DEVELOPMENT OF CANNON TECHNOLOGY IN INDIA

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Cannons constitute an important section of artillery. The developments of cannon technology, in the Indian sub-continent, specifically relating to cast bronze and forge welded iron cannons have been presented here. The incendiary devices used before the advent of cannons, casting techniques of bronze cannons and the design and construction of forge welded iron cannons have been discussed and overviewed along with Indian innovations in cannon technology. Further studies in this direction in the Indian sub-continent have been proposed.

Keywords: Bronze, Cannon technology, Casting, European, Forge welding, Gunpowder, Incendiary, Mughal, Turkish, Wrought iron.

INTRODUCTION

The invention of cannons and their use in warfare added a totally different dimension to battles. It was an effective arm of both the army and navy, and still it is so. When it was used in the army, it added destructive power to the artillery. Its use in ships was often a decider. The use of cannons in navy posed its own unique requirements and alterations in cannon technology ¹, but the basic operation of the cannon, the mighty fighting machine, remained.

The origin of cannon technology is not clear, as there are claims to this technology by Europeans, Chinese and Arabs. It is clear that the development of cannon was the outcome of the invention of saltpetre in China sometime in the 10th century and realization of its propellant properties. Gunpowder contained a properly combined mixture of saltpetre, charcoal and sulfur. The story of early gunpowder is available in the literature ¹–³, while some historical and technical aspects of saltpetre ⁴ and gunpowder ⁵ in the Indian sub-continent are available in this volume.

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The first illustration of cannon in Europe is dated to 1326, wherein a gunner is shown firing an arrow-like projectile from the cannon using a red-hot iron. A hand cannon of similar design, dated to about early 1300, has been recovered from the sea near Sweden, and currently placed in the National Historical Museum at Stockholm. There are several references to the use of cannons in battles in Europe during the 14th and 15th centuries. Cannon technology was further advanced by the Ottoman Turks who used it devastatingly in the siege and capture of Constantinople in 1453. It is clear that the Ottoman innovations reached the Indian shores through two routes, through the land from the northwest and through the sea to the Deccan (i.e. peninsular India). Before understanding the development of cannon technology in the Indian sub-continent, it is important to review the early incendiary devices that were used before the advent of cannons.

**Early Devices**

Prior to the advent gunpowder and cannon technology, several incendiary throwing devices were used in the Indian sub-continent, during both field and water battles, as well as in sieges of fortifications. That the Indian sub-continent was witness to numerous battles and wars provided the necessary potential and zeal for inventing different types of war machines. We hear about the use of war devices called *nafit-andāz* (naphtha throwers), *atish-bāzī* (fire-playing devices), *hukkahe-atish bāzī* (vessels filled with fire), *manjānik*/*maghrībis*/*arrādās* (elaborate tension machines for throwing fire arrows), *carkh* (magnified cross-bow catapult worked by tension by means of pulleys and ropes) and *bān* (iron cylinder containing gunpowder attached to a long bamboo or reed, which steadied its flight). One of the primary ingredient was naphtha, an invention of the Arabs that traveled to Europe through Greece, whence it was called Greek fire.

The history of gunpowder usage in India originated with the use of the rocket-like object called *bān*. There is an excellent discussion on the use of *bān* and its history in Khan’s excellent book on the history of armed warfare in the Indian sub-continent. The erudite scholar has presented a comprehensive history of cannons in the Indian sub-continent in his book. In this presentation, the developments in cannon technology in the Indian sub-continent through the medieval period have been critically addressed from a technical viewpoint.
The use of gunpowder to project a missile was introduced in the Indian sub-continent in the 15\textsuperscript{th} century. The Tārikh-i-Ferishtā mentions that, in 1368, Muhammad Shāh Bāhmani I captured 300 gun carriages in a battle with the Hindu king of Vijayanagar. There is record that Māhmud Shāh II of Gujarat, in 1482, sent out a fleet containing gunners and musketeers against the pirates of Bulsar. Moreover, Māhmud Shāh II used cannons to break the walls of Champanir and fired shells at the palace of the Rājā in 1484. Immediately after the Portuguese set foot in India, they noted that a Gujarat vessel fired several guns at them in 1500. Even more notable is the Portuguese report of the naval fleet of the Zamorin of Kerala carrying 380 guns in 1503.  

There have been claims by several authors that Indians used gunpowder and cannons even earlier to this date. These arguments have been discussed and refuted by learned scholars. However, all the scholars agree on the use of artillery in India in the later half of the fifteenth century.

It is relevant to note that the kingdoms in south, both Muslim and Hindu, were advanced in artillery compared to the Delhi rulers of this period because of their contact with outside world, especially Turkey, through the sea route. The south Indian kingdoms imported their gunners (topci) and artillery from Turkey and the Arab countries, with whom they had developed good relations.

A big impetus to cannon technology was provided from the beginning of the sixteenth century with the introduction of new skills and concepts from Europe and Ottoman sources. Khan attributes this to two reasons, namely the arrival of Portuguese at Calicut in 1498 and Babur’s occupation of Delhi and Agra in 1526.

**Wrought Iron Cannons**

Khan contends that one of the most important skills borrowed from Europe in the beginning of the sixteenth century was the making of cannons out of wrought iron. Shipwreck finds have confirmed that the Europeans were using a type of forge welded iron cannon in their ships in the 16\textsuperscript{th} century, which were known as "port pieces". Therefore, the design of early Indian forge welded cannons may have been based on this European model. That the
Europeans designed forge welded cannons even prior to the 16th century is proved by the early forge welded bombards like Mons Meg in Edinburgh, England and Dulle Griet in Ghent, Belgium. However, the forge-welded cannons fell into disuse in Europe, with the last one reported to have been made around 1520. One of the causes for this was the ease of casting bronze cannons while compared with the difficulty in manufacturing forge-welded cannons. Another probable cause must have been the perfect bore that could be obtained with the case of the cast cannons in contrast to the rougher surface created in the case of forge welded cannons by the use of staves. Therefore, the engineering was more involved in the case of forge welded cannons when compared with bronze cannons. Another possible reason could be the advent of cast iron technology in Europe and this drastically affected cannon production. However, the cast iron cannons were not viewed with favor initially because they tended to fail without notice. The bronze cannons were more reliable because they were more tough and they bulged at the breech before failing, thereby providing sufficient warning to the gunners.

