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TECHNICAL REPORT ARCCB-TR-89002

HIGH SPEED ABRASIVE BELT GRINDING

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JOSEPH BAK

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is the culmination of a two-phase project established to reduce current stock removal costs and eliminate finish turning operations of tubes by combining rough stock removal and finish grinding. The first phase was designated for engineering and investigation into the feasibility and application of abrasive belt grinding technology. This information was then used to generate a specification establishing some criteria for design and (CONT'D ON REVERSE)		

20. ABSTRACT (CONT'D)

manufacture of a machine to remove heavy stock and finish tubes utilizing abrasive belt technology. The specification was subsequently used for the acquisition of a machine to perform the tasks. The second phase was designated for testing of the equipment and establishing production parameters.

High speed Gun barrel machining

Fig A

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INTRODUCTION

When large caliber gun tubes are fired, the counteracting force in the opposite direction of the projectile travel is called recoil. There are variations in design as to how the gun is held in its respective recoil movement or mechanism. Some guns have recoil slide surfaces machined on the outside diameter of the breech portion of the tube. This portion of the tube would then be captured in a bearing cylinder simulating a hydraulic piston absorbing the recoil forces. This design is used for tubes mounted in a vehicle such as a tank.

Other guns have hoop assemblies shrunk on a precision outside diameter near the breech end. The hoops are then machined and fitted with brass/bronze alloy slide rails on which the recoil sliding movement occurs. This design is used on some of the towed howitzers.

In either case, these gun tube breech end surfaces must be machined to close tolerances along with finish requirements and configuration criteria such as roundness, cylindricity and size.

STATEMENT OF THE PROBLEM

The procedure used for machining these surfaces is to remove (rough machine) the majority of stock by lathe turning, then remove the remainder by cylindrical grinding to the drawing requirements. Carbide inserts used on these long lathe cuts wear, and therefore cannot be used to finish machine the slide surfaces since they are not able to maintain size within the geometric tolerance requirements. The subsequent precision grinding operations are done in large cylindrical grinding machines using large abrasive grinding wheels.

Approximately 0.030-inch is left on the diameter for this finishing grinding operation.

The operations presently used to remove material from the recoil surfaces of gun tubes are some of the most costly with respect to time, tooling, handling, and machinery. For this reason they become good candidates for cost reduction programs by way of improvements or changes to the present processes.

APPROACH TO THE PROBLEM

To align the problem into the proper perspective, an 8-inch M201 gun tube was chosen as the subject component for this project because it is the largest tube presently being manufactured at Watervliet Arsenal. Figure 1 is a drawing of the 8-inch M201 gun tube showing the tube's configuration along with identifying rough and finish diameters and their respective tolerances. It was determined that if gains can be made on this tube, being the largest, results could be applied to the smaller tubes as well.

The volume of stock to be removed on this tube is approximated by the following formula:

$$\text{Volume} = \frac{\pi}{4} [(\text{Large Diam.})^2 - (\text{Small Diam.})^2] \times \text{Length}$$

OR

$$V = \frac{\pi}{4} [D^2 - d^2] L$$

Figure 2, which is a sketch of an 8-inch M201 gun tube, shows the collar, thread blank, and hoop zones with their respective finish size and distance from the breech face. Therefore, using D for the rough diameter and d for the

finish diameter along with their respective distances L from the breech face,
the following calculations were made:

Zone 1 - Thread Blank and Collar

Rough Diameter - 17.750 Inches
Finish Diameter - 17.350 Inches - Thread Blank
17.388 Inches - Collar

$$V = \frac{\pi}{4} [D^2 - d^2] L$$

$$V = \frac{3.1416}{4} [(17.750)^2 - (17.350)^2] 12$$

$$V = \frac{3.1416}{4} [315.0625 - 301.0225] 12$$

$$V = \frac{3.1416}{4} (14.04) 12 = \frac{529.297}{4} = 132.32 \text{ cu. in.}$$

Zone 2 - Hoop Zone Located Between 14 and 92.4 Inches From the Breech Face

Rough Diameter - 17.220 Inches
Finish Diameter - 17.010 Inches

$$V = \frac{\pi}{4} [D^2 - d^2] L$$

$$V = \frac{3.1416}{4} [(17.220)^2 - (17.01)^2] [92.4 - 14]$$

$$V = \frac{3.1416}{4} [296.53 - 289.34] 78.4$$

$$V = \frac{3.1416}{4} [7.19] 78.4$$

$$V = 442.73 \text{ cu. in.}$$

Zone 3 - Hoop Zone Extending 111.4 to 145.9 Inches From the Breech Face

Rough Diameter - 15.720 Inches
Finish Diameter - 15.500 Inches

$$V = \frac{\pi}{4} [D^2 - d^2] L$$

$$V = \frac{3.1416}{4} [(15.700)^2 - (15.500)^2] [145.9 - 111.4]$$

$$V = \frac{3.1416}{4} [247.12 - 240.25] 34.5$$

$$V = \frac{3.1416}{4} [6.87] 34.5$$

$$V = 186.15 \text{ cu. in.}$$

Total Stock Removal

132.32	Cu. In. Zone 1
442.73	Cu. In. Zone 2
<u>186.15</u>	Cu. In. Zone 3

761.20 Cu. In.

The stock removal rate for the lathe turning operation prior to finish grinding is approximately 1.8 cubic inches per minute (extracted from the production time standard). The average stock removal rate for the grinding operation is 0.354 cubic inch per minute.

Several attempts had been made utilizing various carbide inserts to accomplish the metal removal operation in one set-up, but these attempts were not successful. During the long cuts, the tool points would break down, resulting in the diameter differential or taper which is totally unacceptable. This necessitates that the finish grinding operation be essential to the production process.

In order to consider other possibilities which could be acceptable, an investigation outside the scope of standard tooling and procedure changes was

initiated. A method, which would remove a high volume of stock at a rapid rate and also be capable of finishing the slide surfaces to the tolerance, finish, and configuration requirements in one set-up, was needed. This approach set the guidelines used for this effort.

Recent advancements in abrasive belt machining technology showed some promising possibilities to this application. The development of coated abrasives for the machining of metal, other than polishing, was delayed for several years because of the lack of adequate waterproof adhesives. This prevented the belts from being used with coolants. Their application was restricted to woodworking and gentle polishing of metals for finish exclusively. However, the introduction of waterproof adhesives opened the door to the development of better abrasive belts which could now remove metal at a greater rate without developing excess heat when used with coolants.

Additionally, coated abrasive backing materials were also an area which had to be developed. Backing which holds the adhesive and the abrasive grit is generally either paper or cloth. Paper is usually limited to non-critical applications, such as the home-workshop market and very light duty sanding applications. The cloth, on the other hand, must meet two somewhat conflicting criteria; it must be flexible enough to bend around pulleys (contact wheels or rolls) yet be strong enough not to tear and wear when pressure is applied, and pressure is, obviously, one of the key factors in grinding.

In order to accommodate the increased cutting forces necessary to obtain greater stock removal rates, it became necessary to design and manufacture

more massive and more sturdily built machines. Normally, when belts were used in a polishing application they would free float over the workpiece without changing its contour. Machines are now being designed with two or more pulleys, one of which is called a contact wheel, which forces the abrasive belt surface against the work (Figure 3).

SOLUTION TO THE PROBLEM

An investigation into the private sector resulted in the discovery that belt manufacturers had conducted extensive testing using these newer products relative to backing, abrasive materials, and waterproof adhesives. Their results proved to be positive in the area of stock removal rates and other characteristics, such as finish, size control, and roundness.

Special machine tools were also built using coated abrasives in lieu of grinding stones (wheels) as a result of demands made by manufacturers with specific applications. This was an indication of the confidence being rendered to this technology as being competitive with some of the traditional, standard methods of stock removal, e.g., lathe turning and cylindrical grinding.

Based on this information, a specification was prepared utilizing all of the technical data pertaining to coated abrasive belts and associated equipment. This specification entitled "High Speed Abrasive Belt Grinder," #LCB0467-01-II, was used for the acquisition of a machine tool utilizing this technology (Appendix A). In light of the fact that there was no hard data on some of the aspects of the process, the document was written as a performance specification. This means that some of the detailed requirements are specified by result (performance) criteria as opposed to definitive hardware,

procedures, or methods on how to execute them.

The specification was approved and solicitation for technical proposals was initiated constituting a two-step procurement action. Competitive bidding resulted in a contract award to Production Grinding Equipment Co. of Youngstown, Ohio, in the amount of \$297,610 with a proposed delivery date of April 1982. During the course of the contract, Production Grinding Equipment Co. experienced financial difficulties and was forced into bankruptcy. A court appointed trustee, in charge of legal affairs for the company, offered to complete the contract because it had progressed to a feasible point. This necessitated extensive travel and meetings to investigate the status of the equipment and the facilities in which the work would be continued. This was concluded with a report submitted to the Arsenal contracting officer identifying all of the major items that were manufactured, needed fabrication, purchased, and ready for assembly. As a result, it was agreed to continue the contract under direction of the trustee and arrangements were made for the shipment of an 8-inch M201 gun tube and tooling to the subcontractor's plant in accordance with the specification. The designated subcontractor was Turner Machine Co. of Salem, Ohio.

