TITAN A16 - MANUFACTURING ADDENDUM
Document 2: Process Specification & Material Handling

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1. PURPOSE AND SCOPE

This document provides manufacturing guidance for TITAN A16 precision test articles. It supplements the primary blueprint (Document 1) with process-specific requirements, material handling protocols, and quality assurance procedures.

Intended Audience:
- Precision machine shops
- Manufacturing engineers
- Quality control inspectors
- Material suppliers

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2. MATERIAL PROCUREMENT

2.1 Base Material Options

The manufacturer shall use one of the following approaches:

Option A: Monolithic Custom Billet (Preferred)

Specification:
- Composition: Tantalum-Titanium-Gold-Carbon alloy
- Form: Cylindrical billet, Ø32 mm × 12 mm minimum
- Processing: Vacuum Induction Melting (VIM)
- Purity: ≥99.95% per constituent element
- Total impurity limit: <0.001%

Supplier Requirements:
- Provide material certification including:
  - Chemical composition analysis (ICP-MS or equivalent)
  - Processing history (melt parameters, cooling rate)

- Grain size characterization
- Mechanical properties (if available)

Option B: Hybrid Construction

If monolithic billet is unavailable or cost-prohibitive:

1. **Base components:**
   - Tantalum base plate: Ø32 × 10 mm, ≥99.95% purity
   - Titanium rings: 5 pieces, Ø32 × 2.2 mm each, Grade 2 or Grade 5
   - Gold interface layers: Electroformed or sputtered, 20-30 μm thickness

2. **Assembly method:**
   - Diffusion bonding (900°C, vacuum, 50 MPa pressure) OR
   - Precision press-fit with subsequent stress relief

3. **Post-assembly:**
   - Machine all features from assembled stack
   - Verify interface integrity via ultrasonic inspection

Note: Option B requires additional documentation of interface bonding quality.

2.2 Material Certification Requirements

All material suppliers shall provide:

Document	Requirement
Mill Test Report	Chemical composition, lot number
Material Traceability	Heat number, batch identification
Physical Properties	Density, hardness (if measured)
Processing History	Melting method, thermal treatment
Inspection Records	Dimensional verification of stock

Certification shall accompany material shipment. Machining shall not commence without approved certification.

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3. MACHINING PROCESS REQUIREMENTS

3.1 Pre-Machining Preparation

Billet Inspection:
1. Verify dimensions of raw stock (±0.1 mm acceptable)
2. Visual inspection for surface defects, cracks, porosity
3. Ultrasonic inspection for internal voids (if equipment available)

Setup:
- Clean billet with isopropyl alcohol or acetone
- Mount in precision chuck or fixture
- Establish work coordinate system (WCS) at geometric center
- Use soft jaws or protective inserts to prevent marring

3.2 Machining Sequence (Standard Path)

The following sequence minimizes stress accumulation and maintains geometric accuracy:

Operation 1: Rough Turning
- **Tool:** Coated carbide insert (TiAlN or TiCN)
- **Speed:** 150-250 SFM (adjust for material hardness)
- **Feed:** 0.005-0.010 in/rev
- **DOC:** 0.030-0.050 in per pass
- **Coolant:** High-pressure synthetic (minimum 100 PSI)
- **Objective:** Establish OD within 0.5 mm of final dimension

Operation 2: Face Milling (Top and Bottom)
- **Tool:** D25-40 mm face mill, carbide inserts
- **Speed:** 800-1200 RPM
- **Feed:** 200-400 mm/min
- **DOC:** 0.1-0.2 mm per pass
- **Objective:** Parallel faces within 0.01 mm, surface prep for features

Operation 3: Central Bore - Drilling
- **Tool:** Ø3.0 mm carbide drill (140° point angle)
- **Speed:** 2000-2500 RPM
- **Feed:** 50-80 mm/min
- **Coolant:** Through-spindle (preferred) or flood
- **Peck depth:** 2 mm increments for chip evacuation
- **Objective:** Pilot hole through entire height

Operation 4: Central Bore - Reaming
- **Tool:** Ø3.03 mm carbide or HSS reamer (adjustable preferred)
- **Speed:** 600-800 RPM

- **Feed:** 25-40 mm/min (slow feed for finish)
- **Coolant:** Flood, low pressure to avoid deflection
- **Passes:** Single pass if possible; maximum 2 passes
- **Objective:** Final bore diameter Ø3.03 ±0.03 mm, Ra <1.0 µm

Operation 5: Top Lattice Node Pockets
- **Tool:** Ø2.0 mm carbide drill or end mill
- **Speed:** 2500-3500 RPM
- **Feed:** 80-120 mm/min
- **Depth:** 1.0 mm exactly (use depth stop or Z-limit in program)
- **Pattern:** 12 positions per coordinate table (see Section 7)
- **Objective:** Clean, concentric pockets, no burrs

