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History of Escapement Mechanisms

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***Abstract*—This paper describes a history of development one of the most important part of mechanical clock – escapement mechanism. Escapement mechanism is a device designed to maintain a constant average speed of the escape wheel, by allowing it to rotate to the desired angle at certain impulse of time. While doing that it simultaneously support the oscillations of the pendulum or balance spring, by compensating for friction losses and air resistance. 7 century long history of escapement mechanisms, from 13th century verge mechanism up to modern-day escapements that can be found in luxury watches, will be shortly presented. Through lives of famous clockmakers and their achievements in field of making escapement mechanism will be given a new insight in science of time keeping - horology.**

***Keywords*— escapement, mechanism, history, watches, clock**

I. INTRODUCTION

The escapement mechanism is a key part of every mechanical clock, because it maintains and counts oscillations of the oscillator and thus measures the flow of time. It can be also said that escapement is a device that transfers energy to the timekeeping element (the "impulse action") and allows the number of its oscillations to be counted (the "locking action"). The impulse action transfers energy to the clock's timekeeping element (usually a pendulum or balance wheel) to replace the energy lost to friction during its cycle and keep the timekeeper oscillating.

II. EARLIEST TYPES OF ESCAPEMENT

One of the oldest known type of escapement mechanism is called verge ("verge and foliot") escapement shown in Fig 1. The verge escapement consists of a wheel shaped like a crown, with teeth shaped like saw and vertical rod, the verge, with two metal plates, the pallets, that engage the teeth at opposite sides of the crown wheel. This type of escapement was in use since 13th century and it was, as expected for this early innovation, very inaccurate but it allowed for a first time for clocks to be completely mechanical. During the entire middle ages, watchmakers were building it in clocks who were built mainly as public, tower. These public watches were supplied with massive mechanisms of great dimensions.

Fig. 1 Verge escapement

However, the late middle Ages also recorded the appearance of hand and pocket watchmakers. The first portable timer, the so-called. The Nuremberg egg (Fig. 2), which could be worn in a pocket or purse (Ger.: taschenuhr), was constructed in Nuremberg by watchmaker Peter Henlein, (1485-1542)

Fig. 2 Nuremberg egg clock

This one and timepieces similar to him from the same period (mid-16th century) had spring propulsion which drives escapement "verge and foliot". Due to the extremely small accuracy (the error was a few hours a day), they were used more as fashion details and status symbols, and less as instruments for measuring time. Only after Huygens's invention of the balance wheel with

spiral spring 1656-1657. that pocket and hand watches become reliable and more accurate timepieces and in the following centuries, they are more and more perfect, more popular and more important in everyday life.

III. XVII CENTURY – BIRTH OF MODERN ESCAPEMENT MECHANISM

The turning point in the development and improvement of timepieces took place in 1656, when Dutch scientist Christiaan Huygens, (1629-1695) Fig 3 constructed the first watch with a pendulum and a spiral spring watch. Since then the history of time measuring instruments has been more history of the development of the escapement mechanisms. The "verge & foliot" speed controller conditions had huge pendulum oscillation amplitudes (even over ± 50°), which significantly increases the impact of a circular error on the total drop of isochronism [1], [2].

Fig. 3 Christiaan Huygens, (1629-1695)

Need to reduce the amplitude of the pendulum vibrations was the main reason for the introduction of a new type of regulator in the constructions of the timepieces. It was anchor escapement, whose design was explained by English watchmaker William Clement (1633-1704) and British scientist Robert Hook (1635-1703), in 1670. The earliest known anchor clock is Wadham College Clock, a tower clock built at Wadham College, Oxford, in 1670, probably by clockmaker Joseph Knibb (1640-1711). Its advantage was that it reduced the wide pendulum swing angles of the verge to 3–6°, making the pendulum nearly isochronous. Further improvement of the anchor escapement, perhaps the most significant in the history of clock construction, was accomplished by Thomas Tompion, (1639-1713), Fig. 4, the father of British horology, according to the idea of mathematicians and astronomers Richard Towneley, (1629-1707), in 1675.

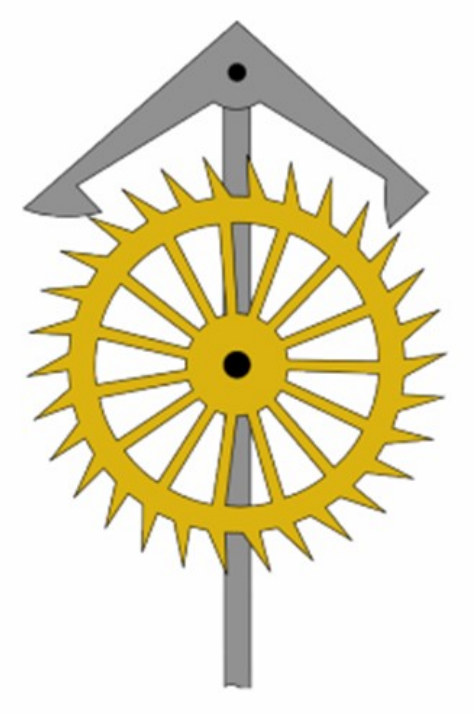

Fig. 3 Anchor escapement

Fig. 4 Thomas Tompion, (1639.–1713.)

