Advancements in Superabrasive Bore Finishing Tooling

By: Robert Marvin, Director
Global Bore Honing Operations, ENGIS Corporation

Figure 1: Superabrasive Single-Pass Bore Finishing System

There are various processes and techniques that can be used for finishing the bores in components to high precision tolerances. These include Fine Boring, Precision Grinding, Reaming, Honing and Hand Lapping. Each process offers certain advantages over the others, as well as limitations. For example, hand lapping normally produces better bore geometry and surface finish than conventional honing but is much slower and more labor intensive. Precision reaming can generally remove more material than conventional honing but cannot achieve as high of bore precision. This has led to the development of a hybrid process that combines aspects from each of the other processes to allow for higher production rates and overall bore precision. This process is Superabrasive Single-Pass Bore Finishing.

Superabrasive Single-Pass Bore Finishing (fig. 1) was originally developed in the 1970's as a means for precision finishing through bores in cast iron valve bodies. Over the years the process has been refined to a point where almost any application, in a wide variety of materials can be finished in production. Ongoing research and development programs continue to find ways of improving the process and the tooling to push the envelope of what can be achieved in regard to bore precision and productivity.

THE SINGLE PASS PROCESS

Utilizing a combination of superabrasive plated tools, pre-set to exact dimensions, the tools are passed through a bore, rotating as they complete the honing operation. While in most situations, each tool completes a single pass through the bore, certain part geometry and finish requirements may require a multi-stroke pattern. In the example below, to achieve the desired bore dimension and finish, four tools are required. (See Figure 2) Tool #1 will perform the roughing operation, removing the most material, with the largest superabrasive particles. As we progress to Tool #2 and #3, the amount of material removed decreases, the superabrasive particles gets finer, as we get closer to the final specification. The final tool, #4, will have the finest grit of the tool set, and remove the least amount of material. Factors that determine the number of tools are amount of stock to be removed, surface finish requirement, and geometrical requirements. The geometrical requirements may be roundness, concentricity, bow, or size. Using a tool set of different particle sizes a allows tools with larger superabrasive particles to remove relatively large amounts of material, and tools with smaller superabrasive particles that have finer surface finish capabilities, to be used progressively for maximum efficiency.

The Single-Pass process is in contrast to conventional honing where the tool or part is reciprocated many times while the abrasive portion of the tool is gradually expanded and retracted during each cycle. (Figure 3) It is this pre-set sizing characteristic of the tool, combined with the slow wear of the superabrasives, that allows the Single-Pass process to achieve the tightest bore size requirements with unmatched statistical process control.

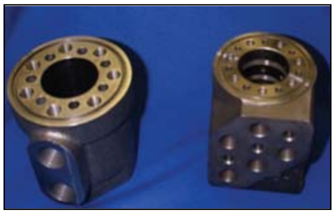
IMPROVED SIZE CONTROL

Many hydraulic and automotive sub-assemblies require extremely tight clearances between mating components such as a spool and valve sleeve. Traditionally these types of components would be separated into classes for matching during assembly, or painstakingly matched during the finishing operations. The ideal method would, of course, be to make all of the components to an exact size and eliminate the need to match altogether, however, in most cases this has not been possible in production. The following case history illustrates how bore size tolerances to under +/-0.0013mm are now being achieved in production while maintaining statistical process control.

Case History #1

In order to achieve the best possible bore precision with the Single-Pass process, it is very important that the cutting tools are allowed to follow the centerline of the existing bore with as little force as possible. This is accomplished by allowing either the component or the tooling to float. For applications where the part length is over three times the diameter of the bore, both axial and radial float

STEERING HOUSING		REQUIREMENTS	
Material:	Ductile Iron	**Bore Tolerance:**	+/-0.0013mm
Bore Size:	42.164mm	**Roundness:**	0.0013mm
Type:	Semi-Blind	**Straightness:**	0.0013mm
Length:	96mm	**Surface Finish:**	0.5Ra



