Spotlight

The Beryllium Advantage

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Since its formation, VUE Audiotechnik has been engaged in a strategic development partnership with Materion Electrofusion, the world's leading supplier of genuine beryllium. VUE's goal is to develop an expanding family of high-performance compression drivers that benefit from beryllium's unique ability to dramatically improve high-fidelity (hi-fi) performance.

The first results of this collaboration were revealed last June in the form of VUE's h-12 and h-15 two-way systems, which benefit from a new compression driver with a Materion Truextent beryllium diaphragm at its core. This compression driver enables the h-Class to deliver significant improvements in both hi-fi output and response linearity.

The h-12 and h-15 are only the beginning. VUE is actively developing more beryllium-based designs intended for a broad mix of applications. This article explores beryllium as a high-performance alternative to aluminum and titanium. We'll cover beryllium's history as an acoustic material and detail modern manufacturing methods that are reigniting interest in beryllium for advanced transducer design. Comprehensive data covering theoretical and actual performance tests are included.

History of Beryllium in Transducer Design

A relatively rare metal, beryllium has long been used in high-tech applications ranging from X-ray tubes to scientific instruments and precision aerospace components. Beryllium's advantages for transducer design have also long been acknowledged. Its exceptionally high stiffness-to-mass ratio is far beyond that of aluminum or titanium, enabling beryllium to deliver much greater high-frequency output and lower distortion. Early successes, such as Pioneer's TAD drivers in the 1970s, proved that beryllium could deliver on this promise, and over the years, companies (e.g., JBL and Focal) have continued to offer a limited number of beryllium-based designs.

Despite its many benefits, beryllium has never been adopted as widely as aluminum or titanium, and has mostly been relegated to esoteric hi-fi systems and high-end pro audio components. This is largely due to expense and complexity, since beryllium is more rare, and traditionally more difficult, to isolate and refine. But modern-day refining and manufacturing techniques are reducing beryllium's cost, while at the same time enhancing its durability. As a result, VUE Audiotechnik is aggressively pursuing beryllium-based designs to advance loudspeaker performance and reliability.

Beryllium Foil Changes the Game

Early beryllium components were manufactured through a method known as physical vapor deposition (PVD), which is a process that involves depositing thin layers through the condensation of the vaporized element onto a form. Unfortunately, this method not only limits thickness, but also produces a relatively coarse grain structure that is more likely to generate potentially harmful breathable particles if breakage occurs.

In recent years; however, Materion Electrofusion has pioneered the use of rolled-foil beryllium for acoustic applications. Its Truextent beryllium foil benefits from the rolling process by achieving a more durable grain structure and the minimization of residual internal strains. As a result, rolled-foil beryllium components are significantly tougher, and when failure does occur, they generally do not result in breathable particles.

In addition to improved durability, Materion's efforts have resulted in manufacturing efficiencies that reduce cost. Thanks to these efforts, the potential now exists for beryllium-based transducers to expand beyond the high end and into broader sound reinforcement applications.

Pistonic Motion and the Speed of Sound

To understand how beryllium's unique qualities translate into better hi-fi performance, look at what happens inside a transducer during operation. A diaphragm should move in a perfect pistonic motion (e.g., a piston), with all points moving in uniform and only in the desired direction. Breakup occurs when the forces acting upon the diaphragm overpower its structural integrity and different points on the surface begin moving in different times relative to one another. Because beryllium is extremely light and stiff, it does a better job of maintaining its structural integrity under load and avoiding these breakups.

Even more critical is the efficiency at which sound travels through beryllium. This is important because the frequency at which the first breakup occurs in any metal is analogous to the speed of sound through that metal. The speed of sound through beryllium is nearly 2.5 times faster than the speed of sound through aluminum or titanium. This means the first breakup will occur at a much higher frequency—well outside the audible range in most cases. What's more, when breakup does occur, beryllium's greater stiffness ultimately reduces the amount (i.e., amplitude) of those breakups.