This invention is called Deadbeat escapement, which is shown in Fig. 5. and is less tolerant of inaccuracy .It was initially used only in precision clocks, but its use spread during the 19th century to most quality pendulum clocks.

George Graham, (1673-1751), in Figure 6, was Tompion's pupil and a contemporary Great Master of the Honored Guild of Watchmakers in London. He perfected Deadbeat escapement in 1715 and enabled his massive application.

Beside Graham's anchor wheel regulator, the same class of escapements also has many other design of escapement mechanisms. There are some timepieces

which are built to be stationary (towers or walls) like Amman-Lepo's (Amant-Lepaute 1741, 1750) and Brokó (Achille Brocot 1849) which is a pin-pallet mechanism. Also there are regulators for mobile (hand and pocket) watches like Tompion's cylinder (Tompion 1695) shown in Figure 7, "duplex" (Pierre Le Roy 1748) and "virgule" (Lépine Jean Antoine 1780).

Fig. 5 Deadbeat escapement

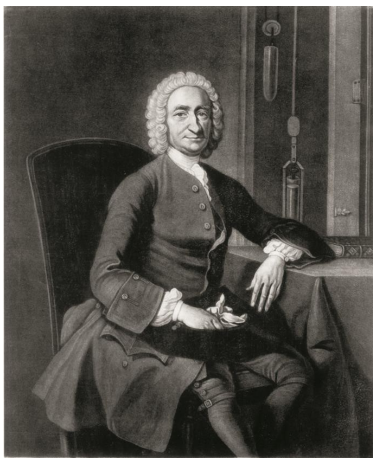

Fig. 6 George Graham, (1673.–1751)

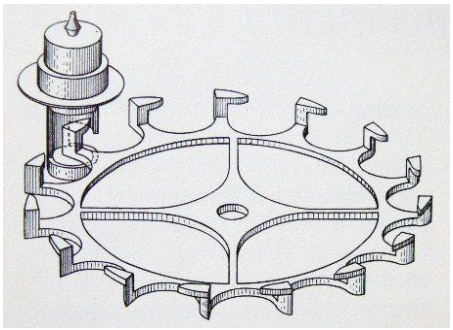

Fig. 7 Tompion cylinder escapement

IV. LEVER ESCAPEMENT

Further development of the walk regulator was achieved by designing the so-called lever or free escapement mechanisms. This invention proceeds precisely from the idea that the impulse function should be completely released from the direct impact of the drive, and that the oscillator itself be as free as possible from any influence of the regulator. The realization of first principle led to the construction of the so-called gravity-based escapement mechanisms. Second principle led to the technical solutions of chronometric regulators and they are called: English and Swiss lever escapement with an anchor. The first Gravity-based escapement mechanism was constructed by English watchmakers Thomas Mudge, (1715 - 1794) and Alexander Cumming (1732 - 1814) in 1766 [1]. The invention is perfected by Henry Kather, (1777-1835) around 1830, and James Mackenzie Bloxam around 1850. However, the realization of these conceptual solutions was hampered by the unstable behaviour of their impulse function, known as approximate tripping (Ger: “Galoppieren”). This significant problem was finally solved by the great British horologist and lawyer Edmund Beckett Denison, 1st Baron Grimthorpe, QC, (1816-1905), Figure 8, the invention of the famous "Double Three-legged Gravity Escapement", (Fig. 9), which was incorporated into the mechanism of the clock "Big Ben" in 1856. It still regulates the work of the Great Westminster Clock with exceptional accuracy and reliability [3].

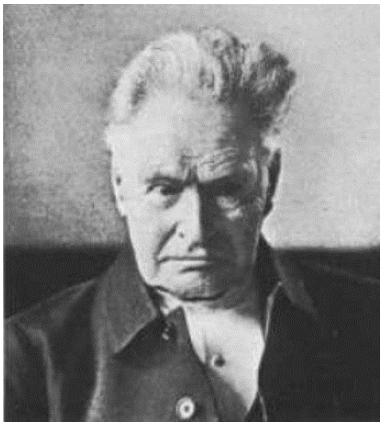

Fig. 8 Edmund Beckett Denison,, (1816.-1905.)