It is very interesting at this point to compare the forge-welded cannons of the Indian sub-continent with that of the forge-welded cannons (bombards) of Europe. Unlike the European examples of Mons Meg and Dulle Griet, the Indian cannons do not reveal a smaller diameter powder chamber and a larger diameter stone chamber. There is only one exception to this, namely the Bachawali cannon (Fig. 1), now located at the Hazaraduari palace complex at Murshidabad in the state of West Bengal. This cannon reveals a smaller diameter powder chamber. Unfortunately, the date of manufacture of this cannon is not known because the brass plates that were fixed to the cannon, which provided this information, are missing. Like the case of many archaeological objects placed in public domain in current day India, the brass plates have been vandalized.

Lack of precise dates is a problem with forge-welded cannons because we obtain precise dates (or inscriptions) only in few forge welded iron cannons. According to Khan, the earliest dated forge welded cannons are two wrought-iron guns lying in the public gardens at Khandwa (Madhya Pradesh). They bear inscriptions of dates 1585 and 1589. Forge welded cannons preceding these dates are available, based on the dating of bastions on which the
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Fig. 1: The Bachawali cannon of Murshidabad.

Cannons are located. For example, the Lambacari cannon on the Haidar Burj at Bijapur has been dated by Deloche to 1582. Incidentally, inscriptions are more readily available on bronze cannons and therefore, this may suggest that bronze cannons were more prized than forge welded iron cannons, probably due to the greater cost of raw material and manufacturing of bronze cannons. It is known that Sher Shāh Sūri (1549-1545) requisitioned all the available copper in the market as well as in the households of the troopers for making mortars (deg-ha) in 1543. Khan supposes that this could be an indication of copper being in short supply at this time. However, this could also indicate an increase in the output of cannons manufactured during his reign.

With reference to Sher Shāh Sūri, it is to be noted that some of the earliest dated wrought iron cannons belong to his period. They are dated to 1542-43 based on a Persian inscription on one of them stating that it was made by one Saiyid Ahmad Rumi. They are of roughly the same design and length as his cast-bronze cannons, classified as zarb-zans, of the period. (The zarb-zan was a smaller cannon, about 4 to 5 feet in length and muzzle diameter of 1 to 2 inches, which was much more mobile than large cannons.) The condition, design and technical details of these cannons deserve a careful look because they are some of the earliest forge welded cannons of India.
Cast Bronze Cannons

Around the beginning of the sixteenth century, the techniques of casting of bronze cannons were also improved with knowledge inputs from external sources. The Turks were particularly skilled at casting massive bronze cannons. The Mughal emperor Babur successfully adopted several war tactics of the Rumis. Some notable Rumis in the service of Babur were Ustad Ali Quli and Mustafa Rumi. Ustad Ali Quli was an expert gunfounder and his casting of a large cannon is graphically recorded in Babur Nāma. The leading cannon founders were given the title Rumi Khan. Therefore, the Turks were experts in casting massive bronze cannons and they rendered this service for North Indian as well as Deccani kings. One wonderful example of a massive cannon cast by a Rumi is the Mālik-i-Maidan (King of Battlefield) cannon (see photograph of this cannon in the article by Deloche in this volume) located on the Sherji Burj in Bijapur. This all-bronze cannon was cast by a Turkish engineer (Mohamed bin Hasan Rumi) for a Deccani king Nizam Shah in 1548-9. Incidentally, this is one of the largest bronze cannons in India. Its length is 426 cm, muzzle diameter is 149 cm and the bore diameter is 71.2 cm. Its estimated weight is 55 tons.

The design features of the relatively early massive bronze cast cannons needs to be critically analyzed. There are several such cannons located in Deccan forts and they can be dated precisely based on information provided in the inscriptions on their surface. Some examples are cannon dated to 1534-5 at Narnala fort, Akola District, Maharashtra, at the Cāñhi Burj of the Udgir Fort, Bidar District, Karnataka and one in Gulbarga dated to 1557. The design features of smaller cast bronze guns are available from the dated zarb-zans of Sher Shāh Sūri.

Therefore, it appears that the technology for manufacturing cannon reached India from Europe. While bronze-casting technology was adopted from the Ottoman Turks, the forge welded cannon technology seems to have been developed through contact with ‘port pieces’ of the Europeans. However, it must be emphasized that this in no way diminished the engineering ingenuity of the Indians because the cannon technology was further developed based on local need and talent. These developments will be understood in the following section, with specific reference to the casting and forge-welding techniques.
DEVELOPMENTS IN CAST BRONZE CANNON TECHNOLOGY

The destructive power of cast bronze cannons was clearly established in the Indian sub-continent by Babur, although cannons were introduced earlier. The developments in cast bronze cannon technology in the early 16th century appear to have been drastic as the distance traveled by mortal increased from about 1200 meters in 1527 (time of Babur) to about 5500 meters in 1540 (time of Humayun). There were several innovations affected by Sher Shah Suri, who deposed Humayun and ruled India for a short period. It is clear that he paid a lot of attention to use of gunpowder and he was more interested in smaller arms than large massive cannons. Some of his earliest small sized cannons are known and need to be critically studied. These smaller cannons were put to effective use, both for waging offensive field battles and for defending fortifications.

Artillery progressed further under Akbar's (1556-1605) rule. It attained greater efficiency and several innovations were affected. There is mention of one Fathullah Shirazi, one of the jewels of Akbar's court, who joined the court in 1583AD. Innovations carried out by Fathullah Shirazi included a machine for cleansing gun barrels, a portable cannon and a multi-barrel cannon. Jahangir inherited an efficient artillery from Akbar, and there were not many improvements implemented by him.

The use of large sized artillery again gained prominence during Aurangzeb's reign. This was necessitated by his numerous war campaigns in the Deccan. He laid several long sieges on Deccani fort, such as those at Bijapur, Golconda and Senji. It is debatable whether the forts were captured due to his artillery or by deceit. More often, the impregnable forts were captured by clever trickery and outright betrayal, and not by damaging the bastions and fortifications with cannon fire power.

