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MECHANICAL ENGINTUNING IN ANCIENT EGYPT, PART 105: FASTENERS INDUSTRY

***Galal Ali Hassaan**

Emeritus Professor, Department of Mechanical Design & Production, Faculty of Engineering, Cairo University, Egypt.

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***Corresponding Author**
Prof. Dr. Galal Ali Hassaan
Emeritus Professor, Department of Mechanical Design & Production, Faculty of Engineering, Cairo University, Egypt.

ABSTRACT

This is the 105 research paper aiming at investigating the fasteners industry in ancient Egypt in a series of research papers aiming at exploring the mechanical engineering evolution in ancient Egypt. The paper aims at answering the question: Did the ancient Egyptians know fasteners? and how did they used them in domestic and military applications?. The paper presents documented answers through type of fasteners used and examples from different historical eras from Predynastic to Late Period.

KEYWORDS: Mechanical engineering history, ancient Egypt, fasteners industry, mortise-tenon joints, dovetail joints, pins, rivets, nails, ropes, leather straps**.**

INTRODUCTION

The ancient Egyptians were pioneers in all aspects of daily life. They used good number of fasteners in their furniture, boats and ships, wooden coffin, carpenter tools, farming tools industries. In this research work we explore the types and used of fasteners in ancient Egypt with examples from different historical periods.

Lucas (1934) in his paper about wood working in ancient Egypt outlined that in a six play wooden coffin from Saqqara produced during the Old Kingdom, the different pieces of wood were fastened together using mortise-tenon joints, where the tenons were secured in position using wooden pegs. The layers of wood were pegged together and covered by a golden sheet

fastened in place with golden rivets.[1] Scott (1965) presented photos for a furniture-leg from the 1st Dynasty having tenon for assembly, a stool from the 16th Dynasty using mortise-tenon joint to assemble legs with the chair frame, a chair of Pharaoh Tutankhamen from the 18th Dynasty with mortise-tenon joints to assemble the seat-frame and the legs, a headrest from the Middle Kingdom with mortise-tenon joints to support 6-columns to a curved headrest and a flat base, a bed frame from the 1st Dynasty with mortise-tenon joints for the assembly of the legs and the frame-sides, a table from the 17th/18th Dynasties with mortise-tenon joints (with pins) to assemble the table parts.[2]

Piecione (1981/1982) investigated the use of the expression 'MD3.T' (meaning pegs) in ancient Egypt. He presented three uses of this expression: in shipbuilding as a carpenter's peg, in medicine as an oral brace and in fowling as a gripping dowel to keep the net securely fastened to the ground.[3] Shalev, Kahanov and Doherty (1999) investigated some nails dated to 400 BC found in a ship sack in the Mediterranean near Haifa 2400 years ago. They presented photos for some copper nails used to fasten the wooden components of the ship structure.[4] Mark (2009) in his work about the construction of Khufu I vessel investigated in details the use of mortise-tenon and long ligature joints. He investigated also the different lashing patterns for both types of joints.[5]

Ward and Zazzaro (2010) investigated an evidence for the seagoing ships at Wadi Gawasis of Egypt. They presented evidence for the use of ancient Egyptians of the Old and Middle Kingdoms different types of fastening techniques such as: mortise-tenon, dovetail, ligature joints and copper alloy fasteners.[6] Mark (2012) studied the Abydos BG 10 boat from the Early Dynastic Period outlining its structure and design methodology. He outlined the use of lashings of 75 mm wide flat woven straps. He stated also that hull-planks were edge joined with mortise-tenon joints and there was no evidence for using any girders in the BG 10 boat.[7] Mashhour and Zaghlol (2017) applied the Finite Element Method to analyse the stiffness of a stool from the Old Kingdom. They outlined that some of the supports of the stool structure were secured to the structure elements using mortise-tenon joints.[8]

Mady (2019) investigated the use of pegs in securing tenons in mortises by ancient Egyptian shipbuilders. He presented evidence from Wadi Gawasis illustrating the earlier use of pegs during the Middle Kingdom. He presented drawings for segment T64; plank T34 from Wadi Gawasis containing pegs securing tenons. He also presented a scene from Qaha tomb showing 13 pegs [9]. Edwards (2019) traced the use of dovetail joints in the furniture industry.

