# GRAVITON® Ti Armwand White Paper

## 1. Introduction & Context

The GRAVITON® Ti Armwand is the culmination of more than thirty years of progressive research, experimentation, and scientific collaboration in analogue playback technology. Its lineage traces back to the pioneering A.C.T. One Tonearm, introduced by Wilson Benesch in 1992—a design that broke with convention by replacing traditional metals with carbon fibre composites to exploit their superior stiffness-to-mass ratio and damping properties.

Figure 1: The A.C.T. One Tonearm on the original Wilson Benesch Turntable in 1992.

In those early years, empirical testing guided critical insights into tonearm behaviour. Measurements and listening evaluations revealed that fibre orientation, material damping, and structural geometry dramatically influenced resonance control and energy transfer. These discoveries laid the groundwork for a new engineering philosophy that sought to merge high-performance materials with carefully considered design principles.

Decades later, partnerships with leading research institutions validated and expanded these early findings. The Femto Institute in Besançon, France, provided molecular-level insights into composite resonance behaviour during the EU-funded SSUCHY Project, while Sheffield Hallam

University contributed advanced material testing and performance validation. In parallel, the Advanced Manufacturing Research Centre (AMRC) in Sheffield and Renishaw PLC introduced additive manufacturing techniques, enabling the creation of titanium structures with intricate biomimetic lattices and tessellated forms.

This extensive programme of study has yielded one of the most advanced tonearm designs ever realised. The GRAVITON® Ti Armwand integrates a graphene-enhanced quadruple-helix carbon fibre armtube with selectively laser-sintered titanium components that mimic nature's most efficient structural geometries. This hybrid construction addresses the complex mechanical demands of a tonearm—resonance suppression, precision stiffness, and energy transfer—while eliminating redundant material and reflective interfaces.

By blending empirical experience, state-of-the-art scientific research, and advanced manufacturing, the GRAVITON® Ti Armwand establishes a new benchmark in tonearm engineering. This paper will guide the reader step-by-step through the design journey, illustrating how each principle, from fibre orientation to biomimetic titanium lattices, contributes to a structure that redefines what is mechanically and sonically possible in high-fidelity playback.

## 2. The Foundations of Tonearm Design

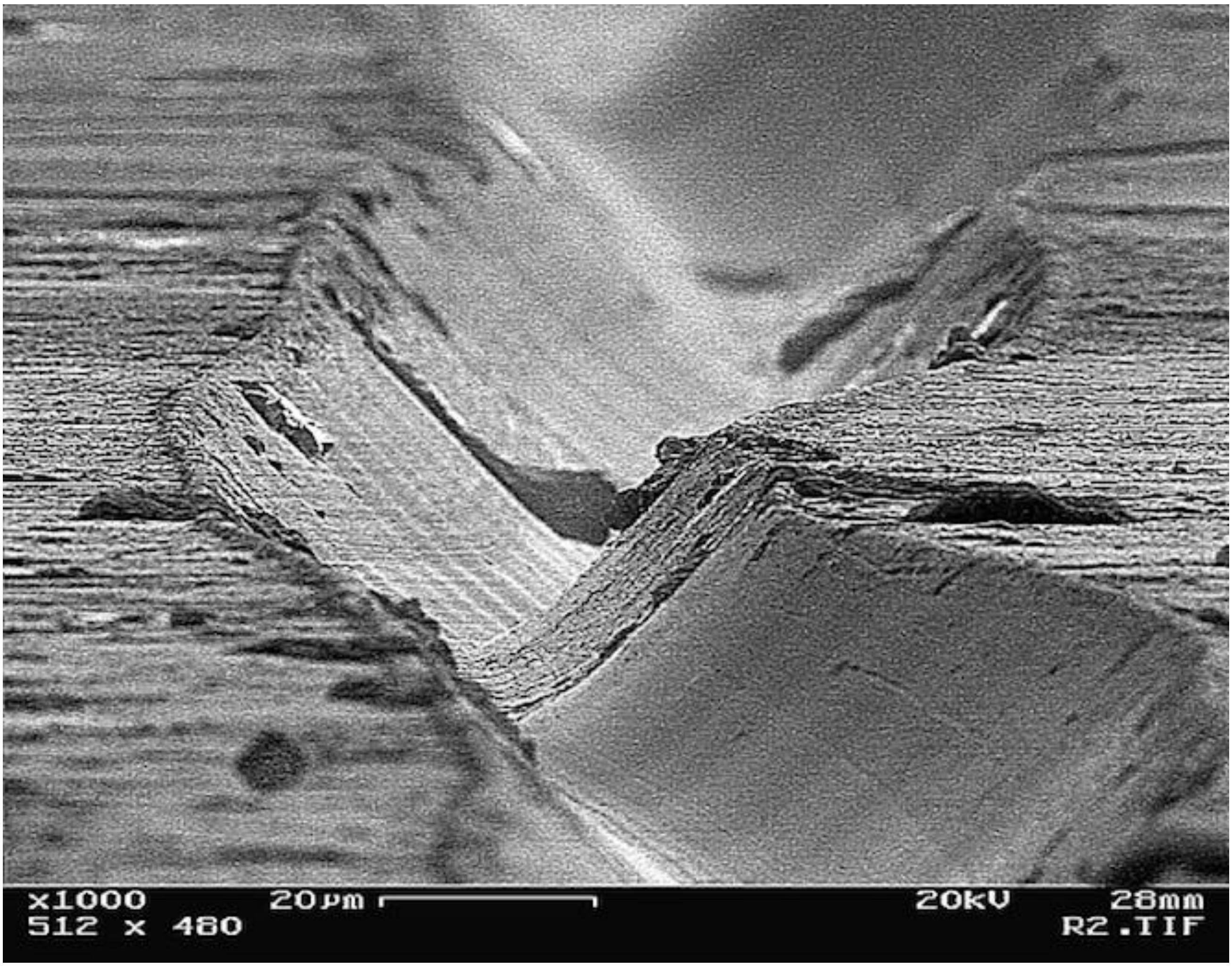


Figure 2: A Microscopic image of the groove of a vinyl record.

### 2.1 Functional Role of a Tonearm

Figure 2 above reveals the microscopic world of a vinyl groove: a V-shaped trench just 25–50 microns wide—half the width of a human hair—its walls etched with undulating modulations that encode the left and right channels of a stereo recording. Within this scale, even the smallest deviation matters. A tonearm must therefore operate as a neutral, ultra-precise measuring tool—analogous to a micrometer—tracing this microscopic landscape with absolute fidelity. Vibrations at the stylus-cartridge interface can trigger tonearm resonances, distorting playback if not controlled. Effective tonearm design mitigates this by minimising vibration pathways, suppressing resonances, and maintaining a clean, uninterrupted energy transfer away from the stylus. In such a context, the tonearm becomes an instrument of precision engineering, operating at a scale where a single micron determines the difference between perfect groove tracing and audible distortion.

Fibre orientation is central to this goal. The A.C.T. One Tonearm demonstrated that arranging carbon fibres helically along a hyperbolic curve maximises energy dissipation and structural rigidity. In contrast, unidirectional (U.D.) carbon fibre—while extremely stiff—exhibits negligible inherent damping because its fibres channel energy rapidly along their length with minimal boundary interaction. Woven carbon fibre fabrics overcome this limitation through millions of fibre interfaces that introduce micro-damping, which is essential to resonance control.

## 2.2 Key Performance Requirements

**Specific Stiffness**

Empirical studies established that reducing mass while maximising stiffness improves transcription accuracy. The GRAVITON® Ti achieves benchmark stiffness via its quadruple-helix graphene-reinforced carbon fibre armtube, which demonstrated a deflection of just 0.003 mm under an 8.5 MPa load, ensuring high resonant frequencies and precision tracking.

**Controlled Damping**

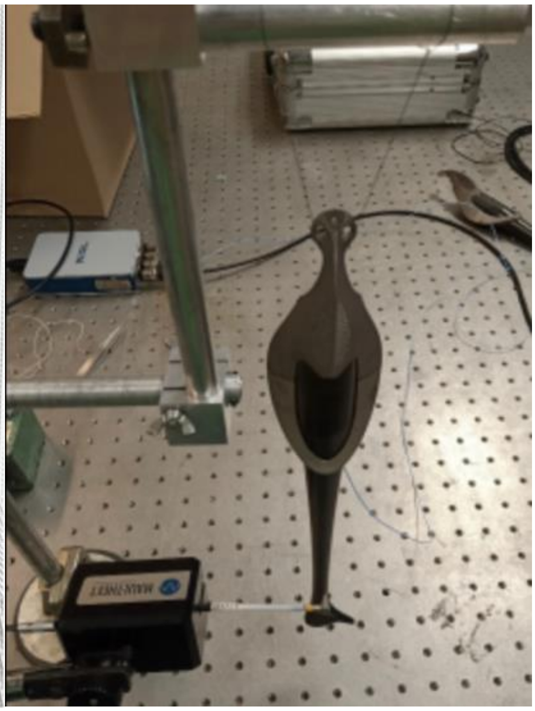
Although stiff materials resist deformation, they resonate audibly in the 4–6 kHz range. By leveraging the micro-damping of woven carbon fibre and integrating viscoelastic adhesive interfaces at titanium junctions, the GRAVITON® Ti efficiently dissipates vibrational energy, preventing resonance build-up and tonal coloration.

**Precision Geometry and Energy Transfer**

Additively manufactured titanium follows the helical geometry of the carbon tube, creating smooth energy transfer pathways and eliminating abrupt reflective surfaces. Its hollow, tessellated, and biomimetic internal structures optimise stiffness-to-mass ratios, further dampening energy while preserving mechanical neutrality.

Through this synthesis of anisotropic materials, fibre orientation, and advanced geometry, the GRAVITON® Ti Armwand achieves unrivalled resonance control and precision, operating as a transparent link between cartridge and playback system.

Figure 3: Professor Morvan Ouisse of the Femto Institute in Besancon, France whose original work and collaboration with Wilson Benesch was through the SSUCHY Project in the development of bio-based composite materials technologies for the Fibonacci Series loudspeakers. Subsequent work on the GRAVITON® Ti Armwand provided Wilson Benesch with new insights into material behavior at the molecular level. This body of work represents a significant study of resonance in lamellar structures composed of both oil based and bio based materials. Work in this field continues.



