# NEW POWDER APPLICATIONS

**HIGH-PERFORMANCE ALLOYS, PRECISELY CONTROLLED PROCESSES, AND STATE-OF-THE-ART ENGINEERING METHODS HAVE LED TO SIGNIFICANT GROWTH IN THE P/M INDUSTRY.**

By Richard H. Slattery

Powder Metallurgy is a proven technology to produce high strength gears and tailored gear shapes for both automotive and industrial applications. Advances in powder production, compaction, and sintering combined with unique secondary processing methods have enabled overall part densities above 7.5 g/cm³. These techniques have proven successful in displacing many components from competing technologies in a variety of end user applications. The reason for P/M's success is its ability to offer the design engineer the required mechanical properties with reduced component cost. At the present time, P/M is successful in many performance areas. Discussed here are three applications that expand the potential for P/M use in additional environments.

## Application One

The first application is a planetary gear set. This gear set is used in a motorized lift gate in a new SUV/mini-van hybrid vehicle. The key design features include precise AGMA tolerancing achieved through innovative tool design to produce high-precision custom involute gear members to reduce noise. These parts are also sinter hardened—a hardening process that does not require conventional oil quench and temper methods—for a high level of dimensional control through minimized quench distortion. Finally the parts are treated with a proprietary corrosion inhibiting plating that is both environmentally friendly and does not require surface preparation such as resin impregnation or shot peening, which is typical for most powder metallurgy components. The physical properties of the gears are listed in tables 1 and 2.

This seven-piece P/M gear set (see figure 1) represents a significant cost savings over conventionally produced cut steel gear sets, without sacrificing quality. The innovative gear geometry, coupled with the unique processing methods, yields a high-strength, quiet-running gear set with high wear resistance properties and corrosion resistance.

## Application Two

The second application is a powder metal crankshaft gear for an industrial consumer. This copper infiltrated helical crankshaft gear is compacted with a custom geometry to allow for subsequent gear tooth modification for high strength and minimum noise, or gear whine. This gear has a 25.5° helix angle, a custom involute profile, which includes designed in tip relief, and a "mirror-like" surface finish on the tooth flanks. The teeth

**TABLE 1 —** Planetary and Ring Gears – FLNC 4408-90 HT

| Characteristic | | SI Units |
|---|---|---|
| Tensile Strength | 100,000 psi | 690 Mpa |
| Yield Strength | 90,000 psi | 620 Mpa |
| Apparent Hardness HRC | 30 | 30 |
| Mico Hardness HRC | 55 | 55 |
| Fatigue Limit (90% Survival) | 33,000 psi | 230 Mpa |
| Density g/cm³ | 6.95 | 6.95 |

**TABLE 2 —** Spur Sun Gear – FN 0205-105 HT

| Characteristic | | SI Units |
|---|---|---|
| Tensile Strength | 120,000 psi | 830 Mpa |
| Yield Strength | 105,000 psi | 720 Mpa |
| Apparent Hardness HRC | 30 | 30 |
| Mico Hardness HRC | 55 | 55 |
| Fatigue Limit (90% Survival) | 35,000 psi | 240 Mpa |
| Density g/cm³ | 6.95 | 6.95 |