He stated that the dovetail joint was originated during the Egyptian 1st Dynasty was depicted in boxes, coffins and ivory work.[10] Patricio (2020) investigated the solid ebony chair of Pharaoh Tutankhamen from the 18th Dynasty and the chairs of Queen Hetepheres from the 4th Dynasty. He outlined that in the Pharaoh's chair dowel joints were used between stretchers and legs, four mortise-tenon joints were used in the seat frame and golden nails were used to secure the sides of the legs. In the analysis of Queen Hetepheres chairs, he stated that mortise-tenon joints were used to secure the legs with seat and golden nails were used to reinforce the lower section of the two chairs. The chair arms were secured in place using mortise-tenon joints and strengthened with leather strips and two flowers on each arm secured with leather strips.[11]

Yoshimura (2022) in his master thesis performed a comparative study for the 1st and 2nd boats of Khufu, 2nd King of the 4th Dynasty. Regarding the jointing technique followed by the ancient Egyptian shipbuilders of the Old Kingdom he quoted the jointing techniques: scarf joints, mortise-tenon joints, V-shaped lashing holes for ropes. He stated that the two boats of Khufu were the oldest types discovered for 'sewn boats'.[12] Hassaan (2022) while investigating adhesive use in the furniture industry outlined the use of dovetail joints and mortise-tenon joints. He also presented axes using wedges and holes to facilitate using cords to secure the blade of the axe to its handle.[13]

Mortise Tenon Fasteners

The ancient Egyptians were pioneers in establishing industries based on using mortise-tenon joints such as furniture, shipbuilding and wooden coffin industries. They used mortise-tenon industries since more than 5100 years. Here are some examples:

- The first example is a bed frame from the 1st Dynasty (3100-2900 BC) in display in the Petrie Museum, London and shown in Fig.1.[14] The bed has the features:

- The tenon has a rectangular form and integrated with the leg.
- The mortise is cut in the bed side.
- The designer didn't use any external fasteners such as dowels.

Figure 1: A bed frame from the 1st Dynasty.[14]

- The second example is the 43.6 m length Khufu's ship from the 4th Dynasty (2500 BC) in display in a Giza solar boat museum near Khufu's pyramid.[15],[16] The shipbuilder of Khufu's ship used mortise-tenon joints to fasten the planks of the hull together. A line diagram of the jointing scheme of Khufu I ship is shown in Fig.2.[17] Characteristics[17]:

- The planks jointing plan was for using mortise-tenon joints of 7-23 mm length.
- The mortise-tenon spacing was 1.4-1.5 m.

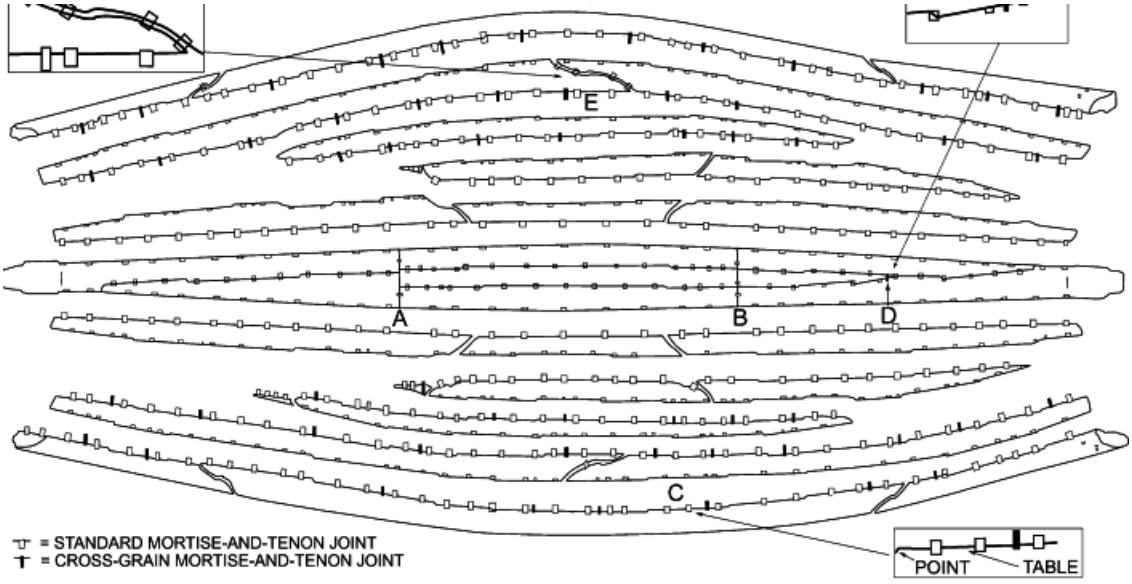

Figure 2: A Planks jointing diagram of Khufu I ship from the 4th Dynasty.[17]

- The third example is a stool from the 12th Dynasty (1991-1802 BC) in display in the Metropolitan museum of Art, New York and shown in Fig.3.[18] Characteristics:

- The legs of the stool were secured to its frame using mortise-tenon joints.
- The tenons are all through the mortises.
- There are no other fasteners to secure the tenons in position.

