The Pantograph: Rare Models and Application

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Abstract. The paper describes the role that pantograph has played in the development of Science and Technology. The widespread application of pantographs dates back to the 18th century, and we can easily trace the links between Natural Science and Engineering, including the applied technical disciplines. The authors aim to strengthen interdisciplinary scientific connections between the students and specialists in technical and humanitarian sciences. Based on the study of rare copies of pantographs from the Bauman Moscow State Technical University (BMSTU) Museum collection, the authors trace the development over time of this unique in its simplicity mechanism both when used in the activities of naturalists, scientists and inventors, and in the ordinary human life. Originally created as a tool of proportional mathematics, the pantograph in the modern world is used in copying machines for wood, bone and metal processing; in the constructions of collectors for electric transport, manipulators for loading work, in furniture elevators, and much more.

Keywords: Pantograph · History of Mechanism and Machine Science (HMMS) · Historical drawing device · «Nairne & Blunt» · Watt Mechanism · Coradi mechanism · Kinematic Mechanism Model · Natural Science

1 Introduction

In the modern world, we are surrounded by objects that may have an ancient history. We rarely think about it, but often, over time, the purpose and form of many things undergo significant metamorphoses. An example of such transformations is the pantograph, an instrument of proportional mathematics covering a long-long period: Antiquity, the Middle Ages, the Renaissance and the Enlightenment.

If a researcher turns to Internet resources regarding a pantograph, the result of the search will be found as designs of collectors for electric vehicles, manipulators for loading and unloading operations, lift furniture mechanisms, racks for a convenient microphone placement, and much more.

The authors are more interested in the engineering scope of pantograph application, but in this paper limit themselves to the field of material processing: wood, bone or metal and Natural Science. The historical view will be clear and not boring for readers with humanitarian interests [1].

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2 What is a Pantograph?

2.1 Pantograph and Theory of Machines and Mechanisms

We know that from the point of Theory of Machines and Mechanisms (TMM) the traditional pantograph is a planar parallelogram linkage with 2 (two) internal degrees of freedom (DoF) and 4 (four) moving links connected with solely revolute pairs. The spatial pantograph is a complex spatial linkage with 3 (three) internal DoFs in which the 4 (four) moving links are connected with spherical joints and 2 (two) additional out-of-plane links are connected with universal joints. The out-of-plane links constrain the linkage to maintain the essential parallelogram and also constrain all links to move similarly [2].

Pantograph can be made of different sizes and designs (suspended, on wheels, etc.). Its links bend and allow a user to make two or more copies of original image or also smaller or larger copies of it. Its name is derived from two Greek words: $\pi\alpha\nu\tau$—“all, every” and $\gamma\rho\alpha\varphi$—“to write”, i.e. “write everything”, thus emphasizing the multifunctionality of the device [3].

Anton Serdeczny in his paper “The stork’s beak. Deciphering the legacy of a myth” calls pantograph «Stork’s beak», giving us a beautiful interpretation of the myth reveals the ambivalent attitude of Enlightenment thinkers towards popular culture [4].

Pantograph has been used for hundreds of years. Although its application is limited in modern times, it is still known and the study of its rare and new models may be very beneficial.

2.2 Brief History

The ancient Greek engineer, Hero of Alexandria, described the pantograph in his work “Mechanics” [3] and this may have been the first mention of this ancient mechanism. The further development of pantographs was closely related to Mathematics.

As we known, the first known scientific description of pantograph was given by Christophori Scheiner (1575–1650), a German astronomer, mechanic and mathematician in his work “Pantographice,...” [5], published in 1631. In the treatise, the author describes the device he invented in 1603, and shows the scope of application: from astronomy to civil and military sciences, as well as the arts.

However, a little earlier, Jacques Besson (1540–1573), a French inventor, mathematician and philosopher, in his treatise “Theatrum Instrumentorum et machinarum” [6] gave a scheme of operation of mechanisms where plane-parallel movement of a pantograph is used, and also showed a method for constructing figures of constant width by copying a template.

Subsequently, during the Enlightenment the pantograph became not only a device for cartographers, architects and draftsmen, but it found the way into “high society”: many French and English ladies used the pantograph to obtain reduced copies of their favorite and fashionable prints, of sketches for embroidery or design of women’s albums, and even for fun.

Several rare copies of pantographs have been preserved all over the world, some of them are kept in the Bauman Moscow State Technical University (BMSTU) Museum.

3 Models from the Bauman Moscow State Technical University Museum

3.1 "Nairne & Blunt" Pantograph

The pantograph of the English company "Nairne & Blunt" (Fig. 1), is one of the earliest exhibits of the Bauman Moscow State Technical University (BMSTU) Museum [7, 8]. It was manufactured in the period 1774–1793, when two partners Edward Nairne and Thomas Blunt jointly manufactured various optical, physical and other scientific instruments. Later, in 1793, Blunt would open his own store in London at 22 Cornhill Street, thereby ending the partnership with Nairne.