The remainder of this article will explore these exact qualities in greater detail. Evaluations will be conducted in three phases, comparing aluminum, beryllium, and titanium in each phase. The first phase will use

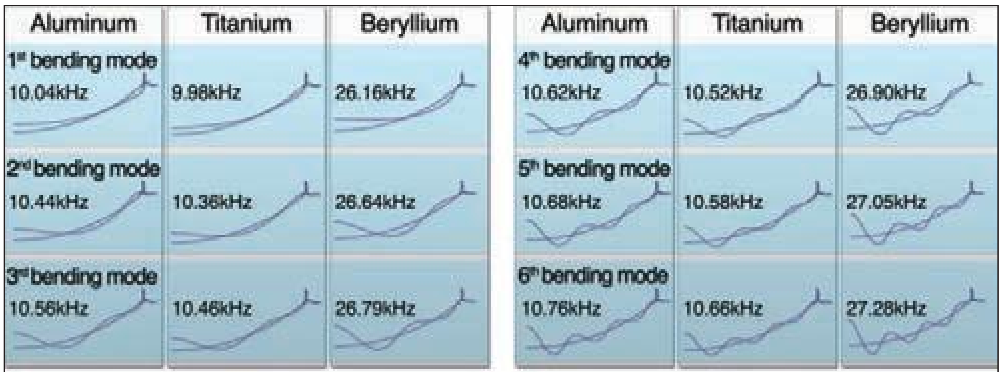

Figure 1: The first six bending modes for aluminum, titanium, and beryllium

Natural Frequency	Aluminum (Al_N)	Titanium (Ti_N)	Ti_N/Al_N	Beryllium (Be_N)	Be_N/Al_N
First mode	10.04 kHz	9.98 kHz	0.99	26.16 kHz	2.61
Second mode	10.44 kHz	10.36 kHz	0.99	26.64 kHz	2.55
Third mode	10.56 kHz	10.46 kHz	0.99	26.79 kHz	2.54
Fourth mode	10.62 kHz	10.52 kHz	0.99	26.9 kHz	2.53
Fifth mode	10.68 kHz	10.58 kHz	0.99	27.05 kHz	2.53
Sixth mode	10.72 kHz	10.66 kHz	0.99	27.28 kHz	2.54

Table 1: The numbers compare the bending mode frequencies for aluminum, titanium, and beryllium

mathematical modeling to evaluate the theoretical benefits of all three as a diaphragm material. The second phase will measure an individual dome's physical performance through vibration testing, and the final phase involves actual acoustic analyses of a fully assembled compression driver.

Modeling the Difference

It's relatively easy to use mathematical finite element analysis (FEA) modeling to evaluate a theoretical diaphragm's motion. We constructed a finite element model using an identical, 100-mm diaphragm geometry with the only variable being the material. This analysis intentionally ignores outside influences (e.g., acoustical load, phase plug, and horn geometry) to focus exclusively on each metal's fidelity. The unique properties of aluminum, titanium, and beryllium were fed into the model while the theoretical diaphragm's actual geometry was unaltered. The first six bending (breakup) modes are shown in **Figure 1** and charted in **Table 1**.