**FIGURE 1 —** Planetary Gear Set for Tailgate Latching Mechanism

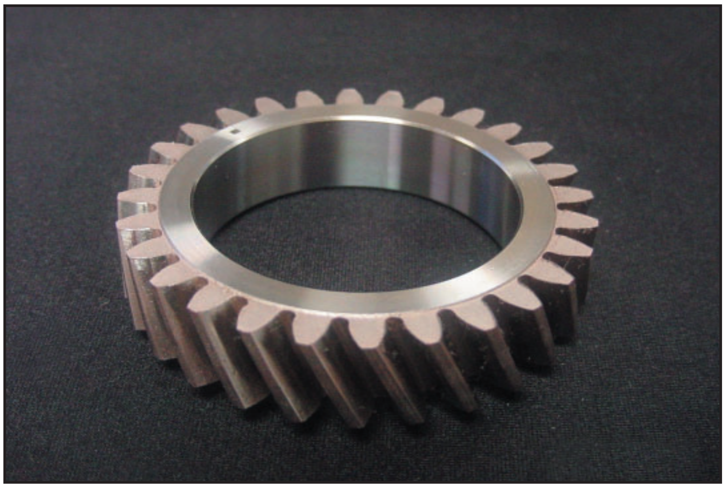


**FIGURE 2 —** Copper Infiltrated P/M Crankshaft Gear

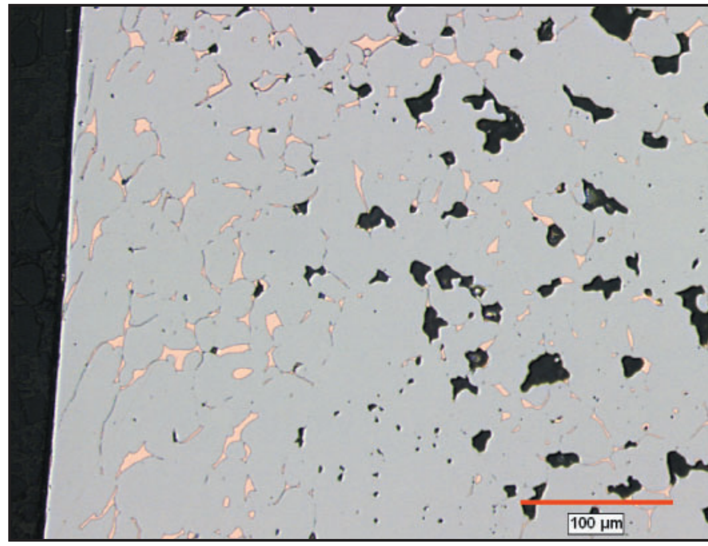



**FIGURE 4 —** Photomicrograph of densified region

have a maximum helix error (lead) of 0.015mm and a profile error of less than 0.03mm. Additionally, the gear has an accurately machined inside diameter (0.024mm total tolerance) and locating face enabling precise assembly (see figure 2).

This gear is sintered near net shape, and its physical strength, along with precise dimensional control, replaces a far more expensive wrought steel gear. It requires a high level of tool geometry control, along with minimum weight and sectional density variation at compact, and a very consistent sinter temperature profile. The gear is then precision machined and the teeth are rolled for densification and final qualification of the gear geometry.

As for physical and mechanical properties, the material is an MPIF FX 1008-50 at a 7.3 g/cm$^3$ minimum density and an apparent hardness of RB 90. The elongation exceeds 3 percent, and the impact strength exceeds 15J (10 ft lbs). This elongation enables very high press fit interference on the mating crankshaft to eliminate the potential of gear slippage in service. The tensile strength of this material is >600 MPa (90,000 psi). The gear teeth are rolled to full density at the tooth flank surfaces (see figure 4).

This is an economically attractive, high-strength, precise, copper-infiltrated helical gear with a custom involute form.