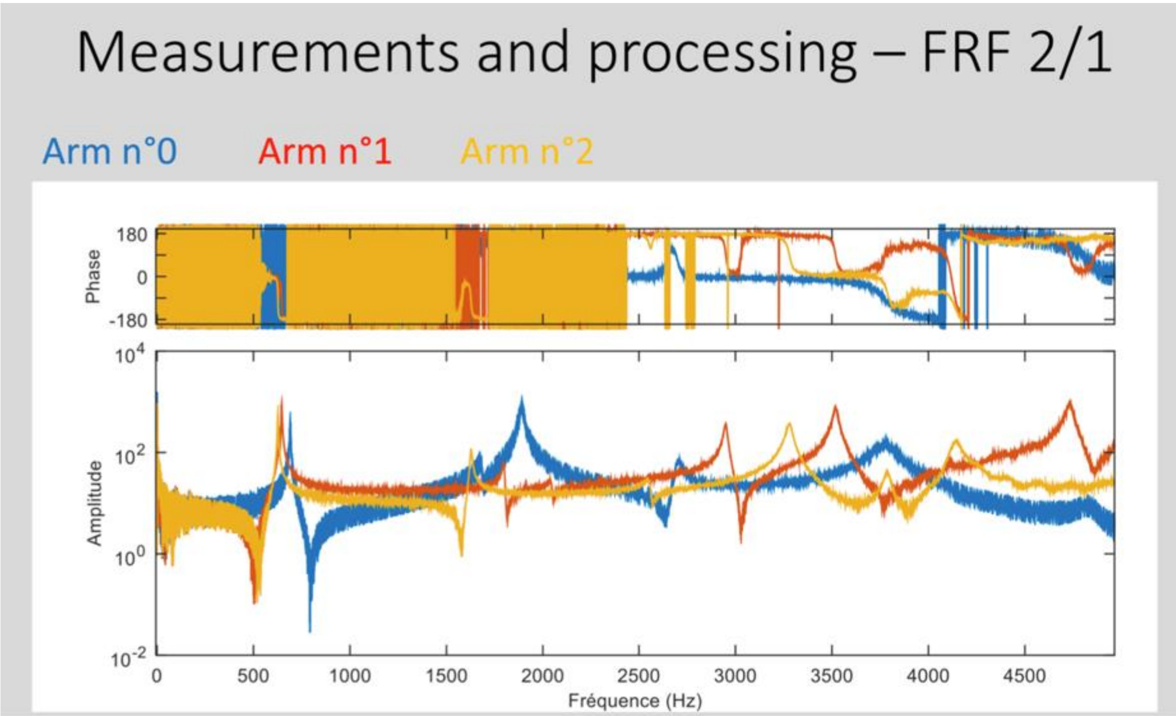



Figure 4: The measured behaviour of three possible GRAVITON® Ti Arwand designs. The results illustrate the centrality of advanced material engineering and how it can reduce resonance amplitude and improve stability across the frequency range.

## 3. Materials Science Fundamentals

The GRAVITON® Ti Armwand represents over three decades of continuous research into material behaviour, stemming from pioneering empirical studies of the late 1980s and culminating in scientifically validated design insights through collaborations such as the

SSUCHY Project and the Femto Institute. This section outlines the fundamental material principles that underpin its design.

### 3.1. Isotropic vs. Anisotropic Materials

A critical distinction in tonearm design is between isotropic and anisotropic materials:

- **Isotropic materials,** such as metals, exhibit uniform properties in all directions. While they offer predictable behaviour, they also readily transmit and reflect vibrational energy, making them less suitable for precision applications where damping is required.

- **Anisotropic materials,** such as carbon fibre composites, display direction-dependent properties. This allows engineers to align stiffness and damping characteristics with precise structural and functional requirements, creating pathways for controlled energy transfer and dissipation.

The GRAVITON® Ti Armwand leverages both: anisotropic carbon fibre for tailored stiffness and damping, and topologically optimised titanium structures whose tessellated geometry introduces anisotropic-like behaviour to metallic components. This hybrid design extracts the best from each material class, ensuring unmatched rigidity and vibration control.

### 3.2. Carbon Fibre Behaviour and Energy Pathways

Carbon fibre's behaviour is central to the GRAVITON® Ti Armwand. Two principal fibre types are utilised:

- **Unidirectional (U.D.) fibres**, which provide high stiffness along a single axis but offer minimal damping.

- **Woven 0/90° fabrics**, in which perpendicular fibres intersect, generating boundary layer damping through internal friction.

In the GRAVITON® Ti Armwand, woven fabrics are helically oriented, extending the energy path and forcing vibrations to dissipate through inter-fibre interaction. A single helical fibre is approximately 50% longer than a linear equivalent, creating a tortuous return path for vibrational energy and significantly improving damping.

Boundary layer damping is further enhanced by the woven fabric's perpendicular fibres, which compress against each other dynamically. This interaction, maximised by the helical layup, yields damping behaviour far superior to that of U.D. fibres alone, making it the foundation for Wilson Benesch's composite engineering philosophy.

### 3.3. Empirical Validation and Scientific Confirmation

During the development of the original A.C.T. One Tonearm, extensive trials compared aramids, glass fibre, carbon fibre, and hybrid composites. These experiments established a precise balance between stiffness and damping that delivered exceptional real-world performance, even in the absence of modern analytical tools.

Decades later, research following the SSUCHY Project, which fostered new partnerships with the Femto Institute in France, provided the first scientific measurements of composite behavior at the micro- and nano-scale. Led by Professor Morvan Ouisse, this work revealed in detail how energy travels through anisotropic lamellar structures, confirming that the empirical stiffness-damping balance determined in 1989 was remarkably close to optimal.

From this collaboration, several critical advances have been incorporated into the GRAVITON® Ti Armwand:

- **Graphene-enhanced resin systems**, increasing intrinsic damping through nano-scale energy dissipation.
- **Precisely located U.D. carbon reinforcements**, adding stiffness exactly where it is required.
- **Closed-cell Rohacell sandwich cores**, enhancing stiffness and damping simultaneously.
- **Bio-composite damping layers**, derived from SSUCHY research, adding natural damping properties.

This progression from hands-on experimentation to scientifically verified optimisation underscores a continuous design lineage: the principles first established in 1989 have not only endured but are now enhanced by cutting-edge measurement and advanced materials science.

Further testing conducted at Sheffield Hallam University demonstrated the exceptional structural rigidity of the GRAVITON® Ti Armwand. Under a stress load of 8.5 MPa (85 bar / 1,232 psi), the armtube exhibited a deflection of only 0.003 mm. Such remarkable stiffness elevates the armwand’s resonant frequency while maintaining high damping, ensuring superior tracking precision and minimising distortion for absolute fidelity in vinyl playback.

## 4. Geometry & Fibre Orientation

The geometry of the GRAVITON® Ti Armwand is inseparable from its material science. Where Section 3 establishes the fundamental behaviour of materials, Section 4 explores how form amplifies those properties, using biomimetic principles inspired by nature and realised through Wilson Benesch's unmatched in-house composite engineering capability.

While some tonearms employ carbon fibre armtubes, their execution is fundamentally different. In many cases, these are either:

- Off-the-shelf carbon fibre tubes repurposed for audio, or
- Basic pre-preg layups, limited by generic OEM supplier capabilities and lacking optimisation for tonearm-specific requirements.

The GRAVITON® Ti Armwand stands apart. Wilson Benesch engineered the hyperbolic armtube from first principles, designing and machining bespoke moulds in-house for seamless headshell integration. The entire component is manufactured in Wilson Benesch's Sheffield facility, utilising Vacuum Resin Transfer Moulding (VRTM) and decades of accumulated expertise in advanced composites.

*Insight: What is VRTM?*
*Vacuum Resin Transfer Moulding (VRTM) is an advanced composite manufacturing process. Dry carbon fibre is placed into a precision mould, and then resin is drawn in under vacuum pressure. This ensures perfect fibre wet-out, minimal voids, and a high fibre-to-resin ratio. The result is stronger, lighter, and more consistent structures compared to basic layup methods*.

This vertical integration and proprietary development process ensures a level of control and performance refinement that cannot be achieved through outsourced or generic methods. The result is an armtube and headshell that are moulded together as a single uninterrupted component, optimised specifically for audio reproduction with no compromises.

### 4.1. Hyperbolic Curves and Optimised Beam Design

The GRAVITON® Ti Armwand adopts a hyperbolic curve, inspired by natural forms such as tree trunks and bones, which taper to deliver high stiffness at their base while reducing unnecessary mass at their extremities. This geometry:

- Eliminates redundant mass furthest from the pivot to reduce inertia.
- Focuses stiffness where bending forces are greatest, mirroring natural load paths.
- Ensures uninterrupted energy transfer, avoiding abrupt diameter changes that would reflect vibrations.

Wilson Benesch's in-house machining of bespoke moulds ensures that this hyperbolic geometry is faithfully realised through VRTM, with precision control over fibre placement and consolidation—something impossible with generic tubing or bonded assemblies.

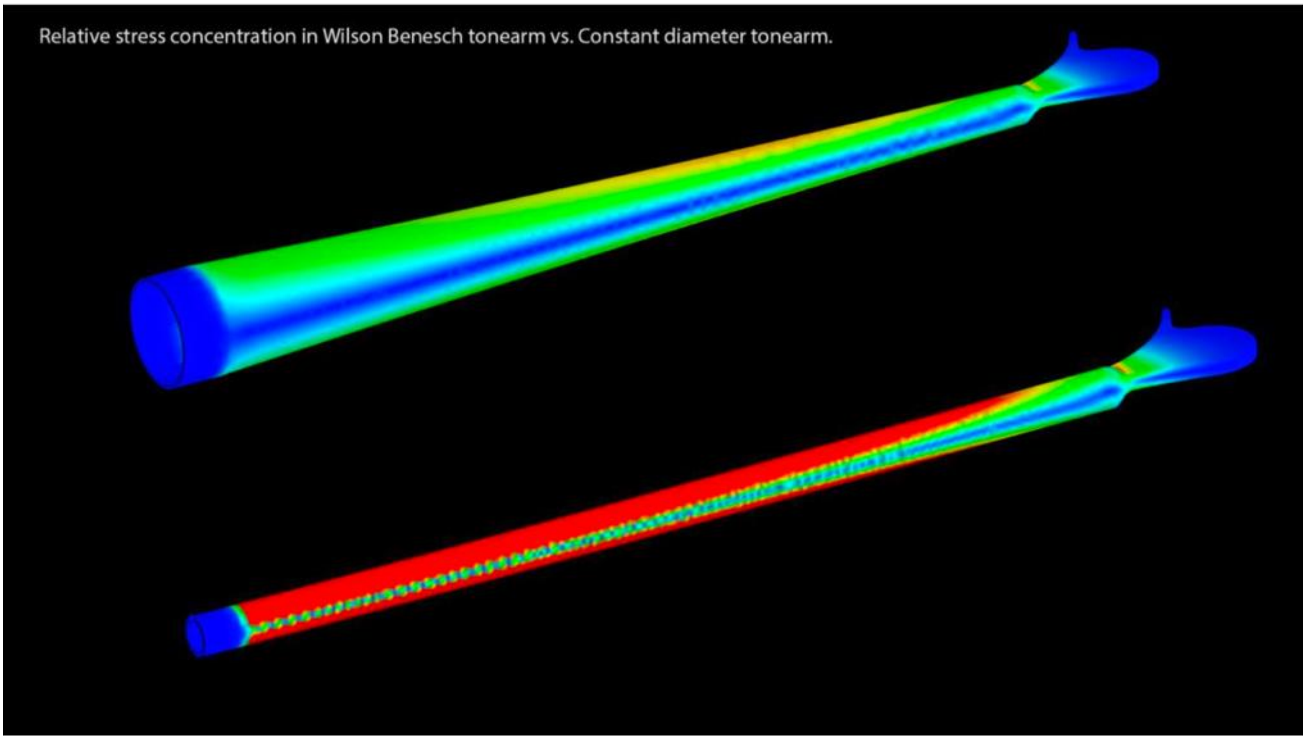



Figure 5: Finite Element Analysis shows the Relative Stress concentration across the hyperbolic geometry of the Wilson Benesch armtube versus that of a tube of constant diameter.

