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Low Cost and Agile Manufacturing of Firearms

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to

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Low Cost and Agile Manufacturing of Firearms

Report No. 300-695-301

December 12, 1997

EXECUTIVE SUMMARY

Under contract with Remington Arms Company, Inc., Machining Xcellence™ Division of the Institute of Advanced Manufacturing Sciences, Inc. (IAMS) conducted a technical search for selecting cost-effective candidate processes for agile manufacturing of firearm components under M/710 program. IAMS' Machining Xcellence Division partnered with the Engineering Research Center for Net Shape Manufacturing (ERC/NSM) at the Ohio State University (OSU), in Columbus, Ohio for this investigation. ERC/NSM has been conducting contract research for over eleven years in manufacturing of discrete parts to net or near-net dimensions by way of die-casting, polymer processing, sheet and billet forming.

This investigation began during a plant visit to the Remington Arms Company, Inc., KY on November 3, 1997.

OBJECTIVES OF THE M/710 PROGRAM

A team of engineers (one from IAMS and another from ERC/NSM) visited the Remington Arms Company, Inc., reviewed the project and program objectives, and held discussions with the company associates about major components and subsystems of the gun and the required physical and mechanical properties of individual part. The engineers' objectives were:

- to conduct a technical search for various manufacturing processes which will lower the manufacturing costs than the current product. The target is 30% lower production cost,
- to recommend candidate processes for a 'build to order' production technology rather than 'build to stock'. The production volume will range from 25,000 to 250,000 units annually.

CONCLUSIONS

The objectives of this project have conflicting goals. The present technology for building rifles has been fine-tuned through long experience and competitive pressures. Lower costs tend to favor mass production technologies. To achieve 30% cost reduction, we may have to forgo more agile "build to order" methods.

RECOMMENDED MANUFACTURING PROCESSES FOR LOW COST AND AGILE MANUFACTURING OF FIREARM COMPONENTS:

The following recommendations of manufacturing processes for robust, low cost and agile manufacturing of firearm components are made:

1. The gun-stock, as the most expensive sub-assembly, should be the primary subject of attention. Other similar operations traditionally use lots of manual labor. It is possible to replace that labor with modern CNC equipment that is custom built. .IAMS'/(ERC/NSM)'s engineers need to review the present manufacturing methods before they can come up with any suggestions for modifying the existing process. If the cost of manufacturing gun stock is reduced by 1/3'rd, the goal of 30% overall cost reduction will also be fulfilled the same time.

2. The barrel/receiver assembly is the second most expensive item. The gun barrel should be manufactured by radial forging. Remington Arms Company, Inc. is, probably, already employing this manufacturing process. The receiver could be redesigned for manufacture by semi-solid forming (SSF) technology. High-speed-machining is recommended to minimize the cost of machining the SSF receiver.

3. The bolt assembly is the third most expensive component. The company may be able to gain a few percentage points by semi-solid forming the bolt integral with the handle.

4. Remington Arms Company, Inc. is already employing powder metal technology and should continue to use that with more cost-effective ways, if possible.

5. Remington Arms Company, Inc. is presently employing conventional machining. It is recommended that high speed machining (HSM) should be potentially applied to all machined components.

6. Assembly technology seems to play an important role in reducing the overall cost of M/710 Rifle Program.

7. Investment casting is, probably, too slow and the resulting product may not be strong enough.

8. Technical search has shown ECM to be an economical candidate process for manufacturing firearm components. However, ECM does not seem to be cost-effective. This manufacturing process also seems to be too slow.

9. The design changes will be needed if the suggested new processes are to be implemented. Thus, the in-depth cost analysis of selected new processes will require more time and input from associate staff.

INTRODUCTION

Remington Arms Company, Inc.'s research and development division located in Elizabethtown, Kentucky is involved in designing various gun and rifle parts which are manufactured and finally assembled in Remington Arms Company, Inc., New York division. The company has started a new M/710 Rifle Program for the year 1998. During our visit to the company, we learned during our discussions with Remington Arms Company, Inc.'s associates, specially, with Mr. Jim Ronkainen that the company is looking for emerging technologies and robust processes for agile manufacturing for a 'build to order' production system for production volumes from 25,000 to 250,000 units annually. The emphasis is on the selection of processes which will reduce the overall manufacturing costs by thirty percent.

IAMS' and ERC/NSM's engineers have conducted a technical search. This report presents the candidate processes for cost-effective manufacturing of firearm components and also provides recommendations for candidate manufacturing processes for low cost and agile manufacturing of firearm components.