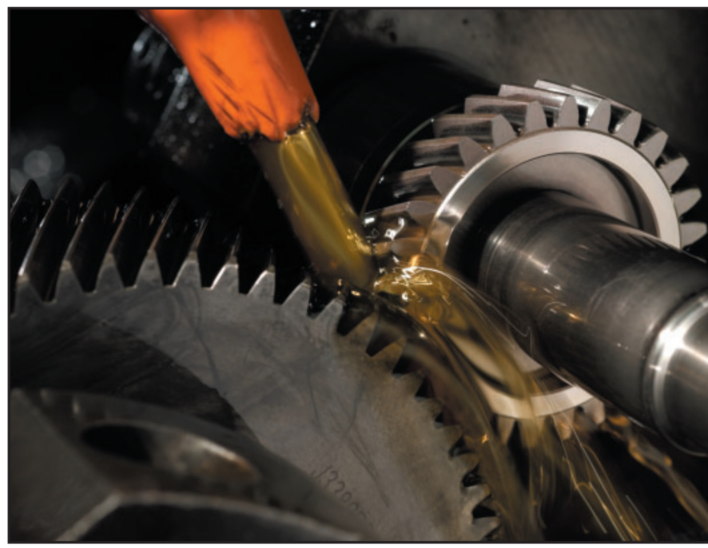


**FIGURE 5 —** Rolling a PM Gear

## Application Three

Achieving higher sintered density is perhaps the primary method to improve the performance of a P/M part. However, recent work has shown that heat treat practice and secondary operations can also have a significant effect on actual part performance.

It is well known that carburizing produces favorable compressive stresses on the surface of components. This applies to P/M components as well, and when coupled with a low core carbon can provide a wear resistant gear with impact toughness due to core ductility. One area in which P/M has typically been inferior to wrought steel is rolling contact fatigue resistance. In gear rolling contact fatigue, the high subsurface stresses resulting from the gear contact has shown the need for full density in the active profile region to withstand the Hertzian contact stress associated with rolling contact fatigue of high performance gears. In this application surface densification is used to achieve the required pore free layer in the contact area (see figure 5). Surface densification results in the following benefits:

- Provides a pore-free case and a porous core
- Potentially lower component cost because the high density region is only in the critical stress region of the part
- Improved gear geometry and tolerance because the P/M gear is rolled against a precision roll die
- Potentially adds the ability to crown the tooth of the densified P/M gear

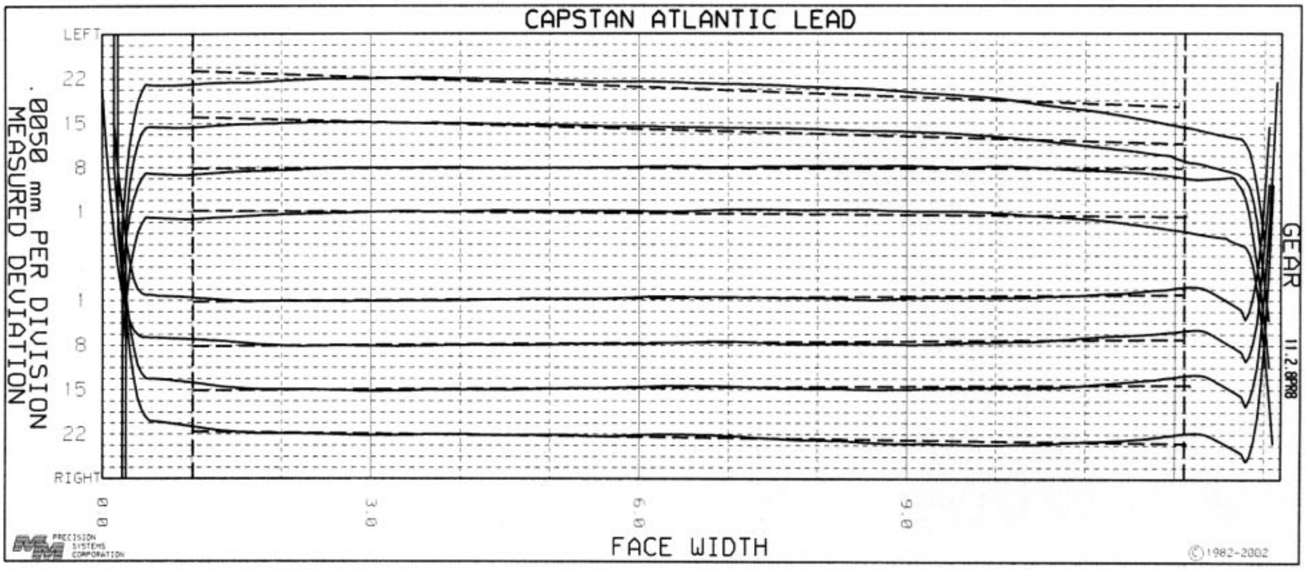
Machining of P/M gears, unlike its wrought steel counterpart, is limited to the inside diameter. The benefits from this single machining operation are precise inside diameter tolerances and near-perfect alignment of the gear teeth to the central axis of the gear.