### 4.2. DNA-Like Helical Fibre Orientation

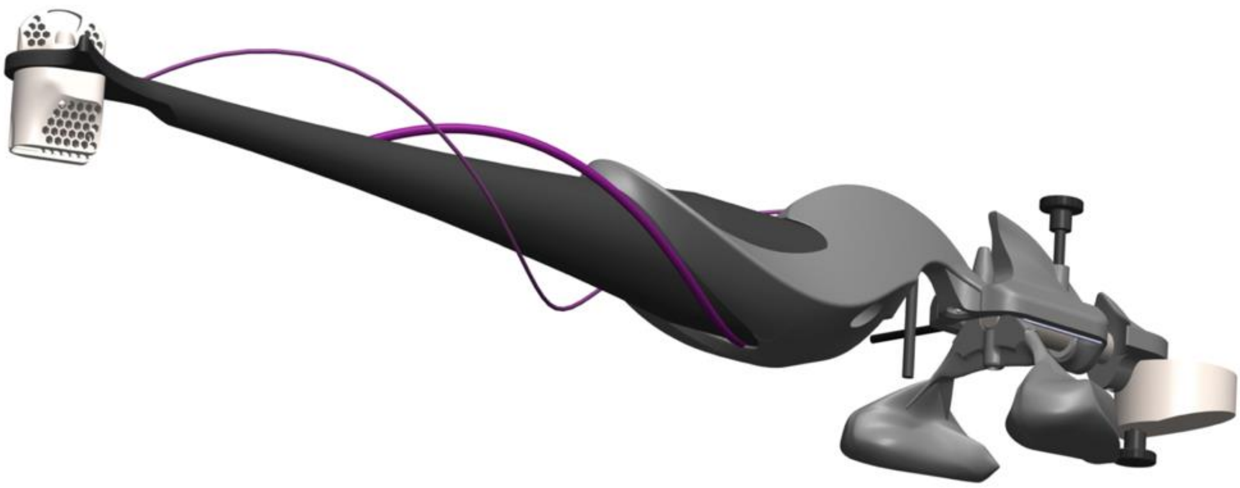


Figure 6: A graphical illustration of a the double helix geometry of the carbon fibre armtube of the GRAVITON Ti Tonearm

Hand-laid by skilled Wilson Benesch technicians, as seen in figure 6, the carbon fibres are meticulously arranged in a dual helix orientation, mimicking DNA's double-helix structure and the spiral grain of trees. This arrangement optimises structural and vibrational performance by:

- Maximising torsional rigidity, resisting twisting forces more effectively than straight fibre layups.
- Extending energy pathways, with helical fibres ~50% longer than linear fibres, forcing energy dissipation through tortuous paths.

- Enhancing damping, as the woven 0/90° fabrics compress dynamically within the helix, introducing boundary layer damping similar to fibrous biological tissues.

Unlike outsourced pre-preg layups, where fibre orientation is constrained by supplier processes, Wilson Benesch's in-house hand layup allows precise tailoring of fibre architecture to the hyperbolic form, unlocking performance gains unique to this approach.

### 4.3. Single-Piece Continuity and Reflection Control

A defining feature of the GRAVITON® Ti Armwand is its single-piece moulded headshell and armtube, formed as one continuous carbon fibre component. This construction stands in stark contrast to the vast majority of tonearms, which utilise bolt-on or mechanically fastened headshells, often made from different materials and joined at abrupt angles. These discontinuities act as reflective junctions, disrupting energy flow and allowing vibrational energy to reflect back toward the stylus.

Nature, by contrast, favours continuity and integration in structures tasked with bearing load and dissipating energy. In tree trunks, fibres run unbroken from root to crown, distributing stress smoothly. In long bones, continuous mineralised layers and internal lattices transfer and absorb load without interruption.

Where continuity is lost, energy is reflected—sometimes destructively.

- **Coastal wave impact** on flat concrete seawalls creates violent rebound, while rocky shorelines with irregular, layered surfaces dissipate energy progressively.

- In **acoustic environments**, smooth rock faces such as those in canyons reflect sound in the form of echoes, whereas natural fibrous landscapes such as forest absorb and scatter energy, softening or entirely eliminating its return.

The GRAVITON® Ti Armwand applies this same logic. Its seamless, single-piece construction ensures that vibrational energy is not bounced back at joints or boundaries, but is instead dissipated smoothly through the continuous, hyperbolic, helical carbon fibre structure.
This delivers:

- **A consistent stiffness gradient** with no sudden shifts in material or geometry.

- **A clean, unbroken energy pathway**, minimising reflections and resonant build-up—which is particularly important to avoid in the cartridge, where significant resonant energy is generated as the stylus tracks the groove.

- **Perfect integration into the titanium counterbalance structures**, which themselves follow the helix—maintaining energy flow and reducing as much as possible any reflection points.

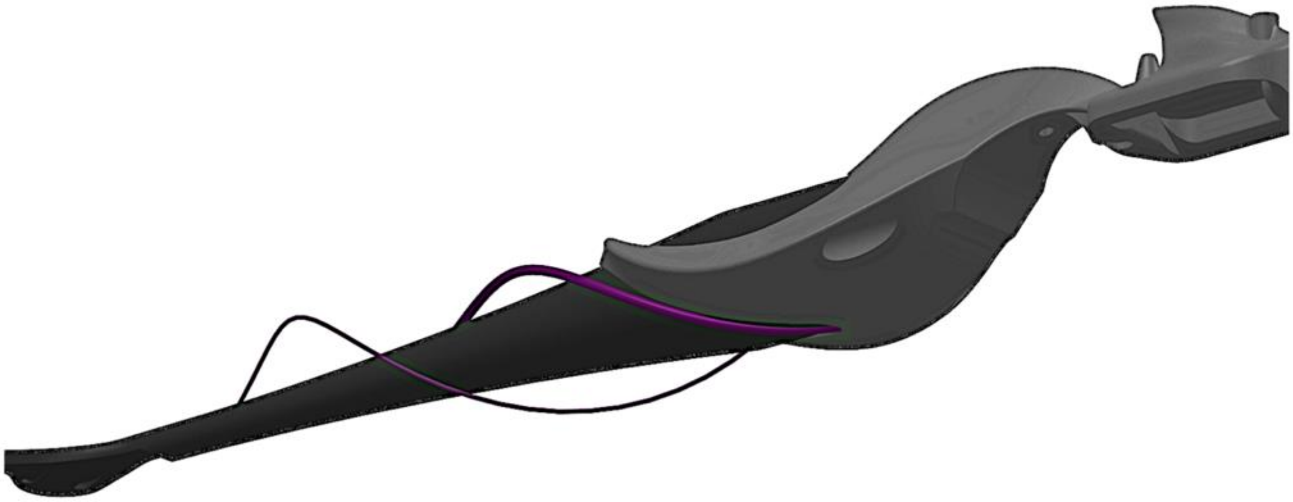


Figure 7: Graphical illustration showing how the additively manufactured titanium counterbalance structure is optimised to follow the double-helix geometry of the carbon fibre armtube. This seamless integration ensures a continuous energy pathway with no abrupt material junctions, minimising reflections and enabling smooth dissipation of vibrational energy through the armwand and counterbalance system.

This level of structural harmony is only possible because Wilson Benesch controls every aspect of design and manufacture in-house: from the machining of proprietary moulds, to the hand-laying of carbon fibre, to the execution of Vacuum Resin Transfer Moulding (VRTM). The result is a carbon fibre armwand that manages energy with unprecedented precision, directly reducing resonances at their source and delivering a purer signal from the cartridge.

## 5. Hybrid Construction: Carbon Fibre & Titanium

The GRAVITON® Ti Armwand represents the fusion of two advanced engineering materials: anisotropic carbon fibre composites and additively manufactured titanium. This hybrid construction combines Wilson Benesch's 35 years of expertise in composite fabrication with next-generation additive manufacturing (AM) technologies developed in close collaboration with the Advanced Manufacturing Research Centre (AMRC) in Sheffield.


This work was led by Dr James Hunt, whose team of multidisciplinary engineers helped translate early Wilson Benesch concepts into manufacturable titanium components using Selective Laser Sintering (SLS) on Renishaw PLC's metal AM platforms. The collaboration built upon decades of design insight and introduced a new level of engineering sophistication into audio design—establishing Wilson Benesch as the first company in the world to produce a titanium tonearm via additive manufacturing.

**Figure 8:** A 2018 news clipping announcing the success of the AM collaboration between Wilson Benesch, the AMRC and Renishaw PLC, marking a world-first in titanium tonearm design through additive manufacturing. Read in full here.

**Figure 9:** Example of a generic titanium component being manufactured in a Selective Laser Sintering (SLS) machine. The laser melts and fuses titanium powder layer by layer, illustrating the same process used to create the titanium structures of the GRAVITON® Ti Tonearm.

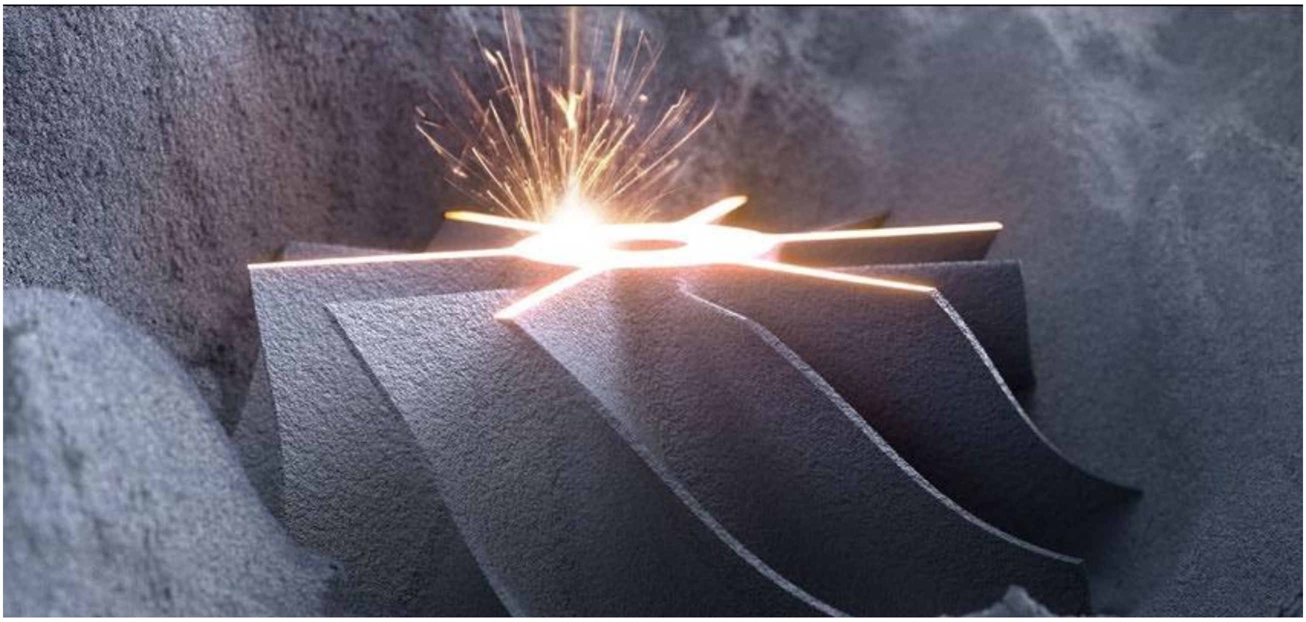


**Figure 10:** Sculpted by Wilson Benesch Design Director Craig Milnes, this simple wax model was hand-crafted at the outset of the project to visualise basic geometry and mechanical requirements of the titanium counterbalance structure before the team at The University of Sheffield and the AMRC began the additive manufacturing design process.