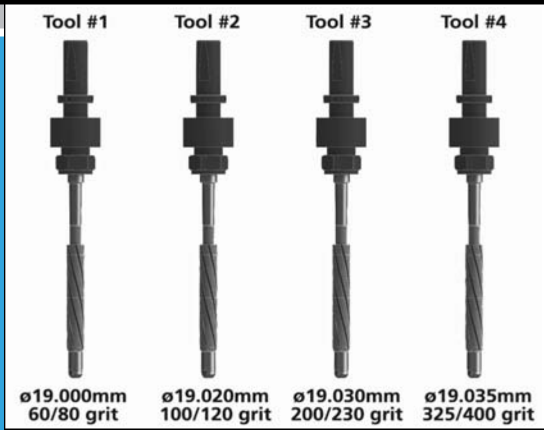


Figure 2: Typical Single-Pass Tool Progression

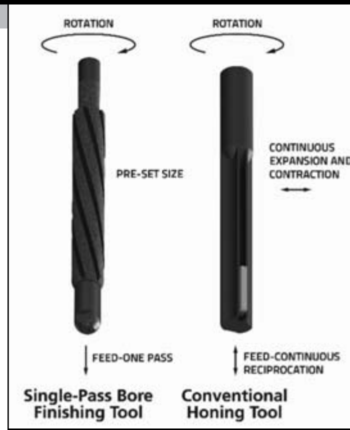


Figure 3

should be applied. Due to the shape and weight of the steering housing in Case History #1, it was determined that it would be best to hold the part rigid and float the tooling; spring loaded holders were used to provide the radial float for the tool assemblies and a special free pivoting union was incorporated inside the mandrel of the tool for additional angle float. (Figure 4)

Once the Single-Pass tooling is properly broken in, size can be maintained for relatively long periods of time. It is extremely important to not only monitor and control the size of the final finishing tool, but of each individual tools in the progression as well.

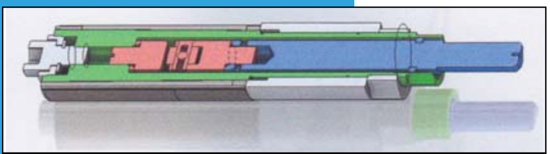


Figure 4: Tool Assembly Illustrating Internal Float Mechanism

For this application up to 0.038mm of Ductile Iron material needed to be removed. The bore had limited clearance at the bottom for the tool to pass through so a semi-blind bore finishing tool design needed to be incorporated. With this design, the taper of the mandrel runs the opposite direction from standard tooling (larger diameter in the front of the tool) and the adjustment nuts are located behind the superabrasive sleeve. The tooling progression utilized a series of 6-tools ranging from 40/50 down to 200/230 mesh diamond. (Figure 5)

Single Pass Bore Finishing System

	DIAMETER	GRIT SIZE
Station #1:	42.130mm	40/50
Station #2:	42.147mm	40/50
Station #3:	42.157mm	40/50
Station #4:	42.161mm	60/80
Station #5:	42.163mm	100/120
Station #6:	42.164mm	200/230

Figure 5: Tooling Progression

BORE QUALITY	REQUIRED	ACHIEVED
Size:	+/-0.0013mm	0.0007mm (1.67Cpk)
Roundness:	0.0013mm	0.0003mm
Straightness:	0.0013mm	0.0007mm
Surface Finish:	0.5Ra	0.25Ra

Figure 6: Application Results

In order to achieve the required bore precision each phase of the process had to be correct. This includes the Superabrasive Tooling, Part Holding Fixtures, Floating Mechanism, Machine Tool and Gage System. To be statistically capable for size the actual process tolerance needed to be held within a total range of 0.7um, including variation in bore shape and overall gage accuracy and repeatability. (Figure 6)

Case History #2

ABS PUMP CYLINDER		REQUIREMENTS	
Material:	Hardened Steel	Bore Tolerance:	+/-0.004mm
Bore Size:	8.000mm	Roundness:	0.002mm
Type:	Blind Bore	Straightness:	0.005mm
Length:	16mm	Surface Finish:	Special

Anti-lock brake systems were developed for automobiles in the late 1960's. Their primary use was to avoid wheel lock up by rapidly pumping the breaks when engaged. Since the actual time that the system would be employed is very short, life cycles of some of the components could be measured in minutes rather than hours. Advanced features on modern automobiles such as "Electronic Stability Control" and "Adaptive Cruise Control" have greatly increased the usage of these components and, in turn, require a much longer service life.

