DESIGNER NOTEBOOK

Growing The Loudspeaker Ecosystem

A discussion of the use of beryllium in transducers.

by Michael Adams & Ken Berger

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 HF 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 allows the h-Class to deliver significant improvements in both HF output and response linearity. The h-12 and h-15 are only the beginning, and VUE is actively developing more beryllium-based designs intended for a broad mix of applications.

This article will explore beryllium as a high performance alternative to aluminum and titanium. We'll cover the history of beryllium as an acoustic material, and detail modern manufacturing methods that are re-igniting interest in beryllium for advanced transducer design. Comprehensive data covering theoretical and actual performance tests will be presented as well.

BERYLLIUM PERSPECTIVE

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, allowing 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 indeed deliver on this promise, and over the years companies such as 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 due largely to expense and complexity, since beryllium is rarer and traditionally more difficult to isolate and refine.

But modern day refining and manufacturing techniques are reducing the cost of beryllium, while at the same time further enhancing its durability. As a result, VUE Audiotechnik is aggressively pursuing beryllium-based designs in an effort to advance loudspeaker performance and reliability.

CHANGING THE GAME

Early beryllium components were manufactured through a method known as PVD (Physical Vapor Deposition), 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 respirable particles if breakage occurs.

In recent years, however, Materion Electrofusion has pioneered the use of rolled foil beryllium for acoustic applications. Their 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 respirable particles.

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

THE SPEED OF SOUND

Understanding how beryllium's unique qualities translate into better HF performance begins by looking closely at what happens inside a transducer during operation. A diaphragm should move in a perfect pistonic motion (like a piston), with all points moving uniformly and only in the desired direction.

Breakup occurs when the forces act-

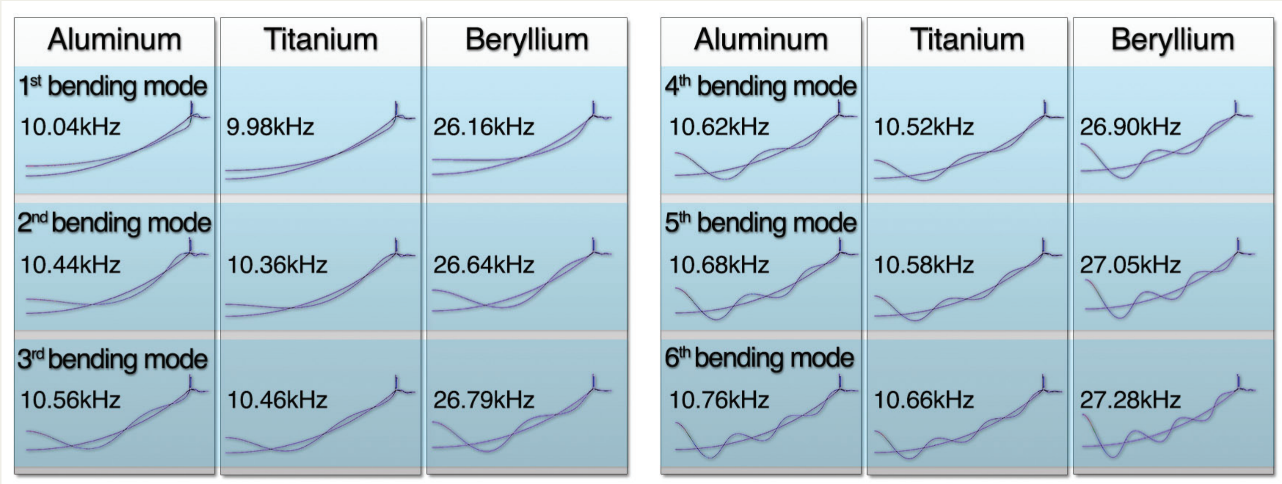


Figure 1: The first six breakup modes.

ing upon the diaphragm overpower its structural integrity, and different points on the surface begin moving at different speeds 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, however, is the speed 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 (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 mathematical modeling to evaluate theoretical benefits of all three as a diaphragm material. The second will measure physical performance of individual domes through vibration testing, and the final phase involves actual acoustic analyses of a fully assembled compression driver.

Natural Frequency	Aluminum (Al_n)	Titanium (Ti_n)	Ti_n / Al_n	Beryllium (Be_n)	Be_n / Al_n
1st mode	10.04 kHz	9.98 kHz	**0.99**	26.16 kHz	**2.61**
2nd mode	10.44 kHz	10.36 kHz	**0.99**	26.64 kHz	**2.55**
3rd mode	10.56 kHz	10.46 kHz	**0.99**	26.79 kHz	**2.54**
4th mode	10.62 kHz	10.52 kHz	**0.99**	26.90 kHz	**2.53**
5th mode	10.68 kHz	10.58 kHz	**0.99**	27.05 kHz	**2.53**
6th mode	10.76 kHz	10.66 kHz	**0.99**	27.28 kHz	**2.54**

Figure 2: Charting resonant frequencies.