Scientific instruments, manufactured by "Nairne & Blunt", also are valuable and rare exhibits of the Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera) in Saint Petersburg (Russia), of the National Maritime Museum (NMM) in Greenwich (London), of the Amsterdam Museum (the Netherlands) and of many other scientific museums of the world. Most likely, the pantograph "Nairne & Blunt" came to the Bauman Moscow State Technical University (BMSTU) Museum as a result of foreign trips of the university teachers in the period 1855–1870.

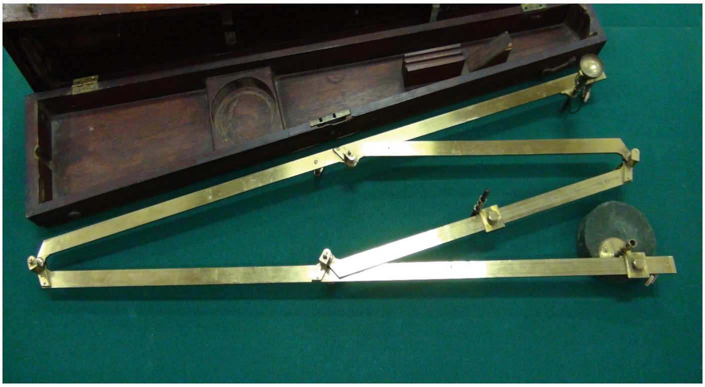

Fig. 1. "Nairne & Blunt" pantograph, 1774–1793, the BMSTU Museum Collection.

3.2 "Charles Blunt" Pantograph

The next pantograph from the BMSTU Museum collection was made in the workshop of Charles Blunt (Charles Blunt, son of Thomas Blunt), in London at 38 Tavistock Street, around 1811–1818 [7, 8]. Its construction has a number of local technological simplifications (Fig. 2), and was easier in manufacturing than the first pantograph, but both devices have the same layout solution, approximately equal dimensions and weight. Small differences in details indicate that at the beginning of the 19th century, English manufacturers of mathematical instruments had to sacrifice the aesthetics of the appearance of mechanisms for the sake of the competitiveness of their products during the rapid development and increase in the number of similar firms during the Industrial Revolution [7]. But at the same time, both English pantographs are still difficult to be manufactured as they needed the high share of manual labor. These particularities clearly demonstrate to the Museum visitors the technological capabilities of the craftsmen of that time.

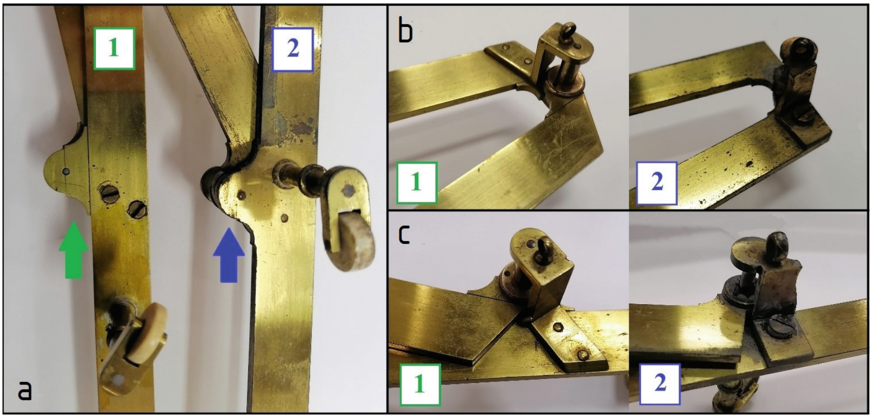

Fig. 2. Comparison of two pantographs from the BMSTU Museum collection: 1) "Nairne & Blunt", 1774–1793; 2) "C. Blunt", 1811–1818. a) more precise shaped sawing of the flat hinge (arrow); b) and c) – more elegant design of fastening points and joints in the model 1.

3.3 "Watt Parallelogram"

At the end of the 18th century, the English inventor James Watt used the so-called "parallel motion" to direct the piston and valve in his steam engine. The unit that implemented this idea was called the "Watt parallelogram" or "Watt mechanism" (Fig. 3a). This is a slightly different type of pantograph. The diagram (Fig. 3b) shows the trajectory of the Watt mechanism. This is not entirely parallel movement, more precisely, a lemniscoid, (Watt's curve), a plane algebraic sextic curve, a special case of a slip curve. The curve traced out by the midpoint of a line segment whose end points move along two circles of equal radius [7–10]. This curve has a parallel section of the required length to perform its task of plane-parallel movement (Fig. 3c).