To kick-start the design process, Wilson Benesch produced a simple wax model to visualise the mechanical and geometric requirements of the titanium counterbalance structure. This helped to define crucial design principles:

- The titanium geometry must follow the helical structure of the carbon fibre armtube to avoid reflective energy at the interface.
- The part must contain no redundant mass, especially above the stylus pivot centreline.
- Bearing position, load transfer, and wiring pathways must be integrated into the geometry from the outset.

These considerations became the brief for the AMRC engineering team, who—through surface topology optimisation and AM design practices—translated the functional demands of the tonearm into highly organic titanium structures. The resulting titanium parts, fabricated layer by layer via selective laser sintering (SLS) from titanium powder, are a triumph of form following function.

This project established not only a world-first for additive tonearm design but also a working methodology with leading UK research institutions. It catalysed further innovations—ultimately informing the full system-level design of the GRAVITON® Ti Armwand as a holistic, high-precision tonearm system.

### 5.1. Why Titanium?

Titanium was selected for its unique ability to combine **strength, stiffness, and damping** properties that far exceed those of conventional tonearm metals such as aluminium or steel. Key advantages include:

- **High Specific Stiffness:** Titanium achieves exceptional rigidity with minimal material, supporting the low-inertia demands of tonearm design.
- **Damping Properties:** Unlike aluminium or steel, which readily “ring” when excited, titanium dissipates vibrational energy effectively, minimising metallic resonance.
- **Geometric Continuity with Carbon:** Titanium sections are grown via SLS to follow the hyperbolic helix of the carbon armtube, eliminating abrupt junctions that reflect energy back into the cartridge.

A visco-elastic adhesive membrane bonds titanium to carbon, creating a damped transition layer that both maximises energy transfer and suppresses reflections.

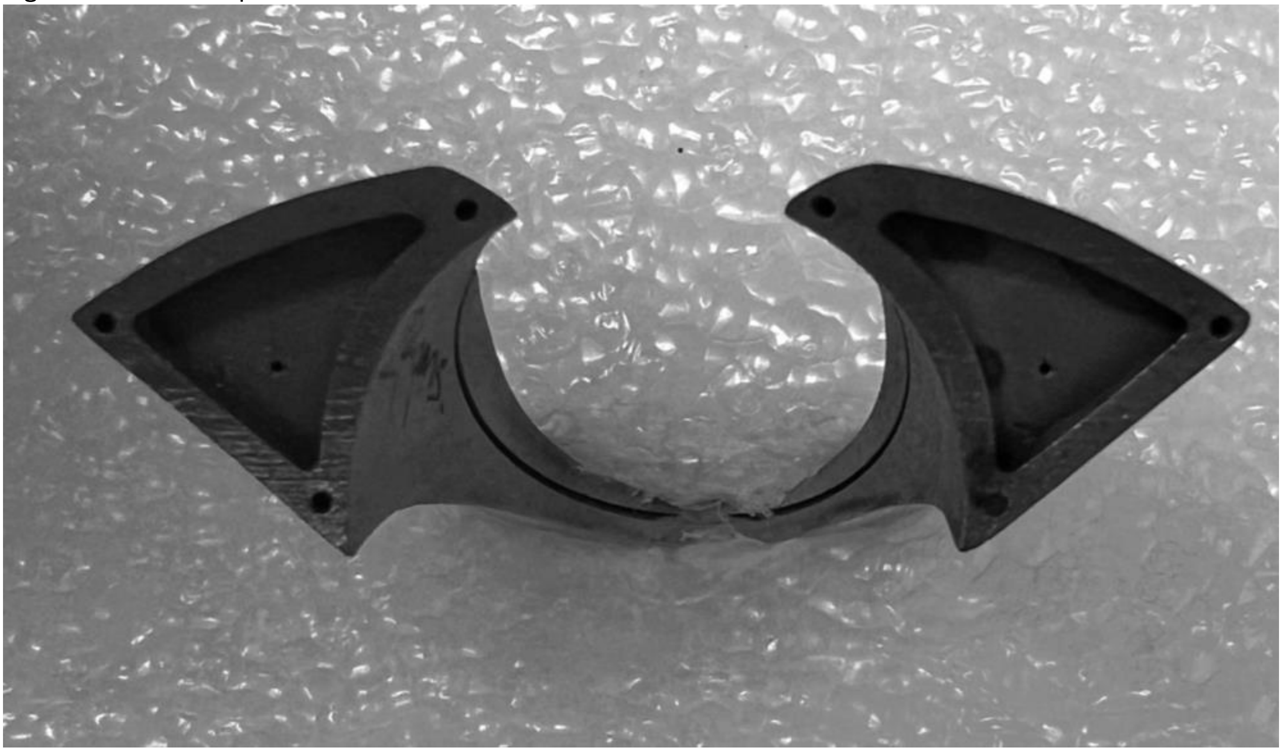
### 5.2. Biomimetic Titanium Design

The titanium counterbalance structure is grown in three physically separate parts, each engineered to meet precise mechanical and acoustic requirements. Together, they form a unified, biomimetic titanium system directly inspired by natural structures such as bone lattices, bird beaks, and evolved skeletal geometries.

**Part One: Triangular Front Section**

Part One is the forward-most titanium section, interfacing directly with the carbon armtube. Positioned furthest from the pivot, it achieves maximum stiffness while minimising mass. Its organic form resembles the lower jaw of a humpback whale, shaped to resist bending forces efficiently.

Figure 11: A view of part one of the titanium counter-balance.



**Key attributes:**

1. **Highest Specific Stiffness:** Its hollow triangular cross-section, curved form, and contoured surfaces resist bending forces with minimal redundant material.

2. **Intimate Carbon Fit & Surface Area:** Its internal surface precisely matches the hyperbolic, helical contour of the carbon armtube, maximising surface contact for energy transfer and enabling the use of a viscous adhesive membrane that damps energy flow and suppresses reflections.

3. **High Compression Assembly:** A threaded section allows 6mm bolts for precise, high-compression assembly before final bonding. Bolts may be removed post-bonding to further reduce mass.

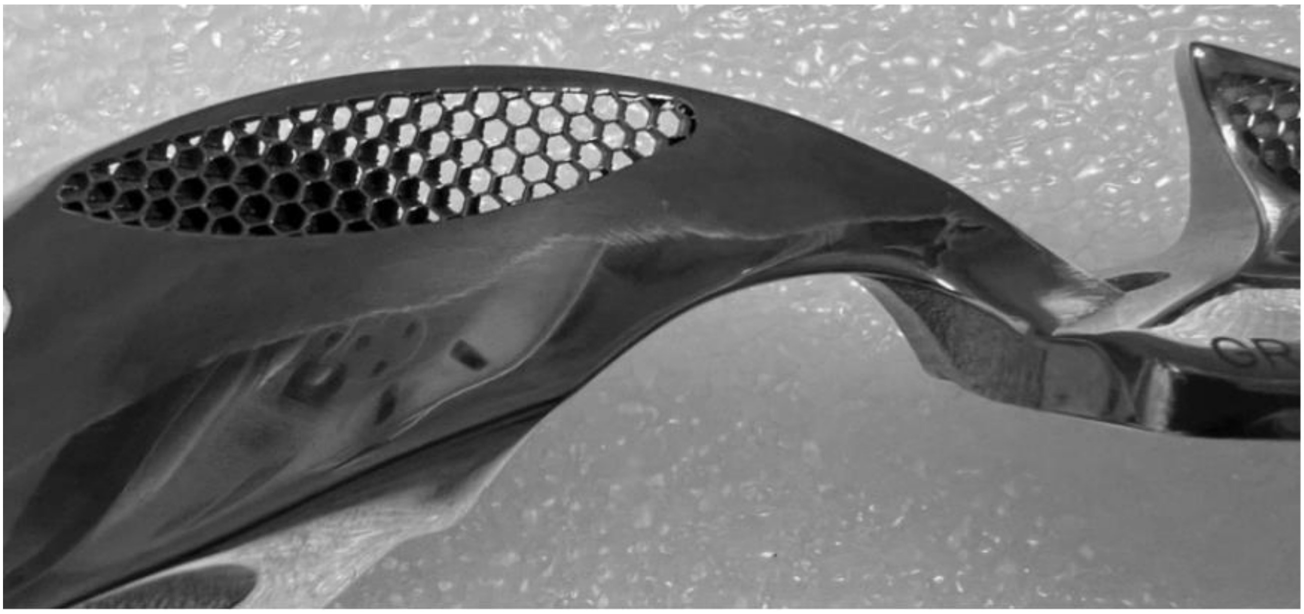
4. **Helical Geometry Alignment:** Its form follows the dual-helix fibre orientation of the carbon armtube, ensuring energy continuity without abrupt terminations.

5. **Optimised Mass Distribution:** Hollow design places 90% of its mass below the stylus centre line, improving balance without sacrificing stiffness.

Only SLS additive manufacturing can achieve this whale jaw-like geometry, which integrates hollowing, curvature, and precision interfaces impossible with conventional machining.

**Part Two: Pivot Integration & Tessellated Structure**
Part Two connects Part One to the bearing pivot, incorporating the counterweight mount, azimuth assembly, and anti-skate beam. It blends progressive stiffness with damping derived from internal tessellated lattices, directly inspired by trabecular bone architecture.

Figure 12: A view of part two of the titanium counter-balance.



**Key attributes:**

1. **Bearing Precision:** Micrometre-level geometry ensures precise pivot alignment for ultra-low-friction performance.

2. **Energy Focus to Pivot:** Its triangular, widening geometry channels stiffness along optimal load paths toward the pivot.

3. **Cable Management:** An internal cavity routes wiring above the bearing, preventing torsional loading on the pivot. (see image 5)

4. **Intimate Carbon Interface:** A bonded viscous adhesive layer maximises contact area, enabling damped energy transfer between carbon and titanium.