A new date of February 1983 was set for completion of the assembly. Assembly of the machine and the subsequent testing took place at Electric Furnace Co. of Salem, Ohio, where adequate space was available.

In March 1983, a visit was made to Salem, Ohio, to witness the operational and preliminary testing of the equipment (Figures 4,5,6,7). Because of several minor discrepancies, the equipment did not perform according to the

specification requirements. These problems were eventually corrected and preliminary acceptance of the machine was completed in April 1983. The machine, equipment, and tube were then shipped back and received at Watervliet Arsenal on 9 August 1983.

TEST RESULTS

Upon completion of the machine installation at the Arsenal, a second 8-inch M201 gun tube was loaded into the machine for test grinding. The gun tube was then ground to meet drawing requirements. Subsequent inspection found the tube to be within the tolerance limits and geometric criteria of the drawing. The aforementioned machining performed on the abrasive belt grinder was in lieu of finish turning which is normally done on a lathe prior to finish grinding.

The diameters of the zones which were machined were from 0.220 to 0.250 inch larger than the finish sizes specified on the tube drawing. The total amount of stock removed was in excess of 600 cubic inches. A 46 grit belt was used to rough grind approximately 90 percent of the stock and a 60 grit belt was used to finish the test. As a safeguard, approximately 0.050 inch of stock was left on the diameters of these machined zones for finish grinding which was done in a conventional cylindrical grinding machine later. This exercise was used to establish optimum grinding data, such as work speed, wheel speed, and traversing speeds.

These speeds varied with respect to the diameter which was being ground and whether it was a roughing or finishing cut.

During test grinding, stock removal rates were calculated numerous times

while roughing the excess material. The best rate obtained was 5.5 cubic inches per minute for short duration cuts of approximately 5 to 10 minutes. For rough grinding, the machine is capable of maintaining a constant stock removal rate of 3 to 4 cubic inches per minute.

Inspection data from both 8-inch M201 gun tubes which were ground in the abrasive belt grinder indicated that the machine is capable of holding diameters within the component drawing tolerance limits of -0.003 inch on the hoop zones and -0.002 inch on the collar zone.

Based on the positive inspection reports, permission was then granted to use another 8-inch gun tube, machined through the finish turning operation and designated for finish grinding, to be finish ground in the high speed abrasive belt grinding machine.

During set-up, a cathead was installed on the breech end plug center to allow radial adjustment of the tube to maintain wall thickness variation tolerance. The cathead allows the tube's outside diameter to be made eccentric with the machine's center of rotation, in effect, adjusting wall thickness variation with respect to the tube's bore (centerline).

A 60 grit belt was used exclusively for this operation because there was only 0.030 inch of stock, diametrically, to be removed. Initial grinding was done on the tube's hoop zone (approximately 72 inches long). This long area allowed the machine to be adjusted to eliminate any taper in the machine set-up. Taper corrections were made by the machine's tailstock offset adjustment built into the machine for this purpose.

As the initial grind was taken on the hoop zone, measurements were made at each end, in order to make a proper tailstock adjustment. Therefore, the

following formula was used for this particular situation and is derived from a formula used for pivotal table cylindrical grinding machines.

$$\frac{1/2 \text{ dia. diff. (") } \times \text{ tube length (")}}{\text{grinding length (")}} = \text{adjustment (")}$$

Minor adjustments were necessary, mainly to overcome the influence of roller rest pressure which is necessary to keep such a long tube supported while grinding. Once this long hoop zone was straight, the remainder of stock was removed to within the drawing tolerance. The second zone, being much shorter, was well within the straightness requirement without making a tailstock adjustment. The only adjustment necessary was to release the roller rest on the shorter zone and apply pressure on the roller rest located at the end of the zone just completed.

During this finish grinding operation data were being established on work speed, wheel speed, and traversing speeds to obtain the optimum grinding conditions.

The operator control panel (Figure 8) was equipped with a digital readout to control the contact wheel position and thus maintain the grinding work diameter. The panel also displayed wheel speed in surface feet per minute, work speed in revolutions per minute, and traverse speed or feed in inches per minute. Cutting pressure was controlled by an ammeter displayed on the operator control panel, which measured current load on the spindle motor.

During the finish grinding of 8-inch M201 gun tubes, it was determined that the best results were obtained using a 60 grit zirconium/aluminum

abrasive belt with water soluble coolant which is used in the standard grinding machines. Grinding parameters, best suited for this operation, were work speed between 20 and 30 RPM, contact wheel speed of 2000 to 3000 surface feet per minute, and a traverse speed of 12 to 24 inches per minute.

Finally, Watervliet Arsenal Quality Control personnel inspected the gun tube and determined it met drawing requirements. The 17.010-inch diameter hoop zone (Zone 2, Figure 2) is approximately 78 inches long and has a tolerance of -0.003 inch. The machine was able to hold this tolerance within -0.001 inch. This zone was ground first and used to eliminate any taper in the machine by adjusting the tailstock offset. Therefore, the rest of the ground surfaces which were shorter in length were well within the tolerance envelope.

A machine tool operator was assigned to learn the proper operation of the machine and the finish grinding operation under the guidance of the project leader. Another 8-inch M201 gun tube was loaded into the machine and ground to train production personnel. This gun tube was completed and inspected by Quality Control and also found to conform to the finish drawing requirements.

To complete machine testing and operator training, three more 8-inch M201 gun tubes were finish ground by production personnel. All of these tubes were inspected and accepted. This concluded the acceptance testing of the machine for 8-inch M201 gun tubes. This also concluded the current order for 8-inch M201 gun tubes.

A meeting was then requested with Arsenal manufacturing management personnel to discuss the possibility of utilizing the machine for medium-sized

gun tubes such as the 105-mm M68, 155-mm M185, 155-mm M199 and 120-mm M256. It was agreed that grinding and stock removal rates were not a problem since the machine performed these tasks well during acceptance testing on the 8-inch M201 production gun tubes. The problem was meeting the 32 root mean square (RMS) finish requirements on the medium-sized gun tubes. The finish requirement on 8-inch M201 tubes was 125 RMS and this was met easily using a 60 grit zirconium/aluminum belt. It was agreed that some testing would be necessary to determine whether the machine would be able to maintain the finish requirements of medium gun tubes. However, testing could not be done using production tubes because of the risk of them not passing inspection. It became necessary to wait until a smaller tube was rejected from production and classified as scrap. The tube also had to be machined up to a certain point as to accommodate tooling and holding devices used during the grinding operations. A 155-mm M185 tube became available and test grinding commenced with an 80 and 60 grit zirconium/aluminum belt.

This grinding test resulted in limited success because 32 RMS finish requirements could not be achieved. Many variations of wheel speed, work speed, traverse speed, and grinding pressure were tested. The very best finish obtained was in the range of 50-70 RMS which was not acceptable on the production tubes (32 RMS minimum was required). Much of the problem with surface finish was attributed to the belt's wearing and metal particles loading up between the grit. This caused the belt to rub instead of cut and develop vibration between the workpiece and contact wheel which, in turn, necessitated changing speeds and/or feeds to eliminate or minimize vibration, but the

vibration could not be completely eliminated. The vibration marks in the workpiece were detrimental and contributed to the inability of obtaining the required surface finish. The finer the grit of the belt, the worse this condition was. Therefore, it was determined that the machine was very useful for heavier and rougher work where coarse belts could be used, stock removal rates would be high, and the finish requirements not so stringent. The 8-inch M201, having a great deal of stock to be removed in several zones and the finish requirement of 125 RMS, became the ideal component on which to utilize the high speed abrasive belt grinder.

Because the production on the 8-inch M201 gun tube had been curtailed and the floor space was needed for other equipment, it was decided to put the machine into storage until such time that orders on the 8-inch M201 gun tube are resumed. The machine is now in the Producibility Engineering and Packaging storage for the 8-inch M201 gun tube.

CONCLUSION

Even though there were some significant administrative problems in this project such as, the contractor's financial difficulties resulting in delays and subsequently not following the completed effort through, a great deal of positive information was obtained. For instance, stock could be removed at a much faster rate (3 to 4 cubic inches per minute) in lieu of cylindrical grinding and lathe turning. A component could be rough machined rapidly with a coarse grit belt, the belt could be changed in approximately 2 minutes, and then finish ground with a new sharp finer grit belt.

The 8-inch M201 gun tubes which were finish ground utilizing the high

speed abrasive belt grinder were completed without the contractor's input. The first tube had to be loaded in the machine and initially set-up to perform the operation. The following three tubes were completed while training an operator to run the machine, which cannot be considered a production mode. Also, during the grinding of these tubes, determinations were being made on the speeds and feeds which produced the best results. Overall, four gun tubes were finish ground in five days (8 hours per day) or 40 hours total. The time standard for the finish grinding operation is 6.44 hours per tube or 1.25 tubes per day which equates to 6.25 tubes in a 40-hour week.

