

# A study on the working mechanism of astronomical clock in *Sejong* Era<sup>1)</sup>

세종시대 천문시계의 작동 메커니즘에 대한 연구

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## Abstract

*Heumgyeonggaknu* (欽敬閣漏, an alternative, namely “*Ongnu*”) is an astronomical clock was made by *Jang Yeong-sil* (蔣英實) in 1438 and it was designed to run on water-hammering method (水激式). It is not only an automatic water clock that makes the sound at every hour on the hour by striking bell, drum and gong, but also an astronomical clock that shows the sun’s movement over time. The structure of *Heumgyeonggaknu* is divided into three parts, mountain(*Gasam*), flatland and support. The appearance of *Heumgyeonggaknu*’s *Gasam* (假山, pasted-paper imitation mountain) is divided into the top of the mountain, the foot of the mountain and the flatland. The sun-movement device, *Ongnyeos* (玉女, jade female immortals; I) and Four Gods (四神, shaped of animal-like immortals) are equipped on near the top of the mountain. *Musas* (武士, warriors) and *Sasin* (司辰, time manager) are equipped on the foot of the mountain. Twelve Gods (十二神), *Ongnyeos*(II) and *Gwanin* (官人) are equipped on flatland. In this study, we clearly and systematically understood the time-announcing mechanism of each puppet. Also we showed the inner structure based on working mechanism, shape of connector and control device of water wheel.

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1) 이 연구자료는 Kim SH, Lee YS, Lee MS, A Study on the *Ongnu*’s Operation Mechanism of Astronomical Clock in *Sejong* Era, JASS, 28, 79-91(2011)의 논문을 내용을 바탕으로 함경각루의 내부구조에 대한 연구를 추가하여 기술한 것임.

Keywords: *Heumgyeonggaknu* (*Ongnu*), *Jang Yeong-sil*, water-hammering method, water clock, astronomical clock, water wheel, time-announcing mechanism, time signal puppets

## 1. Introduction

For the kings of *Joseon* (朝鮮) dynasty, astronomical observation was very important in politics. Understanding of the precise movement of celestial bodies was enabled by using various astronomical instruments including large and small size *Ganui* (簡儀, simplified armillary sphere), *Honui* (渾儀, armillary sphere), *Honsang* (渾象, celestial globe), *Angbuilgu* (仰釜日晷, hemispherical sundial), *Ilseongjeongsiui* (日星定時儀, sun-and-star time determining instrument), *Gyupyo* (圭表, gnomon), *Jagyeongnu* (自擊漏, striking clepsydra) and so on. However, most of the astronomical instruments were installed in the back garden of the palace and thus it was inconvenient for the king to check the time instantly.<sup>2)</sup> Thus, *Heumgyeonggak* (欽敬閣) was built at the west side of *Cheonchujeon* (千秋殿, the office of the king) and *Ongnu* (玉漏, jade clepsydra; also called *Heumgyeonggaknu* (欽敬閣漏) after the name of the building in which it was installed) was installed in it so that the king could check the time immediately.<sup>3)</sup> In this study, we analyzed the outward and internal working structure of *Heumgyeonggaknu* based on the records in *Sejong sillok* (世宗實錄) which introduces the operation structure in details. Additionally, we completed the schematic diagrams of each part and the overall 3-dimensional reconstruction image and thus understood the operation mechanism organically.

## 2. Outward Structure and Operation Contents of *Heumgyeonggaknu*

The outward structure and operation structure of *Heumgyeonggaknu* were described in *Sejong sillok*.<sup>4)</sup> The records shows the specifications and detailed operation mechanisms including the operating principle of *Heumgyeonggaknu*, the operation of the sun movement device, the *Ongnyeos* (I) (玉女, jade female immortals) and Four gods

2) *Sejong sillok*, 80:5a:line 11.

3) *Sejong sillok*, 80:5a:line 11~12.

4) *Sejong sillok*, 80:5a:line 5~6a:line 8.

(四神, Shaped of animal-like immortals) at the top of the mountain, the operation of *Sibodae* (時報臺, time signal platform) and the time-signaling puppet, the operation of *Ongnyeos* (II) and Twelve gods (十二神, shaped of animal-like immortals) on the flatland and the operation of *Nusudae* (漏水臺, supply of water platform) (Table 1).