1. Investment Castings:

In general, investment casting uses a mold that has been produced by surrounding an expandable pattern with a refractory slurry that sets at room temperature. The pattern (usually of wax or plastic) is then melted or burned out, leaving the mold cavity. Today, investment casting companies injection mold precise and reproducible wax or plastic patterns in machined injection molds to be invested into shell or solid molds of modern ceramics into which a wide range of alloys can be cast for the manufacture of precision parts. The investment castings are characterized by [1]:

- economy of manufacture,
- intricacy,
- avoids expensive assemblies of inexpensive sub-components,
- achieves close tolerances and fine finishes inexpensively,
- employs less expensive tooling than die casting,
- allows inexpensive changes of design and alloy,
- permits near or full net shape as-cast,
- quicker, from part inception to production; typically ten weeks,
- quality of components,
- fully dense structure affords full mechanical properties , unlike porous powder metal,
- process is capable of providing tolerances of 0.005 inch/inch or better, and 125 RMS.

The companies are employing the most modern of manufacturing and high tech methods to constantly improve the quality and economy of their output of investment cast components. High tech is being applied to simplify and speed the transfer of engineering data and to rapid prototype castings or injection molds. Modern CNC equipment is able to produce higher quality injection molds in less time. In-house advanced processes can produce even higher quality, lighter, stronger, and thinner castings than ever before.

2. Powder/Metal Injection Molding:

Components made from wrought or cast materials usually require multiple secondary finishing operations which increase the manufacturing cost. Powder injection molding (PIM) is a cost effective process for complex shape manufacturing metal components that eliminates secondary operations by combining the net shape and mass production features of plastic injection molding and the efficient material utilization of powder metallurgy. Very fine metal powder, combined with binder material, is injected into a die. Part is ejected, the binder is melted or dissolved, and vacuum sintered, resulting in a part 94-99% of theoretical density. Primarily ferrous alloys are molded.

Powder injection molding is an established, growing technology and is most widely used for high-volume production of small size parts. PIM has not been used extensively for larger parts due in part to the need for process simulation tools relating to mold design. The tolerances of 0.003 inch/inch or better can be achieved with a surface finish of 45 RMS. Literature search reveals that parts in a quantity 10,000 and up can be produced using this technology with a normal lead time of 4-6 weeks. PIM is a highly economical process for mass production of parts that are difficult to form or machine by conventional methods. The use of the PIM molding processes for small component production:

- reduces component weight,
- increases efficiency,
- reduces manufacturing defects, and
- improves cost effectiveness.

3. The Powder Metal Process:

Powder metallurgy is the process whereby metal parts in large quantities can be made by compressing and sintering various powdered metals such as brass, bronze, aluminum, stainless steel, and iron. Compressing of the metal powder into the part to be made is done using accurately formed dies and punches in special types of hydraulic or mechanical presses. The 'green' compressed pieces are then sintered in an atmosphere controlled furnace at high temperatures, causing the metal powder particles to be bonded together metallurgically. A subsequent sizing or coining operation and supplementary heat treatments may be employed. The physical properties of the final product are comparable to those of cast or wrought products of the same composition, if the parts are processed to provide high density. A lower density will result in lower physical properties. The advantages of powder metallurgy are [2]:

- parts requiring irregular curves, eccentric, radial projections, or recesses often can be produced only by powder metallurgy,
- parts that require irregular holes, key ways, flat sides, splines or square holes that are not easily machined, can usually be made by this process,

- tapers and counter bores are easily produced,
- axial projections can be formed but the permissible size depends on if the powder will flow into the die recesses,
- slots grooves, blind holes, and recesses of varied depth are also obtainable,
- the process provides close dimensional tolerances, minimal machining, good surface finish, and excellent part to part reproducibility for moderate to high volume part production.

The limiting factors in the powder metal processes are:

- features should be avoided that result in tooling with thin sections or sharp inside corners,
- multiple axial projections result in complex tooling and there are limitations on the number which can be formed,
- undercuts, cross holes and re-entrant angles cannot be molded and therefore must be machined after sintering,
- tolerances in diameter usually cannot be held closer than 0.001 inch and tolerances in length are limited to 0.005 inch.

4. Forging and Forming:

The process of hot working metals has long been used to ensure strength, toughness, reliability, and the highest quality in a wide variety of products. Today, these characteristics assume even greater importance as operating temperatures, loads, and stresses increase, and as reliability and toughness become more practical. The products are being designed with forged components that can accommodate the highest possible loads and stresses. Recent advances in forging technology such as the forging of previously "unforgeable" materials have greatly increased the range of properties available in forgings. Economically, forged products are becoming even more attractive because of their inherent superior reliability, improved tolerance capabilities, and the higher efficiency with which forgings may be machined and further processed by automated methods.

