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Deep Hole Drilling for the Rear Endplate of the BaBar Drift Chamber

1 Gun Drilling

The holes for the field-wire feedthroughs in the drift chamber endplate are to be 2.5 mm in diameter, while the read endplate will be about 25 mm thick. Thus the depth:diameter ratio is about 10:1. In the drilling industry any hole with this ratio greater than about 3:1 is considered a deep hole.

To use twist drills for deep holes one must first drill a spot hole, then drill using a 'pecking' cycle with the drill bit lubricated by a spray mist, followed by a ream to set the final diameter. This appears to be the technology used is past drilling of drift chamber endplates. See the Appendix for a description of drilling the BES chamber.

The highest-quality deep holes are drilled with another approach called gun drilling. In this the lubrication is provided by high-pressure oil that flows through a channel inside the drill bit and out its tip. Drilling is continuous (no 'pecking') and single pass (no spotting or reaming). Typical tolerances are straightness of 0.001″ per foot, holes diameters to 0.0005″, and hole taper to less than 0.0005″. Hole centering to 0.0005″ is obtained by drilling through a bushing to contain the whipping of the long gun-drill bit.

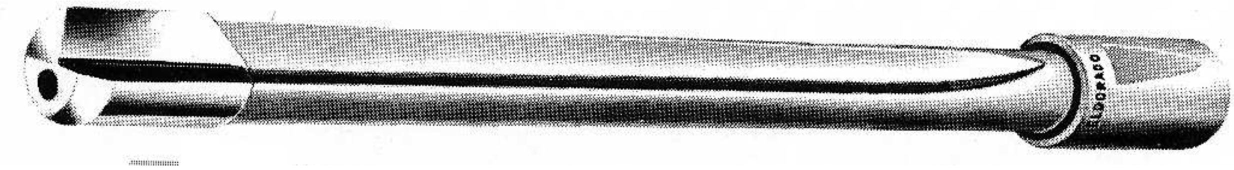

Figure 1: A gun-drill bit showing the hole in the tip for the coolant oil and the V-groove for chip removal.

Figures 1-4 show various aspects of a gun-drill bit. The figures were provided by Eldorado of Milford, CT (Robert Fecteau, 203-878-1711) who developed this technology in 1948. Figure 6 shows an air cylinder made by Eldorado to hold the bushing through which the drilling is done; the bushing can be moved into contact with the work piece for drilling, then pulled back a few mm while the piece is moved to the next hole position.

