A Study on the Internal Structure of *Heumgyeonggaknu*

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Heumgyeonggaknu is a water-hammering type automatic water clock which was made by *Jang Yeong-Sil* in 1438. The water clock that is located in *Heumgyeonggaknu* consists of *Suho* which is equipped with 2-stage overflow. Constant water wheel power is generated by supplying a fixed amount of water of *Suho* to *Sususang*, and this power is transferred to each floor at the same time. The 1st floor rotation wheel of *Gasam* consists of the operation structure which has the shape of umbrella ribs. The 2nd floor rotation wheel is made so that the 12 hour signal, *Gyeong-Jeom* signal, and *Jujeon* constitute a systematic configuration. The 3rd floor rotation wheel is made so that the signal and rotation of *Ongnyeo* and four gods can be accomplished. Based on the above conceptual design, this paper analyzed the internal signal generation and power transmission of *Heumgyeonggaknu*.

Keywords: *Heumgyeonggaknu*, water-hammering method, *Geolteok*, *Jujeon*

1. INTRODUCTION

This study revised and supplemented the proceedings data of “2012 International Symposium on Historical Astronomy” (Held in Seoul, Korea, 17-19 May 2012), and added the analysis of internal parts.

The observation of astronomical phenomena (天文) was a critical factor in the King of *Joseon* Dynasty governs the country. A number of astronomical instruments (天文儀器) were used to understand the movements occurring in the sky. As the astronomical instruments of those days were mostly installed in a garden in the palace, it was inconvenient for the King to figure out the time.¹ Hence, the water clock for the King was made by building *Heumgyeonggak* (欽敬閣) pavilion on the western side of *Cheonchujeon* (千秋殿) pavilion and installing *Heumgyeonggaknu* (欽敬閣漏, alias ‘*Ongnu*’) within *Heumgyeonggak* pavilion.² In this study, the internal components of *Heumgyeonggaknu* were analyzed based on the record of 『*Annals of the Joseon Dynasty*』 (朝鮮王朝實

錄)』 which introduces the structure of *Heumgyeonggaknu* made by *Jang Yeong-Sil* (蔣英實). Especially, the operation mechanism was systematically examined by presenting the internal parts and configuration as schematic diagrams.

2. SURVEY OF HISTORICAL RECORDS AND EXTERNAL STRUCTURE

2.1 History of *Heumgyeonggaknu*

Table 1 summarizes the historical records survey of *Heumgyeonggak* and *Heumgyeonggaknu* collected from 『*Annals of the Joseon Dynasty*』, 『*Seungjeongwonilgi*』 (承政院日記), 『*Gukjobogam*』 (國朝寶鑑), 『*Jeungbo-munheonbigo*』 (增補文獻備考), 『*Sinjeung-donggukyeojiseungram*』 (新

¹*Sejong sillok*, 80:5a:line 11; 且諸器皆設於後苑, 難以時時占察.

²*Sejong sillok*, 80:5a:line 11-13; 乃於千秋殿西庭, 建一間小閣, 糊紙爲山, 高七尺許, 置於其中. 內設玉漏機輪, 以水激之.

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Table 1. Records of *Heumgyeonggak* and *Heumgyeonggaknu*.