Operation 6: Triple Helix Thread Geometry
- **Tool:** Ø2.0 mm PCD ball end mill (preferred) or carbide
- **Speed:** 8000-10000 RPM (high-speed finishing)
- **Feed:** 200-300 mm/min along helix path
- **Depth:** 0.5 mm radial cut (measured from OD surface inward)
- **Coolant:** Air blast or minimal mist (avoid wash-out)
- **Objective:** Three interwoven helical grooves, smooth finish

Operation 7: Final Finishing Pass
- **Tool:** Ø2.0 mm PCD ball mill or ceramic insert
- **Speed:** 10000-12000 RPM
- **Feed:** 100-200 mm/min
- **DOC:** 0.05-0.1 mm (skim pass)
- **Objective:** Surface finish Ra 0.8-1.6 µm on all functional surfaces

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3.3 Tooling Recommendations

Operation	Tool Type	Material	Notes
Rough turning	CNMG insert	Coated carbide	Positive rake for Ta/Ti
Face mill	45° insert	Carbide	Use sharp inserts, minimal wear
Bore drill	Solid carbide	Uncoated or TiN	Coolant-fed if possible
Bore ream	Adjustable reamer	Carbide/HSS	Check size before final pass
Node pockets	Drill or end mill	Carbide	Use peck cycle for depth control
Helix threads	Ball end mill	PCD (preferred)	Carbide acceptable, faster wear
Finish pass	Ball end mill	PCD or ceramic	Light load, high speed

Tool Inspection:
- Inspect cutting edges before use (10× magnification minimum)

- Replace tools at first sign of chipping or excessive wear
- Record tool changes in process traveler

3.4 Coolant and Lubrication

Coolant Type:
- Synthetic water-soluble (preferred): 5-8% concentration
- Semi-synthetic acceptable
- Neat cutting oil for reaming operation only (improved finish)

Delivery:
- High-pressure (≥100 PSI) for roughing and drilling
- Flood cooling for face milling
- Minimal mist for PCD finishing (avoid thermal shock)

Maintenance:
- Monitor coolant concentration daily
- Filter particulate matter (10 μm or finer)
- Check pH weekly (target 8.5-9.5 for synthetics)

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4. THERMAL PROCESSING

4.1 Stress Relief (Post-Machining)

Required after all machining operations are complete.

Parameters:
- **Temperature:** 540°C ±10°C
- **Ramp rate:** 100-150°C per hour (gradual heating)
- **Soak time:** 2 hours minimum at temperature
- **Atmosphere:** Argon, nitrogen, or vacuum ($<10^{-4}$ Torr)
- **Cooling:** Furnace cool to <100°C before removal

Equipment:
- Vacuum furnace (preferred)
- Inert atmosphere tube furnace (acceptable)
- Temperature uniformity: ±5°C across work zone

Documentation:
- Record actual time-temperature profile

- Provide furnace calibration certificate (within 6 months)
- Photograph part position in furnace (for traceability)

4.2 Optional Ultrasonic Conditioning

If equipment is available, the following process may enhance resonance stability:

Parameters:
- **Frequency:** 360 Hz ±5 Hz
- **Duration:** 15 minutes
- **Amplitude:** Low intensity (excitation below yield stress)
- **Mounting:** Suspend freely or mount on soft foam

Purpose: Stabilize residual stress patterns, "tune" resonance characteristics

Note: This step is experimental and not required for acceptance.

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5. DIMENSIONAL INSPECTION PROTOCOL

5.1 Inspection Equipment Requirements

All critical dimensions shall be verified using:

Coordinate Measuring Machine (CMM):
- Accuracy: ±0.002 mm or better
- Environment: Temperature-controlled (20°C ±2°C)
- Calibration: Current within 12 months (NIST-traceable)

Surface Profilometer:
- Contact or optical acceptable
- Measurement range: Ra 0.1-10 μm
- Calibration: Current within 6 months

5.2 Measurement Locations and Acceptance Criteria

A. Outer Diameter (OD)

Measure at 8 angular positions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) at mid-height (Z = 5.0 mm).

Target: Ø30.00 mm
Tolerance: +0.03 / −0.00 mm
Acceptance: All measurements within tolerance, range <0.02 mm

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B. Total Height

Measure at 4 radial positions: near bore (r = 5 mm), mid-radius (r = 12.5 mm), and near OD (r = 14.5 mm).