Further enhancement of the gear geometry is then achieved by a rolling operation. With the incorporation of a specifically engineered rolling process one has the ability to achieve maximum fatigue endurance while optimizing tooth alignment and imparting a crown, through surface densifying the gear teeth to depths in excess of 0.7 mm. An additional benefit of this operation is a “mirror-like”

OPERATOR : Leo Bessette
PART NAME : GEAR, CRANKSHAFT
INSPECTION NOTES :
.007 MAX POSITIVE INVOLUTE FROM PITCH DIAMETER TO O.D.

DATE : 25 May 2005
TIME : 11:20

PART # : 3631 FINAL
SERIAL # :

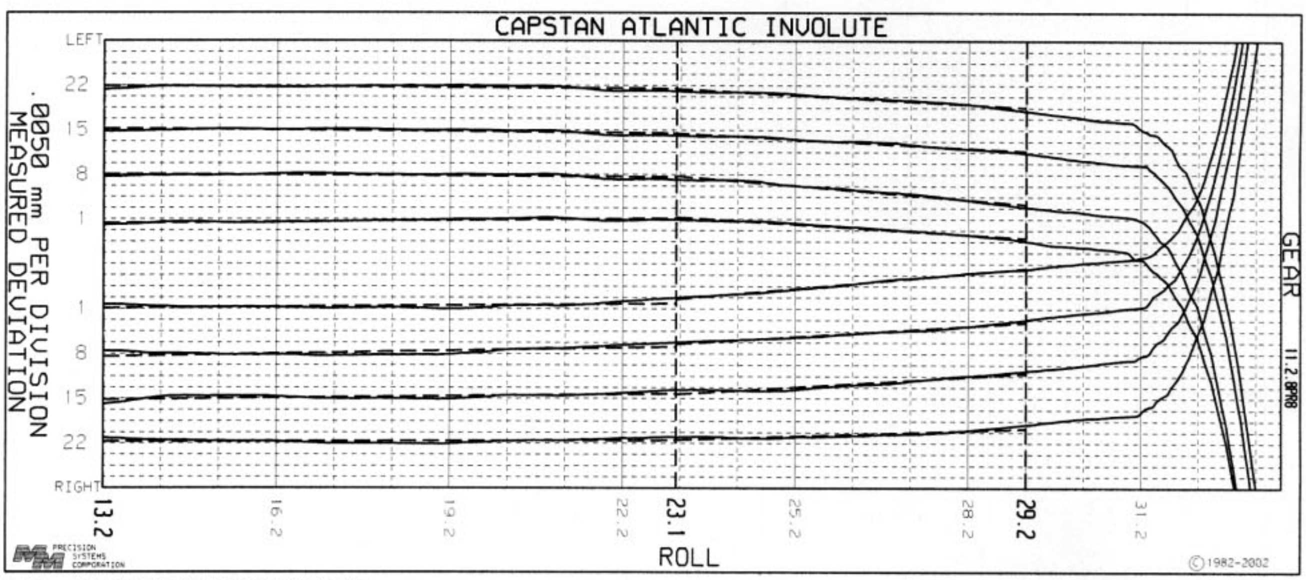



NOTE: "*" INDICATES OUT OF TOLERANCE

| | LEFT FLANK | | | | RIGHT FLANK | | |
|---|---|---|---|---|---|---|---|
| TOOTH | SLOPE | HOLLOW | CROWN | TOOTH | SLOPE | HOLLOW | CROWN |
| 1 | -.0028 | .0069 | .0022 | 1 | -.0032 | .0033 | .0014 |
| 8 | -.0001 | .0043 | .0011 | 8 | -.0032 | .0037 | .0016 |
| 15 | -.0122 | .0077 | .0022 | 15 | -.0026 | .0044 | .0015 |
| 22 | -.0162 | .0087 | .0030 | 22 | .0052 | .0045 | .0019 |