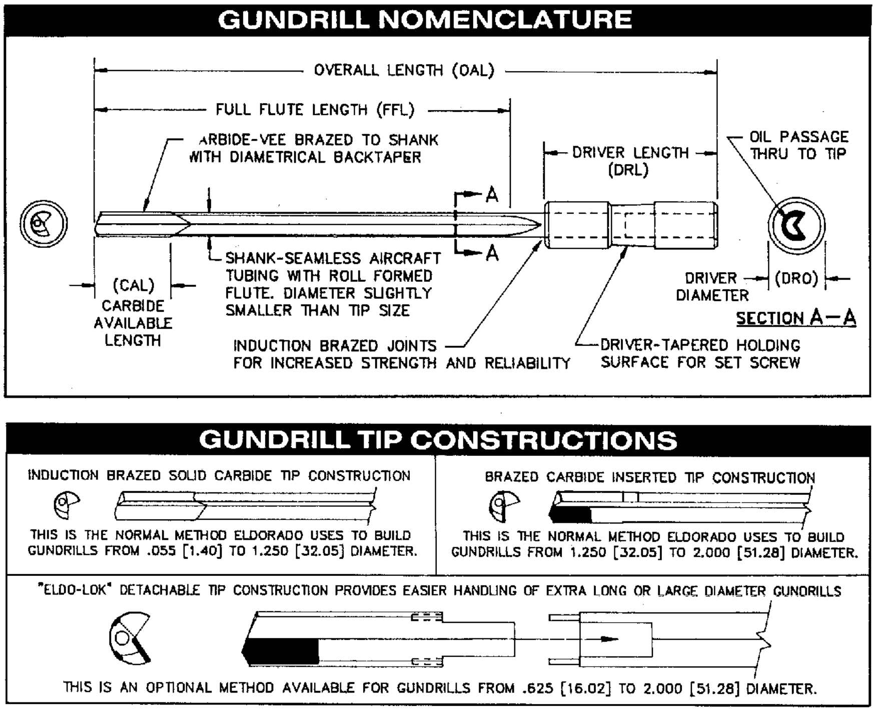

Figure 2:

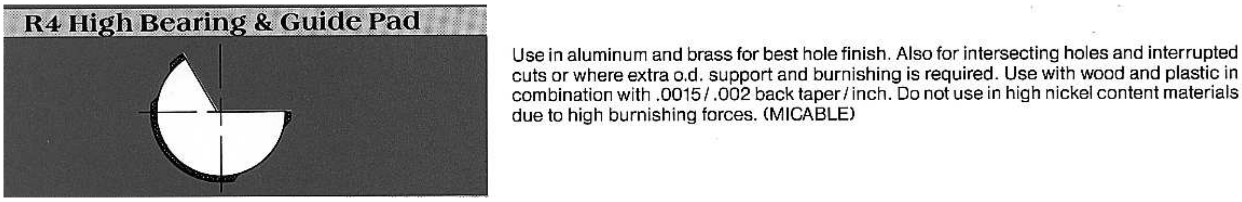

Figure 3: End view of the carbide cutting and bearing surfaces on a gun-drill bit.

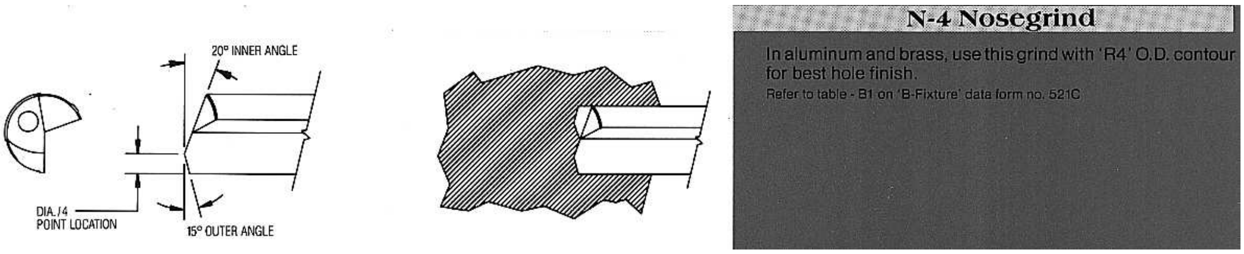

Figure 4: Side view of the tip of a gun-drill bit.

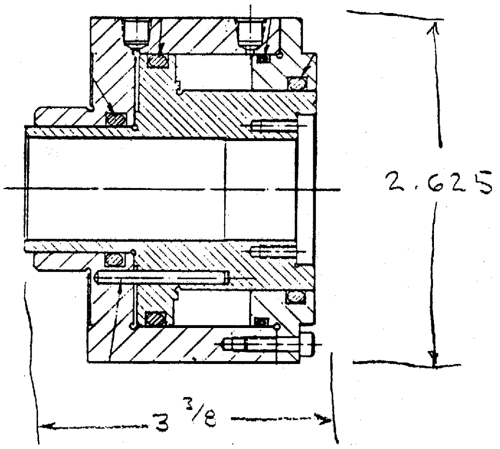

Figure 5: Sketch of an air cylinder to position the bushing against the work-piece.