Invention of "Watt parallelogram" led to the fact that in the first half of the 19th century a huge family of flat mechanisms with straight guides appeared. Many well-known mechanical scientists, such as Oliver Evans (1755–1819), Ferdinand Redtenbacher (1809–1863), Franz Reuleaux (1829–1905) and others had been creating straight line mechanisms (pantographs) for converting rectilinear reciprocating motion into rotational and vice versa [7].

A mechanism [11], called later as "Chebyshev linkage" or "Straight-line Mechanism of Chebyshev" (Fig. 4) is among them.

It was invented by the great Russian mathematician and mechanic, Pafnuty Lvovich Chebyshev (1821–1894). This is an example of a six-link (one fixed) and seven-joint

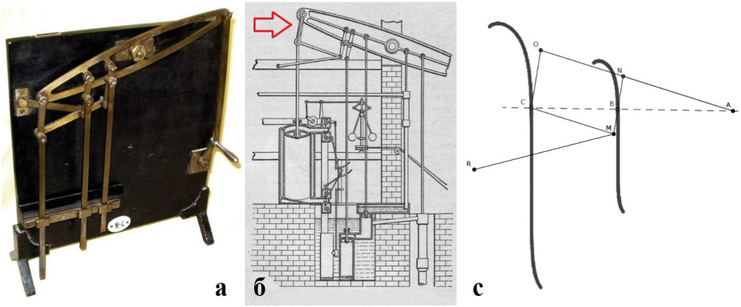

Fig. 3. a) A model of the Watt's steam engine from the BMSTU Museum collection, made in 1862–1867 in the university workshops; b) a diagram of the Watt's steam engine; c) a diagram of the trajectories of the Watt's mechanism.

Fig. 4. Six Link, Straight-Line Mechanism of Chebyshev [12]

compound mechanism with one degree of freedom as an approximate straight-line mechanism [12]. Chebyshev spent several decades trying to find a theorem that would establish whether a linkage mechanism could draw an exact straight line.

Several models of this type of mechanisms ("Chebyshev linkage") are kept in the BMSTU Museum [13]. One of them is on Fig. 5.

The mechanism is intended for use in steam engines to transmit movement from the piston to the balancer. It ensures that the piston attachment point moves along a trajectory close to a straight line.

The mechanism diagram was proposed by Chebyshev, the model was manufactured in the eighties of the 19th century in Berlin (Germany) in the workshops of Gustav Voigt.

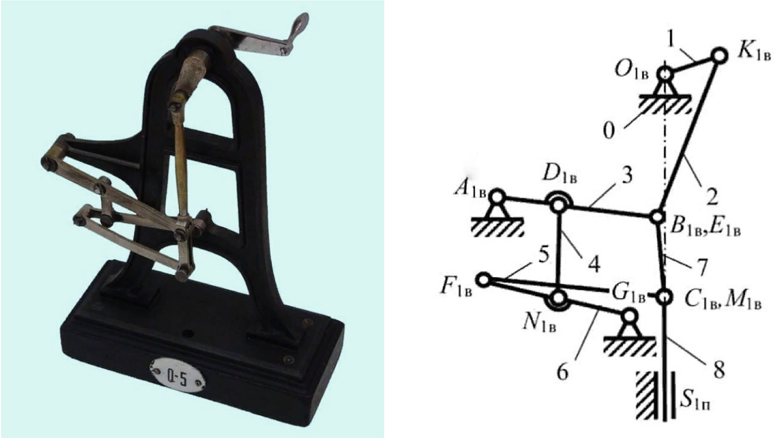

Fig. 5. Chebyshev's six-link straight-line mechanism (Q-5) [10], page 55–56, [13].

3.4 Coradi Pantograph

In the 19th and beginning of the 20th centuries, the pantograph became more accurate and rigid. For ease of use, new complex components and even lenses appear in its kit. One model from the BMSTU Museum of Coradi type pantograph [7, 8, 14], produced in the second half of the 19th century by the American company Keuffel & Esser Co is on Fig. 6a. In this device, with the help of a thread and a system of blocks, the copying unit interacts (Fig. 6c) with a spring-loaded drawing device (Fig. 6b), which allows the pantograph user, when necessary, to lift the lead and interrupt the stroke until the copier needle moves to the desired point on the plane. The inventor of such a system is considered to be the Swiss instrument maker Gottlieb Coradi (1847–1929) from Zurich.

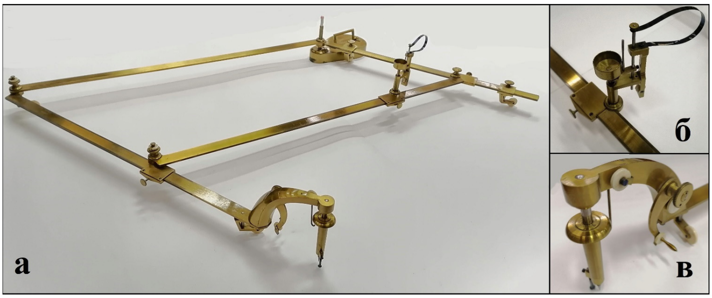

Fig. 6. a) Coradi pantograph, second half of the 19th century; b) drawing device with a flat spring; c) copying unit with a system of blocks and a lever. From the BMSTU Museum collection.

