Shaping and surface finishing of fuel injection components with MICROFLOW™

Introduction

Reducing fuel consumption and emissions is one of the mega-trends in the automotive industry driven by Euro 6, Euro 7, PRC and CAFE regulations. All over the world legislation is setting up restrictions to reduce air pollution and protect the environment (see figure 1). Downsizing of the engines combined with higher performance leads to an extending need of optimized fuel injection systems. Increasing the efficiency of these fuel injection systems is a big contribution for the automotive market to achieve the required goals.

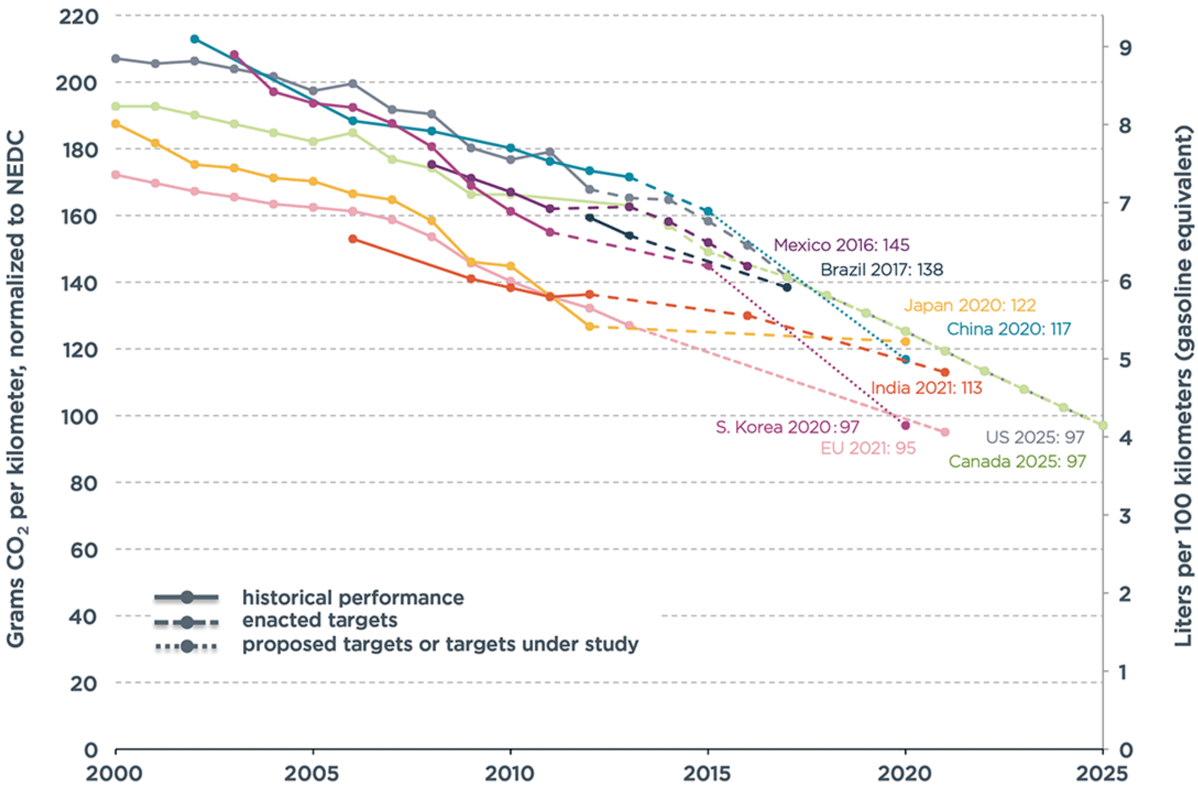

Figure 1: Historical fleet CO_2 emissions performance and current or proposed passenger vehicle standards (Source: ICCT)

The Problem

OEMs for the time being do achieve and fulfill the demanded emissions only in special test modes like, for example, the New European Drive Cycle (NEDC), the Federal Test Procedure (FTP-75) or the Highway Fuel Economy test cycle (HWFET). But The World Harmonized Light Test Cycle and Procedures (WLTC/P) will dramatically show that the vehicles' true in-use performance shows much higher fuel consumption and emissions (see figure 2).