In consideration of the stock removal rates obtained during the roughing operation, it is estimated that in a production mode, an 8-inch M201 gun tube could be rough ground in lieu of finish turning in 5 hours, then finish ground in 3 hours, for a total time of 8 hours per gun tube. The combined time standard for both operations is 13.68 hours. Projected savings are 5.68 hours per gun tube.

In order to substantiate the fact that this technology is viable and is being used by other manufacturing firms, a visit was arranged with a large company which had purchased a similar machine from the same supplier.

The machine that was observed had been procured exclusively for the purpose of grinding paper rolls made of various materials such as rubber, aluminum, and steel coated with nickel or chrome. The rolls were not a production item and the material to be removed was minimal. The finish requirements were below 32 RMS which would be considered a polishing process.

The machine did not perform adequately in its initial testing runs, and

subsequently was rebuilt with high precision bearings in the motor spindles, headstock spindle, and contact wheel spindle to eliminate any vibration. The machine was then mounted on a heavy foundation and located in an area of the plant where there was no vibration transferred from other equipment. The endeavor was very costly but was deemed necessary for the unique application of the machine.

Our application was somewhat different in that the machine was required to remove stock at a high rate in conjunction with finish grinding in a production atmosphere which it had done on the 8-inch M201 gun tube. Modifications of any kind were not attempted as the project was completed and funds had been depleted.

When production schedules warrant the use of the machine, it should be removed from storage set-up and used. As any other new technology, it must be utilized and refined in order to improve its efficiency, producibility, and acceptance by the user.