Figure 3: A stool from the 12th Dynasty.[18]

- The fourth example is a chair from the 18th Dynasty (1550-1292 BC) in display in the British museum, London and shown in Fig.4.[19] Characteristics:

- The legs were secured to the chair frame using mortise-tenon joints.[19]
- The tenons were further secured using dowels.[19]

Figure 4: Chair from the 18th Dynasty.[19]

- The fifth example is ship-planks for a seafaring ship reconstructed in 2008 simulating one of the seafaring ships of Hatshepsut, 5th Pharaoh of the 18th Dynasty (1479-1458 BC) shown in Fig.5.[20] Characteristics:

Figure 5: Ship-plans with tenons from the 18th Dynasty.[20]

- The tenons had rectangular cross-section.
- The tenons were equally spaced for a long part of the plank shown in Fig.5.

- The sixth example is chair from the 18th Dynasty (1400-1292 BC) in display in the Brooklyn Museum, New York and shown in Fig.6.[21] Characteristics:

- Mortise-tenon joints were used to connect the chair parts to each other.[21]
- Dowels were used to secure the tenons in positions.[21]

Figure 6: Chair from the 18th Dynasty.[21]

Dovetail Fasteners

The ancient Egyptians were the first humans inventing the dovetail joints from more than 5000 years during the 1st Dynasty (3100-2900 BC) where they used them in producing their furniture.[22] Here are some examples:

- Good number of household furniture were found in the tomb of Hesi-Re, High Official served during the reign of King Djoser of the 3rd Dynasty of the Old Kingdom (2686-2667 BC). Carpenters of the 3rd Dynasty used complex varieties of joints including dovetail joints.[23]
- In the 12th Dynasty of the Middle Kingdom, the temples and pyramids builders used dovetail joints to join rock-blocks together using separate dovetails. Fig.7 shows a cavity of a dovetail joint from the pyramid of Amenemhat I, Founder of the 12th Dynasty (1991-1962 BC).[24] Characteristics:

Figure 7: Dovetail joint cavity from the 12th Dynasty [24].

- The cavity is carved in both parts to be joined.
- The dovetail is a separate piece of two tails with mirror image matching the cavities in the two rock stones. Fig.8 shows a typical dovetail belonging to Senusret I, 2nd King of the 12th Dynasty (1971-1926 BC). It has a straight part in the middles and dovetails at the ends. The dovetail was marked by the Cartouche of the King.
- The ancient Egyptians produced dovetails from wood or metal.

Figure 8: Dovetail from the 12th Dynasty [24].

- The dovetail joint design for furniture industry is different than that for stone works. An example for using dovetail joints in furniture industry is the chest of Ramose and his wife Hatnover from the 18th Dynasty (1498 BC) in display in the Metropolitan Museum of Art, New York and shown in Fig.9.[25],[26] Characteristics:

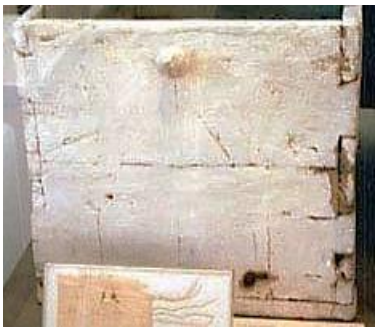

Figure 9: Chest from the 18th Dynasty.[25]

- The two wooden parts connected by dovetail joints had 90 degrees between them.

- One of the parts was cut at the edge with a tail shape with a specific distance between them.
- The other part was cut for cavities to locate the tails of the other part.
- This ancient Egyptian jointing technique is still internationally in use for carpentry works.

Pin Fasteners

The ancient Egyptians were pioneers in producing pins from bone and ivory before 4000 BC (Badarian Culture).[27] They used pins for different purposes some of which were: hair pins lock pins, game pins and surgical pins.

A. Hair Pins

The ancient Egyptian females used pins to fasten hair together to form specific styles for their hair.[27] Here are some examples:

- The first example is a 156 mm length ivory hairpin from Naqada II (3650-3900 BC) in display in the Museum of Fine Arts, Boston and shown in Fig.10.[28] Characteristics:

Figure 10: Hairpin from Naqada II Period.[28]

- The ivory technician could carve the ivory material to take relatively a complex shape (screw tail).
- The tail of the pin took a zigzag shape (may be simulating a snake).
- The incomplete ring on the pin-stem may help in the fastening process of the pin with the zigzagged part of the pin.

