behind the speaker dust cap is the pole piece. During the backward stroke, the air trapped behind the dust cap will cause the dust cap to puff outward, and on the outward stroke, the dust cap will buckle inward, in both cases making unhappy noises. Aside from this problem is that the dust cap may even eventually be blown off (very impressive on the 1812 Overture!).

The pole piece on many woofers are vented both to relieve the under-the-dust-cap cavity pressure and aid cooling the voice coil.

It is not always possible to vent the pole piece, either due to cost considerations or that the venting would reduce the magnetic return path efficiency, such as in the case of a small diameter pole piece. Prevention of pressure build-up can then be accomplished by a breathing dust cap or a vented voice coil bobbin or venting the cone body underneath the dust cap.

A chamber is created by the internal diameter of the magnet and the space between the top and bottom plates. On the downward stroke the voice coil displaces this volume increasing the pressure in this cavity. Without venting, the trapped air will be forced through the voice coil gap at high velocity and the ferrofluid may splash if the excursions of the coil are large.
This pressure can be vented by holes in the back plate or if the pole piece is vented, a crosswise vent can link the back plate cavity to the vented pole piece.

The chamber between the spider and the basket should also be vented to relieve the air pressure in this cavity. The spider is the tan colored woven fabric that can be seen through the speaker basket windows (when looking at the rear of the woofer). Although the spider appears to be an open fabric, the air resistance of the treated fabric is very high.

With proper cavity venting techniques the air velocity and turbulence noise within the voice coil gap is greatly reduced. Although, if all these venting techniques are used, but without using ferrofluid, there will be an increased chance of voice coil rubs and buzzes. Without venting, the high velocity air streaming through the gap (from the unvented air cavities) creates an air bearing effect in the gap - but this is accompanied with a lot of whistling noise. But when the cavities are properly vented and ferrofluid applied, gap modulation noise stops completely, both because of the sealed gap and the fluid damping of bobbin torsional resonances.

What is this air modulation noise? A cone speaker has a number of internal chambers that unintentionally created due to how all the parts go together. These chamber or cavities are behind the spider, behind the dust cap, and behind the voice coil (the space created inside the magnet ring and the back plate). As the speaker moves back and forth, the cone/ spider/ dust cap is either compressing or creating a vacuum in these chambers. This can cause air sucking noise ("air modulation noise"), or even worse, the buckling of the speaker diaphragm elements, or resulting in spurious noise.

It is important that the optimum viscosity of ferrofluid is selected with attention to the viscosity versus temperature curve and the effect on the efficiency and operating bandwidth of the driver. When normal operating temperatures are typical, then the dampening effects of high viscosity ferrofluid can be used as an integral design factor. When high temperature operation is common, then the viscosity should be selected so that the pass-band response of the driver is not affected by ferrofluid at normal operating temperature. The decreasing viscosity of ferrofluid counteracts the effect of power compression during high temperature operation so that the frequency response will not be appreciably altered. **This compensation effect can be seen in the measurements taken of a dome tweeter, with and without ferrofluid in fig. 6.**

Early design efforts to use ferrofluids occasionally went overboard in the use of excessively high damping characteristics. Ferrofluids were used not only to control top end resonance problems, but even as to limit low frequency excursion of tweeters. In the 1970s one Japanese studio monitor (which also made it into the U.S. and was sold into the audiophile market) eliminated the crossover network completely and used high viscosity ferrofluid of a few thousand centipose. Today, most APG (Audio Product Grade) ferrofluids are only a few hundred centipose, or less.

Conclusion

While the vast bulk of speakers that use ferrofluids do so because the manufacturer wanted higher power handling and less production rejects and warranty returns a number of speaker designers have used ferrofluids simply because the treated speakers sounded cleaner.

Both audiophiles and speaker designers have always suspected that the more simplistic testing of speakers, such as frequency response sweeps, does not reveal all that can be heard. More recently, procedures have been devised to capture and quantify performance shifts over time that cannot be discerned by short-term A/B testing procedures. One example discussed was the power compression phenomena where the voice coil heats up, which increases the speaker's impedance, resulting in misaligning the crossover network. Power compression effects due to these shifts in voice coil temperature can be stabilized by the heat transfer effect of ferrofluids, maintaining sound quality even at high decibel levels.

Spectral contamination is another example given of a distortion that is quite perceptible, but previously elusive to measure. While spectral contamination is clearly audible, it does not necessary show itself in frequency or transient response tests, nor is this effect so easily discerned even with total harmonic distortion plus noise testing. One can think of spectral contamination as the noise and rattles of the various parts of a speaker jiggling about, just as one might have with a garbage truck bouncing down a bumpy road, all the oscillating parts (cone, dust cap, etc.) hung onto the speaker frame rattling around. Spectral contamination testing uses a procedure with many simultaneous test tones to evaluate the speaker's self-noise contribution to the signal, and is one of the first acoustical tests that closely approximates the complexity of musical signals. Using this technique, it now can be seen that some forms of spectral contamination can be controlled with the application of ferrofluids, thereby achieving superior clarity and definition.