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GEOMETRICAL CHARACTERISTICS AND SOLID MODELING OF THE GRASSHOPPER ESCAPEMENT MECHANISM

Branislav Popkonstantinović[1]
Ljubomir Miladinović[2]
Marija Obradović[3]
Miša Stojićević[4]

Abstract

This paper presents the geometrical properties of one special type of escapement mechanism – the grasshopper escapement, by which the first marine chronometers were equipped. The most important and distinguish mechanical feature of this escapement is also disclosed that contact surfaces between pallets and escapement teeth do not need lubrication. In addition, paper presents the escapement 3D solid model and explains briefly its operational cycle.

Key words: *clock, escapement, grasshopper, Harrison, mechanism,*

1. INTRODUCTION

It was already disclosed [1], [7], and emphasized that an escapement is a part of every clock and watch which serves as a mechanical regulator with two different functions: the locking and the impulse function. The angular velocity of the clock and watch

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[1] PhD Branislav Popkonstantinović, full time professor, Faculty of Mechanical Engineering, Belgrade, Serbia

[2] PhD Ljubomir Miladinović, full time professor, Faculty of Mechanical Engineering, Belgrade, Serbia

[3] PhD Marija Obradović, associate professor, Faculty of Civil Engineering, Belgrade, Serbia

[4] M.Sci. Miša Stojićević, assistant, Faculty of Mechanical Engineering, Belgrade, Serbia

mechanism is regulated by the locking function while the dissipation of the oscillator energy is recompensed by the action of the impulse function [7]. Grasshopper escapement [3] is a recoil escapement for pendulum clocks invented by British carpenter and clockmaker John Harrison (Fig. 1) around 1722 [4]. Harrison used this escapement in his regulator and turret clocks, and also in the first three of his marine chronometers, H1 - H3, by which the famous problem of Longitude was finally solved. The term "grasshopper" describes the specific skipping and kicking action of the pallets and it first appears in The Horological Journal in the late 19th century.

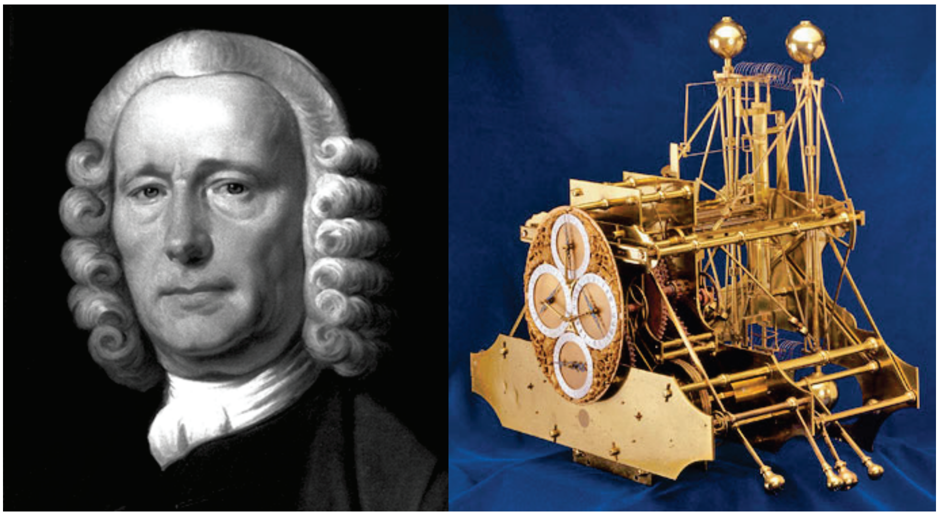

Figure1. *John Harrison and the first marine chronometer H1 equipped with a grasshopper escapement*

Grasshopper escapement shares all characteristics with any other recoil anchor escapement except one: the contact surfaces between pallets and escapement teeth do not need lubrication. This is an important advantage because the clocks equipped with grasshopper escapement do not need to be stopped frequently for cleaning, oiling and adjusting. Moreover, those “grasshopper” clocks are more accurate and reliable than others since the deterioration of lubricant, which is highly detrimental to the clock rate stability, is completely eliminated from the pallets of the grasshopper escapement.

2. GEOMETRICAL PROPERTIES OF THE GRASSHOPPER ESCAPEMENT

The design of the grasshopper escapement can be perceived and comprehended as the modification of an ordinary anchor escapement [2]. This modification was invented and accomplished by John Harrison to eliminate the need for lubrication of the escapement pallet contact surfaces. That distinguish mechanical property of the grasshopper escapement is the direct consequence of its geometrical characteristics.