- The second example is a set of two hairpins from the Predynastic Periods of Egypt (before 3100 BC) in display in the Egyptian Museum, Cairo and shown in Fig.11.[29] Characteristics:

Figure 11: Hairpins from the Predynastic Periods.[29]

- Most probably the pins were produced from ivory.[30]

- The length is 80 mm.[30]
- The far end of the pin was carved as a bird.
- Sure, this bird has something to do in the fastening process of the hair. How great was the ancient Egyptian civilization.

- The third example is a relief for Queen Neferu having her hair under operation for a hairstyle. The Queen was from the 11th Dynasty, reign of Mentuhotep II, 5th King of the 11th Dynasty (2061-2010 BC) and the relief is in display in the Metropolitan Museum of Art, New York (!) and shown in Fig.12.[31] Characteristics:

Figure 12: Queen Neferu from the 11th Dynasty.[31]

- The hairdresser was shown using pins in constructing the style of the Queen's hair.
- The hair pin was relatively long.
- The fourth example is a 70 mm length bone hairpin from the New Kingdom (1550-1077 BC) in display in the British Museum, London and shown in Fig.13.[32] Characteristics:

Figure 13: Bone hairpin from the New Kingdom.[32]

- The diameter is gradually increasing from the tip to its end.
- They could carve the bone without losing its mechanical properties.

- They added a gilded sleeve to its end to facilitate holding the pin efficiently.

B. Lock Pins

Because the ancient Egyptians were a civilized community they used door locks from more than 6000 years ago during Early Naqada I (4000 BC).[33] The lock was produced from wood in which wooden pins will fall into slots in a wooden bar. A wooden key was used to lift the pins out of the slots allowing the lock-bar to move and open the door.[33]

C. Game Pins

The ancient Egyptians invented a number of games for their children and elders. One of those games was the '*hounds and jackals*' game. It appeared in ancient Egypt during the time of the 11th Dynasty (2130-1991 BC).[34] As an example of the hounds and jackals games, Fig.14 shows a typical one from the reign of Amenemhat IV, 7th King of the 12th Dynasty (1815-1806 BC) in display in the Metropolitan Museum of Art, New York.[35] Characteristics:

Figure 14: Hounds and Jackals game from the 12th Dynasty.[35]

- The pins were carved from ivory with hound (dog) and jackal heads.
- There were 29 holes in the game-table.[34]
- The pins were 5 with dog-heads and 5 with jackal-heads.[34]

- The dog-pins had 70 mm length.
- The jackal –pins had 85 mm length.
- The hole-pin tolerance is loose to allow easy settling and lift of the pins.
- The table had a drawer to store the game pins.

D. Surgery Pins

What is this sub-title? … Did the ancient Egyptians know surgery? Yes. This is why we say we are presenting a wonderful great human civilization. A mummy was examined in the Ludwig Maximilians University in Munich where a screw pin took place in the leg of an ancient Egyptian when he was alive.[35]

The surgery was dated to 1000 BC[36], i.e. during the Third Intermediate Period (1069-664 BC). An image showing the iron screw pin in the right knee of the mummy is shown in Fig.15.[37] Characteristics:

Figure 15: Screw pin in the knee of a mummy from the Third Intermediate Period.[37]

- May be the patient was suffering from complete damage of the knee joint.
- The screw pin provides joining the two leg-bones together without relative motion.

- The screw pin is an innovation in this early time.
- Mechanically, the screw pin can transmit more axial load between leg parts than a straight pin. This can be checked by '*Finite Elements Analysis*'.

Rivets Fasteners

- The ancient Egyptians knew rivets more than 5000 years ago where they used them to fasten handles to clay jars in about 3000 BC (during Naqada III Period).[38]
- In the weapons industry, the ancient Egyptians used rivets to fix the handles of copper blades of daggers and swords.[39]
- Here are some examples from different historical eras in ancient Egypt:
- The first example is a dagger from Naqada I/Naqada II Period (3800-3200 BC) in display in the Museum of Artefacts in the Mournhold city (capital of Morrowind) and shown in Fig.16.[40] Characteristics:

Figure 16: Dagger from the Naqada I/Naqada II Period [40].

- The dagger has a triangular copper blade.
- The copper blade was secured to a golden shoulder using a number of rivets.
- The shoulder-handle element is secured to an ivory knob using a rivet.

- The second example is a dagger for Princess Ita, daughter of Amenhotep II, the 3rd King of the 12th Dynasty (1929-1897 BC) in display in the Egyptian Museum, Cairo and shown in Fig.17 [41]. Characteristics:

Figure 17: Dagger of Princess Ita from the 12th Dynasty.[41]

- The dagger blade was made of bronze.
- The blade was secured to a golden shoulder using three golden rivets.
- The shoulder-handle unit was decorated by inlays produced from semiprecious stones.
- The knob took a crescent shape.