5. **Internal Tessellation:** Inspired by bone lattices, this section transitions from hollow walls to an internal tessellated core, combining stiffness and damping while minimising weight.

6. **Solid Termination at Pivot:** Near the bearing, titanium transitions to solid, creating a rigid anchor for precise energy transfer into the bearing point.

This **hollow → tessellated → solid** progression mirrors biological systems like femurs, where dense outer layers integrate seamlessly with internal lattices for maximum structural efficiency.

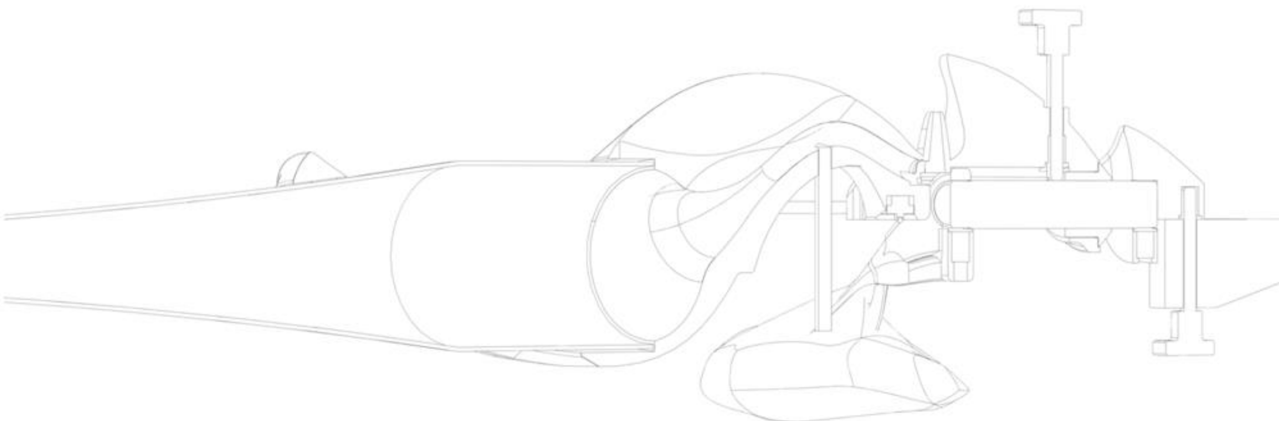


Figure 13: A cross-section drawing of the GRAVITON® Ti Armwand counterbalance and armtube showing clearly the internal cavity through which the tonearm wire moves from the armtube into a position directly above the pivot.

**Part Three: Stabilising System & AI-Optimised Geometry**
Part Three anchors the counterweight system and stabilises the rear of the armwand. It was developed using AI-driven generative design tools and surface topology optimisation, allowing mass to be placed only where structurally effective. Its resulting organic form is purely functional, optimised computationally rather than manually designed.

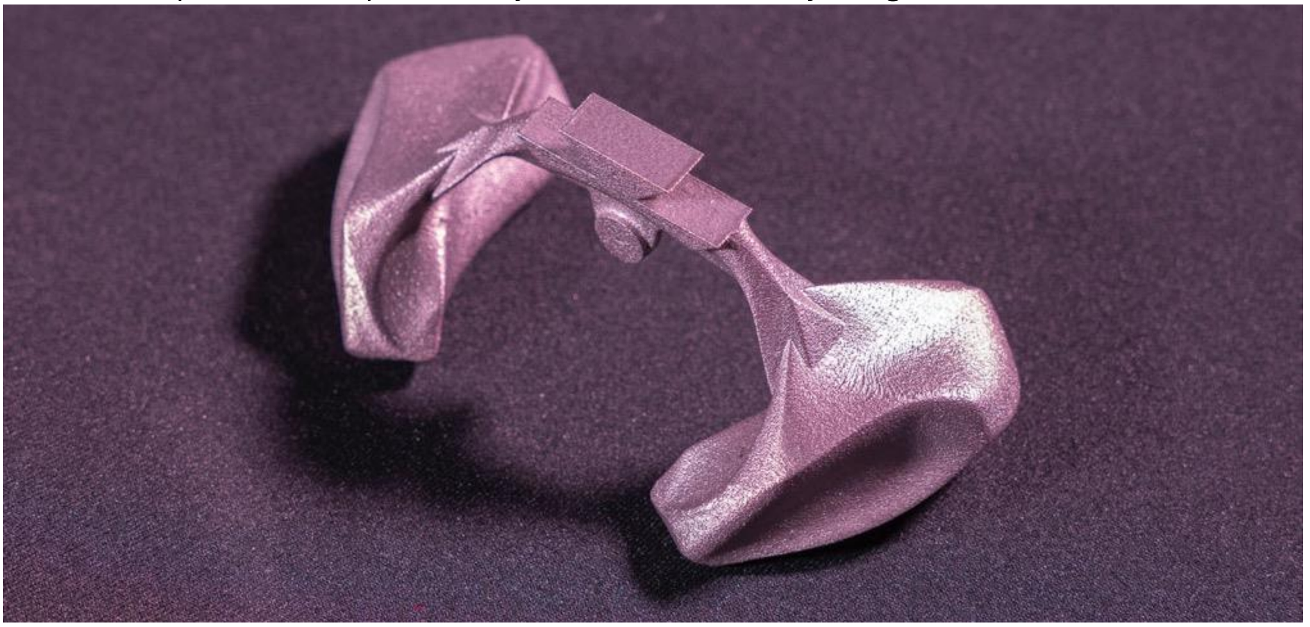


Figure 14: A view of part three of the titanium counter-balance.

**Key attributes:**

- **AI-Optimised Spars:** The connecting spar geometry was evolved via AI generative algorithms, achieving optimal stiffness with minimal material.

- **Internal Lattice & Powder Damping:** Like Part Two, it features an internal tessellated lattice. Additionally, certain cavities contain unsintered titanium powder, behaving like sand in a sandbag to add internal damping to the metallic structure.

- **Biomimicry:** Its structure mirrors bird bone lattices, combining lightweight efficiency and energy absorption with high stiffness.

**5.3. Energy Pathway & Reflection Suppression**
Together, Parts One, Two, and Three form a titanium counterbalance that seamlessly integrates with the hyperbolic, dual-helix carbon armtube, maintaining an unbroken energy pathway from the cartridge to the pivot:

- The carbon's dual-helix fibres dissipate vibrational energy anisotropically.

- The titanium wraps helically around the carbon, maintaining geometric and energetic continuity.

- The visco-elastic adhesive interface dampens transitions and suppresses reflection points.

- Internal lattice damping and powder-in-shell cavities progressively absorb residual energy before final transfer to the pivot.

This is particularly critical at the cartridge, where resonant energy generated during groove tracking must be dissipated smoothly to avoid feedback into the stylus.

### 5.4. Biomimicry Insights: Trabecular Bone and Bird Beaks

The titanium structures of the GRAVITON® Ti Armwand are direct applications of biomimetic design, emulating nature's most efficient load-bearing systems:

**Trabecular Bone (Humans and Mammals):**

- Found in the ends of long bones (e.g., femur, tibia), trabecular bone is a porous lattice of intersecting struts that dissipates loads and resists shocks while minimising weight.
- It adapts anisotropically to stress, reinforcing itself along load paths (Wolff's Law), much like the lattice structure in the titanium armwand.
- The hollow outer cortical bone with an internal trabecular core mirrors the hollow-to-tessellated-to-solid progression in the GRAVITON® titanium sections.

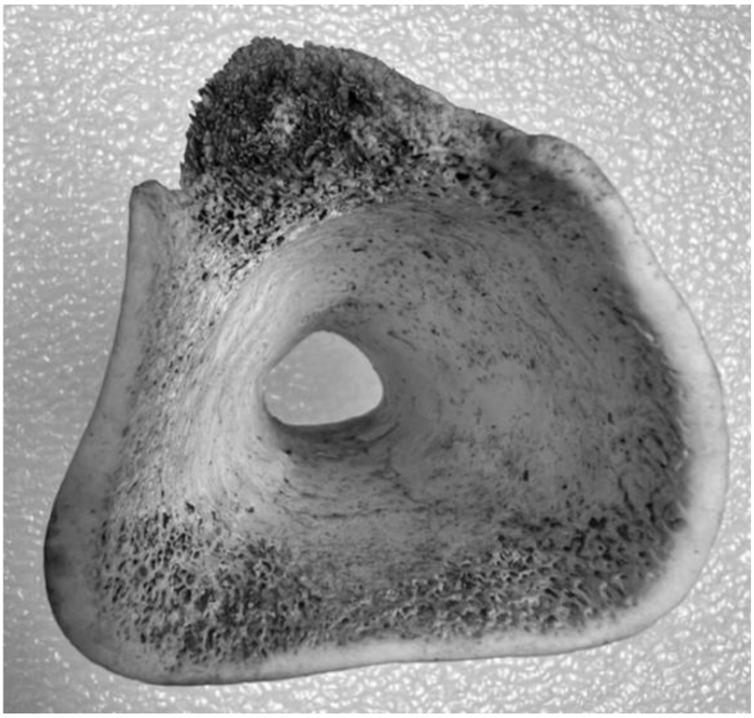


Figure 15: A cross-section of trabecular bone, showing a hollow cortical shell with an internal lattice of struts. This natural architecture achieves high stiffness and shock absorption with minimal mass, directly inspiring the hollow–tessellated–solid progression of the GRAVITON® Ti titanium counterbalance structure.

**Bird Beaks (Toucans, Parrots, Finches):**

- **Toucans:** Their large beaks are hollow shells with foam-like trabecular lattices, achieving stiffness with minimal weight (Seki et al., 2005).

- **Parrots:** High bite forces are supported by dense trabecular reinforcement at the tip, tapering to lighter bases—just like the GRAVITON®'s progressive density shift.

- **Finches:** Variations in trabecular geometry reflect dietary adaptation, mirroring how topology optimisation aligns geometry with load requirements.