Gun drilling is typically performed with spindle speeds of 10,000-15,000 rpm, and feed rates in aluminum of 2-5 inches per minute. This corresponds 12-30 seconds per hole in a 1″-thick plate. At, say, 15 seconds per hole it would require 16 8-hour shifts to drill 30,000 holes. The life of a solid-carbide gun-drill bit is 1-2 shifts. Each bit costs about $125. The bits are resharpenable (in a fixture costing about $2000). In principle, use of a single, resharpened tool would minimize variation in hole diameter.

The lubricating oil in a small-diameter bit needs to be at a pressure in excess of 1,000 psi to insure effective chip removal down the V-groove of the bit. The most specialized item in gun drilling is a rotary gland that induces the high-pressure oil into a shaft rotating at greater than 10,000 rpm. See Figure 6. Variations on this rotary seal are made by Eldorado, Deublin (Bryce Green, 847-689-8600) and by UNISIG (Anthony Fettig, 414-252-5151).

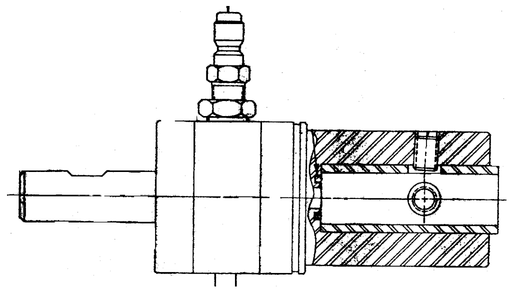

Figure 6: Sketch of a rotary gland that induces 1500 psi cooling into the shaft of a spindle rotating at 10,000 rpm. The shaft at the left is mounted in the spindle, and the gun-drill-bit driver mounts in the shaft to the right.

Eldorado sells a gun-drilling head including spindle, chip box, bushing holder, ball-screw feed and motor control mounted on a steel bed, as shown in Fig. 7. However, it does not appear easy to mount this unit on the Lucas horizontal boring mill with which we propose to do the drilling. We have asked UNISIG to quote on a gun-drilling spindle that could be mounted on the quill of the Lucas machine. It also appears feasible to construct the gun-drilling head ourselves using a compact high-speed spindle such as that shown in Fig. 8 from Setco/Whitnon (Larry Hermanowski, 203-667-2607), along with the rotary gland and bushing holder from Eldorado.

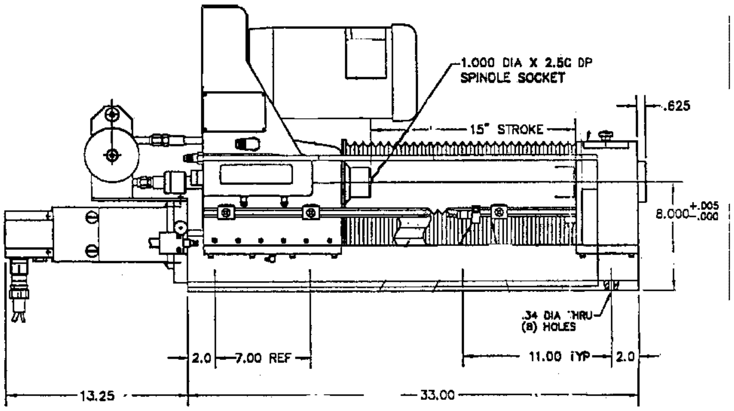

Figure 7: Sketch of the gun-drill machining head sold by Eldorado.

