THE CANNON FOUNDRY OF JAIGARH FORT: A HISTORICAL AND TECHNICAL STUDY

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ABSTRACT:
The historical and cultural significance of the cannon foundry at Jaigarh Fort is extraordinary. This foundry is not only a symbol of the uniqueness of the fort but also a remarkable example of the Rajput martial art and technological prowess in Rajasthan. Among the cannon foundries found in Indian forts, Jaigarh's is considered the best-preserved and most well-planned. It is situated at the northeast corner of the fort. The Rajputs' role in Akbar's empire acquainted them with cannon-making techniques, which were later brought to Amber by Man Singh I and established in Jaigarh. With their efforts, the cannon foundry at Jaigarh was built in 1584, strengthening the Kachwaha rulers' sense of security and independence.

A reverberatory open hearth furnace was constructed in this foundry, where metal was melted and molded. Natural air flow was used to regulate the temperature during the process. Additionally, a sophisticated drilling system was set up to bore holes in the cannon barrels, demonstrating a high level of technical advancement. Jaigarh's cannon foundry was renowned for its complex manufacturing processes and tools, including "kachru," "nagfani," and "dantali." The cannon-making process here was kept a closely guarded secret, with work commencing after religious rituals. Thus, the cannon foundry of Jaigarh Fort was not just a technical unit but also a symbol of the Kachwaha rulers' self-reliance and military prowess.

Keywords: Jaigarh Fort, Cannon Foundry, Military Technology, War Tradition, Kachwaha Dynasty, Secret Military Activities, Rajput Martial Art

INTRODUCTION:

In December 1986, Canadian military historian Randolph George Samuel Cooper noted, "The military technology found here is proof of India's technological heritage. Every citizen of this country should be proud of the technical and martial traditions displayed here." The Jaigarh Fort served as a center for secret military activities and training. The processes and techniques used in cannon-making at Jaigarh are awe-inspiring.

Lieutenant Colonel Karanjeet Singh of the Indian Army (116 Med. Regiment) remarked, "As a gunner officer, I am astonished by the richness of information available in this incredible Jaigarh Fort, its cannons, factories, and technologies."

THE CANNON FOUNDRY AT JAIGARH:

The cannon foundry is one of the most unique features of the fort, symbolizing power. It is considered one of the best-preserved and well-planned cannon foundries among Indian forts. Located in the northeast corner of the fort, it served as the primary workshop for cannon manufacturing.

MUGHAL INFLUENCE AND RAJPUT COLLABORATION :

The Rajputs resisted foreign forces at Khanwa in 1527. Although they were not inferior to the Mughals, Babur's artillery turned the tide of battle in his favor. The Battle of Khanwa made Babur the 'Badshah' of Hindustan.

The Mughal-Rajput alliance of 1562 marked a new chapter in Indian and Rajputana history when Bharmal married his daughter to Akbar. This policy strengthened Akbar's empire while enabling the Rajputs to acquire artillery knowledge. The Kachwahas of Amber foresaw the advantage of joining the Mughals, establishing bonds through marriage.

TECHNOLOGICAL ADVANCEMENTS BY MAN SINGH I :

Man Singh I, one of the greatest generals of medieval India, gained expertise in Mughal artillery during his campaigns in Kabul and other regions. In 1584, he brought cannon-making technology to Amber and established the cannon foundry at Jaigarh.

RESEARCH METHODOLOGY :

This research employs historical and archaeological methods, including primary sources such as historical documents, maps, and on-site studies, as well as secondary sources like ancient texts, historians' writings, and previous research.

A detailed analysis of architectural features, construction materials, and ancient metallurgical techniques was conducted through direct observation of the site. Information from local museums and archives was also studied for comparative analysis.

RESEARCH PROBLEM :

Despite being a significant part of Indian history and architectural heritage, the cannon foundry at Jaigarh remains under-researched. Understanding its construction, technical processes, and historical importance is crucial for recognizing its role in India's military and scientific advancements.

OBJECTIVES AND GOALS :

- Analyze the architectural features and technical processes of the Jaigarh cannon foundry.
- Study the historical, cultural, and political reasons for its establishment.
- Examine the tools, metallurgical processes, and scientific advancements of the era.
- Assess the development of military technology during the Rajput and Mughal periods, highlighting the role of the foundry.
- Evaluate conservation efforts and propose improvements for preserving this heritage.

KEY FINDINGS :

The Jaigarh cannon foundry, established around the 16th century, was pivotal in enhancing Rajput military strength under the Mughal empire. The foundry's advanced techniques and equipment underscore the technological sophistication of the Indian subcontinent.

Man Singh I acquired artillery expertise during his service with the Mughals and used this knowledge to benefit Amber. The foundry exemplifies Rajput self-reliance and preparedness.