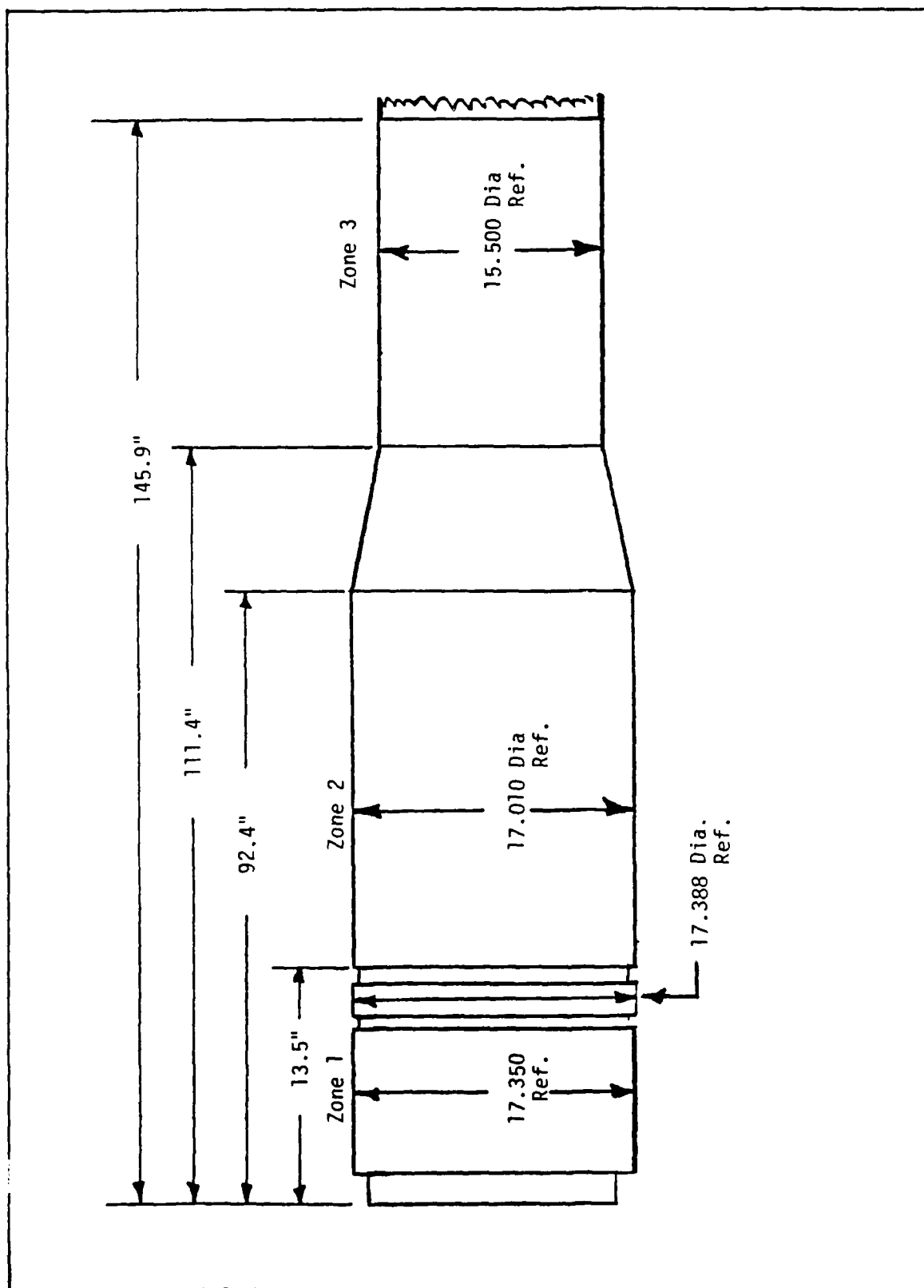


FIGURE 2. 8-INCH M201 GUN TUBE BREECH END - THREAD, COLLAR, AND HOOP ZONES



FIGURE 3. CONTACT WHEEL SUPPORTING THE
ABRASIVE BELT DURING GRINDING

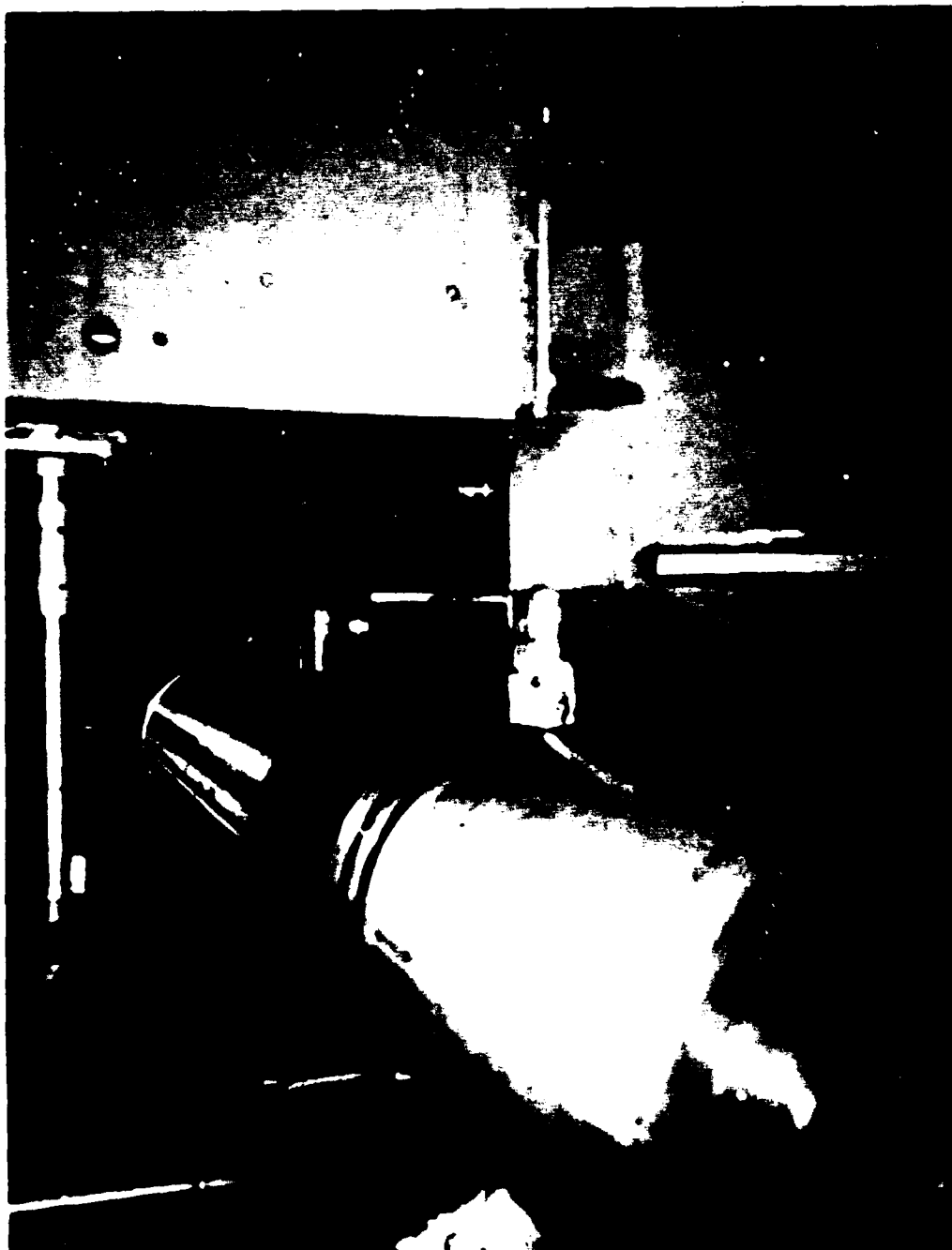


FIGURE 4. ROLLER RESTS SUPPORTING GUN TUBE DURING GRINDING OPERATION

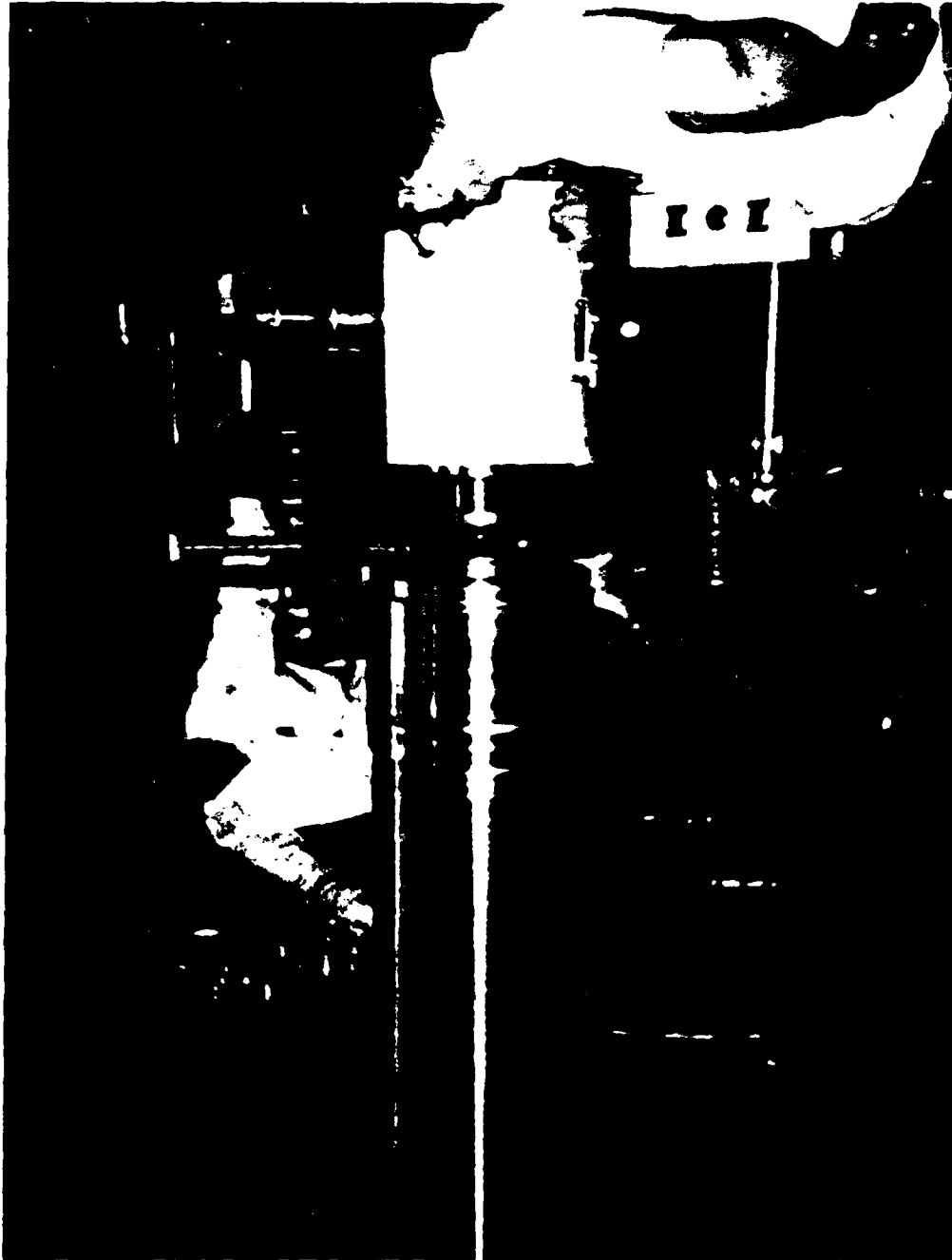


FIGURE 5. 8-INCH M201 GUN TUBE TEST GRINDING AT CONTRACTOR'S PLANT

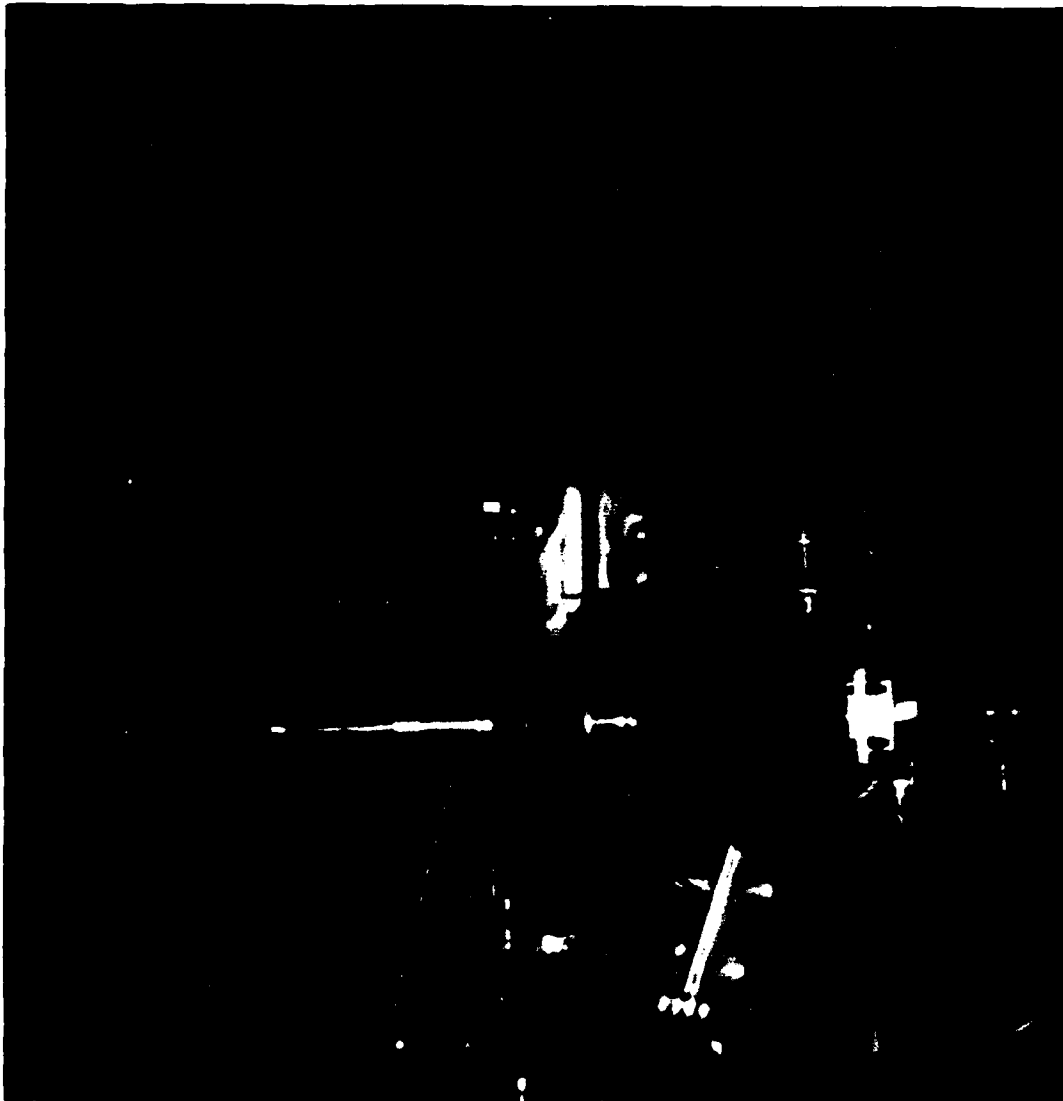


FIGURE 6. OPERATOR AT THE CONTROLS
DURING TESTING

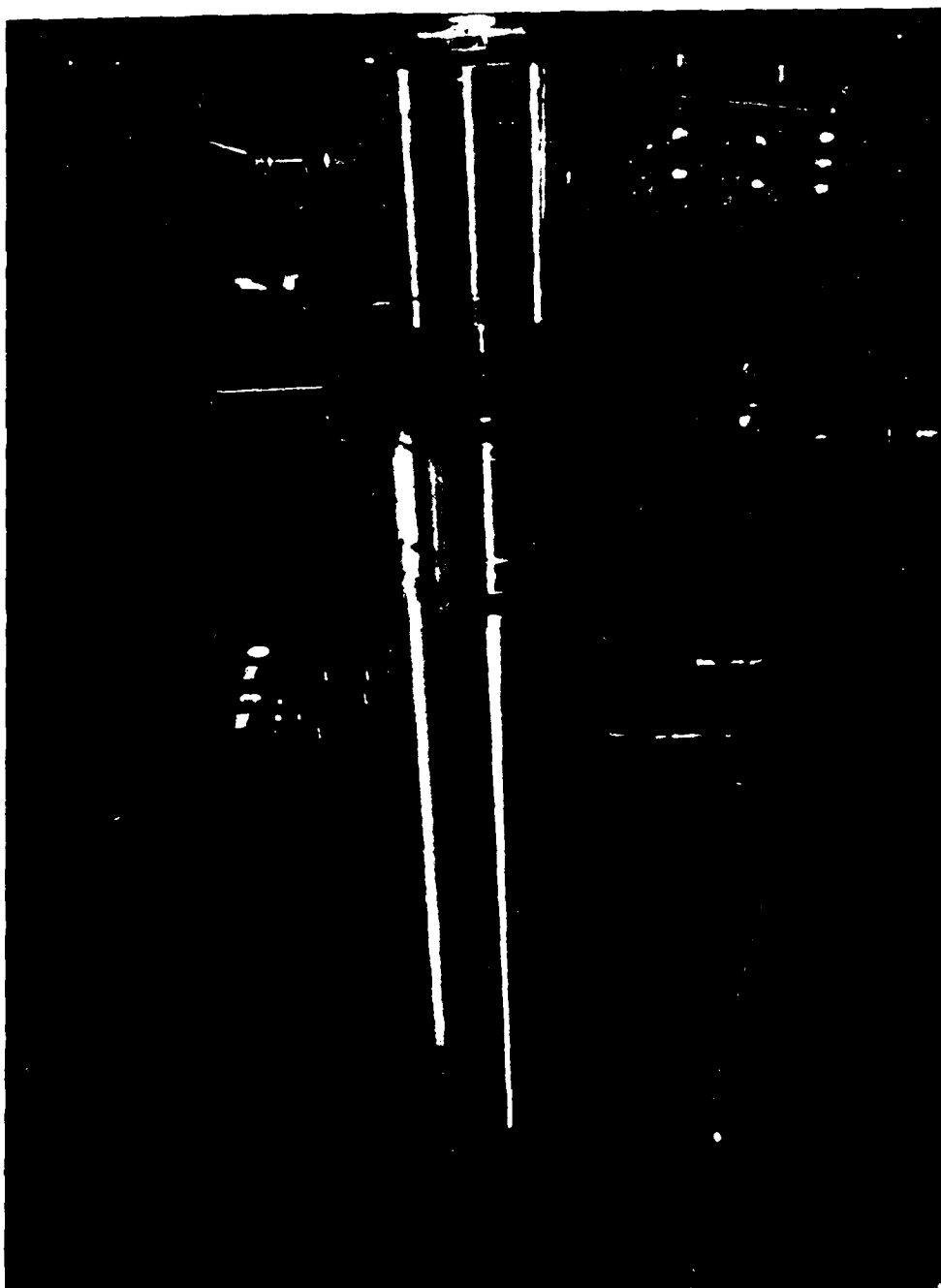


FIGURE 7. GUN TUBE FINISH GROUND AFTER TESTING AT CONTRACTOR'S PLANT

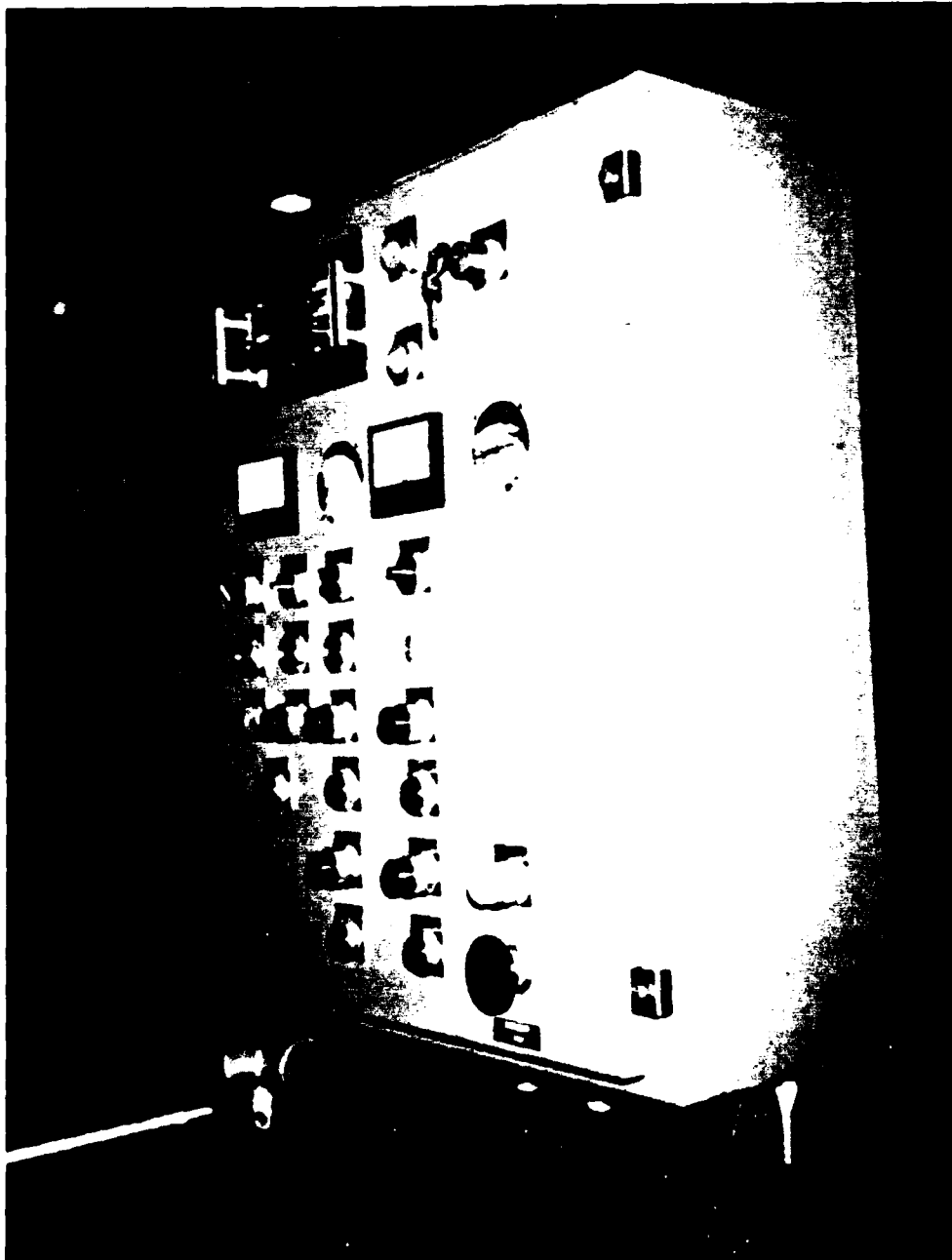


FIGURE 8. OPERATOR'S CONTROL PANEL
LOCATED ON THE CARRIAGE

APPENDIX A

Adv. Engr. Spec. 0467-01-II

GRINDER, ABRASIVE BELT, HIGH SPEED

1.0 SCOPE: This specification covers all labor, material, and performance requirements for the furnishing of one high speed, abrasive belt, grinding machine. This machine will be used to grind right cylindrical surfaces on the outside diameters of gun tubes. The gun tube workpiece material is AISI 4337, vanadium modified, low alloy steel, heat treated to a hardness of 35 to 42 on the Rockwell "C" scale. The size of the workpiece can range from 6 to 18 inches in outside diameter, from 8 to 30 feet in length and weigh up to 15,000 pounds. The machine tool shall be capable of removing an average of 4 cubic inches of metal per minute, including belt changes but not including workpiece loading, securing, and unloading while maintaining a floor to floor time of 3.5 hours for the workpiece described in Paragraph 4.