L.S. BEST FIT LINE TYPE ANALYSIS

| | LEFT FLANK | RIGHT FLANK |
|---|---|---|
| AVERAGE SLOPE | -.0078 | -.0009 |
| TOLERANCE | .0151 | .0151 |
| TOLERANCE | -.0151 | -.0151 |
| AVERAGE CROWN | .0021 | .0016 |
| MAXIMUM HOLLOW | .0087 | .0045 |
| MAX SLOPE VAR | .0161 | .0083 |




NOTE: "*" INDICATES OUT OF TOLERANCE

| | LEFT FLANK | | | | RIGHT FLANK | | |
|---|---|---|---|---|---|---|---|
| TOOTH | SLOPE | HOLLOW | CROWN | TOOTH | SLOPE | HOLLOW | CROWN |
| 1 | -.0047 | .0054 | .0027 | 1 | -.0167 | .0053 | .0036 |
| 8 | -.0117 | .0058 | .0029 | 8 | -.0147 | .0044 | .0025 |
| 15 | -.0091 | .0035 | .0019 | 15 | -.0105 | .0040 | .0020 |
| 22 | -.0085 | .0045 | .0023 | 22 | -.0052 | .0036 | .0018 |

L.S. BEST FIT LINE TYPE ANALYSIS BETWEEN SPECIFIED SEGMENT: C1 AND C3

| | LEFT FLANK | RIGHT FLANK |
|---|---|---|
| AVERAGE SLOPE | -.0085 | -.0118 |
| TOLERANCE | .0290 | .0290 |
| TOLERANCE | -.0290 | -.0290 |
| AVERAGE CROWN | .0024 | .0025 |
| MAXIMUM HOLLOW | .0058 | .0053 |
| MAX SLOPE VAR | .0070 | .0115 |