King Reign Year (Year-Month-Day)	Contents	Historical Records	Remark
<i>Sejong</i> 19 (1437-4-15)	The external form of <i>Heumgyeonggaknu</i> was introduced.	<i>Sejong Sillok</i>	景福宮
<i>Sejong</i> 20 (1438-1-7)	<i>Heumgyeonggaknu</i> was completed. 『 <i>Heumgyeonggakgi</i> 』.	<i>Sejong Sillok</i> <i>Gukjobogam</i>	卷7, 申淑舟
<i>Seongjong</i> 21 (1490-Yun 9-6)	<i>Gasam</i> 's figures and internal striking devices were left in a state of damage for many years.	<i>Seongjong Sillok</i>	
<i>Seongjong</i> 21 (1490-Yun 9-6)	The repair of <i>Heumgyeonggaknu</i> was completed and it was operated only for 10 days of the vernal equinox, summer solstice and autumnal equinox. Introduce the role of <i>Haeja</i> (海子) and <i>Jujeon</i> (籌箭).	<i>Seongjong Sillok</i>	
<i>Jungjong</i> 4 (1509-11-8)	Inherit the royal heritage of King <i>Sejong</i> through the renovation of <i>Heumgyeonggaknu</i> after gathering extensive opinions on this process.	<i>Jungjong sillok</i>	
<i>Jungjong</i> 12 (1517-11-25)	Correction of <i>Heumgyeonggaknu</i> is in progress.	<i>Jungjong sillok</i>	
<i>Jungjong</i> 38 (1543-11-2)	Uigi of <i>Heumgyeonggak</i> 's <i>Gasam</i> was discussed.	<i>Jungjong sillok</i> <i>Gukjobogam</i>	卷20, 申淑舟
<i>Myeongjong</i> 5 (1550-6)	King <i>Myeongjong</i> ordered <i>Sang Jin</i> (商震), who is in charge of <i>Gwansanggam</i> (觀象監), and <i>Kim Ik Su</i> (金益壽) to renovate figures for match with the <i>Binpungdo</i> .	<i>Gukjobogam</i>	卷22, 申淑舟
<i>Myeongjong</i> 5 (1550-8-3)	Prepare for the destruction of <i>Heumgyeonggaknu</i> .	<i>Myeongjong sillok</i>	
<i>Myeongjong</i> 5 (1550-11-6)	<i>Uigi</i> was repaired. It was installed on either side of the thorn.	<i>Myeongjong sillok</i>	
<i>Myeongjong</i> 8 (1553-9-14)	<i>Gyeongbokgung</i> Palace burned to the ground and <i>Heumgyeonggak</i> also burned.	<i>Myeongjong sillok</i> <i>Gukjobogam</i>	卷22, 申淑舟
<i>Myeongjong</i> 8 (1553-12-26)	The foundation of <i>Heumgyeonggak</i> was finished.	<i>Myeongjong sillok</i>	
<i>Myeongjong</i> 9 (1554-8-2)	Reconstruction of <i>Heumgyeonggak</i> was completed.	<i>Myeongjong sillok</i> <i>Sinjeung Dongguk yeoji seungnam</i> <i>Yeollyeosilgisul</i>	卷2, 李荇 卷3, 李肯翊
<i>Myeongjong</i> 9 (1554-8-19)	King <i>Myeongjong</i> congratulated on the reopen of <i>Heumgyeonggak</i> .	<i>Myeongjong sillok</i>	
<i>Gwanghaegun</i> 5 (1613-8-1)	The construction work is progressing despite the request of discontinue from <i>Saganwon</i> (司諫院) and <i>Saheonbu</i> (司憲府).	<i>Gwanghaegun ilgi</i>	After Japanese Invasion of Korea in 1592
<i>Gwanghaegun</i> 5 (1613-8-30)	The chief of <i>Heumgyeonggak</i> construction work reported the building site.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 6 (1614-7-9)	The repair of <i>Heumgyeonggak</i> 's internal devices, the shape of <i>Gasam</i> (假山) and vegetation and <i>Sasin</i> (司辰) was discussed.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 6 (1614-7-18)	King <i>Gwanghaegun</i> ordered to repair of <i>Heumgyeonggak</i> 's west side water clock expeditiously.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 6 (1614-9-14)	The chief of <i>Heumgyeonggak</i> construction work reported the completion of <i>Cheonjiho</i> (天池壺, a water pot for water expel).	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 8 (1616-1-16)	Correction of <i>Heumgyeonggak</i> . <i>Park Ja Heung</i> (朴自興) was named vice chief of <i>Heumgyeonggak</i> correctional administration (欽敬閣 矯正廳).	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 8 (1616-8-12)	Correction of <i>Heumgyeonggak</i> is nearing completion.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 8 (1616-8-20)	<i>Heumgyeonggak</i> correctional administration reported the correction of water clock for night (夜漏). The incorrect time of water clock for night is caused by waste materials of muddy water.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 8 (1616-8-29)	<i>Heumgyeonggak</i> correctional administration reported the correction process of water clock for night.	<i>Gwanghaegun ilgi</i>	
<i>Gwanghaegun</i> 9 (1617-1-18)	King <i>Gwanghaegun</i> ordered chief of <i>Gwansanggam</i> (觀象監) and many of his officials to correct <i>Heumgyeonggak</i> since the vernal equinox.	<i>Gwanghaegun ilgi</i>	
<i>Hyojong</i> 6 (1655-11-17)	A building planned to build on the site of <i>Heumgyeonggak</i> .	<i>Hyojong sillok</i> <i>Gukjobogam</i>	卷28, 申淑舟
<i>Hyojong</i> 6 (1655-11-23)	Demolition of <i>Heumgyeonggak</i> and the use of its old woods and roof tiles were discussed.	<i>Hyojong sillok</i>	
<i>Hyojong</i> 6 (1655-12-4)	<i>Kim Yuk</i> (金堉) contended the irrationality of demolition of <i>Heumgyeonggak</i> for construction of queen mother's building on its site.	<i>Hyojong sillok</i> <i>Imhapilgi</i> <i>Jamgokyugo</i>	卷3, 李裕元 卷6, 金堉

Table 1. Continue.