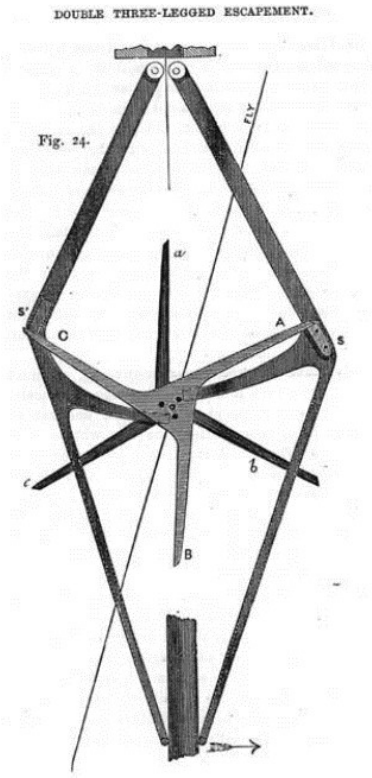

Fig. 9 Double Three-legged Gravity Escapement

An English free escapement with an anchor, characterized by pointed teeth at the center point, was constructed by Englishmen Tomas Madge in 1757, and was perfected by French watchmakers Abraham-Louis Bréguet, (1747-1823), Fig. 10, and Robert Robin, (1742-1999) [4].

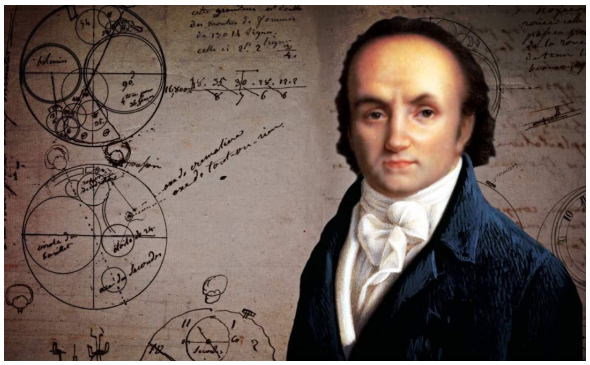

Fig. 10 Abraham-Louis Bréguet, (1747.-1823.)

Swiss escapement with anchor, Fig 11, which differs from the English variant only in the shape of a tooth of the average point, was created around 1910, and because of its simplicity, today it has the widest use in the mechanisms in hand and pocket watches.

The first naval chronometer, was constructed in 1730 by John Harrison (John Harrison 1693-1776), in which he incorporated one version of escapement mechanism - the so-called. "Grasshopper" and solved the famous problem of determining latitude at sea [5].

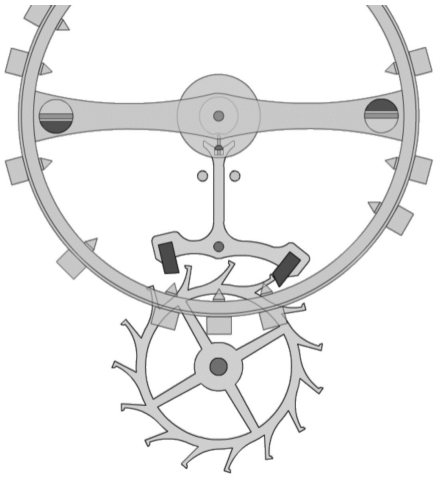

Fig. 11 Swiss escapement mechanism

The first free chronometric escapement was made by French watchmaker Pierre Leo (Pierre Le Roy 1717.-1785) in 1748. The invention was enhanced by the English watchmakers John Arnold (1736-1999) in 1779, and Thomas Earnshaw (1749-1829) in 1783, enabling the mass production of naval chronometers [6].

V. MODERN ESCAPEMENTS MECHANISMS

At the end of this historical review of the development of escapement mechanism over centuries, it is necessary to point out two more modern escapement mechanisms, from the class of free regulators. The first is Rifler's escapement mechanism made by Sigmund Riefler, (1847-1912), which was installed in astronomical watches of the highest accuracy between 1890 and 1965. The error of these timers with pendulum was less than 10 milliseconds a day.

The second free regulator is contemporary, patented in 2000 by Beat Haldimann, (1964.-, 20), one of the 20 most important horologists and watchmakers of the present [7]. Haldim's work and discoveries are the best proof that "the art, science and skill" of building mechanical watchmakers is not only alive, but also through a new Renaissance

Beat Haldimann, (1964.-)

VI. CONCLUSION

This paper started from the oldest rate regulator that was incorporated into medieval timepieces. Since then

many clock makers gave their contribution to develop and upgrade escapement mechanism for greater accuracy and precision of watches. Only a few of them are mentioned in this paper. Their contribution is not on only in field of horology but also a great contribution in fields of mechanism theory and theoretical mechanic.

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