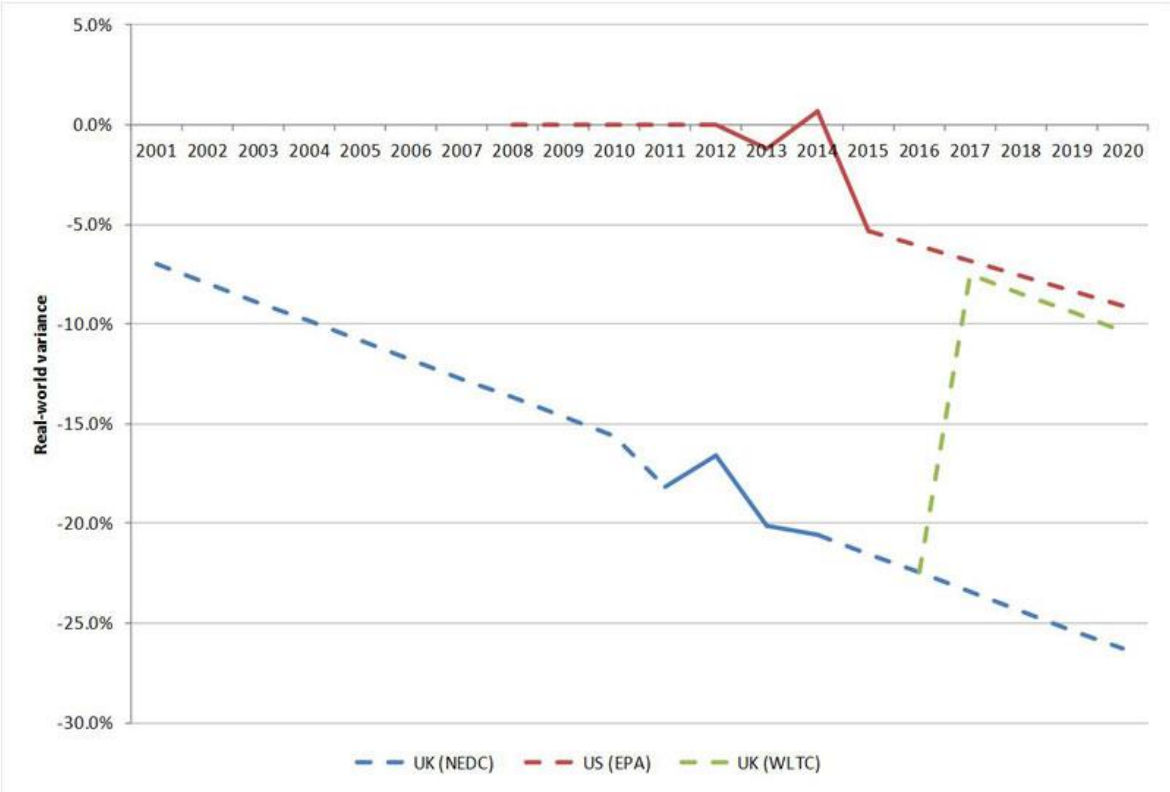

Figure 2: Gap between NEDC and real life driving (Source: Emissions Analytics)

Regarding engine system's efficiency there are different ways to improve. For example, optimizing the calibration of electronic components and sensors, exhaust gas after treatment systems, use of turbo chargers, variable valve timing and others. Especially for diesel fuel systems, there is a trend to more and more higher injection system pressures (see figure 3).