Table 1. Records in *Sejong sillok*(80:5a~6a).

| No | Contents   | Remark                      |
|----|--|-----------------------------|
| 1  | Dimension and Operating Principle of <i>Heumgyeonggaknu</i>          | Water-hammering Method(水激式) |
| 2  | Sun Movement Device  | Astronomical Clock          |
| 3  | Operation of <i>Ongnyeo</i> (I) and Four Gods in Top of the Mountain |                             |
| 4  | Time Signal Platform and Operation of Time Signal Puppet             | <i>Sibodae</i> (時報臺)        |
| 5  | Operation of <i>Ongnyeo</i> (II) and Twelve Gods in Flatland         |                             |
| 6  | Supply of Water Platform   | <i>Nusudae</i> (漏水臺)        |
| 7  | Landscape of <i>Binpungdo</i> (豳風圖) Four Seasons                     | Farmed Landscape            |

### 3. Three-Dimensional Modeling

The key characteristics and working mechanism of the time signal puppets of *Heumgyeonggaknu* are shown in Table 2. *Heumgyeonggaknu's Gasan* was divided into the top of the mountain, the foot of the mountain and the flatland and the puppet name, puppet number, main characteristics and the position were marked. Among the time signal puppets, Four gods and Twelve gods have the shapes of animals, and other puppets are in the form of persons wearing the corresponding official clothes or costumes. The 3D modeling of the time signal puppets was carried out based on these constitutional contents.<sup>5)</sup>

The main structure of *Heumgyeonggaknu Gasan* is shown in Table 3. *Gasan* was divided into detailed instruments including the imitation mountain(*Gasan*), the sun movement device, and the base. The contents of the theatrical direction and motion of each structure were expressed to help the 3D modeling of the entire *Gasan*.

*Sibodae* and *Nusudae* of *Heumgyeonggaknu* had the functions of overseeing and notifying the time and maintaining the time to be accurate. Thus, the overall constitution of *Sibodae* was designed to be in the form of *Eojwa* (御座, king's chair) of *Gyeongbok Palace* (景福宮) upon the embankment. Since *Eojwa* was the core space for a king to care for the state affairs or to carry out the national policy, the design can be well

5) 3D Design by Park, Jae-Hyeon.

corresponding to the observation of the time from the sky and the notification performed on *Sibodae* and *Nusudae*.

Table 2. Characteristics and working mechanism of time signal puppets.

| Time signal puppet        | Number | Characteristics contents   | Position   |
|---------------------------|--------|--|--|
| <i>Ongnyeo</i> (I)<br>玉女  | 4      | <ul style="list-style-type: none"> <li>• Dressed the celestial robe of a fairy</li> <li>• Grabbed a golden bell and stood on cloud</li> <li>• Ringing golden bell every an hour</li> </ul>                         | Top of a mountain                                |
| Four gods<br>四神           | 4      | <ul style="list-style-type: none"> <li>• Shaped of animal-like</li> <li>• Turning(90°) each an 3-double hours</li> <li>• Located below <i>Ongnyeo</i> (I)</li> </ul>   | Four direction                                   |
| <i>Sasin</i><br>司辰        | 1      | <ul style="list-style-type: none"> <li>• Red official uniform</li> <li>• Time management</li> </ul>  |  |
| <i>Jongin</i><br>鐘人       | 1      | <ul style="list-style-type: none"> <li>• Armor and helmet. Hammer</li> <li>• East-<i>Musa</i> (pointing to the west)</li> <li>• Striking bell every an hour</li> </ul>   |  |
| <i>Goin</i><br>鼓人         | 1      | <ul style="list-style-type: none"> <li>• Armor and helmet. Drum stick</li> <li>• Located on the nearby north west-<i>Musa</i> (pointing to the east)</li> <li>• Striking drum every an <i>Gyeong</i>(更)</li> </ul> | Foot of a mountain<br>South, <i>Sibodae</i>      |
| <i>Jeongin</i><br>鉦人      | 1      | <ul style="list-style-type: none"> <li>• Armor and helmet. Gong stick</li> <li>• Located on the nearby north west-<i>Musa</i> (pointing to the east)</li> <li>• Striking gong every an <i>Geom</i>(點)</li> </ul>   |  |
| <i>Ongnyeo</i> (II)<br>玉女 | 12     | <ul style="list-style-type: none"> <li>• Dressed the celestial robe of a fairy</li> <li>• Decorated glowing clouds</li> <li>• Move upward at corresponding time through a hole which is closed normally</li> </ul> | Flatland   |
| Twelve gods<br>十二神        | 12     | <ul style="list-style-type: none"> <li>• Shaped of animal-like</li> <li>• At the double hour animal god stand up</li> </ul>  | 12-direction                                     |
| <i>Gwanin</i><br>官人       | 1      | <ul style="list-style-type: none"> <li>• Official uniform</li> <li>• Supplied a certain amount of water through a golden bottle in <i>Nusudae</i>'s <i>Uigi</i>(欹器)</li> </ul>                                     | <i>O</i> -god(午神) front<br>South, <i>Nusudae</i> |