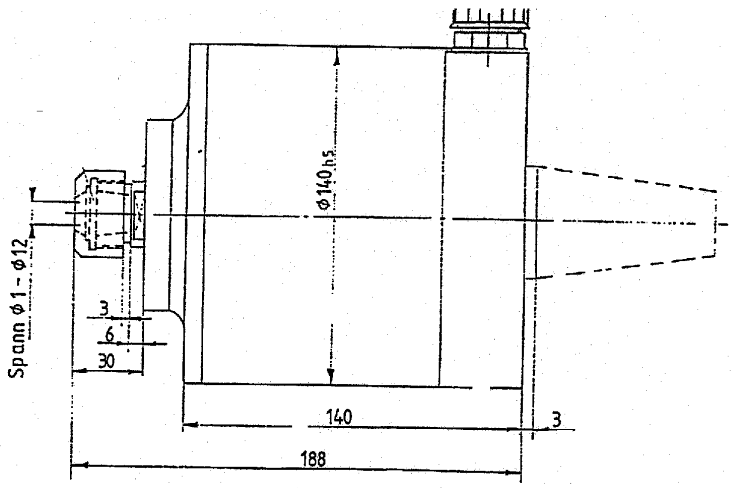

Figure 8: Sketch of a compact 30,000-rpm, 2.5-kW spindle manufactured by Setco/Whitnon.

Eldorado sells recirculating high-pressure coolant-oil systems such as that shown in Fig. 9. These systems use 5- and 10-μm filters to clean the White and Bagley #2190 oil. The oil pressure in the bit is monitored and interlocked to the drill controller to halt drilling in case of a broken bit or one with blocked coolant passages.

A preliminary cost estimate for the gun-drilling head and coolant system is about $25,000.

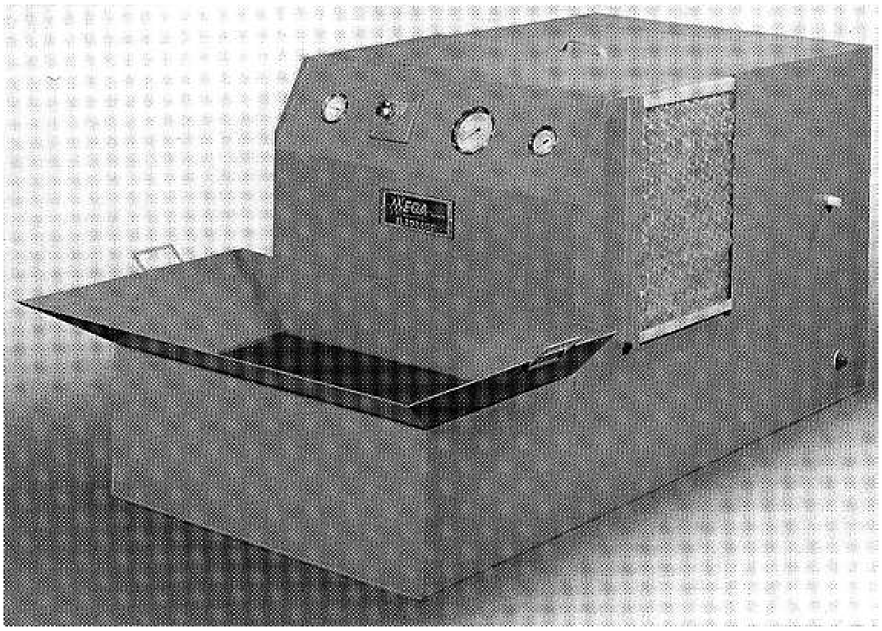

Figure 9: View of the high-pressure coolant-oil system manufactured by Eldorado.

2 Appendix: Drilling the BES Chamber Endplate

The following is from Scott Whittaker of Boston U.; scott@bu.edu, phone 617-353-2690.

Regarding drilling lots of holes in aluminum: we did the end plates for the BES rebuild, and it was quite a project. The plates were 1.5″ thick, 90″ diameter, and had about 25k 4-mm-diameter holes plus a bunch of larger holes for alignment, mounting, pre-stress rods, *etc.*, and 3-4k of blind tapped 3-mm holes on the backside for mounting electronics. Precision goal for the 4-mm holes was 50 microns on the center and -0/+10 microns on the diameter. We did lots of preliminary studies, and learned a lot from them. Here is some of the saga:

The work was done on our Giddings and Lewis 4″ horizontal boring mill. The plates were drilled flat, *i.e.*, they were not distorted into the final position they would assume when all the wires are under tension. The plate was mounted vertically on a CNC rotary table, which we used to index the plate by 90°to four quadrants, since the table travel (84″ horizontal) and head travel (60″ vertical) were insufficient to do the job in one go. Sufficiently rigid fixturing took a bit of work. All the holes in one 90° sector were done by moving the mill table and head, rather than by indexing the rotary table, because we thought the reproducibility would be better that way. The programmable rotary table was handy, however, for doing the auxiliary holes.