With the waxing of the Mughal power, other states rose into prominence in the Indian sub-continent, aided by the efficient use of cannons. Notable among them were the Marathas and the Sikhs. Artillery played an important role in the rise of these powers. Some of the excellent Maratha and Sikh cannons are still preserved at the Rotunda Museum in Woolwich, England. They were captured as war trophies by the British, and transported and
gifted to the ruling monarch back in England. The excellent engineering and construction of these cannons must be appreciated. Some examples of cannons from Maratha, Mysore and Sikh kingdoms at the Museum of Artillery in the Woolwich Rotunda have been published recently. They were all exhibited in a temporary exhibition called Guns of the Rajahs on Firepower, The Royal Artillery Museum between May and October 2003. Similar exhibitions need to be conducted by the Indian museums and military organizations to highlight the wonders of Indian cannon technology to the general public and young school children. This will also provide an opportunity for proper cataloguing of cannons and to implement careful conservation treatments to the cannons, if needed.

Types

Based on design features and size, cast bronze cannons were classified into different categories. In Europe, in the sixteenth century, almost all cannons fell into one of three categories according to design: the culverins, the cannons, and the pedreros. Such classifications also existed in the Indian subcontinent. Therefore, we hear about the use of kazans, zarh zans and firingis during the time of Babur. Based on the painting of the Battle of Panipat prepared at Akbar’s court in 1600, Khan concluded that Babur’s zarh-zans were lighter versions of his kazans, with modifications noticed in the handling arrangements. In both these types, trunions were missing. The zarh zans were placed on carriage with two wheels and drawn by four pairs of bullocks. The larger cannons appear to have been drawn by eight pair of bullocks. While the zarh zans discharged balls about 41 lbs in weight, the larger ones appear to have discharged lead balls almost ten times this weight. The firangi appears to be what was referred to in Deccan as jinjals. In fact this word was used even as late as 1821 to indicate a swivel cannon. Khan also suggests that firangi may be related to the Chinese fo-lang-chi Chhung (similar to European breech-loading naval gun called culverine).

The effectiveness of lighter cannons was also realized and different types were invented in the Indian sub-continent. We shall briefly address some of these because they were unique Indian innovations. The firangi appears to have been modified into these lighter cannon pieces. These lighter pieces were called by different names based on how it was rendered mobile. Smaller and lighter cannons that were carried by men were known as mardum-kash (men-drawn)
and also as narnāl. Small cannons mounted on camels were called as s'aturnal, while those mounted on elephants were referred to as gajnāls and hathnāls. These cannons were unique Indian innovations. Some examples of these cannon types have been discussed by Khan 26. Other types of light cannons mentioned are zambūrk, sāhin, dhamākā, ramjanḵī, and rahkūla 8. Bajwa states that they were usually built of cast brass with iron cylinders, and were between 3 and 6 pounder 35. The technical details of these types of smaller cannons need careful engineering analysis.

Cannons were also classified based on their specific use and purpose, because cannons were designed keeping specific functions in mind. Cannons known as burji-shikans (Breakers-of-Tower) were too heavy to move from one place to another and it was generally lodged on bastions of forts. Cannons mounted on carriage and drawn by elephants were known as fil-kash. Ox-driven cannons were referred to as gau-kash. These cannons were of various sizes and weights.

**Casting Technology**

The early impetus to develop bronze cast cannons was provided by the Turks, who served the Indian chiefs as master gun founders. The Turks were famous for casting massive bronze cannons 17. The requirement for a large quantity of molten metal for casting large bronze cannons was partly solved in the Islamic world of the fifteenth and sixteenth centuries by casting the powder-chamber and the stone-chamber of heavy mortars separately. This certainly seems to have been the case with the early bronze cannons of India.

Bābūr described the casting of a mortar (kazan according to Bābūr) by his chief gun-founder, Ustad Ali Quli Khan, at Agra in 1526 18:

October 22: Ustad Ali Quli had been ordered to cast a large mortar for use against Biana (Bayana) and other forts which had not yet submitted. When all the furnaces and materials were ready, he sent a person to me, and, on Monday the 15th of the month [corresponding to 22nd October] we went to see the mortar cast. Round the mortar mould, he had eight furnaces made in which were the molten materials. From below each furnace, a channel went direct to the mould. When he opened the furnace holes on our arrival, the molten metal poured like water through all these channels into the mould.
After a while and before the mould was full, the flow stopped from one furnace after another. Ustad Ali Quli must have made some miscalculation either as to the furnaces or the materials. In his great distress, he was for throwing himself into the mould of molten metal but we comforted him, put a rope of honour on him, and so brought him out of his shame. The mould was left a day or two to cool; when it was opened, Ustad Ali Quli with great delight sent to say, the stone chamber (*tash-awi*) is without defect; to cast the powder compartment (*daru-khana*) is easy. He got the stone chamber out and told off a body of men to accoutre it, while he busied himself with the casting of the powder compartment.

*Baburnama*’s description of casting the mortar lacks technical details. However, we learn that the casting of cannons was a spectacular sight worthy of personal visit of the supreme monarch. In the European context, we hear about casting of cannons being public events wherein common people specifically came to the foundries to view the actual casting process. Its must have been an exciting experience for the general public to view casting of large cannons, due to large quantities of hot metal flowing through the runners from the furnaces and then filling the cannon moulds.

In this regard, it is interesting to note the technology used in the casting of the great cannon used against Constantinople in 1453 AD. This account is as follows:

*[The founders] take a quantity of very fat clay, the purest and lightest possible, which they make plastic by kneading it for several days. The mass is knit together and prevented from breaking by the addition of linen, hemp and other fibres. The whole is worked into a tough and compact mass. Then they make a long cylinder to serve as the core of the mould. Another [hollow, cylinder] to receive the first is made, but larger in order to leave a void space between the two; it is the space intended to receive the bronze pouring into it from the furnace to take the form of a cannon. The exterior [of the mould] is made of the same kind of clay, but entirely surrounded and reinforced by iron, timber, earth and stones built up around it to prevent the immense weight of bronze from fracturing it and spoiling the cannon. They then erected two furnaces, one on either side and close to [the mould]. These lowerers were made very strong and fortified internally with brick and a very fat well-worked clay, and on the outside built with large cut-stones and cement. And they cast into the furnaces, a mass of copper and tin [weighing]*
about 1500 talents [37 tons]. On it they threw, charcoal and wood, arranging that the metal was covered below, above and on all sides. Round about were the bellows, working without intermission for three days and nights until the whole of bronze, melted and liquefied, became like water. Then the outlets being tapped, the bronze flowed through earthen pipes into the mould until it was filled and the interior cylinder covered so that the metal lay 30 inches deep upon it.

It seems that Ali Quli Khan’s method may be similar to that, but there are fine differences to be noted.

