Manufacturers of heavy-duty diesel engines strive to achieve ever lower emissions, improved fuel economy, refinement, reliability and longer service life. These complex challenges place particular demands on the piston, which has to withstand higher peak cylinder pressure (PCP) and temperature with reduced sliding friction and less wear, while remaining competitively priced. To meet the challenges of engines with PCP values of over 220 bar, Federal-Mogul has developed an innovative manufacturing process for the critical high-precision interface between the piston and the pin.

Higher Piston Loads

Diesel combustion loads are becoming too high for traditional bushings in the piston pin bore to deliver the required durability. Without a bushing, the piston and pin run ‘steel-on-steel,’ which risks scuffing and joint seizure. However, this can be prevented by very precise profiling of the pin bore to distribute the load over a sufficient contact area. Wide variations in thermal and mechanical load during the engine operating cycle necessitate complex geometry for the pin bore to maintain satisfactory contact conditions (Fig 1). Therefore, precise control of the dimensions, shape, and texture of the bore is critical.

Traditional machining methods are unable to maintain the required tolerances beyond a very short batch size, typically 25 parts, because of rapid tool wear. This introduces a heavy overhead burden due to frequent tool replacement, machine resetting, and the sacrifice of the first part in every batch during setup. The lack of robustness in the process dictates 100% inspection and the scrapping of non-compliant parts.

The machining difficulties arise from a number of sources:
- Light cutting tool pressure causes intermittent deflection of the tool and repetitive chatter, leading to cyclic form errors;
- Heat generation from friction during cutting leads to distortion of the part;
- Machine control errors result in imperfect tool positioning; and
- Hardness of the material causes tool wear, leading to drift within the tolerances throughout the batch.

The geometry of the pin bore causes further problems: the profile required is not cylindrical but trumpet-shaped towards the inner and outer end of each boss. Also, the shape is not circumferentially continuous throughout its length (Fig. 2), leading to an interrupted cut that can cause further tool vibration. These limitations mean that the typical geometric surface tolerance is 10 to 12 microns for such a difficult form, or 6 to 8 microns under the very best conditions. However, this application requires a form tolerance of just a few microns, to ensure that every piston functions reliably and avoids the early-life failure known as ‘infant mortality’.

Electro-Erosion Machining

The answer is a completely new approach that entirely eliminates conventional metal cutting from the profiling operation by creating a variation on electro-chemical machining (ECM) called high-precision electro-erosion machining (HPEEM). It removes material electro-chemically: the workpiece becomes the anode of a DC circuit, the shaped tool the cathode, and a low-cost salt-water electrolyte completes the circuit and conveys the eroded material away from the workpiece (Fig. 3).

Conventional ECM typically removes several millimeters of material from a part over a period of 20 to 40 minutes. A moving cathode maintains a constant gap to the work...
piece, but moving the cathode introduces a source of error that typically results in dimensional tolerances of 20 to 30 microns.

To remove this source of error, the HPEEM process takes the imaginative step of fixing the cathode position, and accommodating the changing gap by managing the electrical energy. The result is consistent manufacture to within a form tolerance of a few microns, with a cycle time shorter than one part per minute. The process is suitable for the removal of up to 100 microns, making it highly appropriate for finishing near-net-shape parts that require high accuracy and tight tolerances.

No significant heat is introduced during the process, so dimensional stability and workpiece material properties remain unaffected. In fact, fully hardened material presents no additional challenge, in contrast with conventional machining. Cycle time per piece for this application is only half that of conventional machining, because although the mounting and alignment take a little longer, the metal removal time is much shorter.

In-process monitoring ensures that tolerances are held throughout the production run, largely eliminating the inspection burden associated with traditional methods. Because no tools contact the workpiece, there is no deflection, no chatter, no tool wear, and no production disruption to change tools. Furthermore, the capital investment required for a piston pin bore line can be one-third to one-half as much as a conventional high-precision boring facility.

**Applications**

The process was developed at Federal-Mogul’s advanced manufacturing technology facility in Ann Arbor, Michigan. The company has introduced HPEEM in the manufacture of its PACE award winning Monosteel pistons produced at its volume facility in Puebla, Mexico. Several well-known heavy-duty diesel truck manufacturers in both the on- and off-highway markets use bushingless pistons made by the HPEEM process.

In the light-duty diesel sector, the trend towards downsized engines with higher specific outputs could create additional demand, if higher combustion temperatures necessitate steel pistons but market expectations limit cost ceilings. Pistons made by the HPEEM process could provide the necessary combination of performance, durability, and price for many applications.

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