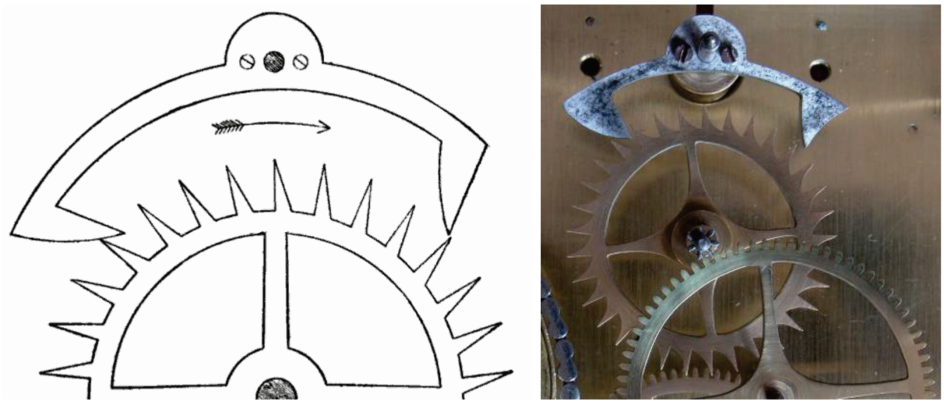

Figure2. *Anchor recoil escapement*

At the very beginning of this discussion, the simple anchor escapement [2], whose design was accounted for by an English clockmaker William Clement and British scientist Robert Hook in 1670, will be analyzed briefly. This recoil escapement given on Fig.2 interacts with oscillator permanently. The effect of sliding friction moment of force is tachy - chronous overall [7], which means that every increase of the driving moment leads to diminished oscillation period of a pendulum and acceleration of the clock rate [8]. The sliding friction can be reduced by pallets surfaces lubrication but since lubricant degrades during the time, the problem persists. One possible and very smart solution to this clockmaker's puzzle is to replace the sliding motion with rotation of a pallet around its fulcrum on an escapement tooth [6]. This kinematical replacement can be achieved only if escapement pallets are not fixed on, but able to rotate around their joints with escapement crank arms.

Fig. 3 discloses the basic geometrical properties of the grasshopper escapement [3]. Escapement wheel is presented by the escapement circle e whit the diameter *De*, and the center in the point *O*. Pallet arms *HA* and *JB* are pivoted to the pallet cranks *GH* and *GJ* in the points *H* and *J*. Since crank arms GH and GJ have the same length, points *H* and *J* belong to the same circle perimeter *c* with the center in the point *G*. Pallet arms *HA* and *JB* are connected to the perimeter of the escapement circle *e* in the points *A* and *B* respectively. The angle *AOB* = σ is the pallet span angle. The entry pallet arm *HA* is the mutual tangent to the escapement circle *e* in the point *A* and a crank circle *c* in the point *H*, while the exit pallet arm *JB* is the mutual tangent to the escapement circle *e* in the point *B* and a crank circle *c* in the point *J*. This "mutual tangents" geometrical characteristic is the essential concept of the grasshopper escapement design. The linkage motion, as carried on the small arcs, is analogous to the motion of two pulley wheels coupled together one half of the time by a common loop belt so as to rotate in the same direction. The other half of the time they are coupled together with the crossed belt and they rotate in an opposite sense with respect to each other. Since pallet arms are the mutual tangents to the escapement and crank circle, the directions of escapement impulse forces are always collinear with the pallet arms. Consequently, the relative sliding motion between contact surfaces of pallets and escapement teeth is eliminated, and thus the sliding friction and the need for the surfaces lubrication [6].

3. 3D SOLID MODEL OF GRASSHOPPER ESCAPEMENT

At the very beginning of the 3D solid modeling of the grasshopper escapement, some parameters must be assumed and others are determined regarding the geometrical properties of this escapement shown on Fig. 2. The pendulum (oscillator) period is T = 2 s (clock rate is 0.5 Hz) and the escapement wheel has Z = 30 teeth. Thus, the angular velocity of the escapement wheel is one revolution per 60 seconds. It is assumed that diameter of the escapement circle *e* is *De* = 170 mm, and the number of teeth spanned by pallets N = 9. Other dimensions are determined by a simple calculation and results are placed in Table 1.