If one compares the accounts, the second account provides more technical details regarding the mould and core used in the casting of the hollow barrel. Another interesting detail that we learn from these accounts is that the stone chamber and powder chamber were cast separately and then joined together.

Looking at the earlier bronze cannon casting technology when the barrel and powder chamber were made separately, we need to understand how these two portions were joined together. Iqtidar Alam Khan mentions that these chambers in early cannons were joined by means of iron rings and he mentions that these can be distinguished in the cannons shown in some of Babūrnāma’s illustrations. Similarly, based on analysis of cannons depicted in paintings of Akbar, Khan concluded that cannons by this time were made by joining the two pieces together and also by a single casting. Therefore, by the time of Akbar, the process of casting of fully complete bronze cannon appears to have been well established.

These issues have to be looked at more critically from a technical viewpoint based on real technical analysis of the cannons of this period. This is important because it is difficult to arrive at the right conclusions based on pictorial evidence alone. For example, Fig. 2 shows a cannon of Aurangzeb now lying in Pune (at War Memorial, length 350 cm and muzzle diameter 46 cm). It is painted such that three prominent white bands are noticed on a black barrel. This resulted in the commentator of this cannon to state that it is a forge-welded cannon with three bands. This is certainly not true as the construction and design of the cannon, and the placing of the inscription on the cannon clearly indicates that this cannon is an all bronze cannon. Therefore, it is easy to mistake cannon types, design features and technical details based on pictures alone.
A first hand study of available pieces is necessary to understand cannon technology in the correct perspective.

The developments in bronze cannon technology of India in the 16th century closely followed those in Europe. Two distinct casting methodologies evolved in the 16th century 37. The first method was used for casting relatively large cannons (i.e. called pedreros) and practiced by Ottoman Turks and the Portuguese. In this method, the gun was cast around a core, which was first lowered into the casting pit. The main part of the mould was made hollow to fit over the core. The mould was then lowered over the core. The material was poured such that the bottom of the cannon filled up last (see Fig. 3a). In the other practice, which was followed by nearly all the European powers, the gun was cast around a core that was lowered into the main ‘sleeve’ of the mould. The core was maintained in position and centered by means of a iron cross or web, located at the breech or at other locations (see Fig. 3b). These are known as chaplets and they held the core in place during the casting process. These were made of wrought iron. These iron rods were incorporated into the casting and these type of cannons are also called as ‘cast-on’ type. The presence of
these rods can be clearly distinguished on the surface by their different coloration.

There is an interesting method of finding out the pour direction by careful compositional analysis. The copper-based alloy used for casting cannons is usually bronze (i.e. copper-tin alloy). If an alloy of copper with tin is allowed to solidify in a mould, the first metal that would solidify will be poorer in tin while the last metal to solidify will be richer in tin. This would be especially true if the metal in the mould solidified at a relatively slow rate. That this is true is indicated by the statement of Babūr that the moulds were broken open after 2

![Diagram](image)

Fig. 3: Comparison of two methodologies of casting cannons: (a) core placed in centre of mould and material poured over, and (b) core placed in the sleeve of the mould and positioned using chaplets and material poured into the mould (adapted from ref. 37).
days thereby allowing the casting to cool down sufficiently slowly. If the hot metal was poured into the open mould, the metal at the bottom would solidify first and then the metal at the top. Therefore, the composition of tin at the top of the casting would be more than at the bottom of the casting. By carefully analyzing the compositions of Indian cannons at the front and back locations (preferably at four points at each location) the technology used for casting the cannons can be confirmed. This kind of analysis can be done with the least amount of damage by using a fine microdrill to obtain samples, which will hardly leave any telltale marks or scars on the surface. It is important to conduct such a study on carefully selected cannons (with known precise dates) to understand the technology of Indian cannon manufacture.

The casting of cannons using a central core with associated chaplets seems to have proceed for some time in Indian history. We have evidence for such use till the end of the 17th century. The presence of iron chaplets can be seen in several of Aurangzeb’s (1658-1707) cannons and therefore, it is clear that the Mughals, during the time of Aurangzeb, still adopted the method of casting cannons using a inner core. In the all-bronze cannons, the core was removed; but in the case of composite cannons (i.e. cannons with interior barrels or staves and cast bronze exterior), the inner iron structure was held in place using chaplets and a strong iron rod placed in the centre of the rear portion (cascable). A vandalized cannon belonging to the Aurangzeb’s reign, now located at the top of the Golconda Fort, provides some valuable clues about the placement of these iron rods in the rear of the cannon (Fig. 4). This cannon is known as Qila Kush. Photographs of this cannon are available in the article by Wagner in this volume.

When the Mughals were casting composite cannons, like the Azdāha Paikār, in which the iron cylinder was first shrunk fit with iron rings and later poured over with bronze, there was need to place the iron cylinder in the center and an additional large iron supporting rod was provided at the bottom of the casting to hold the iron assembly in place. This is indicated by the presence of a long iron rod at the end section of Azdāha Paikār cannon. This would also mean that the cannon was cast such that the mould was placed with the breech end of the cannon at the bottom and the muzzle end of the cannon at the top of
the mould. This can be further verified by careful compositional analysis, as discussed earlier.

Later developments in Europe resulted in casting of a solid gun barrel and later boring out of the central portion by drilling. This was also adopted by the Indian powers by the 18th century. There was a well-established contact with European technology to suit Indian requirements. We have examples of several European gun founders specifically employed in India for casting cannons. They specialized in casting both cast iron as well as bronze cannons.\textsuperscript{41,42}

The method of casting of entire cannon as a solid cylinder and later, using drilling machines, boring out the central portion was a more preferred option with advancement of cannon technology. This was because the center of the hole could be properly controlled, i.e. there was no off-axes bores. Moreover, and also the surface could be finished in a very perfect manner. This also reduced the space/gap between the cannon ball and the barrel, resulting in better accuracy of the cannon ball and also in more velocity for the ball due to low windage.
It is certain that the latest techniques that were available in Europe were also available to the native Indian powers in the 18\textsuperscript{th} and early 19\textsuperscript{th} centuries. When the British defeated Tipu Sultan in 1799, they were astonished by the quality of his cannons. Nearly 927 cannons were captured after the fall of Srirangapatnam in 1799. Out of these, nearly 400 brass cannons were manufactured in Tipu’s foundries (one located at Bangalore and two in Srirangapatnam)\textsuperscript{31}. His cannons were cast by the ‘cast-on’ construction in which the inner core was held in position using iron chaplets. Water powered boring machines were used in Tipu’s arsenals and this produced perfect finish to his guns \textsuperscript{31}. Although some French technicians were employed by Tipu Sultan, as noted by Francis Buchanan, the foundries of Tipu Sultan were operated by the Indian engineers\textsuperscript{31}.