TECHNICAL FEATURES :

1. **Reverberatory Furnace**:
   The furnace was an open-hearth type, utilizing natural air currents to achieve temperatures of 1000-1200°C. It featured advanced systems for charging and pouring molten metal.
2. **Drilling Complex**:
   The drilling mechanism was powered by bullocks and a sophisticated gear system. It demonstrated precision comparable to European artillery manufacturing.
3. **Tools and Techniques**:
   Tools like "*Kachru*," "*Nagfani*," and "*Dantali*" facilitated the complex processes of casting, drilling, and assembly.
4. **Religious Practices**:
   Religious rituals were integral to operations, reflecting the spiritual significance attached to the foundry.

FINDINGS :

During the study of the cannon foundry at Jaigarh Fort, several significant facts emerged, which are not only intriguing from an architectural and technical perspective but also hold historical and cultural importance. This foundry was established around the 16th century with the purpose of strengthening the military power of Rajputana under the Mughal Empire. The study of this foundry highlights the advanced technical and military knowledge prevalent in the Indian subcontinent during that time.

Man Singh I, a commander in Akbar's army, learned the technique of cannon casting while serving the Mughal rulers in Kabul during the 16th century and brought this knowledge back to Amber. Along with this technical expertise, he also brought models of cutting tools and drilling bits to Amber. His father, Bhagwant Das, the then ruler of Amber, established a cannon casting factory in 1584. Cannon production began in 1587, as the oldest cannons found here date back to this year. The successors of Man Singh made optimal use of this cannon-making knowledge for the benefit of their state.

Although they were allies of the Mughals, they understood the necessity of ensuring the security of their homeland. They never forgot their responsibilities toward their people and were always prepared to face challenges. Part of this preparation included the manufacturing of cannons within the foundry located inside the fort.

Casting is the process by which molten metal is poured into molds to create metal products. The required metal is melted and then poured into a cavity, known as a mold. It is left to cool, allowing the molten metal to take the shape of the mold. The melting process occurs in furnaces.

The Jaigarh cannon casting factory covers an area of 162 feet × 57 feet. This casting complex is divided into two main units:

1. **Furnace**
2. **Drilling Complex**

A square area measuring 64 feet × 57 feet acts as a division between these two units.

THE FURNACE:

The furnace is a device in which heat is directly applied to melt the metal or charge. There are approximately 600 types of furnaces, differing in design, size, and shape. A furnace can be as simple as a small pit or as complex as a 40-foot-tall tower. Furnace capacities range from melting a few ounces to hundreds of tons at a time. Major types of furnaces include rotary, converters, electric, cupola, crucible, and reverberatory furnaces.

The cannon casting factory at Jaigarh Fort falls under the category of reverberatory open hearth furnaces. These furnaces burn fuel at one end of the furnace chamber. At Jaigarh, the furnace was the primary structure where gunmetal alloys were melted and poured into molds. This furnace resembles a room, measuring 24 feet 10 inches in length, 12 feet 4 inches in width, and 10 feet 8 inches in height. It has staircases on both sides leading to a roof with three chimneys. The furnace is equipped with a refractory enclosure capable of withstanding high temperatures.

CHARGING WINDOWS:

The furnace has charging windows on both sides (outer dimensions: 1 foot 3 inches wide and 1 foot 6 inches high; inner dimensions: 11 inches wide and 1 foot 2 inches high). These windows have a unique opening mechanism. The doors are connected to roof-mounted hooks via a long rod, operated with an iron handle. Pulling the handle downward opens the charging windows, and releasing it closes them. The windows were used to insert gunmetal slabs or ingots into the hearth of the furnace. Once the metal was placed, the charging windows were tightly closed.

HEARTH OF THE FURNACE:

The furnace hearth is oval-shaped, measuring 6 feet 7 inches in length, 5 feet 6 inches in width, and 4 feet 7 inches in height. The roof has two openings leading to chimneys. The hearth is constructed of fire-resistant materials such as fire bricks and fire clay, capable of withstanding high temperatures and the pressure of molten gunmetal. It also serves as a poor conductor of heat.

A small window (2 feet wide and 2 feet 10 inches high) connects the hearth to the main pit outside the furnace. This window is specially designed in a tapered shape to prevent molten metal from coming into contact with the cooler brick walls of the furnace and to direct it straight into the molds. The window features a pouring spout (4 feet 6 inches wide and 1 foot 4 inches high), controlled by an iron blade to open and close the spout.

MAIN PIT :

The main pit outside the furnace measures 7 feet 8 inches by 7 feet 7 inches. It was used to hold molds where molten gunmetal was poured. The depth of the pit was adjusted according to the length of the cannon mold. The mold was placed upright in the pit, with its opening connected to the pouring spout through small channels to allow the molten metal to flow into the mold.