2. APPLICABLE STANDARDS AND PUBLICATIONS: Various standards and other publications are referenced or required in Section 3 of this specification. Where they are referenced or required, they are meant to indicate an acceptable level of quality, safety or performance. Except where it is indicated in this specification that no substitutions are permitted, offerors may choose to adhere to standards other than those specified, provided that the substitute represents a level of quality, safety or performance equal to or better than the one specified. Any substitutions must be clearly disclosed and explained in the offeror's statement of compliance (see 6.2). Any standards adhered to in complying with this specification shall be the latest issues in effect on the date of solicitation of offers and offerors are responsible for obtaining copies of the most current revisions.

3. REQUIREMENTS:

3.1 General Requirements

3.1.1 Design and Engineering: The machine shall be designed and engineered in accordance with current standards recognized or adopted by the National Machine Tool Builders Association. The design and engineering shall be of the latest type but shall incorporate only concepts, systems and components which have been proved in prior use. Modifications to manufacturers' standard designs to achieve requirements specified herein are not permissible if they result in deviations from good design practice. Examples of such impermissible modifications are placing a 20 HP motor in a power train designed for 10 HP, or raising the headstock on a 25 inch lathe bed to achieve a 32 inch swing.

3.1.2 Materials. Materials incorporated in the construction of the machine shall be of sound and uniform quality, free from defects and shall conform in specification, heat treatment and suitability to the standards recognized or adopted by the National Machine Tool Builders Association for this type and class of equipment.