MODELING THE DIFFERENCE

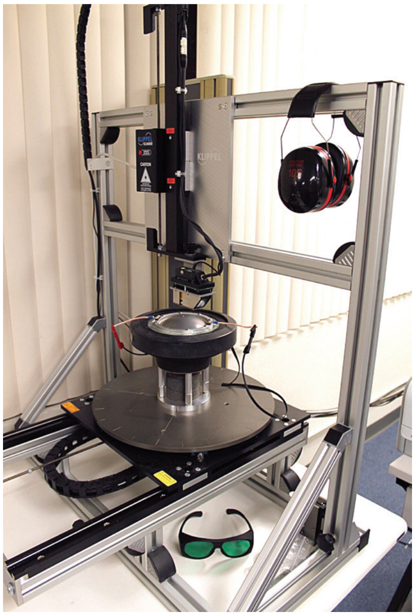
It's relatively easy using mathematical FEA (Finite Element Analysis) modeling to evaluate a theoretical diaphragm's motion. A finite element model was constructed using an identical, 100 mm diaphragm geometry with the only variable being the material. This analysis intentionally ignores outside influences such as acoustical load, phase plug and horn geometry, in order to focus exclusively on the unique fidelity of each metal.

In turn, the unique properties of aluminum, titanium and beryllium were fed into the model while the actual geometry of the theoretical diaphragm was unaltered. The first six bending (breakup) modes are shown in **Figure 1** and charted in **Figure 2**.

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

MEASURING VIBRATIONS

The vibrations of aluminum, titanium and beryllium compression driver



The Klippel SCN laser scanner used to measure vibration.

domes were measured using a Klippel SCN laser scanner. These geometric and vibration scans make it easier to see how the predicted results match the measured results in the next section.

For simplicity, 2D (cross-section) measurements of each dome's total vibration at four frequencies are presented. Beginning at 5 kHz, relatively minor bending (breakup) occurs on all the domes. As the frequency goes up, bending waves become more visible. In looking at the cross sections (**Figure 3**) it's clear that the beryllium dome remains significantly more settled at high frequencies than the other two.

As suggested by our theoretical analysis, it's easy to see (**Figure 4**), that the speed of sound through beryllium is roughly 2.5 times the speed of sound through aluminum or titanium. These measurements confirm this to be true, and demonstrate beryllium's inherent effectiveness at pushing breakup largely outside the audible range.

ACOUSTIC PERFORMANCE

The measurements in **Figure 5** confirm the benefits of beryllium's 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 that a specific horn would introduce.

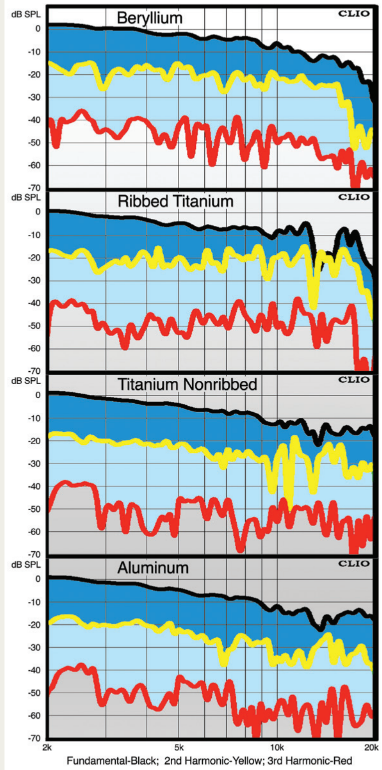
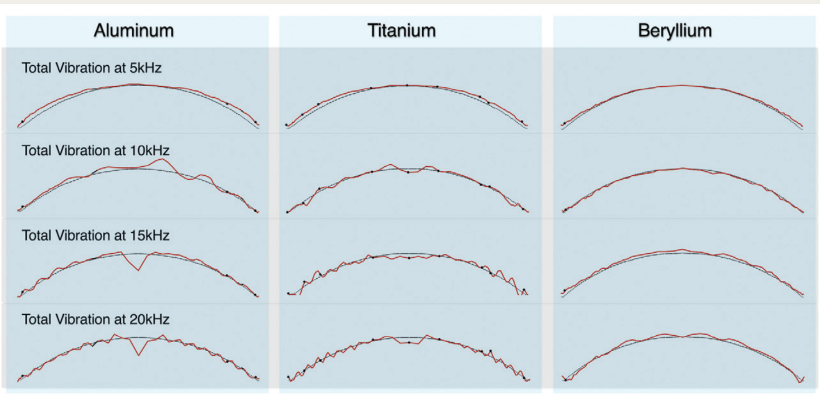


Figure 5: Frequency response and harmonic distortion data.