The Hydraulic Pump is the heart of an anti-lock braking system, providing the proper fluid pressure. The major components for this sub-assembly are the cylinder and the mating piston. To increase performance and overall life of the sub-assembly, it was found that one of the major factors was the surface finish of the cylinder bore. As is the case with many similar applications, having too rough of a surface finish can cause excessive wear of the bore and mating piston during use. Conversely, if the finish is too smooth then proper lubrication between the mating parts may not be possible. To solve this complex problem the surface finish requirement of the cylinder bore had to be more clearly defined, specifying a certain depth of valleys to contain oil for lubrication, and a smooth, finer finish on the outer most material that could come into contact with the piston. (Figure 7)

SURFACE FINISH	
Parameter	Requirement
Rpk:	< 0.15
Rk:	> 0.40
Rvk:	> 0.30

Figure 7

Figure 7 shows the ideal surface finish parameters for the cylinder bore that would help achieve the desired performance of the sub-assembly. It was quickly discovered that conventional bore honing processes would not be able to produce these results in mass production with any acceptable statistical capability. The

Figure 8: Special Designed Tooling Specifically for the Application

Figure 10

Continued development of the Superabrasive Single-Pass process has led to many breakthroughs that are now being employed throughout the Automotive and Hydraulic industries.

Bore size, geometrical shape, and customized surface finishes are now being held to higher precision levels than previously thought possible in mass production.

In fact, bore size control has now surpassed what can be achieved with the outside diameter finishing of the mating components and has reached the limits of current air gage capability.

manufacturer ultimately settled on an Engis Bore Finishing System customized specifically for the application and particular surface finish requirements. (Figure 8)

The customized system utilized a machine tool with six spindles and a rotary table that could use the Single-Pass process for maximum productivity. The part holding fixtures were on a gimbal base that would allow for angular float. Since the bore of the cylinder had limited clearance at the bottom, blind bore style tools had to be used. This style tool also required self-centering floating tool holders for radial positioning.

One of the advantages of using a multi-tool process is that each tool can be set to achieve a certain parameter within the surface finish requirement. For this particular application it was broken up into four distinct stages.

The first stage is to use a 100/120 grit diamond tool to remove the majority of the incoming material and achieve a very specific size and maximum surface finish. By doing so it can be assured that the deepest scratches would not damage the final results.

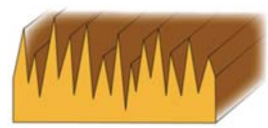
The second stage is to use a 200/230 grit diamond tool to produce a finish that will establish the valleys in the final surface texture.

The third stage uses a 325/400 grit diamond tool that is set to only remove the peaks of the finish produced in stage #2.

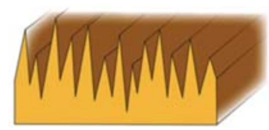
The fourth stage uses a very fine diamond brush that does not measurably change the bore size but does remove microscopic torn and folded debris from the surface.

With the specially designed system the parts were able to be consistently finished to the required surface finish at high production rates. Each machine automatically finished 240 parts per hour and with an overall perishable tool cost of under $0.03 per finished part.

STAGE #1	
Size:	-0.004/-0.006mm
Finish:	< 3.5Rz



STAGE #2	
Size:	-0.001mm
Finish:	1.75 to 2.50 Rz



STAGE #3	
Size:	Final Size
Finish:	< 0.15Rpk

STAGE #4	
Parameter	**Requirement**
Rpk:	< 0.15
Rk:	> 0.40
Rvk:	> 0.30

DUAL DIAMETER FINISHING (STEP-BORES)

Many new hydraulic valve applications are being designed with high precision, dual diameter spool bores. The traditional methods for final honing of these parts have proven to be insufficient for achieving the final precision in production. Besides needing to control the cylindricity and size of both bores, overall concentricity between the two bores must also be improved. To do this it is very important that the honing tool be able to finish both bores simultaneously, while maintaining near perfect concentricity of the cutting surfaces.

The original Dual Diameter, Single-Pass tool designs were very similar to standard thru-bore tooling, only with a step-diameter in diamond sleeve. The concentricity between the two diameters was relatively easy to establish, however individual size control was not possible. To get around this issue, most applications used an additional standard tool to remove the final microns of stock in one of the bores.

New designs now utilize Single-Pass tooling with individual diamond sleeves on the same mandrel, with independent size adjusting features. As shown in Figure 10, the diameter of the front diamond sleeve can be increased by turning the front adjusting pilot nut. The second diamond sleeve is larger in diameter than the front sleeve, and diametrical size can be increased by inserting a removable adjusting nut over the tool and engaging the threaded portion of the mandrel located behind the sleeve. In both cases the adjusting nuts are designed to push the sleeves up the taper of the mandrel and increase the cutting diameter in a very controlled manner. Typically, size adjustments to under a micron are possible.