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REAMING EXPERIMENTS FOR THE LETHALITY TEST SYSTEM

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Abstract

Various reaming techniques were tried for use on the barrel of the Lethality Test System railgun. This report covers the successes and failures of the reamers and the techniques that were tried.

Introduction

The Lethality Test System (LTS) was funded as part of the strategic defense initiative (SDI) program. The LTS was a railgun project whose goal was to provide impact data at velocities up to 15 km/s. The nominal bore diameter of the railgun barrel is 1 in., and the length is 72 ft. The complexities of constructing a successful railgun barrel for such an application requires that we have the capability to finish the bore in-place. The combination of bore size and barrel length, and the differences in the properties of copper and Lexan bore materials required that new bore-finishing methodologies be developed.

In the LTS reamer tests, two types of reamers were used: the first was a six-bladed carbide reamer, and the second was a single-point carbide reamer. All of the tests were made on a 10-foot test bore. Many tool geometries and machine parameters were tested. This report covers only the significant aspects of the reaming and the important lessons learned.

Previous Experience and Present Goal

Previous reaming on LTS prototypes up to 6 ft long had been done with high-speed steel, six-fluted, shell reamers. Neither the previous process nor the reamers performed as well as desired; the following problems were evident:

1. Chips got caught in the reamer, damaging the surface finish on the prototypes.
2. The Lexan cut at a smaller diameter than the copper.
3. The bore was not straight enough.
4. The surface finish was poor, even where chips did not cause the damage.
5. The copper pulled out at the copper to Lexan interface, badly damaging this joint.
6. Tools wore rapidly.
7. The diameter of the bore was out of round and varied along the bore.

Our goal was to correct these problems and produce a bore with the following specifications:

1. Straight to within ±0.003 in./ft.
2. On size to within ±0.001 in.
3. Round to within 0.001 in. total.
4. A surface finish of 32 rms or better.

Setting Up

A new reaming system was built and new reamers were purchased to solve the problems we had built a new power drive with electric motors and variable speed belt drives. The spindle motor was 5 HP, with a variable speed of 240 to 1600 rpm. The slide motor was 3 HP. An electronic speed control that was added to the motor gave us a feed range of 0 to 20 in./min.

We purchased six-bladed carbide reamers, which we honed would wear better and cut cleaner. These reamers had a negative rake of 10 deg. The purchase included rear pilots of various sizes, which were to be used at different bore diameters. The drive shafting attached at the fronts of the reamers by way of a slip joint locked with set screws. The entire assembly, reamer, pilot, and drive shaft, is shown in Fig. 1.

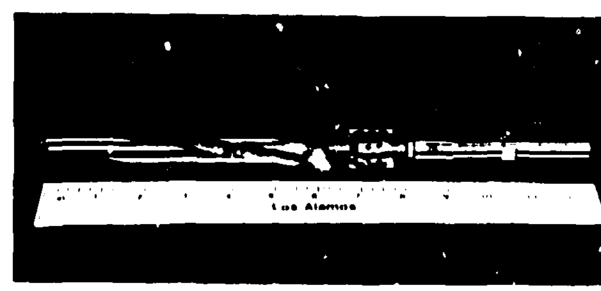


Fig. 1. Six-bladed reamer with rear pilot and front drive shaft.

Because no provision was made to support the shaft in the bore, we had to turn down one end of each shaft, near the joint, to 0.5 in. in diameter and to make shaft supports that would slip onto this section. The shaft with the support is shown in Fig. 2. These shaft supports were made in our shop from maraging steel. They were hardened to about 54 Rockwell for spring strength. The shaft turns inside the support, and the support does not rotate while being pulled through the bore. Calculations showed that a support was needed every 3 ft on the shafting; otherwise excessive sagging would occur between supports, causing vibration in the drive shaft. This support method limited the length of the shaft segments to 3 ft because the supports had to be placed on one end of the shaft.

To start the reamers into the bore, we made 18 in. steel pilot tubes. A pilot tube was made for each reamer size, allowing 0.001 to 0.002 in. of clearance on the diameter. A pilot fixture was built to allow for adjustment in every direction, except the axial direction, of the tube.

The reaming process required that coolant flow through the bore during reaming. A coolant system was built for this purpose. This system had a maximum flow capability of 12 gpm and a maximum pressure capability of 400 psi. It was designed for closed loop recirculation and the chips were trapped and filtered from the coolant.