The sun movement device consisted of the ecliptic ring and the sun device. The ecliptic ring was established as a traditional armillary sphere part and as a movement device to which the armillary sphere mechanism was added to the top. The overall mapping of the flatland was carried out referring to the pictures such as *Binpungchilwoldo* (豳風七月圖). The round shape of the ecliptic ring on *Gasán* was extended to the round shape of the mountain and the base supporting the flatland was designed in a square shape considering the view to the universe at that time which was 'the sky is a circle and the earth is a square (天圓地方).' The overall outer appearance of *Heumgyeonggaknu* is shown in Figs. 1 and 2.

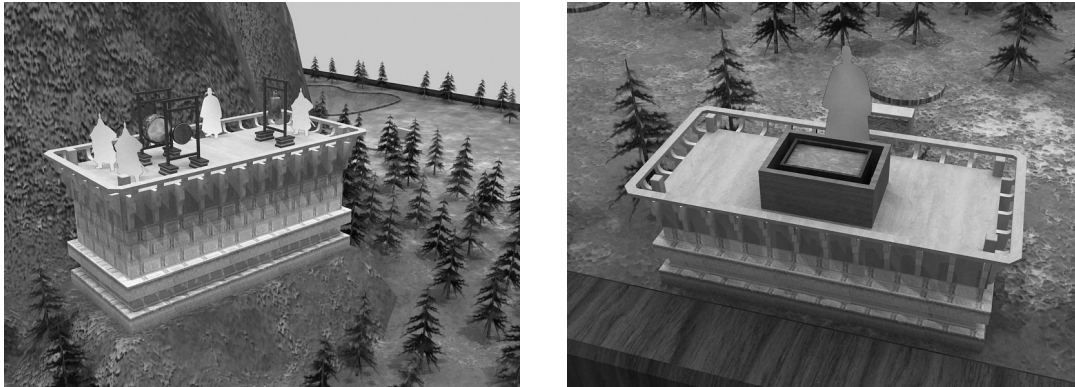


Fig. 1. *Sibidae*(left) and *Nusudae*(right).



Fig. 2. Three-dimensional modeling cut of *Heumgyeonggaknu*.

## 4. Operation Mechanism Analysis

### 4.1 Power Mechanism

The water wheel of *Heumgyeonggaknu* was operated by the water-hammering method. The motion of the time signal puppets and the operation of the sun device were empowered by the dynamic power of the water wheel. Needham et al. (1986) assumed that the power technology applied to *Heumgyeonggaknu* was by the buoyancy of the supplied water. In other words, they assumed that the force generated when the

buoy floated served as the rotational force. Such a method was the characteristic constitution of the water clock designed by Al-Jajari of the Islamic world in 13th century (Hill 1989). However, careful analysis of the records found in *Sejong Sillok* makes it probable that the dynamic power is by the water wheel rotating at a constant speed like in Chinese *Shui yün i hsiang t'ai* that was developed earlier. Hence, the power transmission system inside *Ongnu* was constituted as shown in Fig. 3.

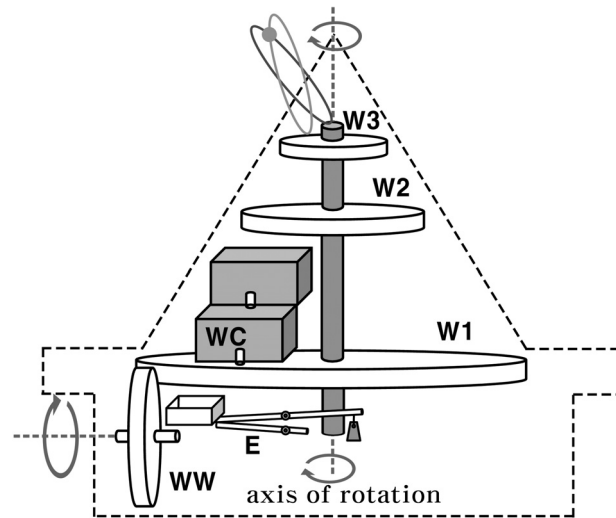


Fig. 3. Keys map of *Heumgyeonggaknu*'s inside and power supply mechanism of *Heumgyeonggaknu*.