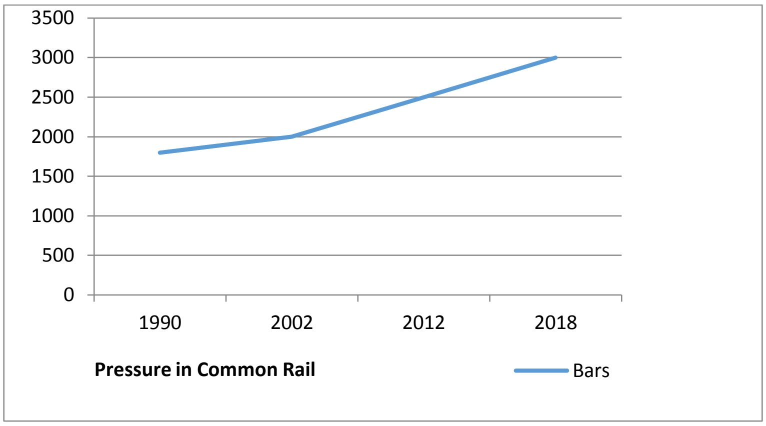

Figure 3: Trend for Diesel Pressure in Common Rail systems (Source: Extrude Hone VOC's)

These increasing pressures are very demanding for the injector components in terms of fatigue strength and surface quality, in particular the spray nozzles used in diesel fuel systems. These diesel injector nozzles are high pressure atomizers.

Manufacturing methods for such spray holes include mechanical drilling operations, laser drilling and electro-discharge machining (EDM) processes. Mechanical drilling operations tend to produce holes having circumferential artifacts through the bore. Hole-to-hole precision and accuracy can be subject to wear of the tool's cutting edges affecting the wall and burr conditions. Laser drilling is common in gasoline systems, but not in Diesel fuel systems for the time being.

A more common approach is to use EDM processes to create micro holes. EDM drilled holes are characterized by a roughened surface layer (see figure 4) of recast metal along the path of the EDM electrode. This surface layer could be removed by the high system pressure when operating in the field and generate changing spray conditions of the nozzle due to the modified geometry and dimensions.

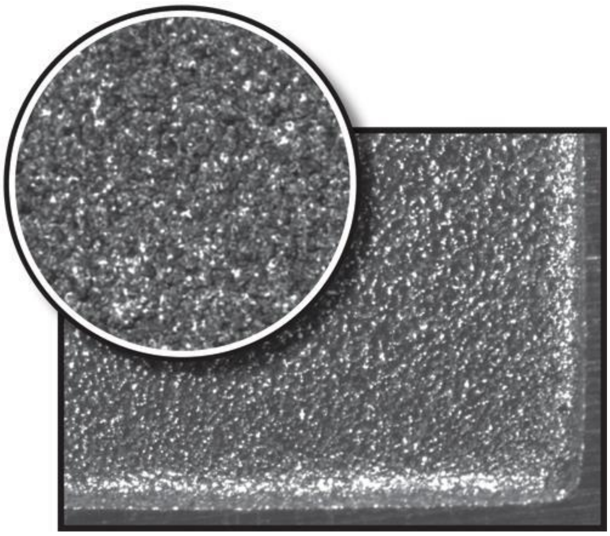

Figure 4: Typical surface roughness with EDM-process

Our Solution

To get an optimal nozzle geometry and an excellent surface quality inside the spray hole, a micro hole finishing operation is employed to refine geometric features necessary for optimal performance. The finishing operation may alter the entrance radius and surface finish. Extrude Hone's MICROFLOW™-process serves as the primary means for systematically refining the geometric features of diesel injector nozzles.

MICROFLOW™ processes direct abrasive-laden viscoelastic media through internal passages, across edges and along surfaces to remove material, polish surfaces and/or radius edges. Rheological and abrasive properties of the media and boundary conditions imposed by the processing equipment and tooling determine the locations, distribution, and extent of abrasive work done to the workpiece.

Details about the Solution

A typical MICROFLOW™ application is implemented as a one-way process in which abrasive media is presented at an elevated pressure on one side of the micro hole passage and a lower pressure is maintained on the other side of the micro hole passage. The pressure differential motivates the media flow through the passage at a high rate carrying the abrasive grains and imposing abrasive work on the walls and edges of the micro hole passage. The precise location and degree of the abrasive work results from pre-specified process parameters and media properties.