EXHAUST FLUES AND FIRE CHAMBER :

The front of the furnace has two exhaust flues with a diameter of 3½ inches each. These were used for zinc-rod testing to observe the color of the molten metal inside the furnace.

The fire chamber, connected to the hearth, is a square structure measuring 3 feet 4 inches on each side and 5 feet 4 inches in height. Wooden logs were placed on iron grates inside this chamber. The grates had 12 square openings (6 inches each) that allowed air to flow from below, aiding combustion. The roof of the chamber had an opening leading to the third chimney.

A window (2 feet 9 inches wide and 2 feet 10 inches high) at the back of the fire chamber was used to insert wood. Once the wood was loaded, this window was tightly closed. Another window (2 feet 2 inches by 2 feet 3 inches) connected the fire chamber to the hearth, allowing flames and gases to enter the hearth for heating.

VENTILATION AND TEMPERATURE CONTROL:

The bottom of the furnace includes a 72-foot-long tunnel, acting as an air conduit based on Bernoulli's principle. Increased air velocity through the tunnel created a low-pressure zone, ensuring natural airflow. The walls of the palace complex and the fort's outer walls also functioned as extended air tunnels.

The furnace temperature gradually rose to around 1000–1200°C. The roof design directed the flames downward toward the hearth. This ensured an even flow of flames and gases over the charge, achieving uniform heating within the furnace.

TESTING AND FLUXING:

During that era, there were no gas analysis facilities in the Jaigarh foundry. The furnace atmosphere was assessed using simple zinc-rod tests. A rod placed at the exhaust would change colors based on the atmosphere inside the furnace—ranging from black to golden or light brown in a reducing environment, with no change in oxidizing conditions.

Another method involved dipping a rod into the molten metal inside the hearth. If the metal adhered to the rod, it indicated further heating was required. If the rod came out clean, it signified that the charge was fully melted.

Fluxes were added periodically to create a covering over the molten metal. Fluxes such as limestone, basic open-hearth slag, fluorite, and soda ash, sourced locally, were used to enhance the fluidity of slag and remove impurities. Once melting was complete, slag was removed, and the molten metal was poured into molds through the pouring spout.

COOLING AND CASTING:

After pouring, the metal began to solidify. The time required for solidification depended on several factors. The large surface area of the molds at Jaigarh facilitated faster heat dissipation, increasing the solidification rate. During cooling, the metal contracted away from the mold walls.

The initial cannons at Jaigarh were made of cast iron, later replaced by bronze. Cast iron typically contains 3–3.6% carbon, along with silicon (0.5–4%) and small amounts of manganese, sulfur, and phosphorus. These components influenced the properties of the final casting.

ADDITIONAL FEATURES:

Near the furnace, a small circular tank (5 feet in diameter and 3 feet 10 inches deep) and two trenches (11 x 8 x 7 inches) were used to cool tools employed in the furnace.

RELIGIOUS PRACTICES:

Adjacent to the furnace is a worship area with numerous 'trishul' (trident) markings. Before beginning work, the goddess Durga was worshiped to seek her blessings for strength and guidance.

TOOLS USED IN THE FURNACE AND THEIR DESCRIPTIONS :

1. **Sangri or Iron Rod**: A long iron rod with a slightly bent tip. It was used for zinc-rod testing to assess the furnace environment and the condition of the molten metal.
2. **Karchu or Spoon**: A long spoon-like tool used to remove coal and ash from the fire chamber or to charge flux into the furnace.
3. **Kalai**: An arm-shaped tool used to stir or mix the molten metal in the hearth.
4. **Panja**: A tool with four iron fingers, used for removing slag from the molten metal and mixing it. Another version, with only two iron fingers, was used to clean the grates of the firing zone.
5. **Dantali**: A tool with small iron teeth and a long handle, used for cleaning the fire chamber.
6. **Nagfani**: Shaped like a cobra's hood, this tool was used for removing slag.
7. **Sariya or Rod**: A long rod with a slightly bent tip, used to clear obstructions from small holes or openings in the furnace.
8. **Sandasi or Tongs**: A larger version of kitchen tongs, used for lifting large and heated objects.

These tools were designed to facilitate the metal casting process in the furnace and were crafted for ease of use in various operations.

THE DRILLING COMPLEX:

The drilling complex housed a mechanical apparatus used to bore holes into cannon barrels. Its design and construction were so advanced that its original structure remains intact today. It provides a significant perspective on technological progress and the science of military warfare. The design, techniques, and precision of the cannons produced here rivaled those of their European counterparts.

STRUCTURE AND MECHANISM:

The complex includes an octagonal chamber, 31 feet high, with a corner-to-corner measurement of 20 feet 2 inches. A central beam, 7 feet 8½ inches high, had thick wooden crossbars attached to it. The beam's circumference where the bars were fixed was 4 feet 3 inches. Four pairs of oxen rotated the wooden bars, which powered the gear system of the complex.

