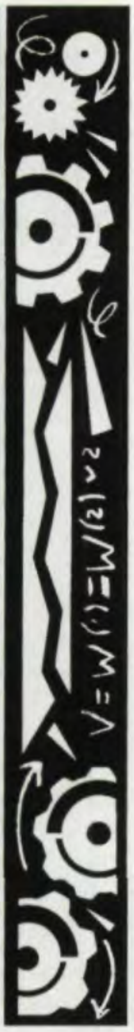
GEAR FUNDAMENTALS



The Beginner's Guide to Powder Metal Gears

What you should know about this gear cutting alternative.

George Shturtz

Increasingly gear designers and product engineers are capitalizing on the economic advantages of powder metallurgy (P/M) for new and existing gear applications. Powder metal gears are found in automobiles, outdoor power equipment transmissions and office machinery applications as well as power hand tools, appliances and medical components.

Helical, bevel (both straight and spiral), rack, face, internal and external spur gears, including compound gears, can be manufactured to final shape with no machining operations. Consequently, material scrap losses are eliminated. Internal configurations (splines, keys, keyways) are formed simultaneously with the gear profile, eliminating subsequent machining operations. P/M gear shapes produced by two or more compacted powder preforms that are sinter-bonded or sinter-brazed together result in complex, single-piece geometries that cannot be produced economically by other manufacturing methods. This efficient utilization of materials and energy increases the competitiveness of the P/M process.

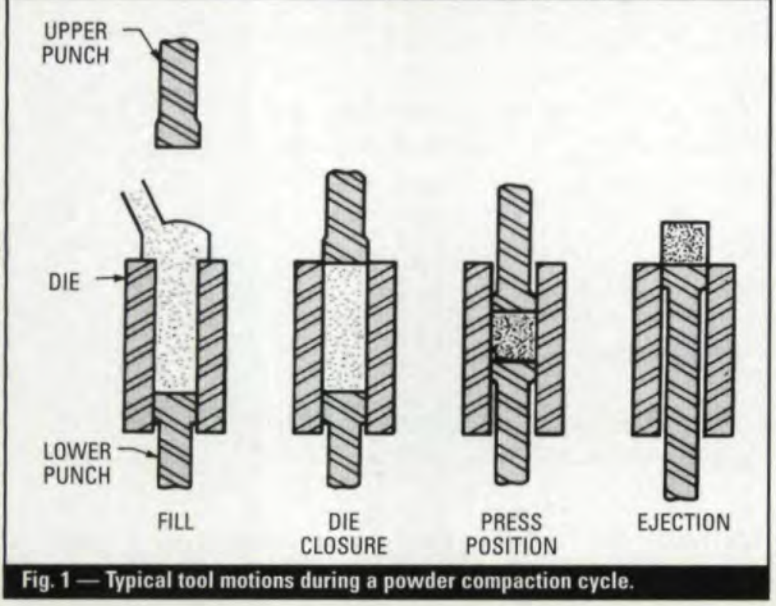


Fig. 1 — Typical tool motions during a powder compaction cycle.

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Powder metallurgy offers a unique combination of benefits for gear manufacturing that presents a cost-effective alternative to traditional metal forming techniques. A wide variety of base metals are currently available in powder form; brass, bronze, iron and numerous steel grades, including stainless. Customized mixing and blending of elemental powders provides a variety of possibilities for the development of alloy compositions formulated for specific mechanical properties.

Conventional powder metallurgy involves the forming of blended metal powders, usually at room temperature, at pressures typically between 20–50 tsi (tons per square inch) of projected surface area. Generally, P/M molds or tooling come in several pieces. The mold for a single-level gear consists of a die, an upper punch and a lower punch. If the particular part to be formed requires a bore or other ID configuration, a core rod(s) is also part of the tooling. Multi-level compound gears or other complex parts may have two or more upper and/or lower punches.

To form the gear, the die is filled with powder at a ratio of approximately two times the parts thickness: e.g., a spur gear that has a thickness of .750" will be compacted from a column of powder 1.500" thick. During the compaction cycle of the most commonly used type of press, the upper punch enters the die while the lower punch, which in the fill position seals off the bottom of the die, remains stationary. As the upper punch travels downward, the compressive forces cause the die assembly to move downward in relationship to the lower punch, resulting in the same effect as if the lower punch were moving upward during the compaction stroke. The rate of movement and pressure of the upper punch and the motion of the die are relatively equal to ensure uniform density within the compacted preform.