- The third example is a dagger of Ahmose I, Founder of the 18th Dynasty (1549-1514 BC), donated to his mother Queen Ahhotep in display in the Egyptian Museum, Cairo and shown in Fig.18.[42],[43] Characteristics:

Figure 18: Dagger of Ahmose I from the 18th Dynasty.[42]

- The dagger was probably manufactured from four to five different materials.
- The blade was secured to the shoulder-hand element using three rivets.
- It is not clear how the knob was secured to the dagger-handle.

Nail Fasteners

The ancient Egyptians produced metallic nails in around 3400 BC[44] (during Naqada II Period) and continued to use it up to the modern days. Here are some examples:

- The first example is life-size copper statue for Pepi I, 3rd King of the 6th Dynasty (2331-2287 BC) in display in the Egyptian Museum, Cairo and shown in Fig.19.[45] Characteristics:

Figure 19: Copper statue of Pepi I from the 6th Dynasty.[45]

- The statue length is 1.77 m.
- Copper plates were beaten to the king shape on a wooden core.
- The copper plates were attached to the wooden core (now lost) using '*copper nails*'.[45]

- The second example is a 30 mm length bronze nail from the 12th/13th Dynasties (1981-1640 BC) in display in the Metropolitan Museum of Art, New York without image display for the nail.[46]
- The third example is a 92 mm bronze nail from the 18th Dynasty (1352-1336 BC) in display in Liverpool Museums, Liverpool and shown in Fig.20.[47] Characteristics:

Figure 20: Bronze nail from the 18th Dynasty.[47]

- The nail had an eccentric head.
- The nail body had a square cross-section.

- The fourth example is a 51 mm bronze nail from the 19th/20th Dynasties (1295-1070 BC) in display in Metropolitan Museum of Art, New York and shown in Fig.21[48] (there was no image available by the museum).
- The fifth example is a collection of bronze nails from the 26th Dynasty (664-525 BC) in display in the Metropolitan Museum of Art and shown in Fig.21.[49]

Figure 21: Bronze nails from the 26th Dynasty.[49]

- The nails had central heads.
- The nails had length between 13 and 42 mm.
- The nails had circular heads of diameter between 5 and 18 mm.

Lashing Fasteners

The ancient Egyptians used the lashing process to join wooden planks together or strengthen other types of jointing means. Here are some illustrations:

- The shipbuilders in ancient Egypt used ropes to hold together the wooden planks of their boats that when expanded by water made the vessel watertight.[50]

- The used halfa grass to lash together planks and frames.[51]
- They used leather or cord lashings to strengthen the mortise and tenon joints.[52]
- There were 14 boats excavated near the temple of Khentyamentiu (at Abydos) dating to Early 1st Dynasty (2950-2775 BC) having sewn wood planks.[53] How the planks of those boats were sewn together was illustrated by Cheryl Ward using a line diagram shown in Fig.22.[54] Characteristics:

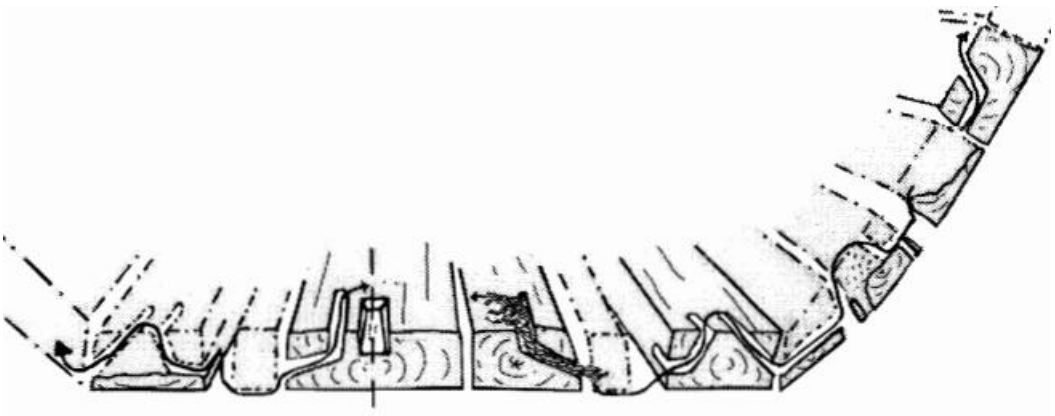

Figure 22: Sewn boat-planks from the Early Dynastic Period.[54]

- The ancient Egyptian shipbuilders could cut channels in the planks with a well-designed pattern.
- A plant-rope or leather straps goes through the plank channels.
- Tightening the ropes or straps brings the planks together.
- This mechanical design approach is more than 5000 years old.