Target: 10.00 mm
Tolerance: ±0.05 mm
Acceptance: All measurements within tolerance, parallelism <0.02 mm

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C. Central Bore

Measure diameter at 3 depths (Z = 1 mm, 5 mm, 9 mm) and 4 angles (0°, 90°, 180°, 270°) = 12 total measurements.

Target: Ø3.03 mm
Tolerance: ±0.03 mm
Acceptance: All measurements within tolerance

Concentricity Check:
- Fit best-fit cylinder to bore measurements
- Compare bore axis to OD axis
- **Acceptance:** Deviation ≤0.02 mm

D. Top Lattice Node Pockets (12 locations)

For each node:
1. **X-Y position** (verify against coordinate table in Section 7)
   - Tolerance: ±0.05 mm from nominal
2. **Pocket diameter** (measure at Z = 9.5 mm depth)
   - Target: Ø2.00 mm
   - Tolerance: ±0.03 mm

3. **Pocket depth** (measure from top surface datum)
   - Target: 1.00 mm
   - Tolerance: ±0.03 mm

Acceptance: All 12 nodes within specified tolerances

E. Surface Finish

Measure Ra (arithmetic average roughness) at the following locations:

Surface	Location	Target Ra (μm)	Acceptance Range
Top face	3 points (center, mid-radius, near OD)	0.8 - 1.6	0.6 - 2.0
Bottom face	3 points (same pattern)	0.8 - 1.6	0.6 - 2.0
Bore inner	2 points (top half, bottom half)	≤1.0	≤1.5
OD surface	4 points (0°, 90°, 180°, 270° at mid-height)	0.8 - 1.6	0.6 - 2.0

Measurement Parameters:
- Cutoff length: 0.8 mm (λc per ISO 4287)
- Evaluation length: 4.0 mm minimum
- Filter: Gaussian (standard)

5.3 First Article Inspection (FAI)

For the first unit manufactured, perform complete FAI per AS9102:

- Full dimensional layout (all features measured)
- Material certification review and verification
- Process documentation review
- Photographic documentation (6 standard views minimum)
- Comparison to engineering drawings/blueprint

FAI Report shall include:
1. Dimensional data table (all measurements with actual values)
2. CMM generated reports (native format + PDF)
3. Surface finish data sheets
4. Material certifications (attached)
5. Inspector sign-off and date

Subsequent units (Unit 2+) require reduced inspection unless nonconformance is detected.

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6. MATERIAL CHARACTERIZATION

6.1 Grain Size Analysis (Required)

Method:
- Scanning Electron Microscopy (SEM) with EBSD (preferred), OR
- Optical microscopy after metallographic polish and etch

Sample:
- Sacrificial witness coupon from same billet, OR
- Edge section cut from non-functional area (if permitted)

Target: Average grain size ≤15 μm

Acceptance Criteria:
- Mean grain size ≤20 μm
- No individual grains >50 μm
- Uniform distribution (no abnormal grain growth)

Documentation:
- Micrographs at 500× and 1000× magnification
- Grain size distribution histogram
- ASTM E112 grain size number (if applicable)

6.2 Composition Verification (Recommended)

If in-house capability exists:

Method: Energy Dispersive Spectroscopy (EDS) or X-Ray Fluorescence (XRF)

Locations: 3 random surface points

Objective: Confirm presence of expected elements (Ta, Ti, Au, C)

Note: Quantitative composition analysis not required if mill certification is complete.

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7. REFERENCE DATA

7.1 Top Lattice Node Pocket Coordinates

Datum: Bore centerline (X=0, Y=0), top face (Z=10.0)

Node	Angle (°)	X (mm)	Y (mm)	Material Zone
1	0	+5.000	0.000	Titanium
2	30	+4.330	+2.500	Gold
3	60	+2.500	+4.330	Titanium
4	90	0.000	+5.000	Gold
5	120	−2.500	+4.330	Titanium
6	150	−4.330	+2.500	Gold
7	180	−5.000	0.000	Titanium
8	210	−4.330	−2.500	Gold
9	240	−2.500	−4.330	Titanium
10	270	0.000	−5.000	Gold
11	300	+2.500	−4.330	Titanium
12	330	+4.330	−2.500	Gold

Calculation verification:
- Radial distance from center: $\sqrt{(X^2 + Y^2)} = 5.000$ mm for all nodes
- Angular spacing: 30° increments

7.2 Material Properties (Reference)

For process planning and thermal calculations:

Property	Tantalum	Titanium (Gr 2)	Gold
Density (g/cm³)	16.65	4.51	19.32
Melting Point (°C)	3,017	1,668	1,064
Thermal Conductivity (W/m·K)	57	17	318
Coefficient of Thermal Expansion (10^{-6}/K)	6.3	8.6	14.2
Specific Heat (J/kg·K)	140	523	129
Hardness (Vickers)	150-200	130-180	25-50