3.1.3 Construction. All parts of the machine shall be new and unused and shall be constructed so as to be capable of withstanding all forces encountered during operation to its maximum rated capacity. Distortion and deflection at maximum load shall be limited to a degree consistent with retention of alignments and tolerances, and the machine shall recover from distortions and deflections at no load. The structure and assembly of the machine and its components shall be sufficiently rigid that workpiece finish and accuracy are not impaired by machine vibrations.

3.1.4 Workmanship. Workmanship throughout the machine and its equipment shall adhere to standards recognized by the National Machine Tool Builders Association for the type, class and size of the equipment.

3.1.5 Maintainability. All parts subject to wear, distortion or failure and all parts which require periodic adjustment shall be readily and safely accessible for repair, replacement or adjustment as applicable. Instructions for maintenance (see 3.1.19g) shall be clear, concise, and definite in application.

3.1.6 Interchangeability. All parts bearing the same part number shall be functionally interchangeable.

3.1.7 Location of Operator's Controls. The operator's controls shall be located in such manner that they are readily accessible to the operator from the position where he will be located to safely and efficiently operate the machine.

3.1.8 General Electrical Characteristics. The electrical system shall conform to JIC (Joint Industrial Council) Electrical Standards for General Purpose Machine Tools.

3.1.8.1 Applicable Power Source. The power source to which the machine will be connected furnishes 480 volt, 3 phase, 60 HZ AC and the machine shall be wired and equipped accordingly. In addition, the machine shall be tolerant enough of line fluctuations to operate normally at source voltages ranging from 432 to 504 volts.

3.1.8.2 Conversion Equipment. If DC or reduced-voltage AC is required or specified for any part of the machine's operation, the necessary conversion or transformation equipment shall be furnished with the machine.

3.1.8.3 Motors. All motors shall have ball or roller bearings and shall be of the optimum type and horsepower rating to meet the intended application and usage based upon accepted engineering practice. Under normal operation of the machine throughout its specified range and capacity, no motor shall be operating at overload. All motors shall be housed in enclosures of the appropriate NEMA type for the class and severity of service, and shall be permanently lubricated, sealed and balanced. Each motor will bear an identification plate containing the identity of the manufacturer, the model, serial, input voltage, amperage, horsepower, phase, frequency and frame or mounting. All motor housings shall be indelibly marked to indicate direction of rotation. Any AC motor rated at 75HP or more shall be equipped with closed circuit transition (e.g. - part winding, reduced voltage auto transformer, wye-delta resistor or resistor type) starter. Power factor correction capacitors shall be installed for AC motors rated at 25HP or greater.

3.1.8.4 Operator Control Voltage. All controls normally actuated by the operator of the machine shall operate at 120 volts or less.

3.1.8.5 Utility Outlet. The machine shall be equipped with a dual-receptacle, three wire utility outlet furnishing 120 volts AC, fused for 20 ampere power draw. This receptacle shall be mounted on an exterior surface of the machine or control and shall be easily accessible. If the machine specified or offered is numerically controlled, a noise suppression device shall be provided to isolate the logic circuitry from electronic "noise" which may be generated by accessories or tools connected to the outlet.

3.1.9 Safety Features.

3.1.9.1 Protection of Machine Operator. Protection of the machine operator and other personnel shall be accomplished in accordance with title 29, Code of Federal Regulations, Part 1910. -- the applicable subparts thereof and the current amendments thereto, except for noise levels (see 3.1.20) and "Point of Operation" guarding. "Point of Operation" guarding will be the responsibility of the Arsenal unless detailed instructions covering the requirements for guards appear in Section 3.2 of this specification.

3.1.9.2 Protection of the Machine. The machine shall be fully equipped with the devices necessary to prevent self-damage in the event of malfunction and/or ordinary operator negligence, insofar as practical. Such devices include, but are not limited to, limit switches, positive end stops, overload protective devices, lubrication fail-safe, etc.

3.1.10 Identification Plate. A corrosion-resistant metal plate shall be securely attached to the machine in a visible location in the vicinity of the operator's work station. This plate shall bear the information called for as follows, with space at the bottom for one additional line of information.

Nomenclature
Manufacturer's Name
Model
Manufacturer's Serial Number
Power Input (voltage, phase, frequency, total amps)
Government Contract No.
Date of Manufacture

3.1.11 Lubrication. The machine shall be equipped with an automatic system to provide positive lubrication at the proper rate to each internal moving part where lubrication is essential to prevent damage. This system shall be interlocked to the machine controller and shall be fail safe. The fail safe system shall be designed so that movement of critical machine components cannot take place until proper lubrication pressure is available at each critical point. The reservoirs of this system shall be sized so that interval of refill shall be not less than 80 hours of machine run time. In addition, the system's reservoirs shall be easily accessible for cleaning and flushing. All filtration devices shall be replaceable or easily accessible for cleaning to prevent passage of harmful contaminants to critical components.

Any exterior lubrication points which cannot be served by the automatic system shall be easily accessible and clearly marked as to type of lubrication required. A lubrication plate shall be permanently fastened to

3.1.11 Lubrication. (Continued)

the machine and shall clearly indicate the type and viscosity of lubricant and the service interval for all automatic and manual lubrication reservoirs and fittings.

3.1.12 Hydraulic System. When a hydraulic system of any type is provided or specified, it shall be appropriately sized and powered for the intended application, and shall conform to JIC Hydraulic Standards for Industrial Equipment. The system shall incorporate cleanable or replaceable filtration devices to insure fluid cleanliness. Reservoirs will be equipped with easily visible gages, to indicate fluid level. If duty cycle of the system under maximum usage will cause the hydraulic fluid to exceed 120°F in temperature, a suitable air-cooled, recirculating water-cooled or refrigerated heat exchanger shall be provided to maintain fluid temperature at or below this level. Complete over-pressure protection will be included. System input pressure in any hydraulic device shall be as low as is practical for the intended application but shall not exceed 3000 psi in any case. In any system which utilizes hydraulics to produce thrust or direct linear motion, anti-surge devices or circuits shall be incorporated to insure uniformity of motion under varying loads, and the anti-surge effect shall be variable for adjustment to varying conditions.

NOTE: All reservoirs shall be easily accessible for cleaning and flushing system.

3.1.13 Painting. All exterior machine surfaces shall be painted except where bright metal is required for machine function or to otherwise adhere to the requirements of this specification. Paint shall be applied in such a manner and shall be of proper quality to afford protection throughout the normal life of the machine. Paint color and finish shall be machine tool gray and semi-gloss. Dangerous and caution areas shall be painted yellow in accordance with OSHA, 1910.144.

3.1.14 Machine Hold-Down and Leveling. The machine base shall be provided with sufficient and properly located holes for positive hold-down when the machine is operating at its maximum rated capacity. In addition, the contractor shall provide with the machine a complete set of hold-down and leveling hardware for each mounting hole, plus two spare sets. The hold-down bolts shall be long enough to permit insertion of a two-inch thick steel plate between the machine base and the floor surface.

NOTE: All hold-down hardware shall be delivered 30 days prior to shipment of the machine.

3.1.15 Threads. All threaded parts shall be in either the inch or metric systems, and shall be uniform within one or the other system throughout the machine.

3.1.16 Gears. All gears used in the machine and its components shall meet or exceed the standards recommended by the American Gear Manufacturers' Association for the type and severity of service required.

3.1.17 Indication of Slide Motion. Any machine slide or ram which is one of the precision axes of tool or workpiece movement shall have its motion and position resolved and indicated by a digital display device. For numerically controlled machines, this requirement is separately covered in Section 3 of this specification. For conventionally operated machines where slides can be power fed or manually cranked by the operator, digital display devices shall be used in lieu of engraved rotating dials. These devices may be mounted on the feed screw or pinion shaft adjacent to the handwheel or they may be mounted in any other readily visible location in the vicinity of the handwheel. These devices shall derive their readings from encoders or similar devices to resolve increments of revolution of feed screws or pinion shafts, and their accuracy shall be equal to or better than that obtainable with engraved rotating dials. The devices shall permit switchable selection of inch or metric modes and resolution of motions shall be obtainable in increments of .001 inch and .025mm or less. The devices shall have sufficient digit capacity to read up to the total available slide motion. Zero reset shall be provided to enable the operator to choose incremental or accumulative movements. Digit size shall be 1/4 inch minimum.

3.1.18 Handwheels. Where power feed and/or rapid traverse of a machine component is provided or specified, associated handwheels or cranks, if any, shall not rotate when power feed or rapid traverse is engaged.

3.1.19 Technical Data. Data shall be furnished as follows and shall be in the English language. Numbers of copies shall be as specified below for orders of a single machine. For orders of more than one machine, a single copy per machine shall suffice, delivered according to the schedules indicated below for each machine, except where programming manuals are required (see item j. below). Only two programming manuals are required regardless of the number of machines ordered.

a. Foundation Drawings, standard or special, (see note) - - to be furnished 210 days prior to scheduled delivery of first machine. (one reproducible)

*b. Machine and Equipment floor plan at a scale of 1/4 inch per foot. In addition to depicting the contractor's recommended floor plan, the drawing shall also depict the range of freedom to relocate the peripheral equipment (such as control consoles, magnetic panels, power units, etc.) within the reach of inter-connecting wiring supplied. This drawing shall also contain information which indicates the type and magnitude of plant utilities (electric power, air, water, etc.) required to operate the machine. This data shall be furnished 210 days prior to scheduled delivery of first machine. (one reproducible copy)

c. Catalog of available tooling and optional accessories -- to be furnished 120 days prior to scheduled delivery of first machine. (2 copies)

*d. Installation instructions and drawings containing all necessary information to install the equipment. This shall include a drawing containing the certified actual locations of all equipment mounting holes. To be furnished 60 days prior to scheduled delivery of each machine. (one reproducible copy)

*e. Lubrication diagram or instructions -- to be delivered with the machine. (two copies)

f. Operating Instructions -- to be delivered with the machine. (two copies)

g. Maintenance and step-by-step troubleshooting instructions for all machine systems -- to be delivered with the machine. (2 copies) These instructions shall include assembly drawings.