- Another example of the stitching technique is the 43.4 m length ship of Khufu, 2nd King of the 4th Dynasty (2589-2566 BC) in display in the Grand Egyptian Museum, Giza, Egypt. An image of the interior reconstruction of the Royal ship of Khufu is shown in Fig.23.[55]

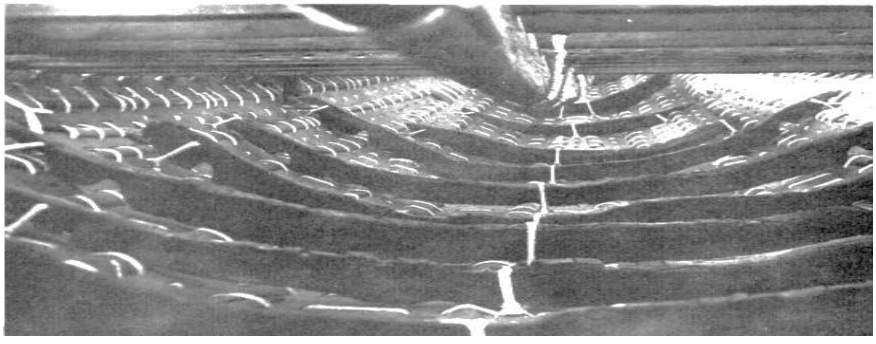

Figure 23: Sewn ship-planks from the 4th Dynasty.[55]

- Another example is a 10 m length boat produced during the reign of Senusret III, 5th King of the 12th Dynasty (1878-1839 BC) in display in the Egyptian Museum, Cairo and shown in Fig.24 [56] (this is a reconstruction of what is known as the 'red boat' showing some of the rope stitches holding the boat-planks together).

Figure 24: Sewn boat-planks from the 12th Dynasty.[56]

Ropes and Leather-straps Fasteners

This fastener application is different than that of '*lashing fasteners*' presented in section VII used in boat and ship construction in ancient Egypt. Here are some other applications for ropes and leather straps with examples from different eras of the ancient Egyptian history:

- The 1st example is a stone hammer from the Predynastic Periods (before 3100 BC) shown in Fig.25.[57] Characteristics:

Figure 25: Stone hammer from the Predynastic Periods.[57]

- The head of the hammer was produced from stone.
- The handle was produced from wood.

- The head was drilled for a hole to suit the handle.
- The blade was secured to the handle using a cord (small diameter rope) with loops surrounding the handle as it meets the blade and X-shaped tightening loops around the blade.

- The 2nd example is a scene for Scorpion, the 1st King of the 1st Dynasty (3100 BC) holding a hoe by both hands in display in the Ashmolean Museum, Oxford and shown in Fig.26.[58] Characteristics:

Figure 26: King Scorpion from the 1st Dynasty.[58]

- The King was in a position showing him ready to use the hoe.
- This hoe is more than 5100 years old.
- The hoe had a standard design of a curved blade joined to a straight handle using a revolute joint allowing the relative angular motion of the two parts of the hoe.
- The angular stroke of the hoe is limited by a rope secured with both elements of the hoe.

- The 3rd example is an irrigation scene from the tomb of Mereruka, Vizier during the reign of Teti, Founder King of the 6th Dynasty (2345-2333 BC) shown in Fig.27.[58] Characteristics:

Figure 27: Irrigation scene from the 6th Dynasty.[58]

- This is a primitive positive displacement pump.[58]
- The main element of the pump is a first-class lever.
- A rope was used to connect a water-bucket to one end of a pole (the lever).
- The lever carries two buckets.
- The flexibility of the rope is desired to keep the bucket surface in a horizontal level.

- The 4th example is a carpenter workshop from the tomb of Meketre, chancellor during the reign of Mentuhotep II and Mentuhotep III of the 11th Dynasty (2061-1908 BC) in display in the Egyptian Museum, Cairo and shown in Fig.28.[59] Characteristics:

Figure 28: Carpenter model from the 11th Dynasty [59].

- A setting carpenter is cutting a piece of wood (work piece) axially using a saw.
- The work piece is secured to a vertical wooden pole using a rope.

- The 5th example is a fishing team on two papyrus boats model from the tomb of Meketre, Chancellor during the reign of Mentuhotep II and Mentuhotep III of the 11th Dynasty (2061-1908 BC) in display in the Egyptian Museum, Cairo and shown in Fig.29.[60] Characteristics:

- The fishing net was produced from ropes with frame produced from stronger rope with rope loops.
- The loops (probably) to help pulling the net after fishing in all directions.