The manufacture of forged products is fundamentally a process of forming metal, under impact or pressure, to economically produce a desired shape with improved mechanical properties. Metallic components can be forged and formed to a required shape. The particular forging method and equipment used in a given instance is dependent on factors such as the quantity of parts to be produced, the characteristics of the material, and the configuration to be forged. Forging, relative to other metal working processes, results in metallurgically sound, uniform, and stable products that will have optimum properties as operating components after processing and assembly. This process is the fine blend of art and science, requiring many critical decisions far in advance of production. Some of the important factors which are to be considered to reduce the forging costs are:

- part configuration and tolerances of the forged product,

- material and forging stock selection,
- applicable specifications,
- weight of the forged part,
- quantity to be produced,
- mechanical properties, and
- design of the forging dies.

Literature search reveals that powder forging (P/F) may be a practical manufacturing technology for firearm component production [3]. The technical and economic feasibility of manufacturing thirty small-caliber weapon components by powder forging has been addressed in the literature and several components were identified as promising candidate. Literature search also reveals that radial forging of tubes with compound angle dies and precision rotary forging may also be a candidate process for cost-effective gun barrel manufacturing [4, 5].

5. Die Casting – Semi-Solid Forming (SSF):

Most metal parts are manufactured by either fully liquid (e.g., casting) or fully solid (e.g., forging) processes. Semi-Solid Forming (SSF) incorporates elements of both casting and forging for the manufacture of near-net-shape discrete parts. The process capitalizes on thixotropy, a physical state wherein a solid material behaves like a fluid when a shear force is applied.. The SSF process requires a non-dendritic feedstock which can be produced by applying mechanical or electromechanical stirring during alloy solidification at a controlled rate, or from fine grained materials produced by powder metallurgy or spray forming methods. This feedstock, usually, in billet form, is then heated to a temperature between its solidus and liquidus and formed in dies to make near-net-shape parts.

Parts produced by SSF have higher structural integrity than castings, yet can be produced at lower cost than forgings. The SSF process is capable of producing parts which are essentially free of porosity associated with conventional high pressure die casting. SSF parts, therefore, can be heat-treated to develop property levels similar to those of permanent mold castings, but at lower cost. In comparison to forgings and parts machined from wrought products, properties are equivalent, but costs are lower since fewer manufacturing steps are required.

The applications of this process are still limited for a variety of reasons, including sparse availability and limited selection of feedstock, lack of material property and process specifications, and lack of appropriate process models. As with any new technology, the implementation of SSF as an accepted industrial process is hindered by the risks involved in purchasing equipment, training personnel, and properly applying the technology.

6. Conventional/High Speed Machining:

Conventional Machining represents a significant segment of the total cost of gun components production. In general, the conventional machining methods for manufacturing gun parts seem to be uneconomical. Abrasive machining processes such as grinding (stock removal operation) can be more economically performed than the more conventional means of turning or milling. The two largest fields for abrasive machining are the production of flat surfaces and form grinding from the solids forging, bar stock or hollow cylindrical items.

It seems worth while to replace conventional machining through high speed machining technology for machining component at faster rates. The process can reduce machining times by up to 50% with overall improved performance.

6. Electrochemical Machining:

The technical search reveals that a research program was conducted to advance high performance gun barrel technology by developing an electrochemical machining process for rifling high performance barrel liner materials [6]. A total of fifteen electrolytes and numerous electrochemical machining parameters were evaluated in conducting electrochemical machinability studies on iron-nickel-base, nickel base, and cobalt base superalloys, and on refractory alloys of columbium, molybdenum, tantalum, and tungsten. Four materials (L-605, VM-103, CG-27, and alloy 718) were selected for electrochemical rifling and fabrication into caliber .220-Swift barrel liners. The rifle liners were insulated externally and assembled into outer barrel jackets using a drawing process, thus producing insulated composite test barrels. A total of twelve test barrels representing the four liner materials and three jacket materials (H-11, A-286, and Pyromet X-15) were fabricated. The results of this program indicated that electrochemical machining is a feasible process for obtaining high quality and low cost rifling, and that extrapolation of this process to larger calibers appears feasible.

7. Electric Discharge Machining:

The literature search reveals that electric discharge machining has not been used in the past for gun manufacturing technology. Also, it does not seem to be an economical candidate process for rifle components manufacturing.

8. Assembly Technologies:

In today's competitive marketplace, the traditional, sequential approach to product development simply can't keep pace. To ensure products assemble and work the first time, manufacturers recognize the need to fully integrate design and manufacturing activities early in the development process. Assembly technology is aimed at the set-up, control, and monitoring of assembly systems and related problems.