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8. HANDLING AND STORAGE

8.1 Handling Requirements

During manufacturing:
- Use non-marring gloves (nitrile or cotton) for all handling
- Avoid direct skin contact (oils can cause surface contamination)
- Support part securely during transfers (do not drop or impact)
- Protect functional surfaces from scratching

After completion:
- Package individually in polyethylene bags
- Include desiccant packet if storage exceeds 7 days
- Store in temperature-controlled environment (15-25°C, <60% RH)

8.2 Cleaning Protocol

Pre-inspection cleaning:
1. Rinse with isopropyl alcohol (IPA) 99%
2. Ultrasonic bath in IPA for 5 minutes (optional, if available)
3. Air dry or dry with lint-free wipes
4. Inspect under 10× magnification for residue

Do NOT use:
- Abrasive cleaners or brushes
- Chlorinated solvents
- Acidic or alkaline cleaners (unless specifically required for etching)

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9. DOCUMENTATION REQUIREMENTS

9.1 Process Traveler

Each unit shall have a completed process traveler documenting:

- [ ] Material receipt and certification review
- [ ] Pre-machining inspection (stock dimensions, visual)
- [ ] Setup verification (WCS, fixture, tooling)
- [ ] Operation completion sign-off (each machining operation)
- [ ] In-process inspection results (bore diameter check, etc.)
- [ ] Thermal processing record (temperature profile, duration)
- [ ] Post-machining cleaning
- [ ] Final dimensional inspection (CMM, surface finish)
- [ ] Material characterization (grain size, composition)

- [ ] Photographic documentation
- [ ] Final acceptance or rejection decision
- [ ] Inspector name, signature, date

Traveler template available upon request.

9.2 Deliverable Package

For each completed unit, provide:

1. **Physical part** (cleaned, packaged per Section 8)
2. **CMM inspection report** (full data, native format + PDF)
3. **Surface finish data sheet** (profilometer readings)
4. **Material certification** (original from supplier)
5. **Grain size analysis report** (micrographs, measurements)
6. **Process traveler** (completed and signed)
7. **Thermal processing record** (time-temperature profile)
8. **Photographic documentation** (minimum 6 views: isometric, top, bottom, 4 sides)

Digital files preferred format: PDF (drawings, reports), CSV (measurement data), JPEG/PNG (photos)

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10. NONCONFORMANCE AND CORRECTIVE ACTION

10.1 Nonconformance Reporting

If any dimension, feature, or material property falls outside specified tolerances:

1. **Stop production immediately**
2. Quarantine affected part(s)
3. Document nonconformance:
   - Feature/dimension out of tolerance
   - Measured value vs. specification
   - Suspected root cause
4. Contact engineering for disposition

Disposition options:
- **Accept as-is:** If deviation is minor and does not affect function (requires engineering approval)
- **Rework:** If feature can be corrected (e.g., re-ream bore, additional finishing pass)

- **Reject/scrap:** If critical dimension cannot be corrected

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10.2 Corrective Action

For any nonconformance:
- Investigate root cause (tooling wear, setup error, material issue)
- Implement corrective action before continuing production
- Document corrective action in process traveler
- Verify effectiveness (inspect next unit with increased scrutiny)

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11. SAFETY CONSIDERATIONS

11.1 Material Hazards

Tantalum:
- Relatively inert, low toxicity
- Dust/fine particles: avoid inhalation (use dust collection)
- Cutting oils may react at high temperatures (use appropriate coolant)

Titanium:
- Flammable as fine powder or swarf (fire risk during machining)
- Use flood coolant to prevent combustion
- Store Ti swarf in water-filled containers
- No grinding of Ti parts (spark/fire hazard)

Gold:
- Non-toxic, inert
- No special handling required

11.2 Machining Safety

- **Personal Protective Equipment (PPE):** Safety glasses, hearing protection, gloves
- **Machine guarding:** Ensure all guards in place during operation
- **Chip management:** Use chip evacuation system; avoid hand removal while spindle running
- **Coolant splash:** Use machine enclosure or protective curtains

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12. REVISION HISTORY

Rev	Date	Description	Author
1.0	2025-12-15	Initial release	MJC
2.0	2026-01-10	Updated material specifications, added thermal processing details	MJC
2.1	2026-01-22	Clarified inspection requirements, added node coordinate table	MJC

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13. CONTACT INFORMATION

Technical Questions:
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For clarification on specifications, tolerances, or inspection requirements, contact engineering before proceeding.

END OF MANUFACTURING ADDENDUM

This document is to be used in conjunction with TITAN A16 Primary Blueprint (Document 1) and CNC Programming Appendix (Document 3).