4 Pantograph, Lathe and Art

4.1 Coping Lathe

Pantographs as well found their application in coping lathes, which in the 18th century reached great perfection and distribution. This kind of machine tools with complex kinematic chain (gearing) were used mainly for the production of artistic products. The coping lathes were capricious and the craftsmen were called artists, and there were very few of them.

The first major study of the relationship between an artistic idea and its subsequent material realization when a lathe used was the work of the French scientist Charles Plumier (1646–1704) "*L'Art de tourner ou de faire en perfection toutes sortes d'ouvrages au tour*", published in 1701 [7, 8]. In addition to the principles and elements of the lathe, the author gave some important recommendations for turning wood, ivory, etc. The book became widely known, contributed to the improvement of machine tools and the skill of craftsmen.

Later, in 1734, Charles-Marie de La Condamine (1701–1774), a French geographer, mathematician and naturalalist of the Enlightenment, published in Paris a two-part essay "Recherches sur le Tour" [15]. The first part was "Description et Usage d'une Machine qui imite les Mouvements du Tour." The second part was "Examen de la nature des Courbes qui peuvent se tracer par les mouvements du Tour." Both parts are an attempt to study in depth the operation of a complex machine tool using mathematical methods.

It is known, although La Condamine understood practical turning, he was primarily a theoretician interested in describing the applied geometry of complex turning. However, La Condamine first outlined the differences between the coping lathe and the ordinary lathe: the first one was intended for applying complex curves to objects and making objects with a non-circular cross-section [7, 8, 15, 16].

4.2 Artists–Engravers and Medallists

The pantograph features to reduce the copied image was very quickly used by artists–engravers and medallists. A copying and engraving machine was born, the kinematic scheme of which later developed, transformed and was used to create a wide group of copying and milling and copying and planing machines [17].

In 1788, the Frenchman Jean Baptiste Barthélemy Dupeyrat (1759–1834) created a slightly more advanced machine tool, which received wide recognition among French artisans and was purchased by the Mints of England (Soho and the Royal Mint), as well as the Mint in Karlsruhe (Germany).

Another practical application of the pantograph in the 19th century was the mechanized drawing of monograms, letters, numbers and various inscriptions on simple and shaped surfaces for memorable gifts, souvenirs, etc. In this case, the engraver could draw an inscription in two ways: with the axial rotation of the tool (drill, bore or milling cutter), that was essentially milling, and with a stationary tool (cutter), that was similar to a stichel engraving [8].

5 Pantographs in the 20th Century

In the 20th century, the decline of the era of drawing pantographs application is gradually coming. Optical projection methods of image transfer will be used for scaling, photochemical copying will be performed, and etc. The pantograph mechanism lasted the longest in the copying-milling and multi-spindle machine tools. At the end of the 20th century, the pantograph was replaced by CNC machine systems, and later, with the development of software and the integration of computer-aided design systems with automated production via CAD/CAM/CAE.

Copying machines with a pantograph mechanism continue to be produced in mechanical engineering (even the term "Duplicarver" has appeared), but rather for hobbies, leisure, small-scale production, artistic processing of materials for engraving, jewelry, as well as restoration work or in the do-it-yourself version.

6 Conclusion

1) Pantographs has played an important role in the development of Science and Technology. The first industrial revolution, which gave rise to the modern industrial era, cannot be fully understood in isolation from its intellectual foundations, the most important of which is Natural Science. Pantographs contributed as well to the development of engraving, geodesy, cartography, navigation, and many other fields.
2) In the 18th and 19th centuries, pantograph mechanism provided Mechanics with many opportunities to create new equipment that allowed solving the problem of using steam as an energy source and transmitting various types of movements of mechanisms.
3) Visitors to the BMSTU Museum can get acquainted with a rich collection of kinematic models of mechanisms, including rare pantographs, the widespread application of which dates back to the 18th century. They can easily discover these devices in the activities of both naturalists and inventors.
4) One of the main goals of the museum's collection is to attract students to the study of the History of Machine and Mechanism Science (HMMS), teaching them a systematic approach to the perception of the development of any scientific discipline.
5) Mechanisms models, and pantographs in particular, clearly demonstrate the deep interconnection of humanities, technical, social and natural sciences and fine art [18].
6) The study of rare and modern kinematic models of mechanism leads to the strengthening interdisciplinary scientific connections between the students and specialists in technical and humanitarian sciences [19].

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