The gear system, located directly below this chamber, consisted of four wheels:

- **First Wheel**: A massive wheel, 9½ inches thick with a diameter of 15 feet 7 inches, featuring 56 teeth or spokes, each 9 inches long with a circumference of 1 foot 2½ inches.
- **Second Wheel**: A twin wheel with a diameter of 5 feet 11 inches.
- **Third Wheel**: A larger wheel with a 4-foot-long beam or shaft.
- **Fourth Wheel**: A smaller twin wheel with a diameter of 4 feet, which connected to the main drilling complex above.

The gear system operated on principles similar to modern gear systems.

DRILLING OPERATIONS :

The main drilling complex measured 34 feet by 28 feet. The fourth wheel was equipped with a frame or socket and screw system. Various-sized cutter heads were attached to the sockets and secured with screws.

A drain measuring 32 feet in length, 2 feet 8 inches in width, and 1 foot 8 inches in depth was used to place the solid cannon barrels after they were removed from the mold for cooling. When the gear system was in operation, the cutters and drilling bits bored holes into the cannon barrels. The size of the bore depended on the cutter heads or drilling bits used.

At Jaigarh, the largest cutter measured 15 feet 8 inches, and the smallest was 7 feet 6 inches. Heavy iron plates were placed over the barrel in the drain to prevent it from moving upward. These plates were inserted into 10-inch-wide side holes for stabilization.

OBSERVATION AND RELIGIOUS PRACTICES :

Since cannon manufacturing was a confidential process, the rulers observed the operations from a two-story balcony in front of the drilling complex.

- **Upper Balcony**: Measured 17 feet 2 inches × 11 feet 8 inches and included an attached bathroom.
- **Lower Balcony**: Measured 22 feet 3 inches × 9 feet 6 inches.

Additional facilities, including a bathroom and toilet, were provided near the complex for the rulers and nobles.

Inside the drilling complex, there is a temple dedicated to Lord Ganesha. Religious rituals were performed before placing the cannon barrel in the trough for boring.

Figure 1: Jaivana Cannon, Jaigarh (The World's Largest Cannon on Wheels)

MOLD PREPARATION:

In all types of foundries, sand is the primary molding material. Until recently, mold-making was considered a craft. The term "sand" encompasses a variety of granular minerals. The sand used in the Jaigarh cannon foundry contained the following key components:

(a) **Quartz**: The primary constituent of sand grains, composed of silica or silicon dioxide bound with some clay.

(b) **Clay Substances**: These act as a binding medium around the quartz grains. Moisture in the clay provides strength to the molds.

(c) **Feldspar, Micas, etc.**: These are fluxing materials present in the sand, and their nature depends on the rock from which the sand was derived.

It is estimated that approximately one ton of sand was used to create a single ton of metal casting. The molds for the cannon barrels at Jaigarh were made using a split-pattern technique, meaning the molds were prepared in two halves and then joined to form a complete cylindrical mold.

A fine-textured clay was mixed with sufficient water to create a paste for mold-making. The inner surface layer of the mold was prepared using a circular beam, and the surface was smoothed to allow artisans to carve patterns and designs into the mold. These patterns, once cooled, were visible on the

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cannon barrels. Over the inner layer, 4–6 additional layers of clay and other adhesives were applied. These layers contained a mixture of silica, mica, coal dust, straw, and coarser sand.

The two halves of the mold were then joined together. Iron sleeves or braces were used to hold the mold tightly, ensuring it could withstand the pressure of molten metal. A metal plate was placed at the base of the mold to provide additional support. The molds required several weeks to dry as there were no stoves or ovens available at that time for this purpose.

Several prepared molds are still present at Jaigarh, although some were recently destroyed. One complete mold currently on display is 12 feet long, with an internal diameter of 11 inches.

Thus, it can be concluded that the Jaigarh gun foundry was a comprehensive cannon manufacturing unit. The rulers of Amber mastered the arts of casting, drilling, and mold-making.

CONCLUSION:

The Jaigarh gun foundry stands as a unique example of technical excellence and symbolizes the scientific, artisanal, and military capabilities of its time. The tools, techniques, and processes available at the foundry highlight the expertise of the rulers of Amber in cannon manufacturing and casting. They developed their local and traditional skills to compete with European cannon-making technologies.

The presence of molds, a drilling complex, and a reverberatory furnace at the foundry testifies that Jaigarh was not only involved in cannon manufacturing but also maintained a high standard of quality. By honoring religious traditions and leveraging technical expertise, the rulers of Amber developed this foundry into a complete military manufacturing unit.

The Jaigarh gun foundry is undoubtedly a historical treasure that serves as remarkable evidence of medieval Indian military science and metallurgical craftsmanship.

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