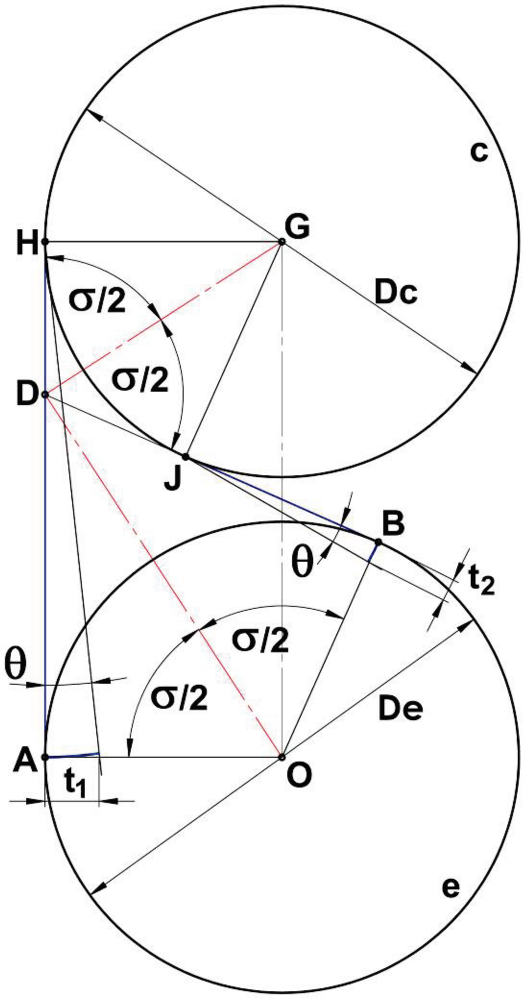

***Figure 3**. Geometrical properties of grasshopper escapement*

***Table 1**: Geometrical parameters of the grasshopper escapement*

Parameter name	Formula	Value
Number of toot pitches spanned by pallets p	$p = N + 0.5; N \in \mathbf{N}$	9.5
Pallet span angle σ	$\sigma = 360^0 \cdot p / Z$	114^0
GH, GJ pallet cranks length	$GH = GJ = D_e / 2$	85.00 mm
AD, BD	$AD = BD = GH \cdot tg(\sigma / 2)$	130.89 mm
DO	$DO = \dfrac{D_e}{2\cos(\sigma / 2)}$	156.07 mm
DG	$DG = \dfrac{D_e}{2\sin(\sigma / 2)}$	101.35 mm
OG centers distance	$OG = \sqrt{DO^2 + DG^2}$	186.09 mm
DJ, DH	$DJ = DH = \dfrac{D_e}{2tg(\sigma / 2)}$	55.20 mm
Entry pallet arm length AH	$AH = AD + DH$	186.09 mm
Exit pallet arm length BJ	$BJ = BD - DJ$	75.69 mm
Pendulum arc	$\theta = 180^0 / Z$	6^0
Pendulum amplitude α	$\alpha = \theta / 2$	3^0
Entry pallet nib length t_1	$t_1 = AH \cdot \pi \cdot \theta / 180^0$	19.49 mm
Exit pallet nib length t_2	BJ pi theta / 180	7.93 mm

Since the entry and exit pallet intermittently and alternately engages and disengages the escapement's teeth, the pallet arms must be capable to skip out of the way of the escapement wheel spontaneously whenever the pallet nib is not resting on the escapement's tooth. This kinematical behavior can be accomplished either by a spring or gravity force. The solution based on the gravity force is used in this case and is practically realized by the tail heavy pallet arms.