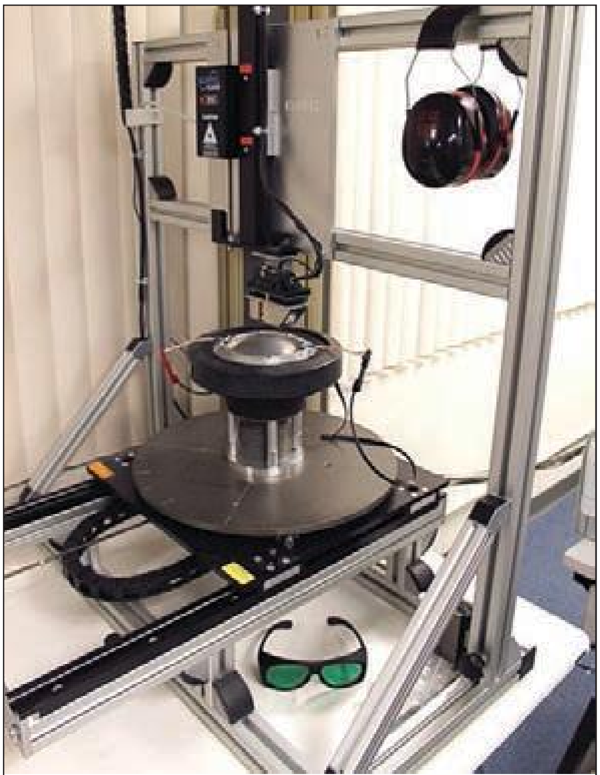

Photo 1: A Klippel SCN laser scanner measured the compression driver domes.

The results show that while each metal's breakup modes are somewhat similar, the beryllium diaphragm's breakup occurs at a much higher frequency than that of the other two (approximately 2.5 times higher), thereby shifting resonant frequencies outside the audible range.

Measuring the Vibrations

We used a Klippel SCN laser scanner to measure the vibrations of aluminum, titanium, and beryllium compression driver domes (see **Photo 1**). These geometric and vibration scans make it easier to see how the predicted results match the measured results in the next section. For simplicity, 2-D (cross-section) measurements of each dome's total vibration at four frequencies are presented (see **Figure 2**).

Beginning at 5 kHz, relatively minor bending (i.e., breakup) occurs on all the domes. As the frequency increases, bending waves become more visible. It's clear that the beryllium dome remains significantly more settled at high frequencies than the others (see **Table 2**).

Frequency	Number of Bending Waves (per Radius)		
	Aluminum	Titanium	Beryllium
5 kHz	~ 1	~ 1	< 1
10 kHz	~ 3.5	~ 3.5	< 1
15 kHz	6+	6+	~ 2.5
20 kHz	~ 9	~ 9	~ 3.5

Table 2: This table compares the number of bending waves per radius of aluminum, titanium, and beryllium.

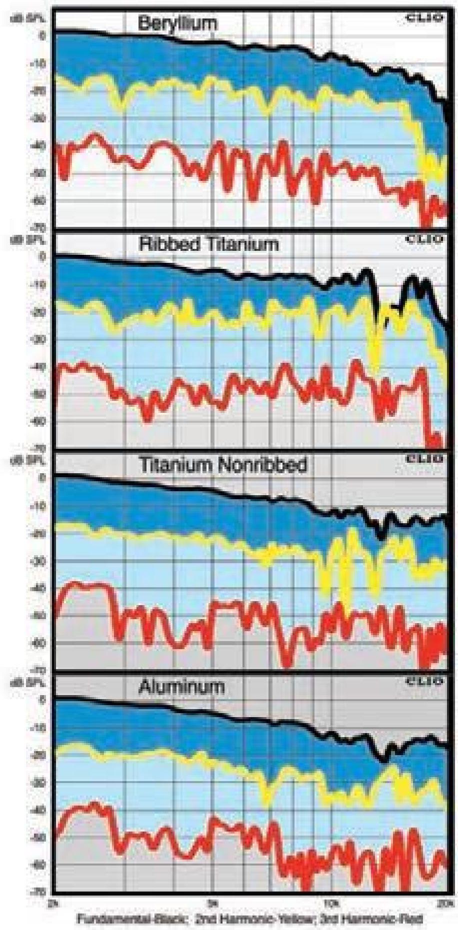

Figure 3: Comparison of frequency response linearity and second- and third- harmonic distortion for aluminum, titanium, and beryllium.