*h. Final electrical and hydraulic schematics -- to be furnished not later than 60 days after machine acceptance at the Arsenal. (one reproducible copy)

i. Repair parts catalog. This catalog shall encompass every replaceable part in the machine and shall include appropriate identification and ordering data. Items which can normally be purchased locally as hardware may be so indicated provided they are sufficiently described. The repair parts catalog shall include illustrations which clearly locate the parts within larger assemblies. To be furnished not later than 90 days after machine acceptance at the Watervliet Arsenal. (2 copies)

j. Programming Manuals, 2 copies (where an NC machine is offered or specified) to be furnished 60 days prior to initial delivery.

NOTE: Items marked (*), in addition to being furnished as specified above, shall be furnished on 35mm microfilm mounted in standard aperture cards.

Each aperture card shall be clearly imprinted or typed to identify the subject of the microfilm. Two complete microfilm sets are required, and shall be furnished at time of machine delivery, marked to the attention of the Arsenal's Contract Administrator. All technical data shall be packaged to insure arrival at the Arsenal in good condition.

3.1.20 Noise Levels. Noise levels shall be measured during the operational test (see 4.4.1) and shall be measured at any or various times during this test at the discretion of the Contracting Officer or his appointed representatives. Noise levels at the vicinity of the machine shall not exceed 85 decibels when measured by a properly calibrated sound level meter set for "A" scale and slow response. "Vicinity of the machine" is further defined as an imaginary line completely surrounding the machine at a distance not exceeding one meter from the nearest point on the machine. The 85 decibel limit is absolute and shall apply at the operator's station, even if inside the one meter envelope. Techniques such as sound level averaging or exposure time weighting shall not be used in meeting this requirement.

Any shields, baffles, enclosures or other devices required to bring the machine into conformance with this noise level requirement shall be furnished by the contractor. Any such devices shall not interfere with the proper operation of the machine and shall be designed to preserve the visibility needed for safe operation.

3.1.21 Machine Start-up and Testing. Upon being notified by the Contracting Officer that the machine has been installed and made ready for start-up, the contractor shall furnish a competent service engineer to place the machine in proper operation. The machine will not be activated and run without the attendance of the contractor's service engineer. In addition to machine start-up, the service engineer will be responsible for performance of all acceptance tests specified in Section 4 of this specification, and shall remain until the tests are complete.

3.1.22 Training Required. The contractor shall provide training of Arsenal personnel. The nature and extent of training provided shall depend upon whether the machine specified or offered is equipped with Numerical Control, and shall adhere to the applicable areas of the following table. Oral and written materials shall be in English.

<u>Type of Training</u>	<u>No. of Persons</u>	<u>Hours of Training Per Person</u>	
		<u>Non-NC Machine</u>	<u>NC Machine</u>
Machine Operation	2	8	24
Mechanical Maintenance	2	8	24
Hydraulic Maintenance (if applicable)	2	8	24
Electrical Maintenance	2	8	8
Electronics (control) maintenance	2	8	40
Programmer training	2	N/A	40

The following notes shall apply to the foregoing table:

a. For all types of training, the associated technical data (see 3.1.19) shall be on hand at the time of instruction, and its use and interpretation shall be covered during the training.

b. For orders of a single machine tool, the number of persons to be provided with each type of training shall be as indicated above. For orders of more than one machine tool, training in machine operation shall be provided for two persons only per type of training.

c. Training in machine operation, mechanical maintenance, hydraulic maintenance and electrical maintenance shall be given on-site at Watervliet Arsenal at the time of machine start-up and testing, and shall be given during normal working hours which are Monday thru Friday from 7:30 AM to 4:00 PM. For orders of more than one machine tool, training in machine operation shall be given at start-up of each machine, and training in mechanical, hydraulic and electrical maintenance shall be given at start-up of the first machine.

d. Training in electronics (control) maintenance and programming (for NC machines) shall be made available on at least four occasions each during a time period of from 60 days prior to initial delivery to two years after initial delivery with one session of each type being available prior to delivery. The Arsenal shall reserve the right to choose any two of the four available sessions of each type, and to train one person at each chosen session. This training shall be formal classroom training and shall be held off-site at a location within the U.S., arranged by the contractor. Schedules for each training session shall be forwarded to the Administrative Contracting Officer (ACO) at least 60 days in advance and shall include appropriate forms and registration instructions.

3.1.23 Repair/Replacement Parts Availability. The contractor shall guarantee the availability of repair/replacement parts for a period of not less than 10 years following date of machine delivery. This applies only to parts manufactured by the machine tool builder.

3.1.24 Pneumatic Requirements. If air is required for any machine operation or function, a suitable dryer and filter shall be supplied. Available high pressure air supply is 80 psi.

If any machine function requires air supply in excess of 80 psi, the equipment needed to supply the higher pressure shall be supplied with the machine. If any machine function requires air pressure of less than 80 psi, the appropriate pressure regulator shall be equipped with the machine.

3.1.25 Special Tools. If any element of machine operation or maintenance requires the use of specially designed tools, these tools shall be provided with the machine.

3.1.26 Control of Cutting Fluids. The contractor shall insure that the machine is designed and equipped to prevent coolant from escaping the confines of the machine or leaking to the floor when producing workpieces of a size within the machine's normal working range. If the Arsenal foresees that, in certain applications, workpieces may extend beyond the normal confines of the machine, special coolant control devices shall be as specified in Section 3.2 of this specification.

3.2 Detailed Requirements.

3.2.1 Machine Tool General Description. The machine tool to be provided in accordance with this specification shall be an external cylindrical grinder using an abrasive belt as the metal removing tool. The machine tool shall be capable of grinding the complete length of the workpiece with the exception of 12" of the end used for gripping the workpiece and imparting the workpiece rotation. The major machine tool components shall consist of, but not be limited to, a headstock, tailstock, bed, grinding head, steady rests, coolant system, hydraulic system, machine operator's control panel, in-process gaging device, and all electrical components necessary for a machine tool to pass the inspections listed in Paragraph 4.

3.2.2 Workpiece Size Ranges. The size of the workpiece which the machine tool shall be capable of machining shall be within the following ranges:

workpiece length 8 feet or less to 30 feet or more
workpiece outside diameter 6 inches or less to 18 inches or more
workpiece weight 15,000 pounds maximum
workpiece inside diameter 4 inches to 9 inches

3.2.3 Workpiece Material. The workpiece material shall be AISI 4337 vanadium modified low alloy steel heat treated to 35 to 42 on the Rockwell "C" scale.

3.2.4 Headstock. The headstock shall be capable of rotating the workpiece with an infinitely adjustable speed ranging from 10 RPM or less to 60 RPM or more. The headstock speed controller shall be located at the machine operator's control panel. A gauge showing the headstock rotation speed shall be located in the machine operator's control panel. Headstock start/stop controls shall be located in the machine operator's control panel.

3.2.5 Tailstock. The tailstock shall be capable of centering the workpiece on the axis of rotation. The tailstock quill shall be hydraulically actuated in forward or reverse motion. Tailstock quill motion shall be actuated by the machine operator from either of two locations at the machine operator's discretion. One location shall be at the machine operator's control panel. The second location shall be at the tailstock. Movement of the tailstock quill shall occur only when the operator is depressing a push button. The tailstock shall be capable of

3.2.5 Tailstock (continued)

being located and clamped any place along the length of the machine bed so as to enable the machine to process any workpiece within the range of workpiece length.

3.2.6 Bed. The bed shall be stress relieved prior to machining of the ways.

3.2.7 Grinding Head. The grinding head shall use an abrasive belt for the material removal tool. The belt on the circumferential surface of the contact wheel shall be the point of contact between the workpiece and the grinding head. The grinding head shall be capable of adjustable speed powered traverse along the workpiece for continuous grinding of the complete workpiece length with the exception of that portion of the workpiece gripped to provide workpiece rotation. The grinding head shall be capable of producing belt speed in an infinitely adjustable range from 2000 surface feet per minute or less to 8000 surface feet per minute or more while removing an average of 4 cubic inches of workpiece material per minute (see Paragraph 4) including belt changes. The belt speed shall be adjustable from the machine operator's control panel. A gauge shall be provided at the machine operator's control panel to indicate belt speed. A gauge shall be provided at the machine operator's control panel to indicate amperage being drawn by the grinding head. The grinding head shall have a pneumatic device to provide constant belt tensioning, a device accessible by the machine operator from his operating position for adjusting the amount of belt tension, and a gauge visible from the machine operator's position to indicate the amount of tension. The grinding head shall have a belt tracking adjustment accessible by the machine operator from his operating position. The grinding head shall have a hinged access panel in the belt guard for changing of the abrasive belt. The access panel shall have a safety interlock to prevent start-up of the abrasive belt until the access panel is latched in place. Starting and stopping of the belt shall be by push button at the machine operator's control panel.