Some of the excellent cannons captured by the British from the Indian states were sent back to England as war trophies. Some others were donated to people/kings who participated and helped the British in the campaign. Most of the cannons that were captured by the British were melted and reused (i.e. re-cast) as British cannons. Therefore, we have lost valuable evidences of how the wonderful cannons of Tipu Sultan looked like, but for few surviving models. For example, at the Rotunda museum in Woolwich in England is displayed a wonderful cannon of Tipu Sultan seized during the British capture of Srirangapatnam \textsuperscript{31}. His remarkable cannons reveal iconic tiger motifs (on the muzzle, trunion ends, cascable and tiger stripes) apart from inscriptions providing the date of manufacture and the engineer responsible for the manufacture of the cannon. Several of Tipu Sultan’s cannons are still preserved in the museum at Srirangapatnam and they need to be studied.

The English fought several battles in India during the early 19\textsuperscript{th} century before consolidating their hold on the sub-continent. The major powers in India at that time were the Marathas and the Sikhs. Some Maratha and Sikh cannons are preserved as museum pieces in England. The remarkable engineering features of the Indian cannons and their unique features were noticed by the British artillerymen, who first saw these pieces. In some cases, we do have sketches of the cannons that were captured, drawn meticulously by some British artillerymen \textsuperscript{31}. Therefore, there was a wealth of cannons that were manufactured and produced indigenously, but only a few surviving examples exist.
as they were melted after capture by the British and they were recast as European models.

Some examples of cannons from Maratha, Mysore and Sikh kingdoms at the Museum of Artillery in the Woolwich Rotunda have been published recently 31. Some of the displayed pieces indicate the pinnacle of the Indian bronze casting technology. They clearly reveal the intricacies of bronze cannon casting technology that the Indians had mastered. Some technical details about these cannons are also available 31. It is, nevertheless, important to conduct a careful research on the models, types, classifications, and names of the early 19th century bronze cannons of the Indian states (Mysore, Sikh and Maratha). Special attention needs to be focused on their unique engineering and technical details, which set them apart from their European counterparts.

A large number of massive bronze cannons are located in fort ramparts all over the forts of the Deccan. In addition, we also notice, massive cannons that were used in the siege operations for capturing the fort and later placed in the fort rampart once the fort was captured. Some examples are *Fath Raïbhār* 38 and *Azdāha Paikār* 39 cannons at Golconda fort in Hyderabad. Cannons like these have to be analyzed critically to estimate the efficiency of these massive cannons in warfare and siege operations. Some thoughts of the author in this direction are available in the discussion of the *Fath Raïbhār* cannon 38.

One important lacuna in Indian cannon research is the lack of specific information regarding the effectiveness of Indian cannon fire. The method of estimating the pressure developed in the powder chamber of the cannons based on the amount of powder used and the size of the cannon bore is known 43,44. Using similar procedures, it must be possible for scholars/engineers/scientists to calculate the firepower of Indian cannons, especially the ones that mention the weight of charge and the weight of the shot that was to be used in the cannon 44. This exercise needs to be performed by knowledgeable and interested scientists and engineers.

**DEVELOPMENTS IN FORGE WELDING CANNON TECHNOLOGY**

The forge-welded cannons can be said to truly belong to India. There are only a limited number of massive forge welded cannons available in
Europe, as per the available literature \(^{10,11,45}\). Therefore, this clearly indicates that making cannons by the forge welding technique was not a popular European method. It appears that the invention of cast iron and its use in, first, cannon ball manufacture and later, casting cannons, was a major technological development. However, it took time for the cast iron cannons to find favour because the bronze cannons were tougher compared to the cast iron cannons. Unlike the bronze cannons that bulged before they failed, the cast iron cannons burst without any warning due to the inherent brittleness of cast iron. However, with developments in cast iron technology in Europe, improved cannons were manufactured. Cast iron cannons were critical elements in the establishment of European colonial power in the pre-modern period, around the world.

In the Indian sub-continent, there was a great reluctance to adopt cast iron technology because of the proficiency of the Indian blacksmiths in the art of producing large iron objects by forge welding. The brittle nature of cast iron did not enthuse the Indian blacksmiths who were master forgers and could handle direct-reduced wrought iron more easily. A complementary reason is the lack of interest shown by the Indian rulers to find out more about cast iron technology from the Europeans, and adapt them to Indian conditions. By the time the Indian states realized the importance of cast iron in manufacturing cannons and undertook steps to set up cast iron gun foundries in their kingdoms (like the Marathas, Sikhs and the Nizams of Hyderabad), the British colonial power in India was established. In order to understand the cast iron technology and its relevance to cannon technology, the developments in Europe have to be studied. This will not be attempted here and therefore, only the forge welding technique of manufacturing cannons will be addressed. It must be again realized that compared to Europe, India is home to a large number of massive forge welded cannons \(^{46}\). These forge welded masterpieces reflect the great glory of the Indian blacksmithy skills during the late medieval period, like the Delhi Iron Pillar in the ancient period \(^{47}\), and the Dhar iron pillar \(^{48}\) and iron beams in the temples of Orissa \(^{49}\) in the early medieval period. We shall look briefly at the salient technological features of Indian forge welded cannons.

**Design**

Most of the early forge-welded cannons are of uniform diameter throughout, very much reminiscent of the European port pieces. As regards their outer
design, we notice forge welded cannons without any trunions but with just
handling rings (for example, massive Rajagopala cannon in Thanjavur), and
cannons that possess both trunions and handling clamps (for example, the long
forge welded cannon at Gulbarga). The later-period forge welded cannons
were also fabricated similar in design to the bronze cannons in that they were
provided with proper trunions, without handling clamps (some examples being
the massive forge welded iron cannons at Bishnupur and Jhansi fort).