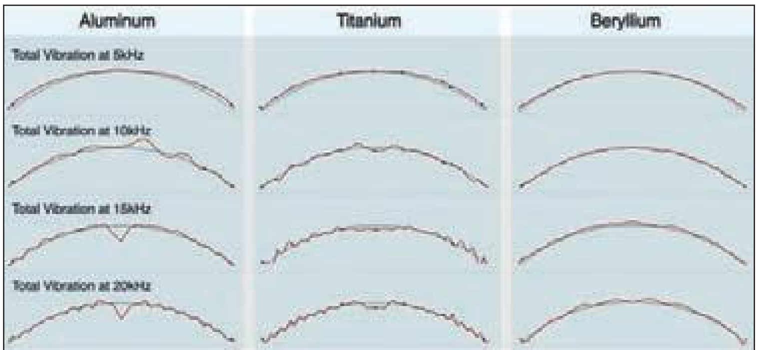

Figure 2: Results of the Klippel vibration analysis

Acoustic Performance

The measurements shown in **Figure 3** confirm the benefits of beryllium's better pistonic behavior, high-frequency response linearity, and distortion. The data shows the actual frequency response and harmonic distortion performance of four different diaphragms on the same motor assembly using a plane wave tube, which was selected to eliminate the effects a specific horn would introduce.

Aluminum was one of the first materials used for compression driver diaphragms because it's both light-weight and relatively stiff. It's also readily available and easy to form. The tests confirm that aluminum exhibits a good frequency response above 10 kHz, while its distortion is also good below 12 kHz. Aluminum does not perform as well in higher power applications due to its lower overall strength.

Titanium's use gained popularity in recent decades due to its ruggedness and ability to provide higher output than aluminum. The trade-off is the high-frequency distortion shown here, which supports the common perception that titanium does not sound as good as aluminum. Ribbing of the titanium dome and diamond-pleated surrounds are a popular method for adding stiffness, thus extending the high-frequency response. The trade-off is higher Q resonances, which create obvious nonlinearity above 10 kHz.

As demonstrated by the vibration analysis, both the aluminum and titanium response/distortion plots exhibit sharp peaks and dips near 10 kHz as a result of destructive interfere with the dome's in-phase motion. The beryllium diaphragm exhibits the best overall performance. It has a smooth, extended frequency response while its distortion is comparable to the other materials below 10 kHz. Above that mark, beryllium performs significantly better than the other two.

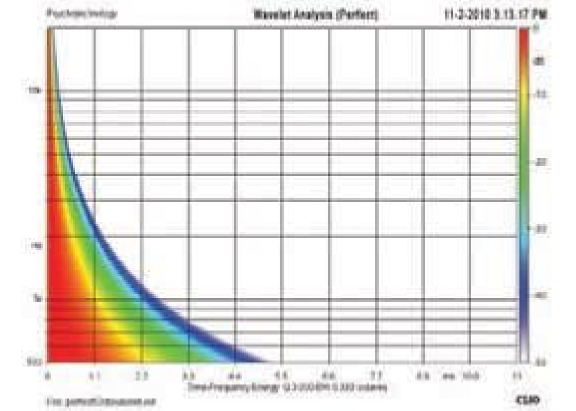

Figure 4: The reference curve for a perfect wavelet shows a decay of 1/1 for each frequency.

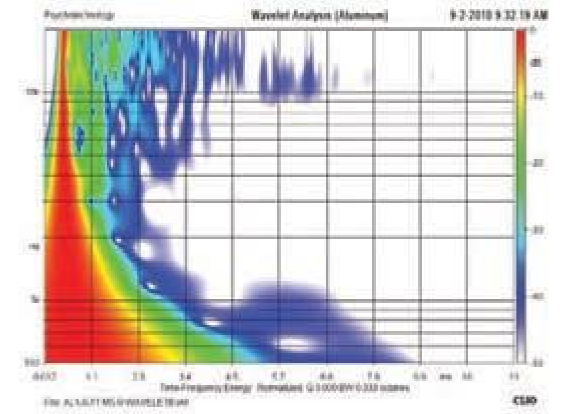

Figure 5: The aluminum diaphragm wavelet graph shows reasonably good decay behavior, both in the upper two octaves and at 1 kHz.