WC: water clock, WW: water wheel, E: escapement, W1: wheel 1 (base), W2: wheel 2 (time signal platform), W3: wheel 3 (top of a mountain).

Producing a constant dynamic power based on the water-hammering method was realized by the control system(*Cheonhyeong* device, 天衡裝置) of water wheel that had the escapement system.<sup>6)</sup> Thus, the mass of the water contained in the bowl was the same with the weight hung at the handle and the dynamic power generated here was transmitted to the water wheel.

## 4.2 Internal Structure of the Time Signal System

6) Kim *et al.*(2011)은 이 부분을 “by the working mechanism of *Nusudae* that had the escapement system” 이라고 표현한 바 있으나(Kim *et al.*, *op. cit.*(2011), p. 84.), 후속 연구과정에서 누수대(*Nusudae*)는 단순히 의기(*Ugi*)를 연출하는 공간으로 분석되었다. 따라서 정량화된 물은 바로 수차의 수수상으로 유입된다.

The power transmitted to the water wheel operated the mechanism wheel of *Heumgyeonggaknu*. There were rotational wheels from the first level to the third level in the mechanism wheel. The rotation wheel at the first level(W1) transmitted the power to the Twelve *Ongnyeos* (II) and Twelve gods on the flatland. The rotation wheel at the second level (W2) transmitted the power to the time signal puppets device. The rotation wheel at the third level (W3) transmitted the power to Four *Ongnyeos* (I) and Four gods. The top level transmitted the power to the sun movement device.

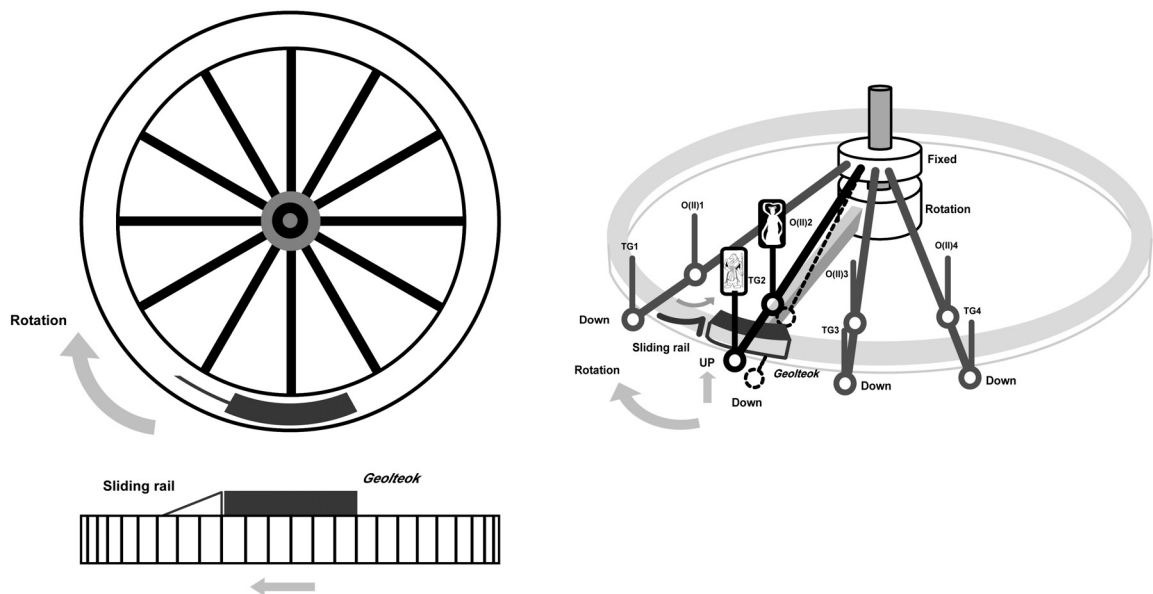


Fig. 4. Keys map of *Heumgyeonggaknu*'s wheel 1.