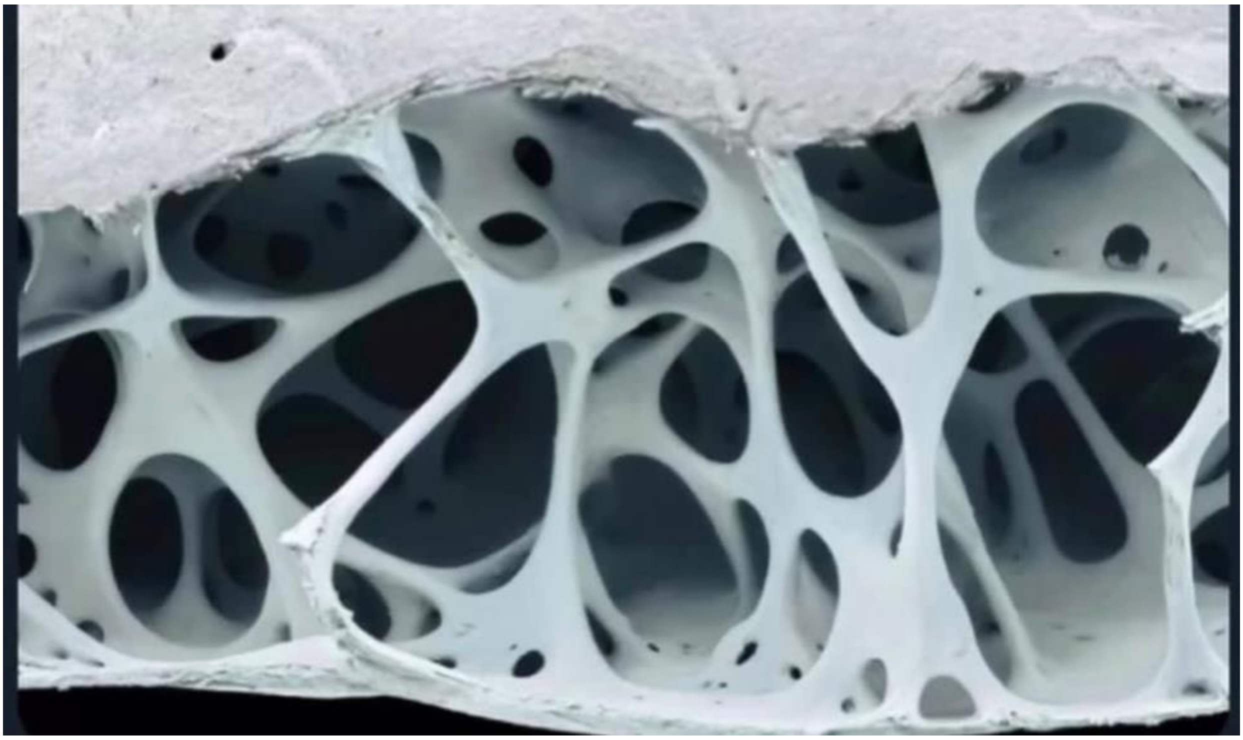


Figure 11: The internal lattice structure of a bird bone. Here the lightness and strength of the bone has been optimised over millions of years. But the generative design tools now being used in CAD systems mean that biomimicry is increasingly having a profound impact on all manufacturing.

These biological systems embody the same engineering principles now applied in the GRAVITON® Ti Armwand:

- Hollow shells for lightness,
- Internal lattices for stiffness and damping,
- Dense terminations at stress-critical points,
- Anisotropic reinforcement following load paths.

By studying nature's evolved solutions and combining them with AI generative design and additive manufacturing, Wilson Benesch has recreated these principles in titanium, producing a function-driven hybrid structure optimised for resonance suppression and energy control.

**The Result: Evolution Meets Fourth Generation Manufacturing**
The GRAVITON® Ti Armwand unites nature's most efficient structural logic—seen in trabecular bone and bird beaks—with Fourth Generation Manufacturing (4GM):

- AI-driven generative design,
- Additive titanium manufacturing (SLS),
- Advanced composite engineering (dual-helix carbon fibre).

The outcome is a tonearm structure with benchmark stiffness, damping, and energy control, purpose-built to suppress resonance at its source and extract the finest detail from vinyl playback.

## 6. Bearing and Mechanical Subsystems

The GRAVITON® Ti Armwand integrates a zirconium-based hybrid kinematic bearing system, combined with precision mechanical subsystems and digitally actuated adjustments. This suite of technologies delivers ultra-low friction motion, optimised Hertzian contact mechanics, and a fully integrated control architecture for nanometre-level setup accuracy.

### 6.1 Zirconium Hybrid Kinematic Bearing

The bearing design is an evolutionary advancement of the kinematic bearing first introduced in the acclaimed A.C.T. One Tonearm. This updated bearing integrates zirconium balls, exploiting their exceptional surface finish to deliver:

- **Ultra-low friction:** Zirconium's polished surface reduces rolling resistance to negligible levels.
- **Superior energy transfer:** Elevated Hertzian contact forces focus energy flow into microscopic contact zones, ensuring efficient vibrational energy dissipation.
- **Stiction-free motion:** The hybrid design uses three 1mm balls—two zirconium for frictionless movement and one damping-enhanced conductive ball for grounding and energy management.

This hybridised approach unites kinematic precision with enhanced damping and conductivity, creating a bearing of extreme sensitivity and stability that supports the GRAVITON® Ti Armwand's ultra-low inertia and resonance control.

***Technical Insight: Hertzian Mechanics in the GRAVITON® Ti Bearing***

The GRAVITON® Ti Armwand's bearing leverages Hertzian contact mechanics—the study of stress and deformation where two curved surfaces meet under load. By using three 1mm balls in a kinematic configuration, Wilson Benesch achieves a precisely defined point-contact system, optimised for both low stiction and high energy transfer efficiency.

**Why Hertzian Mechanics Matter:**

In a kinematic bearing:

- Each ball contacts another at a single, infinitesimally small point.
- These points create Hertzian contact zones, where force is concentrated over microscopic areas, reducing sliding friction to near zero.
- Energy transfer efficiency increases because vibrational energy is channelled directly through these small, stiff contact points rather than being dispersed across larger, more compliant surfaces.

This principle differs fundamentally from conventional journal or sleeve bearings, where broad contact patches increase friction, damp energy inconsistently, and create stiction effects.

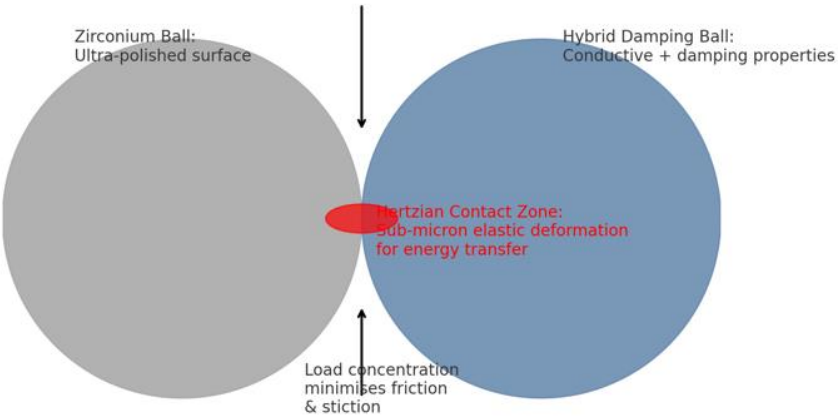



Figure 17: A graphical illustration of the contact points in a bearing.

**Material Selection in Hertzian Contacts:**

- **Zirconium Balls:** Exceptional hardness and superior polish create the smallest, most stable Hertzian contact zones possible, reducing rolling resistance.

- **Hybrid Damping Ball:** One conductive ball introduces controlled damping and electrical continuity without compromising geometry or friction levels.

The precise balance between contact stiffness and vibrational damping is key: overly rigid metallic contacts ring, while overly damped ones lose resolution. Wilson Benesch's hybridised bearing materials optimise this trade-off perfectly.

**Advantages of Hertzian-Optimised Bearing Geometry:**

- **Stiction-Free Motion:** Point contacts allow movement without stick-slip behaviour, crucial for tracing delicate groove modulations.

- **Defined Geometry:** The 3-ball layout eliminates play, fixing the pivot in an exact, repeatable location.

- **Energy Path Control:** Vibrational energy is funnelled predictably away from the stylus, supporting the clean energy pathway described throughout the GRAVITON® Ti design.

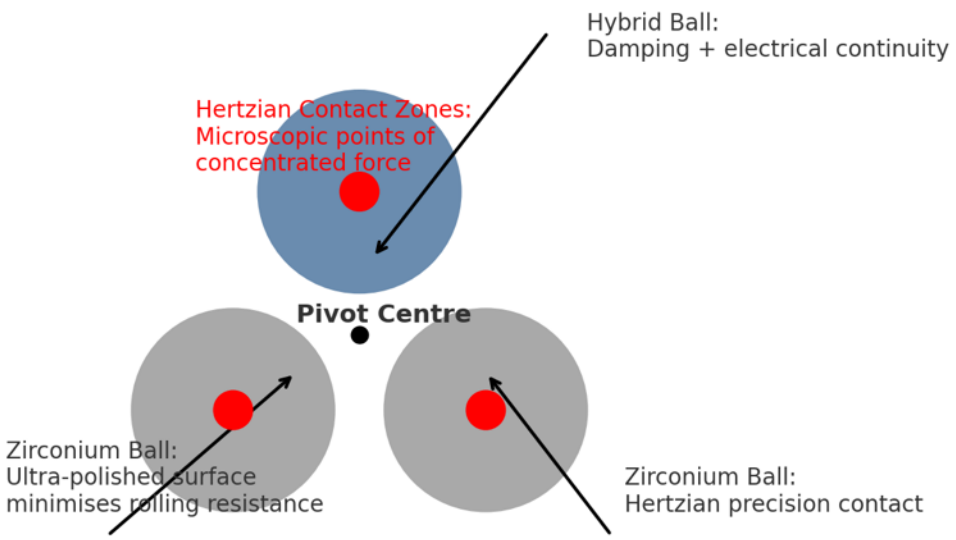



Figure 18: A graphical illustration of the contact points in a kinematic bearing where the load of the contact point is distributed across three points.