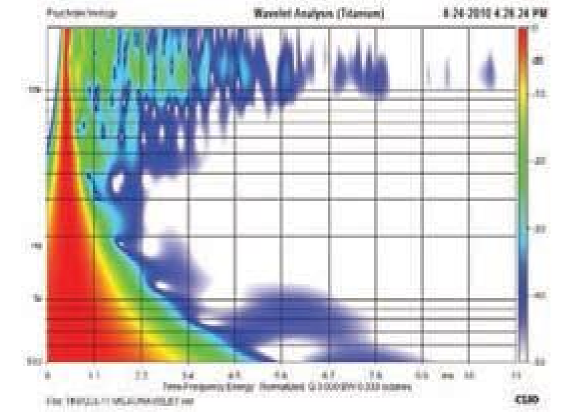

Figure 6: The titanium diaphragm with no ribs wavelet graph is the second worst performer on the wavelet decay test. It suffers from the top octave and 1-kHz ringing.

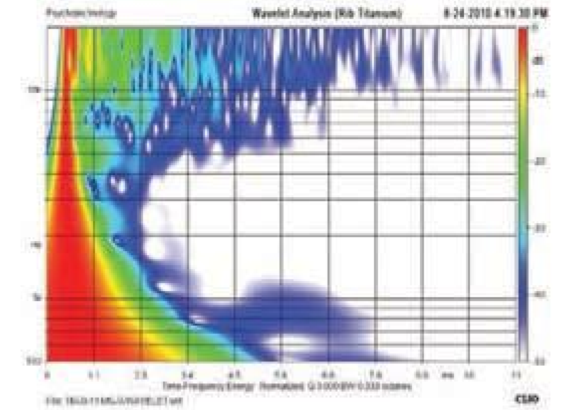

Figure 7: The ribbed titanium diaphragm shows the worst ringing of the group, exhibiting long decay at both in the upper two octaves and at 1 kHz.

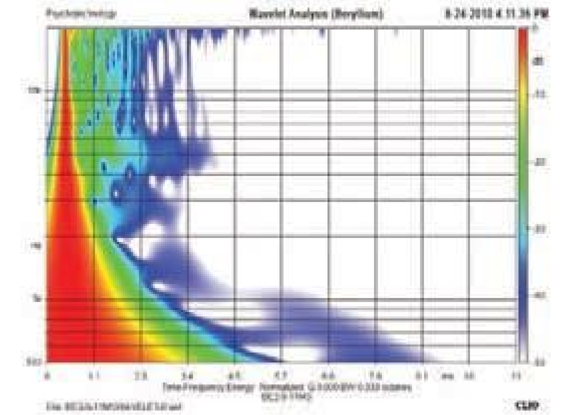

Figure 8: The beryllium diaphragm has the best top octave decay characteristics of all four materials and shape.

Wavelet Analysis of Time Domain Behavior

To fully understand the impact of high-frequency breakup modes and the associated frequency response "peaks," it's helpful to also look at time domain behavior. This type of data (see **Figures 4–8**) has only become readily available in the last 15 years. It is increasingly useful to qualify sound/quality issues that could be heard but were previously impossible to measure.

High-frequency breakups result in a rough and "peaky" frequency response that typically causes a long decay in the time domain (commonly referred to as ringing). This effect is particularly evident in the top octave response and decay differences between the smooth, fast-decaying beryllium driver and the peaky, long-ringing ribbed titanium driver.

Opportunities for Improvement

There are still many opportunities to improve modern-day transducer designs. Due to the efforts of companies such as Materion Electrofusion, the potential for once-esoteric technologies (e.g., beryllium) to improve both performance and reliability is better than ever. Leveraging beryllium's inherent advantages is the best and most immediate way to achieve a notable and measurable improvement in high-output, high-frequency loudspeaker performance. Most importantly, VUE Audiotechnik is committed to bringing these inherent benefits to a much broader market, while also exploring new applications for this exceptional metal throughout the entire loudspeaker ecosystem. For more information visit http://materion.com/Products/Beryllium/BerylliumAcoustics.aspx. ***VC***

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