The cannons that are provided with trunions are more recent. Only
limited information is available about the dates of construction of forge welded
iron cannons. This is because of lack of inscriptions on massive forge welded
cannons, unlike their bronze counterparts. The cannon at Baadal Burj on the
Golconda Fort rampart in Hyderabad is dated to 1644 and this cannon is
provided only with handling rings. In contrast, the more-recent Bhavani Shankar
cannon in Jhansi fort, dated to 1725, is provided with just trunions. This line
of reasoning cannot be strictly true because the provision of trunions could also
be indicative of the cannon being constructed for mobility in field warfare rather
than for placing on a fort bastion.

The massive forge welded cannons that were placed in fort bastions
also reveal two types of designs. In the first type, the cannons are provided with
just handling rings and in the second type, the cannons are provided with both
trunions and handling rings. In the former type, the cannons appear to have
been positioned on massive wooden logs. In all the locations where massive
forge welded cannons are located, the wooden logs are no longer present. How-
ever, an idea of the kind of arrangement used in the past can be had from the
older photograph of the massive Malik-i-Maidan bronze cannon at Bijapur (for
a photograph of this, see Deloche’s article in this volume). In the case of the
second type, the trunions were connected to a curved swivel fork, which ro-
tated on a central iron pivot. The swivel fork was manufactured of forged iron.
A good example of this is the Gulbarga cannon. The movement of these
pivoted cannons was further aided by means of a wooden arrangement that was
fixed to the front of the cannon, which moved in a circular ditch, thereby allow-
ing change of direction. A good example of this is seen in the photograph of
Lambacari cannon at Bidar provided in the article by Deloche. The rings
provided to the cannons, in both the cases, aided lifting and adjusting the
elevation of the cannons. In all the cases, when cannons were used in fort bastions, a wall was provided in the backside of the cannon in order to absorb the recoil force, so that less force was imposed on the forked swivel arrangement\textsuperscript{14}.

**Construction**

There are different aspects of construction of forge welded cannons, as related to different parts of the cannon, for example the barrel, the muzzle and the breech sections. We shall briefly discuss the salient features of the manufacturing methodology for these different parts.

The skill of manufacturing good forge welded cannon clearly rested in the ability to construct the main barrel of the cannon. Interestingly, the origin of the name ‘barrel’ reflects the construction of the early cannons in a manner similar to wooden barrels, i.e. long horizontal staves joined by circular rings.

The skill required to manufacture the barrel by the use of forge welded iron rings must be appreciated, because close dimensional tolerances were required apart from a good understanding of the thermal expansion and contraction properties of the material. When one considers the enormous number of rings used in the construction of each cannon, the excellent blacksmithy skills of the medieval Indian blacksmiths becomes very evident. The rings were placed over the iron staves and over each other by shrink fitting. The principle of shrink fitting is as follows. When iron is heated, it expands and on cooling it contracts. When iron ring is heated, it takes a larger diameter. This heated ring is then placed on top of the iron staves or pre-fabricated ring layer. On cooling down, the ring contracts and closes the gap precisely. Another advantage is that when the rings contract, they are restricted from contracting completely, and therefore the iron staves of the rings beneath are put in a state of compression. These compressive stresses are beneficial because they help in providing further toughness to the walls. Tensile stresses usually cause damage, while compressive stresses are beneficial because the compressive stresses must first be overcome to result in damage. Therefore, the process of shrink fitting was very beneficial to the toughness of the barrel because it helped in producing tight joints as well as provided extra strength to the wall thickness. It is no wonder that the Indian blacksmiths preferred forge welded cannons because, based on simple engineering fundamentals, there were far superior to the cast iron cannons in terms of their strength and toughness.
There are doubts whether the rings were forge welded after being shrunk fit. Radiography studies conducted on the Mons Meg cannon have established that the rings were just shrunk fit and were not additionally forge welded. Similar studies have to be conducted on Indian forge welded cannons to understand the technology of their production as well as fine details of their inner construction.

Some fine points regarding barrel (and cannon) manufacture were obtained by careful technical analysis of massive forge welded cannons.

The barrel of the cannon is an important piece of cannon. This had to withstand the pressure of the exploding gun powder as well as ensure the smooth passage of the cannon ball to reach its destination. Therefore, the basic criteria for making a good barrel must have been the smoothness of the inner surface and the toughness of the barrel wall.

Let us first consider the technology for construction of the main barrel. The basic method was as follows. Long flat iron rods were placed longitudinally, over a mandrel, to produce the inner surface of the cannon barrel. These iron plates are called staves in cannon terminology. Then, carefully prefabricated iron rings, of the required dimensions, were heated and placed over the staves such that the rings contracted on cooling and held the staves together. Usually, an additional one layer or two layers of rings were hooped over the first layer of rings for further strengthening the barrel. The second layer of iron rings was placed such that the rings in this layer closed the gaps between the rings of the first layer. In case a third layer was used, the rings of the third layer closed the gaps between the rings of the second layer. It appears that either two or three layers of rings were generally provided. Three layers are noticed in the design of several cannons, for example Rājagopāla cannon of Thanjavur. The relative positioning of the three layers can be clearly noticed in the cross section of the broken piece of Pillāla Firaṅgī cannon at Ramagiri Fort in Karimnagar district of Andhra Pradesh state, reported by Jai Kishan in this volume. The Kāḍak Bijli cannon at Jhansi is a typical example where two layers of rings are used. The arrangement of the layers is noticed from the cross section in the broken section, provided in ref 54. Another example is the massive forge welded cannon located on Fateh Darwazah in Mudgal fort and this
cannon is shown in Fig. 5. It is interesting to note that when only two layers of rings are used, the rings are relatively thicker.

While considering the basic construction of the barrel, there was need to locate additional rings at certain locations along the barrel, based on requirements. One location was the front face of the cannon, where usually additional rings were provided to strengthen this location (see Fig. 7 of ref 52 for a good example). Another location that was frequently strengthened was the rear portion of the barrel because this had to withstand the forge of the gunfire. A good example is provided in Fig. 6, which shows the forge welded cannon (of length 12'8" and muzzle diameter 17") in Mehrangarh fort at Jodhpur by the name of Nusrāt Laskar (Glory of the Army) 13. Secondly, there were rings that contained the trunions, which were hooped over the barrel at the appropriate location (see Fig. 9 of ref 52 for a good example). Thirdly, there were rings that contained the holding clamps (i.e. containing provision for holes) through which circular handling rings were inserted (see Fig. 8 of ref 50 for a good example). These rings must have been specially pre-fabricated before they were shrunk fit. This implies careful planning, design, engineering and construction of the forge welded cannons.