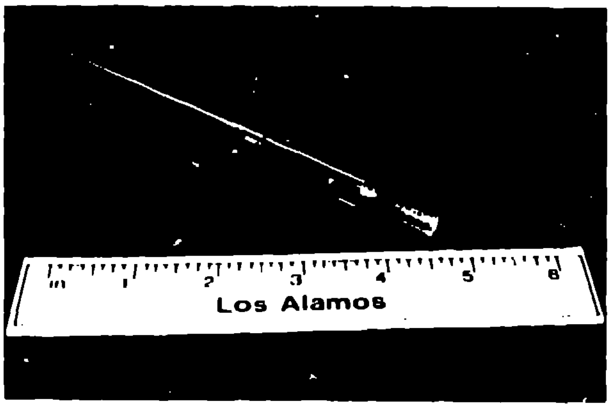


Fig. 2. Shaft support on the end of the 3-ft shaft joint.

Fig. 3. Single-point reamer with stub shaft.

The completed system requires that the reamer drive, bore, and pilot tube be aligned on axis, and we had a 30X leveling scope for this purpose. Clear plastic slugs were made to fit the bore diameters and scribed with a cross hair for use as targets.

Two single-point carbide reaming tools were ordered for evaluation. These tools were modified so that they could be connected to the same drive shaft that was used with the six-bladed reamers. Figure 3 shows the single-point reaming tool.

System Performance

This section discusses the performance of the individual components of the reaming system and describes the different machining techniques that were tried.

Power Drive

Although the speed range of the spindle was 240 to 1600 rpm, the spindle drive put limitations on us. It would not deliver enough power. When we tightened down the clearances on the reamer pilots, the spindle drive belt would slip. Although there was a 5-HP motor on the spindle, we needed at least a 7.5 HP motor with an adequate drive system to do the job better.

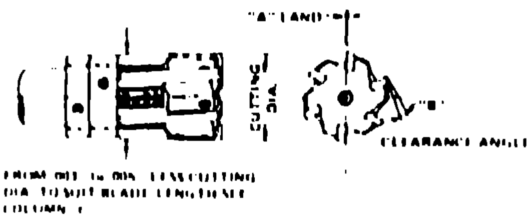
Another problem that limited the rotational drive capability of the system was the strength of the shafting. The 5/8-in. slip-joint shafting twisted at the joints because of weaknesses at these points and had to be replaced. The replacement shafting was made up in the shop from a 5/8-in. drill rod and was simply threaded at the unions. Although this shafting was better than the original shafting, it still was not strong enough at the joint. A 3/4-in. shafting with threaded joints would be more desirable. The threaded joint worked better because it did not come loose during reaming as the original shafting did.

Six-bladed Carbide Reamers

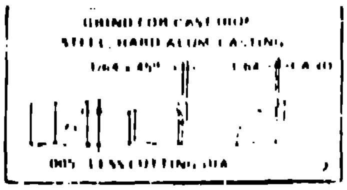
The grinding specifications are shown in Fig. 4. It was recommended that we use a reamer to pilot clearance from 0.0005 in. to 0.001 in. and a feed rate of 16 ipm at a rotational speed of 800 rpm. These recommendations were followed as a starting point but produced very poor results. The surface finish was very poor, the bore was scored by chips being caught in the reamer and the copper was being smeared into the Lexan at the seam, causing heavy damage to the seam.

Reaming tests were conducted with these tools to find the best tool geometry and cutting parameters. An improvement was made by changing the tool geometry from a 45-degree front lead to a 15-degree front lead, with a clearance angle of 3 degrees rather than 10 degrees. The optimum feed rate and spindle speed were found to be 4 ipm at 500 rpm. A continual problem during these tests was that the pilot locked up in the bore. To correct this problem we ground the reamers to 0.003 to 0.004 in. over the pilot diameter to provide adequate pilot clearance in the rough bore. When these improvements were made, we felt that we were getting the best results possible with these reamers, but chips were still getting caught in the reamer and the copper was still pulling into the Lexan.

Results from these tests indicate that these reamers did little to straighten the bore. We measured a 0.0023-in. bow in 36 in. of bore. This



REAMER SIZE	A	B	TAPER PER INCH CLEARANCE C
1" to 1 11/16"	.010	10°	.002



was largely the result of our system limitations for these tests. The alignment system for starting the reamers into the bore was inadequate, and we could not drive the reamer with enough power to allow adequate reduction of pilot clearance. One of the limitations the reamers imposed was that they would not cut the Lexan cleanly. This also restricted the pilot clearance. The copper cut within 0.0005 in. of the nominal diameter, but the Lexan cut 0.0015 in. small on the diameter.

The six-bladed design with the spiraled coolant flutes through the pilot is the best one for making initial passes through the bore. The multiple blades and the spiraled pilot are the best at handling the clean-up job through the mismatched rails. The drawbacks of the tool are (1) that the negative rake of the tool does not cut cleanly, (2) the tools wear quickly, (3) the joint between the reamer and pilot is not precise, and is hard to keep tight, and (4) chips get caught in the reamer.