After completion of the compaction cycle, the upper punch retracts from the die, and the lower punch initiates an upward motion, ejecting the preform from the die. (See Fig. 1.) The compacted preform is the exact shape of the final part. Depending on the final part shape, secondary operations may be required.

The shape of the compacted preform is determined by the shape of the tooling and the axial motion of the compaction press. Two main factors influence part design; the flow behavior and characteristics of the metal powders and the movement of the tools within the pressing cycle. Metal powders do not flow hydraulically, and the allowance for friction between the powder particles themselves and with the moving tool members must be factored in the final P/M part design. The pressing action from both top and bottom largely governs the shape, length and dimensional details of the preform.

The compacted preform then must be thermally processed or sintered. Sintering is the metallurgical bonding of the powder particles at a temperature below the melting point of the base material. Sintering at temperatures of approximately 2050°F produces tensile properties from 18,000–90,000 psi, depending on material composition. The addition of heat treatment can increase the ultimate tensile properties of a single, compacted/sintered component to 130,000 psi and higher. Depending on the required mechanical and physical properties and dimensional specifications, the gear may be complete at the end of the compact-sinter cycle or after heat treatment if required.

Designing P/M Gears

Six major factors need to be taken into consideration when designing a new or existing gear for the P/M process.

1. *The configuration of the gear should allow for ejection from the die.* While P/M is considered a net-shape technology, some features must be eliminated from the final part design or added through secondary machining operations because they would inhibit ejection of the preform from the die. For example, undercuts, reverse angles, details at right angles to the direction of pressing (for example, holes or grooves), threads, diamond knurls and re-entrant angles, all might interfere with smooth ejection.

2. *The configuration of the gear should allow for movement of the metal powders throughout the tool members during the compaction cycle.* As mentioned previously, metal powders do not flow hydraulically. Therefore extremely thin-walled sections, very narrow grooves and deep counterbores should be avoided because metal powders will not fill these parts of a die cavity.

3. *The configuration of the gear should allow for "practical" tooling.* Tooling life can be improved and production efficiencies enhanced by avoiding narrow deep grooves, very sharp edges, complete spherical profiles and knife-thin tool thicknesses. Often design simplification of these features will allow for a more robust or "practical" set of compaction tools without adding machining operations. Another consideration for gear design is to maintain sufficient clearance between the ID and the root diameter, which can range from .035" on small pinions to .300" for more demanding applications.

4. *The configuration of the gear should limit the changes in section thickness.* P/M processes work very well with compound gear geometries. Because the gear profiles are formed during compaction within the tooling, complex compound gears such as gear-pinion and spur-face combinations are well within the capability of the process. Uniform density and high strength is best achieved by limiting the number of section thickness changes (levels) that are designed into the preform. The number of levels a part may have is determined by the specific type of compaction press and/or the design of the compaction tooling.

5. *The configuration of the gear should minimize right angle intersections.* Radii should be incorporated at right angle intersections of section thickness changes. These radii improve the integrity of the preform. Gear engagement should be designed to occur above the radius. Often

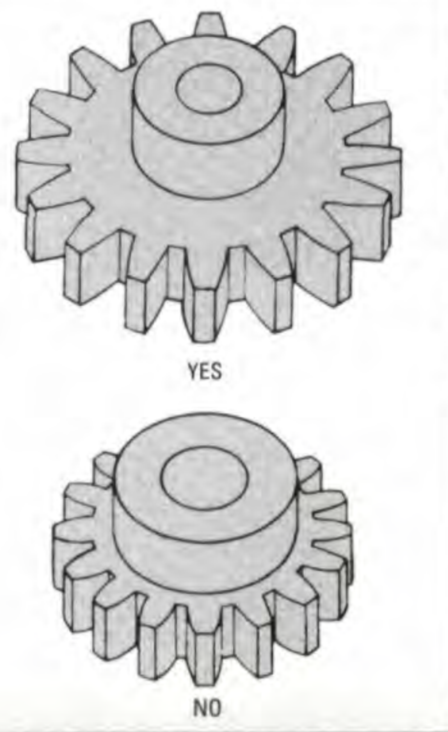

Fig. 2 — Hubs should be located as far as possible from gear's root diameter.

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raised surface features can be added to the compacted preform to assist in this engagement.