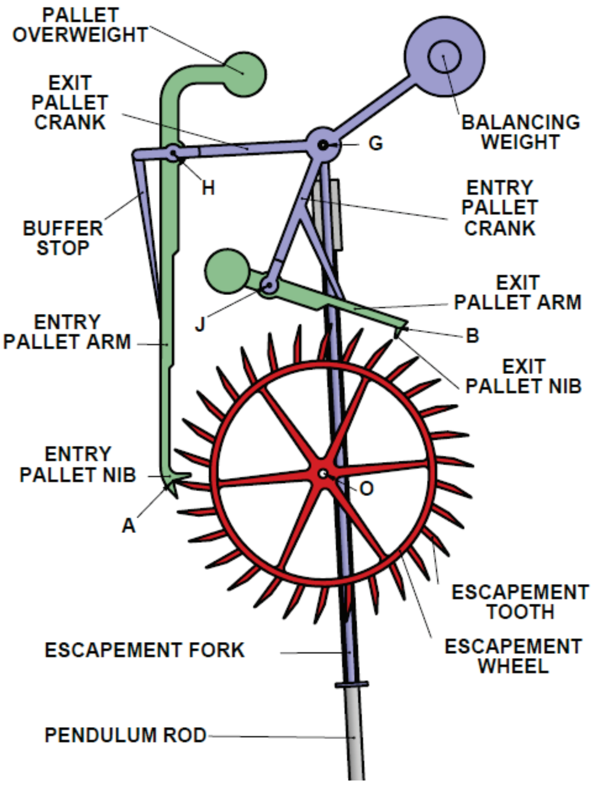

Figure 4*. 3D model of the grasshopper escapement*

Respecting all geometrical parameters determined in previous chapter, the complete 3D solid model of the grasshopper escapement is accomplished and given on Fig 4. Since this paper does not expose the simulation and motion study of the escapement working cycle, the escapement operation is explained just briefly.

The constant momentum of force acts on the escapement wheel in the clockwise direction. When the pendulum is swinging from right to left, the nib of the entry pallet rests upon the escapement tooth; the escapement wheel rotates clockwise and the escapement fork delivers the impulse force to the pendulum. Just before the pendulum reaches the left amplitude position, the nib of the exit pallet enters the space between escapement teeth, engages the tooth and locks the further clockwise rotation of the escapement wheel. However, the pendulum, having momentum of inertia, continues its swing to the left, and the buffer stop on the crank arm continues to poll the exit pallet and the locked tooth to the left. This action forces the escapement wheel to recoil a small amount and thus to release the nib of the entry pallet from the engagement with the escapement tooth. Since tail heavy, the unlocked entry pallet jumps out of the way of the escapement wheel almost immediately and rests upon the buffer stop. Now, the pendulum starts to swing from left to right, the nib of the exit pallet rests upon the escapement tooth; the escapement wheel rotates clockwise and the fork delivers the impulse force to the pendulum. This working cycle will repeat as long as momentum of force is applied on the escapement wheel.

4. FINAL REMARKS AND CONCLUSION

This paper exposes the basic geometrical characteristics of the grasshopper escapement and explains how these characteristics influence its mechanical properties. The most important and distinguish mechanical feature of the grasshopper escapement is disclosed and emphasized that contact surfaces between pallets and escapement teeth do not need lubrication.

Respecting its geometrical parameters, the complete 3D solid model, as well as the motion study and animation of the grasshopper escapement, is accomplished by the using of the “Solid Works 2012” computer application. The escapement operational cycle has been considered and explained just briefly and visualized by the short movie [5].

Besides specified mechanical advantage, this type of escapement has several unfavorable features. First of all, since grasshopper escapement belongs to the group of anchor, recoil escapements, it makes permanent disturbing influences to the pendulum harmonic oscillations. Secondly, the grasshopper pallets tendency to jump out of the way of the escapement wheel has some serious defective consequences. For instance, whenever the clock’s going train is stopped or interrupted by winding, the grasshopper escapement will become temporarily inoperable because its pallets miss the contact with the escapement teeth. Nevertheless, this escapement mechanism remains today a unique, ingenious and admirable clockmaker’s invention.

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Literature

1. Beckett E., A Rudimentary Treatise on Clocks, watches and Bells for public purposes, Crosby Lockwood and Son, London, United Kingdom, 1903.
2. Gazeley W.J., Clock and Watch escapements, Robert Hale Ltd. London, United Kingdom, 2001.
3. Grasshopper escapement, http://www.bealltool.com/pdfs/Grasshopper0001.pdf
4. John Harrison, http://en.wikipedia.org/wiki/John_Harrison
5. Obradović R., Popkonstantinović B., Šiđanin P., Vujanović M., Milojević Z., Computer Graphics and Computer Animation studies at Serbian Faculties, 2nd International Scientific Conference "moNGeometrija 2010", Proceedings, pp. 467-473, Serbian Society for Geometry and Graphics, University of Belgrade, Beograd, 2010.
6. Рашковић Д., Основи теорије механизама, Универзитет у Београду, Завод за издавање уџбеника СР Србије, Београд, СР Србија, 1965.
7. Stoimenov M., Popkonstantinović B., Miladinović Lj., Petrović D., Evolution of Clock Escapement Mechanisms, FME Transaction, Vol. 40, No. 1, pp. 17-23, Faculty of Mechanical Engineering, Belgrade, Serbia, 2012.
8. Woodward P., Woodward on Time, British Horological Institute, United Kingdom, 2006.