Single-Point Carbide Reamers

In an attempt to purchase a better performing reamer, we located a single point carbide boring tool that is quite different from commonly used reamers. This tool is shown in Fig. 3. It solves many of the problems we experienced with the six-bladed reamers, but the standard design purchased leaves some room for improvement for use in railgun bores. The reamer, pictured in Fig. 3, has been modified slightly from its original configuration. The front end was ground down because chips were getting caught in this area, and the wear pads were ground back by 0.125 in. because they were dragging in the cut.

The single-point insert design of this tool required no grinding to size, and the cutter body and pilot are one piece. This tool design saves a lot of time and eliminates the troublesome joints. The cutting action is also quite different from that of a fluted reamer. The fluted reamer is designed to cut at the front or leading edge, but the single-point tool cuts more at the circumference of the insert. The inserts that were used have a 12-degree positive rake angle and they could cut 10 ft of bore with little sign of tool wear. This tool is capable of making a very clean cut, leaving an almost mirror finish on the copper, and of cutting the Lexan cleanly without pushing it back. Consequently, the bore diameter measured within +0.0003 in. of nominal for both the copper and the Lexan. Figure 5 is a photo of the rails after they were finished with the single point reamer.

Fig. 5 Finished rails and single point tool

Straightness measurements indicated that the straightness was not improved from the previous pass made with the six-bladed reamer. This is, unfortunately, the only aspect of the bore that could not be improved with this tool. A longer pilot body with less clearance would be required to straighten the bore. More power and better alignment for starting into the bore would also be required. With the current system, a pilot clearance of 0.001 to 0.002 in. is required to prevent the reamer from locking up in the bore. This clearance is less than that required for the six-bladed reamer because the Lexan cut to the same size as the copper.

One fault in the single-point tool is the use of straight wear pads. The straight wear pads hammer and chatter in a rough bore because the straight edge hits the rail joint abruptly. This problem can be eliminated by first using the fluted reamers to rough machine the bore.

Coolants and Coolant System

The coolant used and the way it is applied can have an effect on the bore finish that is obtained. The best coolant we found for the job is a synthetic water-soluble coolant that is recommended for use with copper and Lexan and is free of hydrocarbons so that it will not cause any off-gas problems when the bore is put under a vacuum. A 20:1 mix of this coolant in water worked very well. For all of the reaming, the coolant system was set up to provide the maximum flow rate of 12 gpm, and the pressure ran from 100 to 150 psi. The coolant was flowed through the bore in the direction of travel of the reamer.

Several other coolants were tried in the hope of finding one with a much higher viscosity, but none could be found that would satisfy all of the requirements. Such a coolant would carry the chips better and give better lubrication and flotation to the reamer pilot.

Conclusions

The Previous Experience section of this report listed seven problems that had been identified and needed to be corrected. Under Present Goals, we listed four specifications. We were able to satisfactorily correct six of the seven problems and to meet three of the four specifications that were our goals. The specifications for hole size, roundness, and surface finish were all exceeded by a wide margin. The size of the bore was machined within +0.0003 in., and though true roundness of the hole could not be measured with our equipment, the diameter measurements that were taken are evidence that the roundness of the bore is also within +0.0003 in. The surface finish was visually inspected. It was obviously far better than a 32 RMS finish. The single point reaming tool left the surface with an almost mirror finish. This sample in Fig. 5 shows some burnishing in the copper surface, but otherwise it is a good example of what can be accomplished with the single point tool.

The only specification that could not be met with the single point reaming system was the straightness specification. The alignment system was the biggest contributor to this problem, and it is the first thing, given the time and money, that needs to be corrected. A larger spindle drive and stronger drive shaft would be the next improvements to make to the reaming system. With these corrections, reamers with longer pilots could be run with tighter clearances to achieve the desired straightness. Both the six-bladed and the single-point carbide reamers have advantages. A hybrid of the two designs may be the best tool for the job.

From our experiences in testing these machines, we learned important lessons about successfully reaming a railgun bore. The more passes that are made during reaming, the better the chances will be of producing a good bore. This means that more material has to be left for removal than was previously thought. At least 0.100 in. on the diameter of the bore is required, and even more would be advisable to allow for multiple passes to be made. In this way, we can gradually bring the bore into tolerance. The reaming tests were done in bores that had crooks of up to 0.030 in. per foot, and normally, 0.010 to 0.020 in. would be cut from the diameter in one pass. As the numbers indicate, several passes are required to straighten a crook of this size. The reamer must be allowed to follow the curvature of the bore, to some extent. At certain locations in the bore, the reamer may cut into one side and not take out a full diameter cut. When this occurs, the reamer will chatter and leave a very poor finish. To avoid excessive damage to the bore, it is best to back the reamer out and start through the bore again with a tool, such as the six-bladed reamer, that is 0.010 to 0.020 in. larger, until a full diameter cut can be maintained through the bore. This will result in a fairly clean bore that can be finish machined with the single-point tool.