At present, this technology is being extensively used in electronic and packaging industries. However, assembly technology is constantly being developed, refined and researched to provide the most cost-effective and efficient solutions to all the manufacturing problems. Driven by increasing demands for better quality, faster production and minimum running costs, innovations are constantly being devised, tested and deployed throughout the manufacturing world. The designers can easily evaluate and modify multiple iterations throughout the design process, resulting in shorter manufacturing cycles, accelerating time-to-market, and sharpening the company's competitive edge. Using assembly technology approach, full integration of all component and system technologies to form a self-contained system capable of process control, configuration management, rapid product changeover, etc. is possible in the plant thus, reducing costs.

PRODUCT COMPONENTS AND THEIR COST

The M/710 consists of the following components together with their portion of the overall cost of the product.

Stock	35.9% of the cost
Barrel & Receiver assembly	25.4% of the cost
Bolt assembly	14.5% of the cost
Magazine	9.0% of the cost
Trigger assembly	7.6% of the cost
Miscellaneous components	8.6% of the cost

GUN-STOCK

The gun-stock is the most expensive component of the rifle. Even though cam controlled equipment is used to perform most of the machining, there is quite a bit of handwork in polishing and fitting. The traditional material is walnut family which includes claro walnut, American black walnut, eastern black walnut, and other walnut woods with brown heartwood and light sapwood ring. Some other stock woods include myrtle wood, maple, and madrone. The cost may vary with different type and grade of gun-stock woods selected. It will be appropriate for IAMS' and ERC/NSM's engineers to visit the Remington Arms Company, Inc's plant and observe and scrutinize each and every step of the manufacturing process for gun-stocks before coming up with suggestions for improvements.

If most of the cost of a walnut gun-stock is the raw material; there may not be much that can be done to reduce the cost. The injection molded synthetic stock is known to be much less costly than walnut; however, it may not be as salable as the guns with traditional walnut stock.

BARREL AND RECEIVER ASSEMBLY

Barrel:

The barrel is the longest lead-time item, taking approximately six weeks. It is rotary forged, including the rifling. To our knowledge this is the best method for manufacturing gun barrels. It certainly adds value and quality to the product. In one study, new and efficient metal-shaping procedures for the fabrication of gun barrels were evaluated [7]. The materials considered were Inconel 718, Vasco-Jet M-A(CVM), and a cobalt-base alloy in powder form. Gun drilling, ECM stem drilling, hot piercing and extrusion, and filled-billet extrusion were evaluated for tube fabrication before subsequent precision rotary swaging of the rifling. Gun drilling of these alloys was the most economical tube fabrication procedure. The filled-billet technique is most amenable to consolidation-tube fabrication from powdered alloys. Precision rotary-swaging was evaluated for rifling the tubes and for determining the feasibility of combined rifling and chambering during swaging. In another study [8], hot extrusion/cold swaging production sequence has also been employed in barrel manufacture.

Receiver Assembly:

The receiver is a part machined from steel bar stock with an ultimate tensile strength of 180-ksi. This part has a large number of machined features that are critical to the operation of the rifle. Machining operations include drilling, milling and broaching. The 180-ksi strength is only needed at the barrel end of this component. If the receiver can be redesigned at the barrel end; then, it may be possible to eliminate a large portion of the time consuming machining operations on this part by replacing it with a "Semi Solid Formed (SSF)" component. As mentioned earlier, SSF is a die-casting technique that is used to replace aluminum forgings in automotive applications. Typically an SSF part will have approximately 85% of the strength of an identical forging. The advantage of the SSF part over forging is that it can be net shape or near net shape, minimizing subsequent machining operations. The barrel end of the receiver can still be a steel insert possibly press fit into an aluminum body.

BOLT ASSEMBLY

The bolt assembly primarily consists of screw machine parts. The business end and the firing pin need to be steel; however, it may be possible to replace the body and the handle with one SSF component.

MAGAZINE

The magazine is a sheet metal stamping and a few die cast components. It may be possible to replace it with a new design, a three piece injection molding. It is difficult to foresee that there will be enough cost savings.

TRIGGER ASSEMBLY

The trigger assembly consists of powder metal and stamped/blanked parts. The trigger guard is die cast aluminum. This is the least costly portion of the product.

CONCLUSIONS

The gun-stock, as the most expensive sub-assembly, should be the primary subject of attention. We need to review the present manufacturing methods before we can come up with any suggestions. If we can reduce the cost of a gun-stock by 1/3'rd, we will be well on our way to achieving our goal of thirty percent (30%) overall cost reduction.

The second most expensive item is the barrel/receiver assembly. We suggest leaving the barrel alone; however, the receiver could be redesigned for manufacture by SSF technology. We should consider High-Speed Machining methods in order to minimize the cost of machining the SSF receiver.

The bolt assembly is the third most expensive component. We may be able to gain a few percentage points by semi-solid forming the bolt, integral with the handle.

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APPENDIX - 1

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