Aluminum was one of the first materials used for compression driver diaphragms because it's both lightweight and relatively stiff. It's also readily available and easy to form. The plots confirm that aluminum exhibits good frequency response above 10 kHz, while distortion is also good below 12 kHz.

Aluminum does not perform as well in higher power applications due to its lower overall strength. The use of titanium 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



🡅 Figure 3: Results of vibration testing.

Frequency	Number of bending waves (/radius)		
	Aluminum	Titanium	Beryllium
5kHz	~1	~1	<1
10kHz	~3.5	~3.5	<1
15kHz	6+	6+	~2.5
20kHz	~9	~9	~3.5

🡆 Figure 4: This chart presents similar data by simply counting the number of wavelengths up one side of each dome.

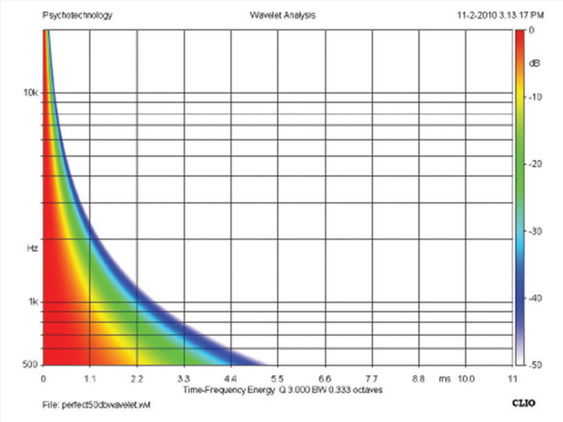


Figure 6: For reference, here is a perfect wavelet; the decay is approximately 1/f for each frequency.

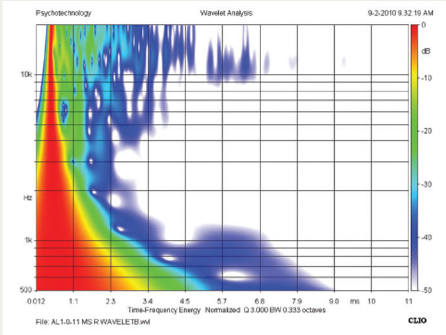


Figure 7: The aluminum diaphragm has reasonably good decay behavior, both in the upper two octaves and at 1 kHz.

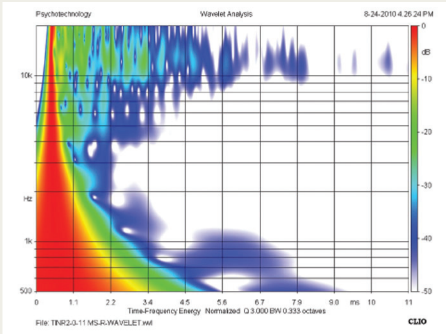


Figure 8: The titanium diaphragm with no ribs is the second worst performer on the wavelet decay test. It suffers from the top octave and 1 kHz ring.

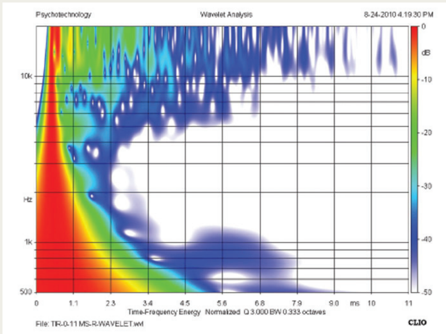


Figure 9: The titanium ribbed diaphragm shows the worst ringing, exhibiting long decay at both the upper two octaves and at 1 kHz.

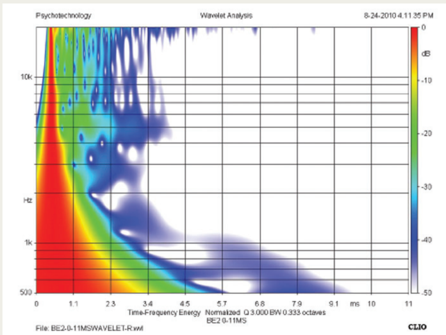


Figure 10: The beryllium diaphragm has the best top octave decay characteristics of the four materials and shapes.

extending the high frequency response. The trade-off is higher Q resonances, which create obvious non-linearities 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 distortion is comparable to the other materials below 10 kHz. Above that mark, beryllium performs significantly better than the other two.

TIME DOMAIN BEHAVIOR

To fully understand the impact of high frequency breakup modes and the associated frequency response "peaks" presented above, it's helpful to also look at time domain behavior. This type of data (**Figures 6 - 10**) has only become readily available in the last 15 years, and 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 results in 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.

CONCLUSION

There are still many opportunities to improve modern day transducer design, and thanks to the efforts of companies like Materion Electrofusion, the potential for once-esoteric technologies like 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.

Editor's Note: Be sure to go to ProSoundWeb to read about the testing procedures utilized for the data included with this article. ■

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