**FIGURE 3 —** Lead Error and Involute Profile of Crankshaft Gear

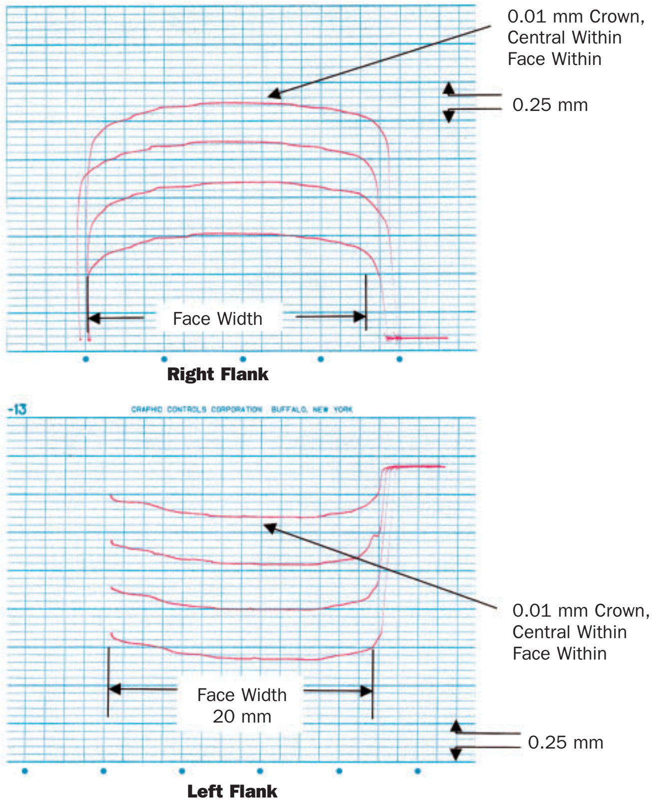



**FIGURE 6 —** Gear Lead Trace With Crowned Helix

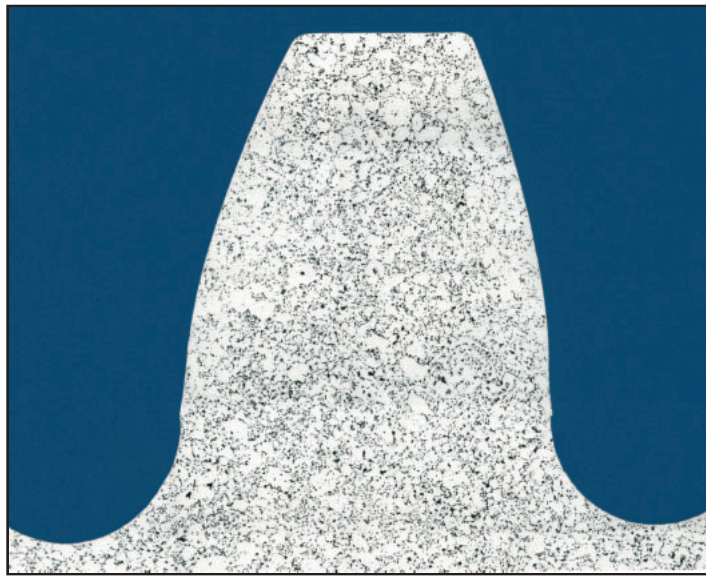


**FIGURE 7 —** Cross-Section of Rolled Gear

**"THE REASON FOR P/M'S SUCCESS IS ITS ABILITY TO OFFER THE DESIGN ENGINEER THE REQUIRED MECHANICAL PROPERTIES WITH REDUCED COMPONENT COST."**

surface finish achieved on the tooth flanks, resulting in a much quieter running gear—which is critical in satisfying ever-increasing NVH requirements.

Shown in Figure 6 is the gear trace of the helix (lead error), showing a crown central within the face width of the gear. First, looking at the lead traces, notice that the start and stop points of the trace are at the same level, while there is a positive crown in the middle of the trace.

Typically with P/M we would see a hollow in the central region of the face width of the tooth caused by the low dense region at or about the middle of the gear's face width. We call this the "density dip" effect. The compaction of a high density gear—with uniform density top to bottom—minimized this "density dip." Thus, in combination with a specifically engineered rolling process, a 0.01mm crown was created on both gear flanks.

Described above is a new parts-making process utilizing Capstan Atlantic's HD4 system that enables the production of high-density P/M blanks. The results are single-pressed sintered densities to 7.4 g/cm$^3$. This, combined with pore-free gear tooth surfaces and the proper heat treatment, results in a powdered metal gear with similar bending fatigue and contact fatigue resistance to its 8620 carburized wrought steel counterpart. In addition to the densified case structure, the surface finish of the rolled part is better than that of a ground finish.

The manufacturing method for the helical pinion:

- Compact (High Dense)
- Sinter (controlled cooling)
- Machine
- Surface densify
- Harden (minimal distortion)
- Finish machine as required

This processing offers the mechanical properties of a high-density part, the surface fatigue resistance of a wrought part, and potentially the low cost inherent to P/M processing. Surface densification gives the following advantages:

- Pore-free tooth surface
- Excellent (mirror) surface finish
- Increased wear resistance
- Reduced noise
- Improved corrosion resistance
- Minimal tooth-to-tooth and total composite error
- Redirects helix angle to improve gear tooth lead while incorporating a tooth crown
- Customized tooth profile
- Improved fatigue endurance

## Summary

Discussed in this article are three powder metallurgy gearing applications, which until recently were not considered feasible for P/M processing. The combination of high-performance alloys, precisely controlled processes, and state of the art engineering methods has enabled continued growth of the P/M industry as it penetrates these and other market segments.

## ABOUT THE AUTHOR:

Richard H. Slattery is vice president of engineering for Capstan Atlantic. He can be reached at (508) 384-3100 ext. 642, or via e-mail at rslattery@capstanatlantic.com. The company's Web site is [www.capstanatlantic.com].