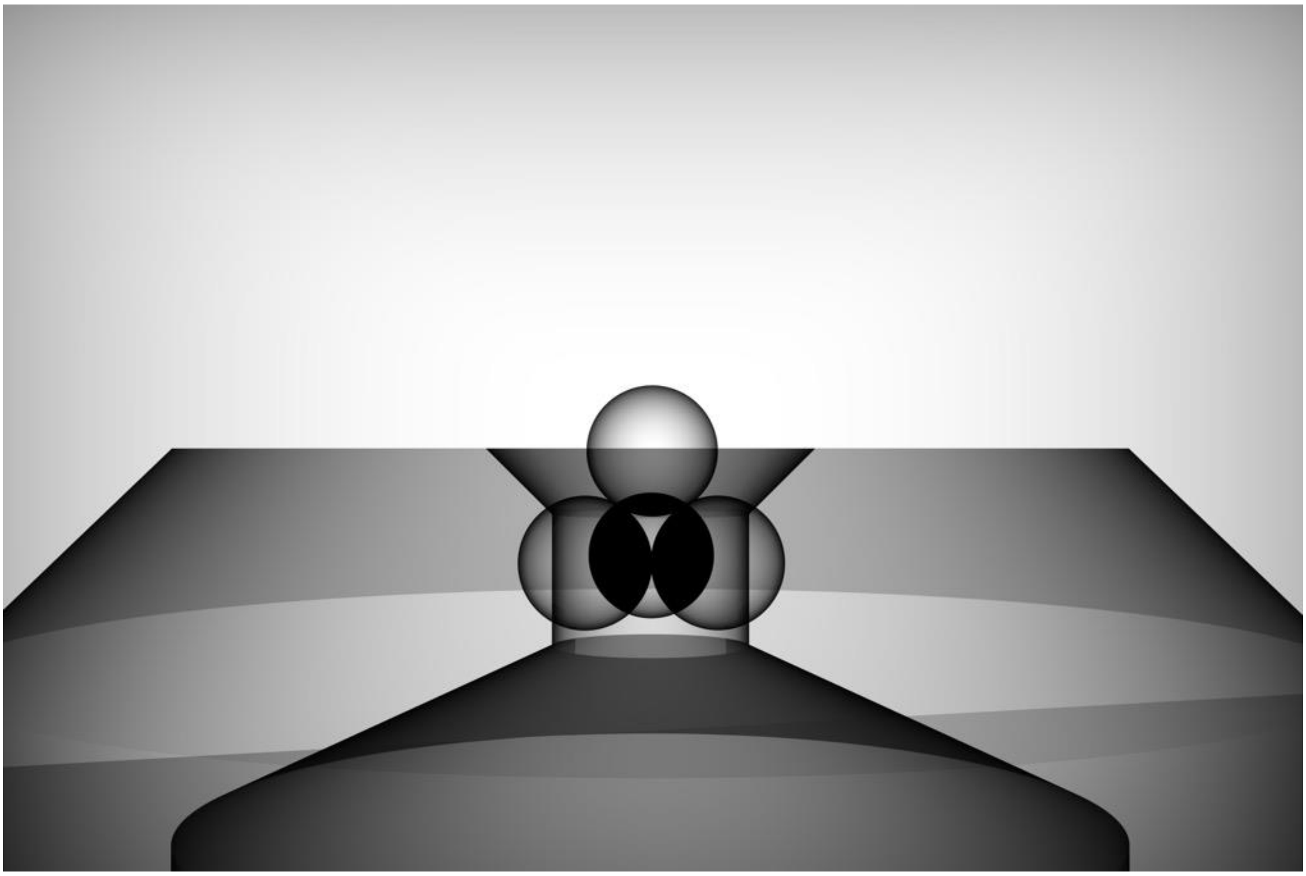


Figure 19: A render of the kinematic bearing in the top of the bearing hub of the tonearm. An x-ray filter has been applied to all components to allow the shapes of the three ball bearings in the bottom of the bearing to be clearly discerned, with a fourth ball bearing siting in the recess formed at the perfect centre of these three ball bearings.

**6.2 EcoGrip High-Precision Chuck**

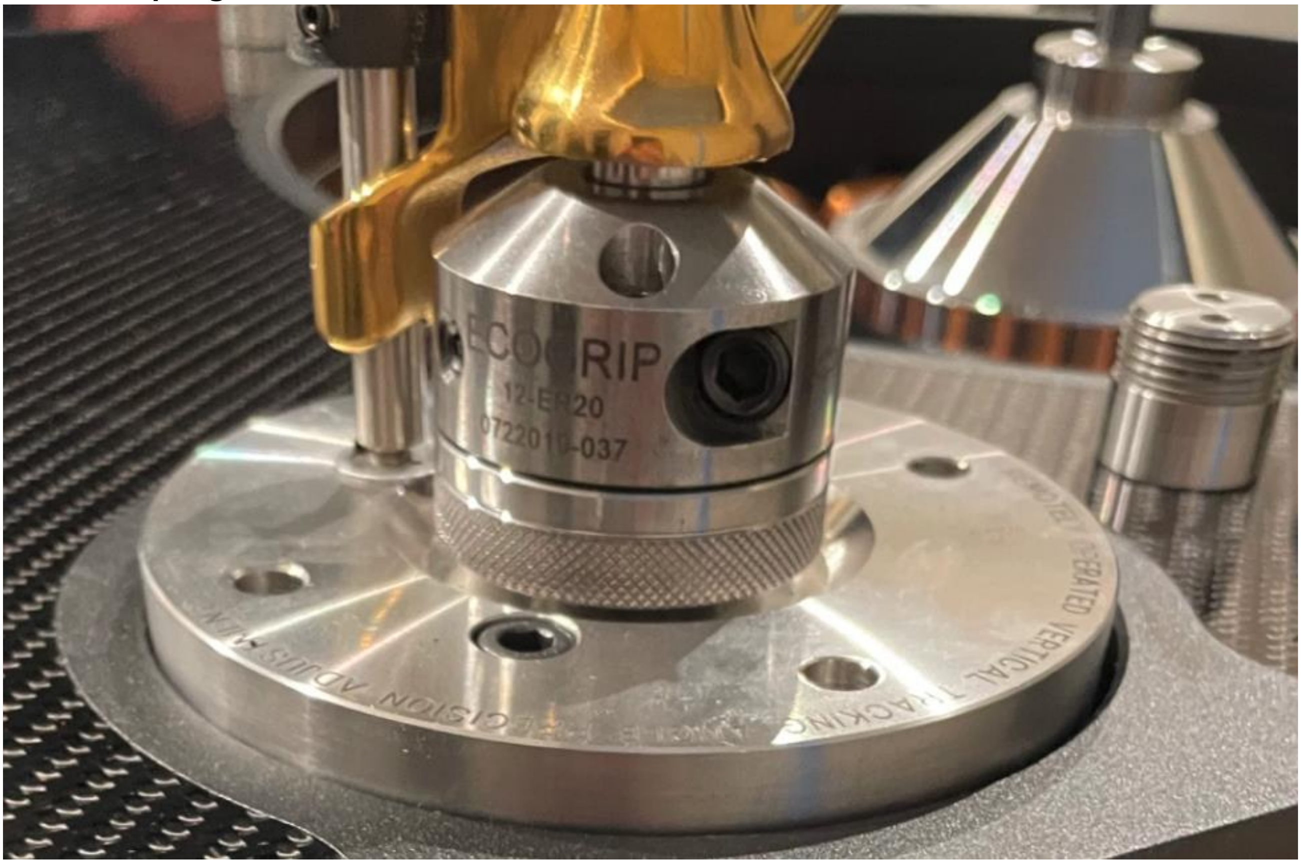


Figure 20: The EcoGrip Chuck of the GRAVITON Ti Tonearm.

At the foundation of the armwand's bearing assembly is the EcoGrip hydraulic chuck, a precision mechanism derived from industrial machining. It ensures:

- **Absolute conformity:** Hydraulic actuation wraps the chuck evenly around the shaft, eliminating any point loading.

- **Friction-free travel:** Graphite lubrication guarantees smooth movement during adjustment.

- **Unaltered geometry:** Locking the chuck does not deform the shaft or shift alignment, preserving exact bearing geometry.

The EcoGrip's manufacturing-grade precision directly underpins the nanometric adjustments achievable in later subsystems, anchoring the bearing assembly with uncompromising stability.

### 6.3 Integrated Damping Reservoir


The bearing design incorporates a silicone damping reservoir that provides optional vertical damping control:

- **Resonance suppression:** Viscous damping attenuates micro-resonances induced by cartridge compliance or record irregularities.
- **Enhanced cartridge matching:** Useful for cartridges with challenging compliance profiles, improving tracking stability.

- **Anti-skate integration:** The damping system is coupled with the titanium anti-skate arm, coated with titanium nitride (TiN) for extreme wear resistance and diamond-like hardness.

TiN vapour deposition, commonly used in cutting tools, ensures long-term durability while visually distinguishing these critical components with a lustrous gold finish.

### 6.4 Piezo-Driven VTA Mechanism

**(The Piezo-driven VTA mechanism is exclusive to Wilson Benesch turntables and not available with third-party turntables)**

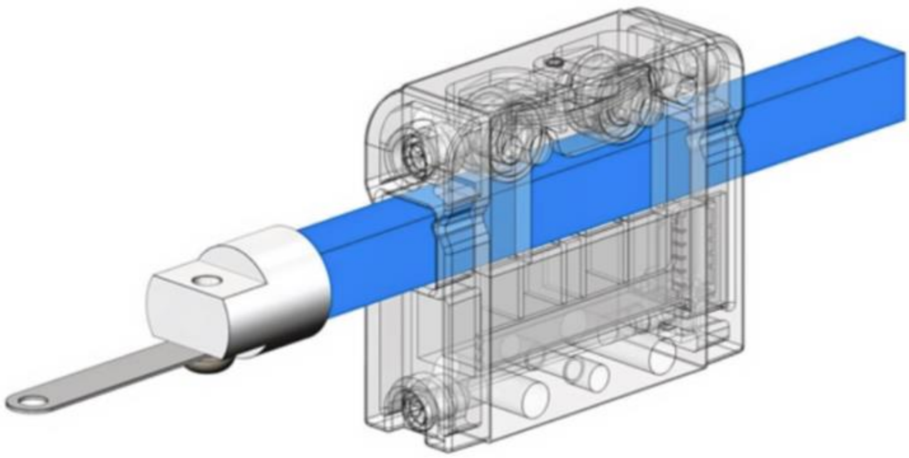


Figure 21: Illustrative schematic of a linear Piezo actuator, similar in principle to that used in the GRAVITON® Ti's Vertical Tracking Angle (VTA) mechanism. In practice, the Piezo system enables nanometre-precise, backlash-free adjustments with full remote control and stored recall positions.

At the heart of the GRAVITON® Ti's mechanical subsystems is the Piezo-actuated Vertical Tracking Angle (VTA) mechanism, which redefines precision in tonearm geometry adjustment:

- **Nanometre resolution:** The linear Piezo actuator moves in 1 nm increments—orders of magnitude finer than human manual adjustments (a human hair is ~80,000–100,000 nm).
- **Thread vs. Piezo:** Conventional tonearms rely on an M4–M6 fine-pitch screw for VTA adjustment, typically moving the arm pillar 0.5–1.0 mm per turn. Even at best, this translates to ~500,000 nm per increment, meaning the Piezo is around 500,000 times more precise.

- **Backlash-free:** Unlike threaded adjusters, the Piezo "walks" in linear micro-steps with no hysteresis, backlash, or locking shift.

- **Remote GUI control:** Via the Wilson Benesch GMT® Control App, adjustments are made from the listening position, with a live numerical VTA readout displayed. This allows users to memorise and return to exact settings with repeatable accuracy.

This unprecedented precision ensures stylus rake angle (SRA) can be optimised audibly and repeatably, unlocking finer detail retrieval and dramatically reducing vinyl wear. Where threaded bolts leave room for mechanical play, the Piezo delivers absolute repeatability—setting a new benchmark in tonearm adjustability.