Figure 29: Fishing model from the 11th Dynasty.[60]

- The 6th example is a stone hammer from the reign of Amenemhat I, Founder of the 12th Dynasty (1991-1962 BC) in display in Metropolitan Museum of Art, New York and shown in Fig.30.[61] Characteristics:

Figure 30: Stone hammer from the 12th Dynasty.[61]

- Two wooden handles were used to hold the stone blade.
- The handles were set in two recesses near the end of the blade.
- The designer user a leather strap to secure the handles on the blade.

- The 7th example is a wooden hoe from the reign of Senusret I, 2nd King of the 12th Dynasty (1971-1926 BC) in display in the Metropolitan Museum of Art, New York and shown in Fig. 31.[62] Characteristics:

- The two parts of the hoe were produced from wood.
- A recess was cut in each part of the hoe near its mid-span.
- The stroke of the hoe was adjusted by a rope going around the hoe parts in the recess and then around the rope-parts defining the hoe stroke.

Figure 31: Wooden hoe from the 12th Dynasty.[62]

- The 8th example is a ceremonially battle axe of Ahmose I, Founder of the 18th Dynasty (1549-1514 BC) in display in the Luxor Museum, South Egypt and shown in Fig.32.[63] Characteristics:

Figure 32: Royal battle axe from the 18th Dynasty.[63]

- The gilded copper blade was secured to a wooden handle using leather straps.
- The blade was mechanically designed to be tightly secured by the leather straps.
- The straps were turned around the blade-handle connection in two different directions.
- The highly professional work of the unit is obvious from the accuracy of the blade production, decoration and fastening.

- The 9th example is a scene of two farm-workers carrying a large basket for crop-collection from the tomb of Nakht, Scribe and Astronomer during the reign of Thutmose IV, 8th Pharaoh of the 18th Dynasty (1398-1388 BC) shown in Fig.33.[64] Characteristics:

- The design of the basket is really intelligent.

- The body of the basket was produced from a net of thin ropes.
- The basket body was strengthened by a thick rope on the top circumference and on its net-body.
- A long wooden pole is passed through a loop on the circumference of the basket.
- This pole when hooked in loops facing each other on the basket top circumference allows the basket to be carried out using two farm-workers.
- When the crops in the basket exceed its top edge, then the designer attached a strong rope facing the pole. This rope can be pulled around the crop and tightened in a rope loop in the other side or in the pole-loop.
- This design allows two similar baskets to be carried on a donkey.

Figure 33: Crop transportation scene from the 18th Dynasty.[64]

- The 10th example is an adze from the 19th Dynasty (1292-1186 BC) in display in the British Museum and shown in Fig.34.[65] Characteristics:

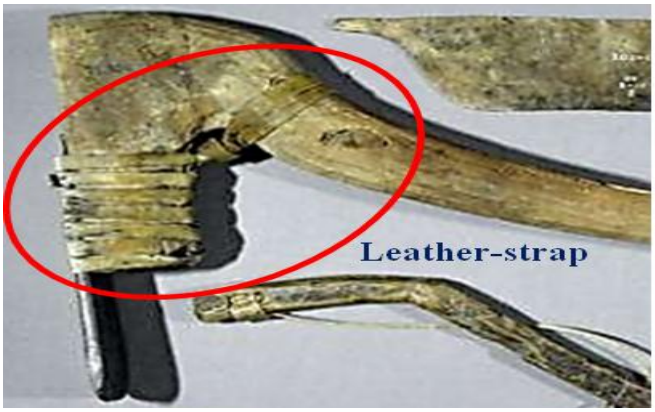

Figure 34: Adze from the 19th Dynasty.[65]

- The adze wooden-handle took the shape of the '*Arabic numeral 7*'. But did the ancient Egyptians know the '*Arabic numerals*'? I leave the answer to the Egyptologists specialized in mathematics.
- The selection of the '*numeral 7*' itself is intelligent regarding the objectives of its use.
- The adze-blade was produced from bronze.
- The blade was secured to the handle using a leather strap in an intelligent way:

➢ The strap was turned around the vertical part of the 7 numeral in the position shown in Fig.34. This was not enough for them.

➢ They took the end of the strap and made a number of turns around the other part of the 7 numeral.

➢ Further, they tightened those turns with extra turns on the strap parts between the 7 numeral parts.

➢ The purpose of this is to prevent the straps from slipping over the vertical part of the 7 numeral when the adze is in operation. This is a real application of '*practical intelligence'*.