6. ***The configuration of the gear should incorporate edge detail (i.e., chamfers on top and bottom of gear teeth and on ODs and IDs).*** This edge detail or chamfer has two main purposes. First, it increases the density in the teeth. Higher tooth density results in improved mechanical properties, particularly strength. It also reduces adverse effects of burrs. The chamfer detail will in most cases keep the burr within the overall thickness (width) of the gear. These burrs are a result of fit clearance of the tooling and, if necessary, can be removed by a vibratory finishing (tumbling) operation or a machining operation.

Typically gears produced in powder metallurgy are in the AGMA range of 6 to 8, with higher AGMA classifications possible, depending on size of the compacted gear and with additional secondary operations.

Conclusion

The net-shape forming capability of the P/M process produces certain forms and geometries (hubs, bosses, counterbores and cam shapes) which are not practical through other manufacturing technologies. Powder metallurgy produces high strength gears of consistent quality at high production volumes while offering very significant economies. P/M deserves serious consideration when designing new gear components, when analyzing current gears for improvement in functional properties or evaluating cost reduction conversion alternatives.

Gear applications that blend the functional requirements of the end use with the fundamentals of powder metallurgy will allow gear designers and engineers to realize the maximum advantages the P/M can offer for long term reliability in demanding applications. While powder metallurgy is best suited and most widely known for high volume production quantities, there are numerous applications where small quantities (as low as a few thousand pieces) can still offer cost benefits over traditional manufacturing methods. ○

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How To Specify P/M Parts

The importance of discussing the part application with your P/M parts manufacturer cannot be overstated. When requesting a quotation, accurate part information must be provided. Refer to the Metal Powder Industries Federation Standard 35 for P/M materials, properties and specifications. In describing a part, stress function and critical requirements for satisfactory service. For optimum results and efficiencies, give the P/M parts manufacturer the widest possible latitude in specifying material, design, physical characteristics, dimensional tolerances, etc. Typical information needed includes the following:

- Information about quantities, including initial needs and a future demand forecast. This enables the most economical approach to costs, manufacturing integration and delivery.
- Detailed drawings of the part and any assembly drawings. Actual samples or prototypes would be helpful. Transmit any information such as knowledge of materials that have worked well in the application.
- Information as to whether the part design can be modified without affecting function. If so, where?
- Part history and usage. Will the P/M part replace one currently in production, or is this a new application? Is the application military, aerospace, medical, etc.?
- Actual service conditions: heat, moisture, impact, corrosiveness, etc.
- Necessary physical, mechanical, corrosion resistance or special properties (tensile, elongation, hardness, flatness, conductivity, impact energy, fatigue strength, etc.)
- The finish required (plating, oxide coating, surface finish).
- Any machining or secondary operations the P/M supplier will be required to perform.
- For gears, specific data are required: a) number of teeth, b) diametral pitch, c) pressure angle, d) measurement over wires, e) tooth thickness, f) backlash, g) helix angle, h) AGMA quality class.

Tools for each P/M part are custom designed and developed specifically for that part. The expense of the tooling may justify the more economical approach of initially testing prototypes machined from P/M slugs.

The quality level and inspection techniques required contribute to the cost of a P/M part. Programs such as SPC and ISO 9000, for example, should be thoroughly discussed and specified by the purchaser and manufacturer prior to submission of a quotation.

More P/M Gear Design Hints

- Carbide dies provide long life and accuracy.
- Residual part porosity tends to dampen sound.
- P/M gears can be made with blind corners, thus eliminating the need for undercut relief.
- P/M gears can be combined with other parts such as cams, ratchets, other gears and various components.
- Helical gears are possible; copper infiltration is sometimes used to improve teeth densities.
- Since tooth configuration is not a problem, true involute gear forms are easier to make than by other methods.

When designing P/M gears:

- Note that hole locations relative to the gear shape itself are affected by the running tolerances of the various tool members. This makes it more difficult to hold the close TIRs (Total Indicator Readings) obtainable with arbor-cut gears, and hubs or pinions that increase the number of concentric tool members increase the TIR tolerance needed. TIRs can be reduced by grinding gear IDs true to the gear pitch diameter.
- As the AGMA class of gear increases, so does the cost of the gear because of the secondary operations required to meet the tighter tolerances.
- To avoid having too-thin members, gear hubs or pinions should be located as far as possible from gear root diameters. (See Fig. 2.)

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