Diesel injector manufacturing operations produce thousands of parts per day. Ideally each of these injector nozzles should perform identically producing the same volume flow of fuel and the same atomization behavior. Due to the pre-aging effect of MICROFLOW™ it is possible to keep these conditions. Flow-tuning control systems within the MICROFLOW ™ processes drive the finished nozzle flow-rate to a prescribed target value. Manufacturers may require flow rate tolerances to be within ± 1% or better.

MICROFLOW ™ applications may also be engineered to produce various effects on the geometric characteristics of finished injector nozzles to get an optimized shape of the spray hole. For example, different extents of edge radius and varying degrees of surface finishing may be achieved by using different media compositions and operating conditions (i.e. using media back pressure) during MICROFLOW ™ processing (see figure 5 and 6).

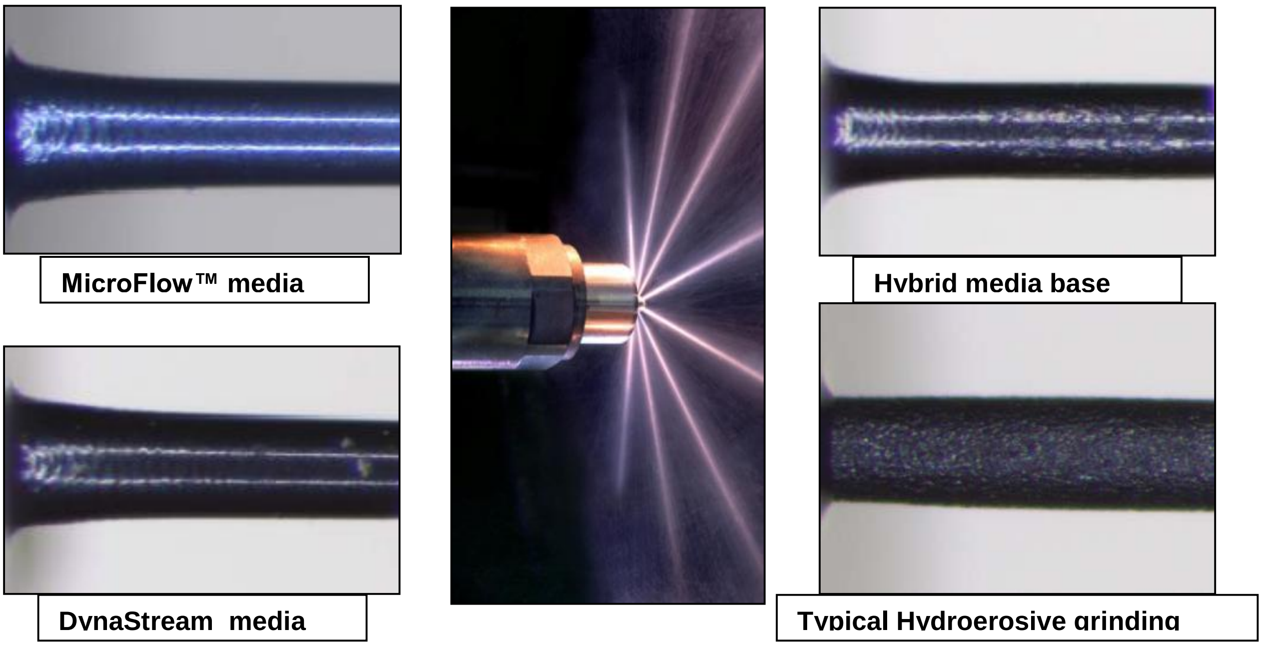

Figure 5: Different shaping of spray hole geometries based on different media

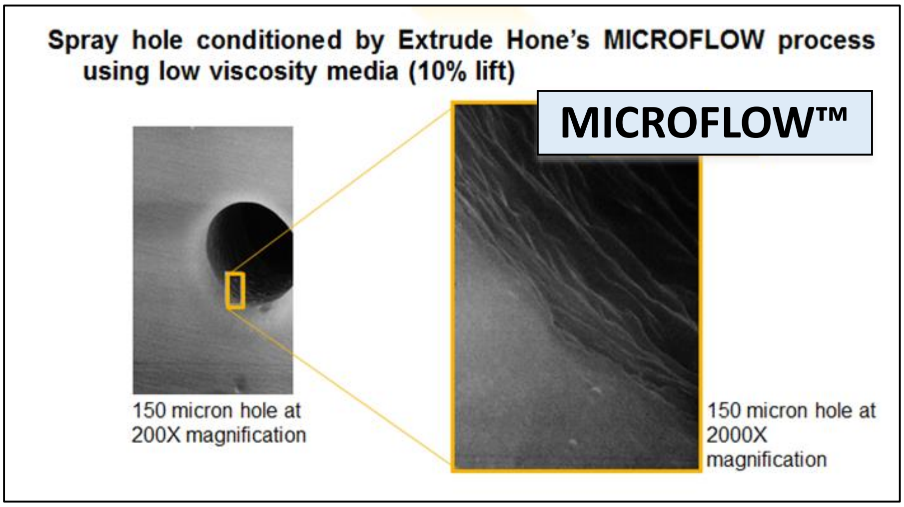

Figure 6: Superior surface finishing at the entrance and inside the spray hole with MICROFLOW ™-process

Heavy-duty MARKET REQUIREMENTS :

- High part variety @ low quantities; high valuable parts
- Flow range from 0,5 l/min - > 40 l/min
- High lift rates required (typically > 30% up to 60%)
- Flexibility
- Short set up & change over times
- Hole Geometry & Flow rate important to Market

Benefits

Diesel engines require the performance of multiple injector nozzles to atomize fuel for the full complement of combustion chambers (i.e. cylinders). Optimal engine performance, including power, fuel efficiency, and emissions, requires consistent cylinder-to-cylinder and therefore nozzle-to-nozzle performance. This consistent performance may only result from precision in the nozzle manufacturing processes, especially when incorporating the benefits of the MicroFlow™ ™ process.