- The 11th example is an irrigation scene using '*shaduf*' from the tomb of Sennedjem, Artisan during the reigns of Seti I and Ramses II, 2nd and 3rd Pharaohs of the 19th Dynasty (1290-1213 BC) shown in Fig.35.[66] Characteristics:

- The design of the shaduf depends on the use of a first-class lever.
- The lever (curved bar) was hinged to a vertical wooden-pole fixed to the ground (revolute joint is sufficient for this application).
- The far end of the lever was loaded by a dead-weight rigidly secured to it.

Figure 35: Shaduf scene from the 19th Dynasty [66].

- The near end is attached to rope with length long enough to reach the water level in the water-source.
- The other end of the rope is attached to a water-bucket.
- The length between load (at far end) and pivot is greater than that between load (at near end) and pivot. Why?.
- Another feature of the intelligence design of machinery followed by the ancient Egyptians.
- This allows raising large quantity of water with maximum value can be calculated easily using the first-class lever mathematics.
- For water quantity more than the maximum value extra effort will be applied by the shaduf operator.
- The flexibility of the rope will allow the operator to navigate outside the lever-pole plane to reach the discharge water-channel.

CONCLUSIONS

- The paper tried to answer two questions about the design and use of fasteners in ancient Egypt.
- The first type of fasteners presented in the paper was the mortise-tenon fastener. Examples of the use of mortise-tenon fasteners were presented starting from the 1st Dynasty in the furniture industry. Examples on using mortise-tenon fasteners in the shipbuilding industry were presented from the 4th and 18th Dynasties. Examples from the 12th and 18th Dynasties were presented covering the furniture industry.
- The second type of fasteners presented in the paper was the dovetail fasteners. Examples of using this type of fasteners in the furniture industry were quoted from the 3rd and 18th Dynasties. How the ancient Egyptians used dovetail fasteners to join rock structures was presented with examples from the 12th Dynasty.
- The third type of fasteners presented was the pin fasteners known in ancient Egypt before 4000 BC. The design of hair pins in ancient Egypt was examined through examples from Naqada II, before 3100 BC, 11th Dynasty and from the New Kingdom.
- Lock pins were used in the design of wooden locks for doors as early as the time of Naqada I.
- Game pins were produced in ancient Egypt since the time of the 11th Dynasty with a typical example presented from the 12th Dynasty.

- They invented also surgery screw-pins with an example presented from the time of the 3rd Intermediate Period.
- The ancient Egyptians knew the rivet fasteners since the time of Naqada III and used this joining technique for domestic and military applications. Examples were presented for rivets used in daggers production during the time of Naqada I/Naqada II, 12th and 18th Dynasties.
- The ancient Egyptians produced metallic nails during the time of Naqada II. Examples were presented for using metallic nails from the 6th, 12th/13th, 18th, 19th/20th and 26th Dynasties.
- Lashing fasteners were used in shipbuilding industry since the time of the 1st Dynasty. Examples from the 1st, 4th and 12th Dynasties were presented.
- Ropes and leather straps fasteners were used in ancient Egypt before 3100 BC. Examples were presented for tools industry during the Predynastic Periods, 1st, 12th and 19th Dynasties. Use of ropes in designing irrigation machines was illustrated through examples from the 6th and 19th Dynasties. Use of leather straps as fasteners was illustrated by an example from the 18th Dynasty. Use of ropes in carpentry work, fishing and crop transportation was illustrated through examples from the 11th, 11th and 18th Dynasties respectively.
- The paper focused on the innovation of the objects presented and the intelligent design of each of them.

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DEDICATION

I have the honour to dedicate this research work to ***Late Professor Ahmed Ezzat Mahmoud***, Former Chairman of the Department of Mechanical Design and Production of the Faculty of Engineering , Cairo University during Early 1970's. I never forget Professor Ezzat who taught me system dynamics courses during the second half of 1960's. He succeeded to make me love system dynamics courses and love the department he was chairing and insist to work with him as a teaching assistant in 1970. Thanks my honest Professor. How great you were.

Your student Galal Hassaan.

BIOGRAPHY

Galal Ali Hassaan:

- Emeritus Professor of System Dynamics and Automatic Control.
- Has got his B.Sc. and M.Sc. from Cairo University in 1970 and 1974.
- Has got his Ph.D. in 1979 from Bradford University, UK under the supervision of Late Prof. John Parnaby.
- Now with the Faculty of Engineering, Cairo University, EGYPT.
- Research on Automatic Control, Mechanical Vibrations , Mechanism Synthesis and History of Mechanical Engineering.
- Published about 300 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Chief Editor of the International Journal of Computer Techniques.
- Member of the Editorial Board of a number of International Journals including the WJERT journal.
- Reviewer in some international journals.