

DLC Coatings: Unlocking New Heights in Precision Transmission for RV & Harmonic Drives, Huasheng Nanotechnology Empowering High-End Manufacturing

1. RV / Harmonic Drive Components: The “Core of Precision Transmission”

RV and harmonic drives serve as the “heart components” of high-precision transmission systems, and the performance of their core parts directly determines operational accuracy and reliability. Key parts of harmonic drives—flexsplines, circular splines, and wave generator bearings—and RV drives—cycloidal wheels, needle gear housings, and output shafts—are widely used in collaborative robot joints, surgical robots, semiconductor wafer handling systems, and high-end CNC machines.

For instance, in robotics, a single six-axis collaborative robot requires 4–6 harmonic drives, and the fatigue life and transmission accuracy of the flexspline directly affect robot positioning error ($\leq 0.01\text{mm}$) and service life.

From a market perspective, the global precision gearbox market is rapidly expanding with the rise of high-end manufacturing. By 2025, the market is expected to exceed CNY 30 billion, with RV and harmonic drives accounting for over 70%. The Chinese market is particularly prominent, with domestic companies like Greens Harmonic capturing 15% of global share. However, surface treatment technology for core components has long been constrained by foreign technology. As robots evolve toward lighter, higher-load, and longer-life designs, component surface performance has become the key to overcoming the bottleneck of “rapid accuracy decay and short lifespan.”



2. Industry Challenges: Four Major Performance Pain Points

Under high-frequency, high-precision working conditions, traditionally treated RV and harmonic drive components face multiple failure risks, limiting equipment performance:

High flexspline fatigue fracture risk: Flexsplines are thin-walled nickel-chromium steel components that undergo cyclic radial deformation. After conventional quenching and tempering, hardness is only 36HRC, while additional stress from tooth engagement accelerates fatigue. Average bending fatigue life is only 8,000 hours, prone to pitting and adhesion failures.

Rapid precision decay: Engagement gaps between cycloidal wheels and needle gear housings must be controlled within 0.005–0.01mm. Traditional shot-peening cannot maintain a durable wear-resistant layer; metallic debris from wear increases gaps, causing precision to drop by over 30% after 2,000 hours, insufficient for micron-level positioning in semiconductor equipment.

Temperature rise and noise issues: Shear heat from the high-speed rotation of the wave generator, combined with frictional heat, causes thin-walled flexsplines to dissipate heat poorly, leading to lubricant degradation. Conventional surface friction coefficients are high (steel-on-steel dry friction 0.5–0.8), generating noise under dry friction or lubricant failure, disrupting quiet environments such as medical robotics.

Poor coating-substrate compatibility: Traditional chrome plating and nitriding involve high temperatures (500–550°C) and brittle coatings. Thin-walled flexsplines often exceed dimensional tolerances ($>0.02\text{mm}$), and coatings can delaminate under repeated flexing, accelerating wear.

3. Technical Adaptation: Why DLC Coatings are the “Performance Savior”

DLC coatings align perfectly with the operational demands of RV and harmonic drive components, providing solutions across three dimensions:

Workload-specific adaptation: For components requiring high-frequency deformation, precision engagement, and low-noise operation, DLC dry friction can be as low as 0.1, reducing tooth friction heat. Combined with 2500HV hardness, DLC resists adhesion and pitting, ideally suited for flexsplines undergoing deformation.

Process compatibility: Huasheng Nanotechnology’s proprietary DLC deposition equipment operates below 150°C, avoiding dimensional changes in thin-walled components (tolerance $\leq 0.005\text{mm}$). Chromium/titanium transition layers achieve

HF1 adhesion grade, preventing delamination under repeated deformation. Compatible with nickel-chromium steel, powder metallurgy, and other substrates.

Economic practicality: DLC treatment extends flexspline fatigue life to over 20,000 hours and precision retention from 2,000 to 8,000 hours, reducing costly downtime (semiconductor equipment can lose >CNY 100,000 per hour of halt) and lowering total lifecycle cost by 40–50%.

4. Technological Breakthroughs: Four Key Advantages of DLC Coatings

Balanced hardness and toughness: By controlling sp³/sp² carbon bonding, DLC achieves ~2500HV hardness. Ultra-thin 2–4μm layers maintain wear resistance while preserving flexspline elastic deformation, resolving “hard coatings are brittle” issues.

Ultra-low friction reduces heat and noise: Self-lubricating DLC reduces friction coefficient to one-fifth of conventional treatments, lowering wave generator frictional heat by 40%, controlling temperature rise below 30°C, and decreasing engagement noise by 5–8dB.

Precision retention: Thickness tolerance ±0.1μm ensures no surface roughness change, enabling direct assembly without secondary machining.

Multi-substrate adaptability: Custom DLC solutions for powder metallurgy cycloidal wheels and nickel-chromium flexsplines, including plasma pretreatment or transition layers to enhance adhesion.

Full-chain applicability: DLC-coated components extend fatigue life, maintain precision, and reduce noise in robotics, semiconductor equipment, and medical devices.





5. Application Deployment: Enabling the Entire High-End Manufacturing Chain

Robotics: DLC-coated harmonic drive flexsplines increase fatigue life from 8,000 to 22,000 hours, with precision retention up to 8,000 hours.

Semiconductor equipment: High-precision DLC on cycloidal wheels reduces robot positioning error from 0.015mm to 0.008mm, meeting 3nm wafer handling requirements.

Medical devices: Silicon-containing DLC on wave generator bearings achieves friction coefficient 0.08, noise <40dB, and passes biocompatibility tests, eliminating heavy metal risks from traditional coatings.

6. Future Outlook: Co-Evolution of Precision Components and DLC Technology

Atomic-level precision coating customization: AI-optimized sp³/sp² ratios and dopants (Si, W) enable tailored coatings for different load levels, e.g., 2500HV high-hardness coatings for 200kg-load flexsplines, low-modulus flexible coatings for light-load surgical robots.

Coating-sensor integration: Smart DLC embeds nano-stress sensors to monitor flex deformation and tooth wear in real-time, enabling predictive maintenance with >95% accuracy; industrial application expected by 2027.

Green full-chain processes: Acetylene-based DLC deposition reduces energy consumption by 50% versus traditional treatments, emits no heavy metals, meets EU

CE and China dual-carbon policies, helping domestic drives enter high-end global markets.

DLC coatings empower RV and harmonic drive components to achieve longer life, higher precision, quieter operation, and global competitiveness.