![Forge welded cannon located at Fateh Darwāzah of Mudgal Fort showing the front portion where two layers of rings are forged over the staves (Photograph courtesy: J. Deloche).](image_url)
Fig. 6: A large forge welded cannon by the name of *Nusrat Laskar* (Glory of the Army) located in Mehrangarh Fort in Jodhpur.

Fig. 7: Forge welded cannon that was originally from Bijapur, now located at Campal, Goa.
Two contrasting arrangements of handling rings can be seen in Figs. 7 and 8. The forge welded cannon (of length 12'4" and muzzle diameter 16.5") in Fig. 7 was originally from the arsenal of Ādil Shāh of Bijapur, but now located in the Old Secretariat Building in Campal, Goa \(^{13}\). Notice the provision of pairs of rings with handling clamps, each containing two handling clamps, in the middle of the cannon on either side of the trunion. Rings containing single handling clamp are seen in the front and in the rear end. In contrast, the forge welded cannon (of length 10' and bore diameter 4") in Fig. 8, which is supposedly from Chattrapati Shivaji’s arsenal \(^{13}\), is provided with just two rings each containing two handling clamps. This cannon is lying in the District Police Headquarters in Pune.

It must be noted that there were other innovative methods by which cannons were handled and manipulated. One was the use of separate handling plates folded over the barrel. A good example of this is shown in Fig. 9, which shows one of the two forge welded cannons at the Kaḷī Darwāzāḥ of the Mudgal Fort \(^{58}\).

It is interesting to note that the rings (attached to the clamps on the cannons) are generally placed along a straight line. This implies that some sort
of rods must have been inserted through all of them at the same time in order to manipulate their direction and elevation. The design of the iron rings also needs to be appreciated. The rings occur in pairs, and generally they are also placed symmetrically and evenly along the length of the barrel.

The next aspect that needs to be addressed is the design of the inner smooth surface. As an exceptional case, we notice a smooth inner surface of cannon barrel in the case of Dal Mardan cannon (see Fig. 5 of ref 52). The method by which this was produced is not known. In contrast, the other more popular method noticed is the provision of staves. Some interesting feature regarding use of staves can be discerned in the Indian forge welded cannons. In several cases, the iron staves are flared out on the open muzzle end (see Fig. 4
of ref 50 for a typical example). In other cases, the staves come to an abrupt end at the muzzle face (see Fig. 4 of ref 54 which shows the damaged front portion of the Kadak Bijli cannon showing details of the staves where it meets the muzzle face). There also appears to be no fixed number of plates used in the construction 50,51,53-56. It is also clear that the thicknesses of the plates used were not constant and they were of different thickness. It would be interesting to investigate if there exists any relation between plate thickness and barrel dimension (i.e. muzzle and bore diameters).

There was a third method by which the smooth inner surface was provided and this was by using a cylindrical plate shaped in the form of a barrel. The iron rings were shrunk fit over this barrel and then later the entire assembly was cast over with bronze. This composite cannon manufacture was another innovation of the Indian cannon technologists. One good example of this kind of cannon is Azdāha Paikār located at Muṣā Burj of Golconda fort outer rampart 39. It appears that similar composite cannons (forged iron interior and cast bronze exterior) were manufactured by the Chinese (see article by Wagner ref. 40 in this volume). The Chinese also manufactured composite cannons consisting of wrought iron interior and cast iron exterior 40.

Out of these three methods of providing the smooth inner surface, the use of staves appears to have been the most popular. This could probably be due to evenness of the surface produced by this method and the maintenance of smoothness even after repeated firing. It is possible that the staves were manufactured of high carbon steel to provide additional strength to the material here. It is important to understand this by undertaking compositional and micro-structural analyses of the staves of forge welded cannons.

Another aspect that is not well known is how the iron staves were joined at the extreme end of the cannon. There is no possibility of understanding the methodology based on the existing complete cannons in the Indian sub-continent. However, there is one forge welded iron cannon that has been opened out in the back portion, i.e. Kadak Bijli cannon at Jhansi Fort 54. This open section in the rear provides valuable clues to understand how the staves were joined to the rear end of the cannon. The iron staves proceed all the way to the rear end, with the thickness of the staves increasing on progressing into the barrel. At the
rear end, the staves are clamped to the rear cascable block by the hooped iron rings. This has been described in detail elsewhere. Some unique features of gunpowder chamber design of Kadak Bijli cannon are also available from this reference.

The next section of the cannon that will be addressed is the cascable. The extreme rear portion of the cannon is known as cascable in western terminology. Remember that in Persian terminology, the rear portion was known as dharu-khānā. This is strictly not the cascable, but refers to the powder chamber.

Let us see how the rear portions of forge welded cannons were designed and constructed. There are several designs noticed. In the first case, the rear part of the cannon ends abruptly with the provision of a rear plate. One such example is shown in Fig. 10, which shows one of the two forge welded cannons that are located at Katī Darwāzāh at Mudgal Fort. In the second case, the rear section is manufactured by using forge welded rings of differing diam-
eters to produce the tapered end (see Fig. 9 of ref 50 for a good example). In the forge welded cannons dated to a later time, the cascable takes typical European cannon designs and this has been skillfully executed by forging (see Figs. 7 and 8 of ref 53 that shows the marvelous design of the rear portion of the Bhavānī Śāṅkar cannon). Moreover, this design also allows for the incorporation of more advanced gunpowder chamber designs, like noted in the Kaḍak Bijli cannon.

Another feature noticed at the back of certain cannons is the provision of sighting arrangement, using which the gunner could take aim before firing. This sighting device sometimes had a counterpart in the front of the cannon for further aiding the sighting operation. These features are noticed in the forge welded cannon in front of the Fateh Darwāzāh in Golconda fort.

In addition to these basic design features, forge welded cannons were provided with several decorative designs. These designs were sometimes chiseled out on the surface, like noted in the case of the Bhavānī Śāṅkar and Kaḍak Bijli cannons in Jhansi fort. This shows the skill of the ancient Indian blacksmiths. They had to first forge weld the iron rings and on top of that the designs were intelligently carved out using chisels.