Cavitation is reported to be a significant contributor to the characteristics of spray break-up during normal injector nozzle performance. Geometric features such as the edge condition at the entrance of the microholes within an injector nozzle, the surface condition, and the hole taper directly influence the cavitation performance of real nozzles. In general, a controlled degree of entrance radius improves the discharge coefficient and suppresses the occurrence of cavitating flow.

The geometric effects discussed above directly influence the consistency of nozzle-to-nozzle performance and the effectiveness of fuel atomization. The results of this influence are more or less engine power, fuel efficiency, and emissions performance. Therefore the control of the geometry is of substantial importance to fuel system manufacturers.

Benefits summary:

- Flow increase up to 60% while maintaining part integrity
- Processing times are typically less than 20 seconds
- Lower risk of cavitation damage
- Better spray impact into the cylinder, better fuel burn, higher efficiency
- Lower risk of hole distortion on higher lift rates
- The capability to create a trumpet shape geometry
- Longer lifetime of the part due to better pre-aging
- Abrasive media flow rates are accurately correlated to ISO 4113 calibration fluid
- Abrasive media will not distort spray geometry
- Tolerances typically to within ± 1% with process capability index Cp ≥ 1,67
- Typical operation range:
    - ➔ Pressure: up to max. 150 bar:
    - ➔ Volume : 300 ml/min – 40 l/min
- Small foot print

Conclusion

While various methods may be used to drill micro holes for injector nozzles, the MICROFLOW ™-process adds value as a finishing operation to improve flow precision and geometric features that dictate atomization performance. MICROFLOW ™-processing of fuel injection nozzles is the solution for shaping the geometry, flow-tuning and increasing the surface quality inside the spray hole. These capabilities of the MICROFLOW ™-process will help OEM’s to achieve and fulfill the demanded emissions given by legislation. With Extrude Hone providing machinery equipment for automotive fuel injection systems as well as for heavy-duty applications with much bigger dimensions and flow rates different market segments and their respective needs and expectations can be covered.