***Technical Insight: Piezo Precision in Astronomy***

*In most conventional tonearm systems, Vertical Tracking Angle (VTA) is adjusted with a simple threaded bolt. While effective in principle, threads introduce mechanical play and backlash: a small degree of looseness that makes ultra-fine, repeatable adjustment impossible. Even when locked, micro-movements can occur under load, subtly altering the geometry and affecting tracking precision.*

*By contrast, the GRAVITON® Ti employs a Piezoelectric actuator — a technology used in high-precision fields such as astronomy, where telescopes rely on Piezo devices to position mirrors with nanometre accuracy. In this application, the Piezo provides backlash-free linear movement in 1nm increments, allowing VTA to be set with unprecedented accuracy.*

*Analogy: If the a high powered telescope relied on a crude M3 thread to set its position, the error margin would be in the order of 25 light years. To put that in perspective, that's like aiming a telescope at earth's nearest galaxy the Andromeda Galaxy (2.5 million light years away) but missing the target by the equivalent distance from Earth to Vega or Deneb, two of the brightest stars in our night sky. By contrast, a Piezo-driven telescope achieves nanometre resolution, placing the telescope squarely on target.*

*Unlike in telescopes, where Piezo devices operate dynamically in real time, the GRAVITON® Ti's actuator is static once set. It enables the user to dial in and recall perfect VTA positions with absolute repeatability. The result is optimal groove tracking, enhanced detail retrieval, and reduced record wear — a level of control no threaded system can match.*

### 6.5 Digital Integration and Automation

**(Only available with Wilson Benesch Turntables not on third party turntables)**

These mechanical subsystems integrate seamlessly with the GMT® digital ecosystem, bringing together bearing precision, damping, and motor control:

- **VTA/SRA remote control** via dedicated LAN-connected smart device.
- **Motor speed regulation** with 0.01rpm accuracy (33/45/78rpm).
- **Automated lift and park:** At motor stop, the tonearm lifts automatically for record exchange.
- **Self-levelling isolation:** Pneumatic actuators automatically maintain turntable level, requiring no manual input.

Finite Element Analysis (FEA) and digital simulation were used extensively in development, ensuring that every bearing and motor interaction was modelled to achieve optimal stability and resonance suppression.

### Conclusion: Precision Bearing Design and Digital Control

By combining zirconium kinematic bearings, the EcoGrip hydraulic chuck, damped bearing subsystems, and Piezo-driven nanometric VTA control, the GRAVITON® Ti Armwand's bearing assembly achieves an unparalleled fusion of mechanical refinement and when installed on a Wilson Benesch turntable a level of precision in VTA setup through digital controls that has never before been possible.

This design embodies Hertzian force optimisation, tribological engineering, and integrated digital control, redefining the tonearm's bearing as not merely a mechanical pivot but an intelligent, actively managed system tuned for absolute analogue fidelity.

## 7. STAGE One: Precision Signal Isolation and Mechanical Decoupling

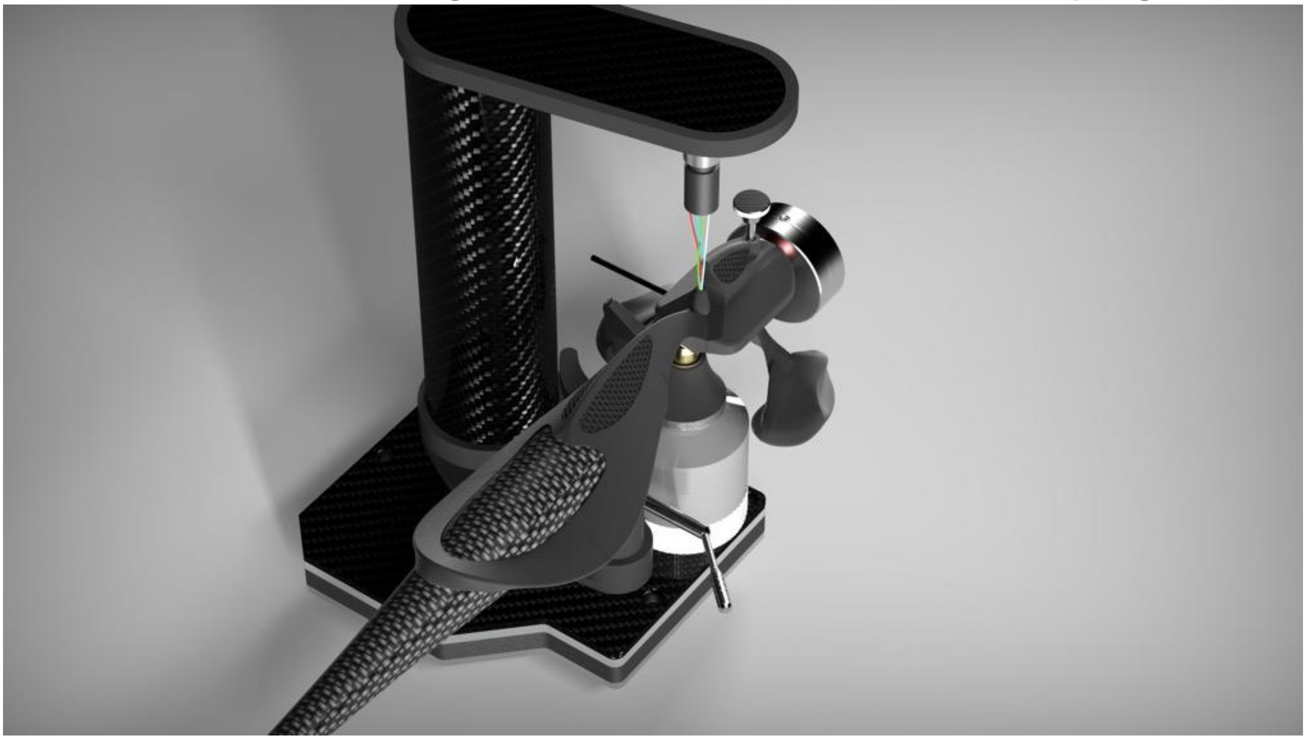


Figure 22: The STAGE One termination stage of the GRAVITON® Ti Tonearm as used on the Dohmann Helix One Turntable. Shown here is the over-arm wire exit positioned vertically above the pivot point, eliminating torsional forces on the bearing assembly. The signal wire passes directly into the carbon fibre-shielded STAGE One enclosure with less than one inch of unshielded cable exposed, ensuring mechanical neutrality and maximum EMI protection for the delicate cartridge signal.

The STAGE One represents a critical evolution in tonearm system architecture, redefining how the signal is preserved, shielded, and mechanically managed from the moment it exits the armwand. It is a mechanically and electrically optimised termination stage that protects the fragile cartridge signal and preserves the neutral behaviour of the tonearm.

At the heart of its design is the "over-arm" configuration, where the tonearm wire exits vertically, directly above the pivot point. This eliminates lateral and vertical stresses on the tonearm bearing—a common flaw in traditional designs where the signal cable loops behind the pivot, often behaving like a torsional spring.

To appreciate the scale of the problem, consider that the stylus is tasked with tracing groove modulations that may vary at the nanometre scale, while the cartridge applies a tracking force of only 1.4 to 1.8 grams, extended over a 12-inch mechanical lever. Even the slightest resistance or tension in the tonearm cable can introduce reactive forces that are orders of magnitude greater than the groove modulations themselves, destabilising the tonearm's equilibrium and impairing tracking precision.

It's like writing calligraphy on tissue paper with a fountain pen while a shifting weight rests on your shoulder—any external force, however subtle, disrupts control and accuracy.

By routing the signal wire vertically, directly above the pivot, the STAGE One ensures zero reactive force is transmitted through the cable to the bearing assembly. This allows the tonearm to operate in a state of pure mechanical neutrality, free from the destructive influence of cable memory, torque, or external movement—ensuring the stylus can perform with maximum resolution and fidelity.

**Signal Shielding & Noise Isolation**
Equally essential is the signal shielding architecture. The tonearm wire is guided from the carbon fibre armwand into a copper-shielded STAGE One enclosure with less than one inch of unshielded cable exposed. This enclosure creates an EMI-resistant chamber that protects the delicate microvolt signal—often as low as 0.2–0.5 millivolts—from environmental interference at the most vulnerable point in the signal path.

At these levels, the phono preamplifier must amplify the signal by a factor of more than 1,000 to reach line level. Any interference, distortion, or mechanical stress introduced here will be magnified exponentially. The STAGE One eliminates these risks by mechanically decoupling the wire and providing robust EMI shielding, ensuring the signal is transmitted with absolute fidelity from the very outset.

**Flexible Signal Termination**
Within the STAGE One enclosure, the tonearm wire is terminated via a binder connector, ensuring a secure, high-integrity signal transfer. The internal layout supports a slot-in / slot-out wiring design, offering flexibility in how the signal is routed to downstream components:

- **Direct Termination**: The tonearm wire is connected directly to a pair of phono interconnects, which can be terminated with either XLR or RCA connectors. This allows the user to send the tonearm signal straight into a phono preamplifier, preserving the purest and most direct signal path possible.

- **Custom Output Option**: Alternatively, the STAGE One can be configured with XLR or RCA outputs on its rear panel, enabling the user to select their preferred phono interconnects for integration with the wider audio system.

This modular approach ensures that while the signal path remains ultra-short and shielded where it matters most, integration into high-performance systems remains flexible and user-configurable.

**7.1 STAGE One Integration & Future Compatibility**
The STAGE One was originally developed as an integral component of Wilson Benesch's GMT One System and Prime Meridian System turntables—flagship platforms designed to embody the highest standards of analogue performance. Within these systems, STAGE One plays a critical role in preserving the mechanical neutrality and signal purity of the GRAVITON® Ti Armwand.

In early 2025, as seen in figure 22, Wilson Benesch engineered a dedicated STAGE One and armboard solution to integrate the GRAVITON® Ti Armwand with the Döhmann turntable platform. This milestone marked the first expansion of the STAGE One architecture beyond the company's in-house systems.

Looking ahead, additional bespoke armboards will be developed to enable the STAGE One and GRAVITON® Ti Armwand to be integrated with a growing range of third-party turntables. This ensures that the technological advantages Wilson Benesch has pioneered—through decades of research and development—can be realised in analogue systems beyond their own, bringing the highest standards of signal preservation and mechanical decoupling to a wider global audience.

## 8. Conclusion

The GRAVITON® Ti Armwand is the result of over three decades of continuous development, informed by empirical experimentation, collaborative research, and cutting-edge engineering. What began with the pioneering A.C.T. One Tonearm has evolved into a state-of-the-art hybrid system that redefines the limits of tonearm performance.

Every aspect of the GRAVITON® Ti Armwand—its quadruple-helix carbon fibre tube, graphene-enhanced damping systems, additive-manufactured titanium structures, and the STAGE One signal termination platform—has been refined to meet the uncompromising demands of high-fidelity audio reproduction. The result is a tonearm system that embodies mechanical neutrality, structural optimisation, and electromagnetic isolation, ensuring the stylus can trace the groove with unmatched precision and transparency.

Beyond engineering achievement, the GRAVITON® Ti Armwand also represents a new design philosophy. By drawing upon biomimetic principles, topology optimisation, and anisotropic material behaviour, it transcends the limitations of legacy designs and opens the door to future innovation. It is not only a tool for playback—it is a statement of how scientific understanding and manufacturing capability can converge to elevate the listening experience to its highest form.

As Wilson Benesch continues to expand compatibility across premium analogue platforms, the GRAVITON® Ti Armwand and STAGE One system stand ready to deliver this transformative performance to a wider audience. In doing so, they reaffirm the company’s commitment to craftsmanship, innovation, and the purest expression of music reproduction.