The rotation wheel of the first level delivered working signal to *Ongnyeos* (II) and Twelve gods. (Fig. 4) The sliding wheel and *Geolteok* placed on rotation wheel. For example, *Ongnyeo* lifts off with time card at noon by rotation wheel and god of noon among Twelve gods stands up simultaneously. This working mechanism continuing until stray out from *Geolteok* on rotation wheel. (*Geolteok* is installed around 30 degrees range from center of rotation wheel) The sliding wheel also can be seen on *Jagyeongnu* and *Honcheonsigye* (渾天時計, armillary clock) and a time card of *Honcheonsigye* should be exposed until next time. (Kim 2007) Especially, we assumed that the time signal mechanism of *Honcheonsigye* was based on the similar mechanism of *Heumgyeonggaknu*.

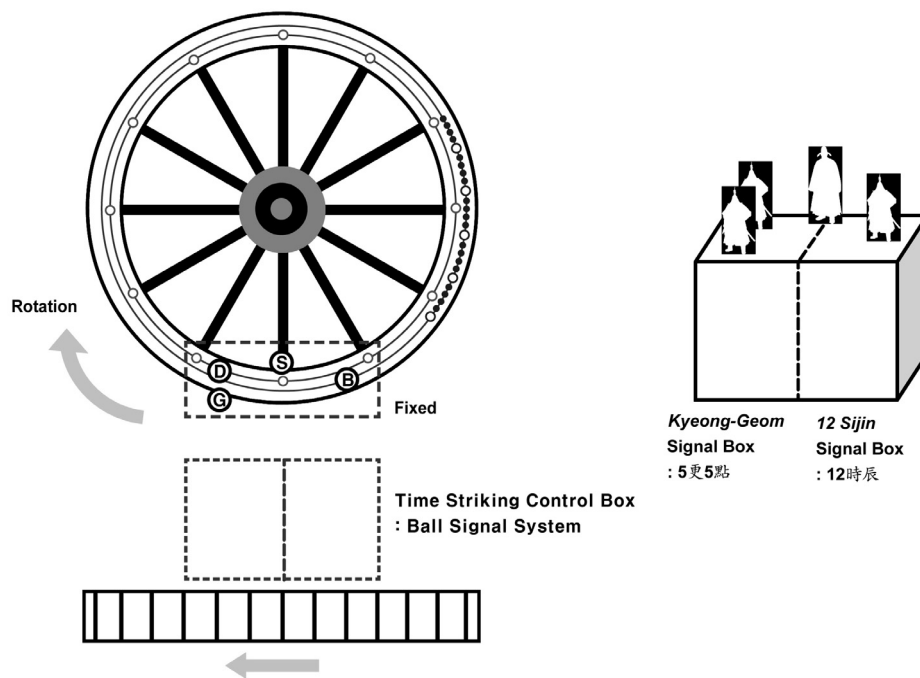


Fig. 5. Keys map of Heumgyeonggaknu's wheel 2.

The rotation wheel of the second level delivered working signal to *Sasin* and three *Musas*. The *Geolteok* placed 12-Si(時) and 5-Gyeong 5-Geom spot on rotation wheel. Twelve *Geolteok* which is placed at intervals of 30 degrees delivered working signal *Sasin* and *Jongin*. *Sasin* and *Jongin* stand face to face and *Jongin* strikes the bell. 25 *Geolteoks* which is represented 5-Gyeong 5-Geom delivered working signal to *Goin* and *Jeongin*. *Goin* plays the drum and *Jeongin* strikes the gong. *Sasin* and *Goin* stand face to face when the drum is playing and *Sasin* and *Jeongin* stand face to face when the gong is ringing. The *Geolteok*'s signals of 12-Si and 5-Gyeong 5-Geom have triggered the signal of marble and it show very similar working mechanism with the striking mechanism with *Jagyeongnu*. The *Geolteok* of 5-Gyeong 5-Geom apparently is used 25 *Geolteok*'s which is placed its seasonable places or replaced the package part of 5-Gyeong 5-Geom's *Geolteok* from appropriate part of rotation wheel.