It was necessary to control the temperature of the workpiece and the mill to a few degrees C to avoid thermal effects. We intervened with the building managers to override various overnight, weekend, and holiday building air conditioning programs designed to "save money". Warmup of the mill for 45 minutes or so was essential: spindle growth (of a significant fraction of a mm as I recall) otherwise messed up our countersink/deburring operation. We instrumented the plate and the mill with temperature sensors hooked up to a PC nearby, which sounded an alarm if the temp got out of tolerance.

We did a number of tests to develop speeds and feeds and the lifetime of one bit. The test pieces were measured on a coordinate measuring machine to verify hole center position, and we used dowels and an intramike to check diameters. For each hole we did a spot to set the position, then drilled, then reamed, then used a countersink to chamfer the edge and deburr. The plate was bolted to a backup plate that was almost as large as the workpiece, which helped with the rigidity of the plate and also reduced the burring on the exit side. We did final deburring on the back side by hand as part of the cleanup. We used high-helix drills, not carbide I think finally, and of course drilled from the inside surface where the hole location precision was required.

We used a 6X speed increaser, made by a Swiss company called IBAG, for the drilling. This was essential to get production time down into a finite number of months. The drilling step took the most time; we got this down to 17 seconds per hole. Movement to the next hole took a second or so, once we revised the program to go in an order that minimized the distance between successive holes. The program specified a drilling cycle that pecked and withdrew the bit to clear chips. This relates directly to hole precision and also to bit life. We checked holes in production with go/nogo gauges; I think we got several hundred holes per bit.

I believe we ran our spindle at 1048 rpm, and hence about 6,300 rpm with the speeder head. Faster would be better, but this big mill wasn't meant to go superfast. You would really need a speeder head to do the job. What you really care about is the feed rate – how fast the hole deepens. The time is not linear with the speed, since the pecking cycle of withdrawing the bit to clear chips doesn't change speed. You really have to do tests with the bits, material to be drilled, lubricant, and the mill – varying the speeds and feeds to optimize the production rate while maintaining acceptable tolerance.

The mill used a water-based lubricant/coolant that also cooled the speed increaser. It was essential to improve the chip filtering on the coolant to avoid fine chips getting into the speed increase and clogging the channels, causing it to overheat. It was also important to clean the lubricant off the aluminum after not too many weeks to avoid corrosion of the aluminum. We did a steam cleaning, followed by alcohol wipes and a deionized water rinse – quite a job.

The second plate took about two months, working two shifts a day. You can check out some pics on http://cbsgi2.bu.edu/cb/bes.html. Physicist input was pretty important, or so I'd like to believe – I was quite closely involved in the project, worrying over the tolerances and how we knew if we were meeting them. I also wrote a computer program that read the CNC program our shop personnel had prepared and checked it for correct hole positions. This had two interesting outcomes: first, we disagreed on a large number of holes and recognized an internal inconsistency in the design drawings that had to be resolved; second, after that was resolved I found the programmer had omitted a 300 micron offset in one of the rows of sense wire holes, which would have been difficult to see but would have been a Big Problem if put into metal. The outcome of all this was very satisfactory. The plates were checked by the Chinese collaborators who strung the chamber, and they reported that all specifications were met, which was "very surprising and admirable"(!). It is actually very difficult to check to the level of these tolerances.