3.2.8 Steady Rests. The machine shall be equipped with two steady rests. The steady rests shall be capable of being clamped in an infinite number of positions along the bed between the headstock and tailstock. Each steady rest shall be capable of being adjusted toward or away from the centerline of rotation from the side of the machine on which the machine operator's control panel is located. The steady rests shall serve as both support for sag of the workpiece and as a backrest to prevent workpiece deflection away from the grinding head. The steady rests shall be designed to allow uninterrupted grinding of the workpiece in the area of steady rest contact.

3.2.9 Coolant System. The coolant system shall be complete with filters, pumps, heat exchanger, reservoir, and all electrical devices and piping necessary to have a functioning system. The primary filtering device shall be a magnetic type. A secondary filtering device may be used to remove particles down to a 20 micron size. The operating temperature of the coolant shall be in the range from ambient to 95°F. Any heat exchanger used to maintain coolant temperature shall be air cooled, recirculating water cooled, or refrigerated type. The coolant system capacity shall be sufficient to maintain workpiece temperature so that the surface of the workpiece shall show no discoloration due to heat. The coolant nozzle for flooding the workpiece/belt contact area shall have a valve convenient to the operator for regulating or shutting off the flow of coolant. The coolant circulating system shall be capable of operating independently from the grinding head. The push button controls for all coolant system functions shall be located in the machine operator's control panel. The push button controls for the pump, and heat exchanger, if supplied, shall display a light to indicate when those portions of the system are operating. The coolant to be used in the testing of the machine (see Paragraph 4) shall be supplied by the contractor and shall be in accordance with MIL-C-46113 and shall not contain any nitrites or amines which could form nitrosamines.

3.2.10 In-Process Gaging Device. Devices shall be incorporated on the machine which shall display, on the machine operator's control panel, the diameter being ground on that pass of the grinding head. The display shall be 1/2 inch high or larger numerals. The devices shall read the workpiece diameter directly, without the need of fixed reference points. The devices shall be capable of displaying for the machine operator when the machine is grinding the following finished diameters:

- 16.878 - .002 inches
- 17.388 - .002 inches
- 17.010 - .003 inches
- 15.500 - .003 inches

For the location of these diameters see drawing 0467-01-01 For traversing grinding operations the gaging device(s) shall indicate whether a taper is being ground.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection. The contractor shall be responsible for the performance of all inspections and tests specified herein. However, the Government reserves the right to insure that the inspections performed by the contractor are fully adequate to confirm the machine's conformation to all requirements of this specification.

4.2 Preliminary Acceptance Inspection. The machine and its equipment shall be subjected to, and pass, a preliminary acceptance inspection at the contractor's plant prior to being shipped. Preliminary acceptance inspection shall consist of the examination specified in 4.3 and the tests specified in 4.4. The date of inspection shall be furnished to the Purchasing Contracting Officer at least ten (10) days prior to inspection so that if he deems it necessary, his representatives may be present to witness the tests. Upon completion of preliminary acceptance inspection, the contractor shall certify in writing to the Purchasing Contracting Officer that the complete inspection has been performed and that the machine and its equipment conform to all specified requirements. This certification shall be required whether or not Government representatives are present for the inspection.

4.3 Examination. The machine and its equipment shall be visually examined for appearance, workmanship, maintainability and completeness, including all specified systems, accessories, markings and safety devices.

4.4 Tests. The following tests shall be conducted:

4.4.1 Operational Test. The machine and equipment shall be continuously operated at no load for a minimum of 2 hours. This test shall determine proper operation of all controls, motors, adjusting mechanisms, and all other components of the machine. This test shall also be a demonstration of the machine's capability to operate throughout the ranges and capacities as specified in 3.2.

4.4.2 Performance Test. The machine shall successfully perform the following test using one scrap Government furnished workpiece in the configuration shown on Drawing 0467-01-01. The test shall consist of the high speed abrasive belt grinding of the following zones:

a. The zone extending from 13.50" from the breech end to 92.40" from the breech end shall be ground from 17.200" $\pm$.02" diameter to 17.010 - .003 diameter while maintaining a 125 RMS surface finish.

b. The zone extending from 111.40" from the breech end to 145.90" from the breech end shall be ground from 15.700" $\pm$.02" diameter to 15.500" - .003 diameter while maintaining a 125 RMS surface finish.

4.4.2 Performance Test (continued).

c. The zone extending from 10.90" from the breech end to 13.50" from the breech end shall be ground from 17.430" - .010" diameter to 17.388" - .002" diameter while maintaining a 125 RMS surface finish.

d. The zone extending from the breech end to 1.52" from the breech end shall be ground from 16.920" - .010" diameter to 16.878" - .002" diameter while maintaining a 125 RMS surface finish.

Parts "a" through "d" shall be accomplished while maintaining an average metal removal rate of 4 cubic inches per minute including belt changes but not machine loading and unloading. The total floor to floor time shall not exceed 3.5 hours.

Watervliet Arsenal tooling, numbers 11578721T030D, 11578721T031D, and 11578721T089C (see notes 1, 2 on drawing 0467-01-01), will be made available for contractor use if the contractor desires. All tooling shall be returned to Watervliet Arsenal.

4.5 Final Acceptance Test. After installation at Watervliet Arsenal, the machine shall pass the examination of Paragraph 4.3, the Operational Test of Paragraph 4.4.1 and the Performance Test of 4.4.2.

5. PRESERVATION, PACKAGING AND DELIVERY. The contractor shall utilize standard commercial methods of preservation and packaging appropriate for machine tools and acceptable to commercial carriers. As a minimum, all areas susceptible to damage from exposure to the elements shall be preserved and/or packed to prevent damage. The machine and equipment shall be blocked, braced and skidded to prevent damage during transport and to facilitate handling, loading and unloading. The contractor shall be responsible for insuring that the machine and equipment are delivered to Watervliet Arsenal in good condition and shall retain this responsibility until the machine and equipment are off-loaded at Watervliet Arsenal by Arsenal personnel.

NOTE: If any special lifting devices are recommended by the contractor to facilitate handling, such devices shall be shipped with the machine. They will be returned to the contractor upon completion of use at the Arsenal.

6. INSTRUCTIONS TO OFFERORS.

6.1 Descriptive Literature. Offerors shall submit, in triplicate, brochures, photographs, illustrations, drawings or narratives which clearly substantiate that the design, construction and operating features of the machine and equipment offered will meet all the requirements set forth in Section 3 of this specification. Literature displaying more than one model or size machine shall be clearly marked so as to indicate the model or size being offered. Offers which do not present sufficient information to permit complete technical evaluation by the Government may be rejected.

6.2 Statement of Compliance. In addition to the descriptive literature in 6.1, offerors must indicate on a paragraph-by-paragraph basis whether or not they comply with the Technical Requirements in Section 3, the Quality Assurance Provisions in Section 4 and the Preservation, Packaging and Delivery requirements in Section 5 of this specification. Inclosed with this specification is a prepared form entitled "Offeror's Statement of Compliance". The left hand margin of this form lists, in order, the numbers of all of the paragraphs in the specification containing requirements which must be addressed by offerors. To the immediate right of each paragraph number are two blocked spaces headed "COMPLY" and "NON-COMPLY". The entry of "X" or a check mark is required in one of these two blocks for each numbered paragraph on the form.- However, offerors are advised that the checking of the "NON-COMPLY" block for any paragraph will result in non-acceptance of the offer unless explanation is provided. For this reason, space is also provided on the form for offerors to explain an entry of "NON-COMPLY". This explanation should point out the degree of, and reason for, non-compliance, or it should explain what is being offered as an equal or better alternative to the specified requirement. Space provided for explanation on the form is limited. If additional space is required, a separate sheet may be used to continue the explanation. If such a continuation sheet is used, it should refer to the paragraph number being explained.

In the lower right corner of each page of the form is a signature block. Each page of the form should be signed by the offeror or his authorized representative.

6.3 Installation. Upon receipt of the required installation and foundation drawings (see 3.1.19) Watervliet Arsenal will prepare the intended installation site prior to delivery of the machine. Upon delivery of the machine, Watervliet Arsenal will install the basic machine on foundation, install major components and run power to main control disconnect switch. However, if the installation instructions supplied by the contractor are incomplete or insufficiently detailed, installation work will stop and the contractor will be required to dispatch a service engineer. Installation will resume upon his arrival and continue under his guidance.

NOTE: If installation instructions, foundation diagrams and electrical and hydraulic schematics are not delivered at or before the times specified (see 3.1.19), the Government reserves the right to forestall delivery and/or final acceptance testing of the machine by an amount of time equal to the delay in receipt of instructions, drawings or schematics.

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