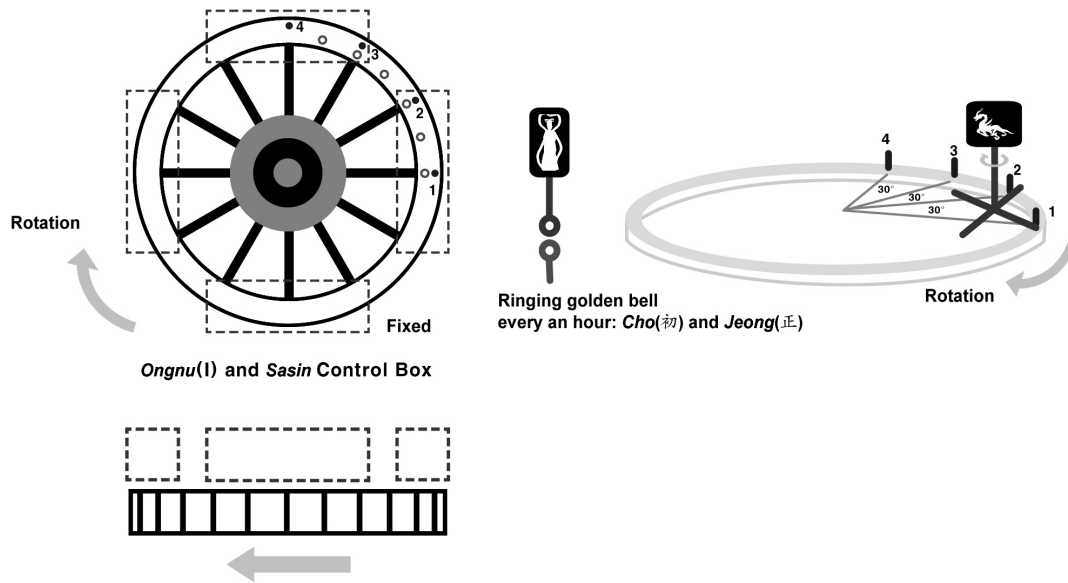


Fig. 6. Keys map of *Heumgyeonggaknu*'s wheel 3.

The rotation wheel of the third level delivered working signal to *Ongnyeos* (I) and 4-Gods. 5 *Geolteoks* were represented *Cho*(初) and *Jeong*(正) of every each hour and 4 *Geolteoks* were rotated the 4-Gods are placed on the rotation wheel. The gear system of *Ongnyeos* and 4-Gods are placed at cardinal points are operated by these *Geolteoks*. A *Ongnyeo* ringing the handed bell every each *Cho* and *Jeong* and 4-Gods are rotated 90 degrees every each hour. The *Geolteoks* of the rotation wheel are placed at intervals of 90 degrees for appropriate working at appropriate hour.

## 5. Conclusions

*Heumgyeonggaknu* was an automatic water clock installed in *Heumgyeonggak*. The name “*Heumgyeong*” which means ‘respect’ was from the sentence in *Yojeon* (堯典) Section of *Seogyong* (書經), ‘Respect as to heaven and let the people know the time and seasons.’<sup>7)</sup> *Binpungdo* for the four seasons were drawn at the four directions of the *Gasan* of *Heumgyeonggaknu*. King *Sejong* watched the difficult situations of the farmers through the pictures of *Binpungdo* and practiced the meaning of ‘*Heumgyeong*’ by means of *Heumgyeonggaknu*.

Three-dimensional modeling was performed with respect to the structure of

7) *Sejong sillok*, 80:5b:line 13~14.

*Heumgyeonggaknu* and the outer appearance recovery model was completed. The detailed appearance of the individual time signal puppets, *Sibodae*, *Japsangs* and *Binpungdo* of *Gasam* was expressed. The costumes and the design of the puppets were realized in the fashion of *Joseon* Era. These modeling works were reflected to the basic design *Heumgyeonggaknu*. In addition, through the analysis and realization of the structure, and the optimized 3D model was completed. As regards the inner structure of *Heumgyeonggaknu*, the role and structure of the water clock, *Nusudae*, water wheel and the gear constitution for each floor were presented.

## References

- Hill D. R. (ed. & transl.) 1989, The book of knowledge of ingenious mechanical devices, Hijra Council, 15-82, Original author: Al-Jazari
- Needham J., Lu G. D., Combridge J. H., Major J. S. 1986, The Hall of Heavenly Records: Korean astronomical instruments and clocks 1380-1780, Cambridge University Press, 6-80
- Kim S. H. 2007, A study on the operation mechanism of Song I-Yong's armillary clock, PhD Dissertation, Chung-Ang University, 160-164
- KIM S. H., Lee Y. S., Lee M. S. 2011, A Study on the operation Mechanism of Ongnu, the astronomical Clock in Sejong Era, JASS, 28, 79-91