In several cases, decorated bands were provided by special forge welded rings, meant specifically for this purpose. These decorated bands appear at different locations on the barrel, i.e. around the trunions, in front and in back portion of the cannon. One typical example of a decorative design on a forge welded cannon (the cannon at Baḷā Burj on Golconda Fort rampart) is shown in Fig. 11. When observations of the cannon were made in November 2003, all the iron rods that made up the decorative design were intact (Fig 11a). Sadly, when the same cannon was studied in September 2005, several of the rods had been vandalized (Fig 11b). This example also clearly brings out the slow but steady vandalization and destruction of these wonderful forge welded cannons because of lack of appreciation of these marvelous pieces. Their remote locations, far removed from public view, also complicate their preservation. There is urgent need to collect all these massive cannons located at remote bastions in fort ramparts and place them in a centrally protected location where it can be supervised constantly. A beginning needs to be made at the Golconda Fort, due to the fast growing population within the fort limits.
Fig. 11: Decorative design in the forge-welded cannon at Bāḍā Burj in Golconda Fort in Hyderabad: (a) observation in November 2003, and (b) observations in September 2005.
EPilogue

There are numerous massive cannons scattered all over the forts of India that are begging for attention. Deloche mentions that in all the forts (like Golconda, Bijapur, Bidar, Gulbarga, Parenda, etc) that he has studied, he found numerous cannons still present in their original condition in their original location. In all the Deccani forts, the cannons are located on ramparts that are difficult for people to negotiate and view these wonderful cannons. Moreover, the ramparts are not properly maintained and it difficult to move around with thick outgrowth all around. Reaching the ramparts is itself a difficult task because the whole area around the ramparts generally serves as public toilets. In spite of these difficulties, there is great need to visit these forts first hand and record the technical details of the cannons located on the ramparts and within the forts. Interestingly, an enthusiastic and dedicated scholar named Jai Kishan has located and described 19 large forge welded cannons at three remote forts (Ramagiri, Elgandal and Jagtial) in Karimnagar district of Andhra Pradesh. There is need to survey all the forts of the Indian sub-continent to identify massive cast bronze and forge welded iron cannons.

In several instances, massive cannons can also be found within modern city and town limits. For example, the Archaeology Department of Andhra Pradesh recovered two forge welded cannons from a remote fort in the state and it was placed in the premises of the Department at Hyderabad (see Fig. 12). The total length of the larger cannon is 550 cm with the diameter of the muzzle being 40 cm and that of the bore, 25 cm. The other cannon is a typical example of a howitzer, a cannon that was used for throwing cannon balls up into the air and inside the fortification. These cannons were in a state of neglect when the author discovered these wonderful cannon pieces, recently. The Department is restoring them. Apart from forts, it is also important to identify pre-modern massive bronze and forge welded cannons present in establishments connected with the military and police. Chatterji, an officer in the Indian army, has catalogued several such cannons. These cannons need to be studied from a technical point of view.

There is great need for scholars from different disciplines to study the wonderful massive cannons of the Indian sub-continent to highlight metallur-
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There is only limited technical literature on how the cannons were fabricated (both iron and bronze cannons) and therefore this exercise would help in understanding the history of science and technology of cannons in armed warfare, a very important aspect of Indian technical and engineering skills during the medieval times. There are several other unresolved questions related to cannon technology in India that need to be resolved like the kind of cannon balls used, the effectiveness of the cannons in breeching fortifications, the estimate of cannon ball travel and thrust based on available cannon dimensions, cannon ball weight and gun powder weight, the manufacture, storage and use of...
gunpowder, details of gun carriages, handling of the large cannons, procedure adopted for firing the cannons, details of accessory and special complementary equipments, the organization of the artillery, the depiction of cannons in Indian miniature paintings from all available sources, the cannon technology as practiced by different powers (Mughals, Marathas, Sikhs, Rajputs), the European gunners and foundry personal who were in the service of Indian monarchs, the locations of foundries and workshops where the cannons were fabricated, the influence of European cast iron technology on Indian forge welded cannon technology, and information about massive bronze and forge welded cannons that were deliberately vandalized (both by the public and the conquering rulers). The last point may seem surprising because the European powers took great efforts to destroy the numerous bronze and forge welded cannons from the Indian forts that they captured. Dupliex mentions that an enormous number of forge welded cannons were taken from Senji Fort to Pondichery and melted there \(^{60}\). Therefore, there is great need to study the history, evolution, epigraphy, social impact of cannon technology apart from detailed technical study of cannon manufacture, material characterization and both destructive and non-destructive testing (like radiography) to determine the inner construction details, as it has been on a large forge welded iron cannon of Europe \(^{11}\).

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**References**


Cannon technology was much developed in Turkey (i.e. the Ottoman Empire) in the fifteenth and sixteenth centuries. The first significant use of cannons was in 1453 during the Turkish siege of the Greek Christian city of Constantinople (modern Istanbul). At that time, the city was the greatest of all medieval fortresses with walls extending almost for 13 miles. Sultan Mohammed II of the Ottoman Turks laid siege to Constantinople in April, 1453. He brought with him 68 massive cannons, the largest of which was a gigantic 26-ft. long gun that weighed 20 tons. It fired 1,200-lb. stone cannonballs, and required an operating crew of 200 men. For 50 days, the Turkish cannons bombarded Constantinople and ripped holes in its walls. However, each time the Turks charged into the gaps, the defenders repulsed them and hastily rebuilt the walls. Finally, on May 29, 1453, a destructive cannonade toppled a wide stretch of the walls, and 12,000 elite Turkish troops successfully entered the city. The Turkish
of the walls, and 12,000 elite Turkish troops successfully entered the city. The Turkish cannons were put on permanent display in Constantinople. However, 354 years later, in 1807, the Turks used them again in battle against a British fleet. The ancient cannons managed to hit a British ship with two 700-lb. cannonballs, killing 60 sailors. In 1867, Sultan Abdul Aziz gifted Queen Victoria of England one of the cannons used at the siege of Constantinople. This 17-ton cannon, called the “Dardanelles Gun,” is now on exhibit at the Royal Armouries Museum in England. For more about Dardanelles Gun, see reference 11 above.


41. L.E. Smith, *A Sketch of the Rise, Progress and Termination of the Regular Corps formed and Commanded by Europeans in the Service of the Native Princes of India, Calcutta, 1805*, pp. 6-7, p. 47, 72-73, 387-388

42. *Poona Residency Correspondence*, Vol 4, p. 298.


* One of the author’s name in the paper had appeared as K. Bhattacharya which is to be corrected as K. Mondol. The Principal author, R. Balasubramaniam deeply regrets to this inadvertent slip --- Editor