King Reign Year (Year-Month-Day)	Contents	Historical Records	Remark
<i>Hyojong</i> 6 (1655)	Two buildings were constructed on former site of <i>Heumgyeonggak</i> for queen mother.	<i>Gukjobogam</i> <i>Gunggwolji</i> <i>Imhapilgi</i> <i>Sinjeung Dongguk yeoji seungnam</i>	卷38, 申淑舟 昌德宮志 卷13, 李裕元 卷2, 李荇
<i>Yeongjo</i> 46 (1770)	<i>Heumgyeonggak</i> was reconstructed for storage of a carved stone astronomical chart (天象列次分野之圖) which was found in <i>Gyeongbokgung</i> Palace.	<i>Jeungbo munheon bigo</i> <i>Seungeongwon ilgi</i> <i>Imhapilgi</i> <i>Yeollyeosilgisul</i>	象緯考 卷3 卷3, 李裕元 別集 卷7, 李肯綽
<i>Jeongjo</i> 18 (1794-3-24)	The repair order of <i>Heumgyeonggak</i> was given. <i>Heumgyeonggaknu</i> already disappeared.	<i>Jeongjo sillok</i>	
<i>Gojong</i> 13 (1876-11-4)	<i>Gyeongbokgung</i> Palace burned to the ground and <i>Heumgyeonggak</i> also burned.	<i>Gojong sillok</i>	景福宮

**Sejong* (世宗), *Seongjong* (成宗), *Jungjong* (中宗), *Gwanghaegun* (光海君), *Myeongjong* (明宗), *Hyojong* (孝宗), *Yeongjo* (英祖), *Jeongjo* (正祖), *Gojong* (高宗), *Gukjobogam* (國朝寶鑑, Precious mirror for succeeding reigns), *Sinjeung Dongguk yeoji seungnam* (新增東國輿地勝覽, newly verified survey of the geography of the Eastern Kingdom), *Yeollyeosilgisul* (燃藜室記述, narratives of *Yeolyeosil*), *Imhapilgi* (林下筆記), *Jamgokyugo* (潛谷遺稿), *Gunggwolji* (宮闕志), *Jeungbo munheon bigo* (增補文獻備考, expanded version of the reference compilation of documents on Korea), *Seungeongwon ilgi* (承政院日記), *sillok* (實錄, Annals of the Joseon Dynasty), *ilgi* (daily records), *Yun* (閏, intercalary month)

增東國輿地勝覽」³, and individual collection of works.³ According to the historical records, the *Heumgyeonggak* and *Heumgyeonggaknu* were first mentioned in the 1437 (the 19th year of the reign of King *Sejong*) record of *Sejong Sillok*. This record stated that the *Heumgyeonggak* is located in the western side of *Gyeongbokgung Cheonhujeon*, and explained the external structure of *Heumgyeonggaknu*. The *Heumgyeonggaknu* was completed in January 1438, and King *Sejong* ordered *Kim Don* (金墩, 1385~1440) to compose the writing for record. This record describes the external form and operation structure of *Heumgyeonggaknu*. However, the detailed operation mechanism of the internal structure is not mentioned in this record, but it mentioned the water-hammering method only. The *Heumgyeonggaknu* remained in existence through maintenance and repair, but it was burned down along with *Heumgyeonggak* when there was a big fire at *Gyeongbokgung* palace in 1553 (the 8th year of the reign of King *Myeongjong*). In the following year, the *Heumgyeonggak* was reconstructed in *Gyeongbokgung* palace, but it was again destroyed by fire during Japanese Invasion of Korea in 1592 (壬辰倭亂, the 25th year of the reign of King *Seonjo*).

The second reconstruction of *Heumgyeonggak* began in 1613 (the 5th year of the reign of *Gwanghaegun*) (Ahn 2010).⁴ The reconstruction was carried out in *Changdeokkung* (昌德宮) palace *Seorinmun* (瑞麟門) gate considering the situation of the times that the *Beopgung* (法宮) was moved to *Changdeokkung* palace and *Changgyeonggung* (昌慶宮) palace. The construction work is processing despite the request of discontinue from *Saganwon* (司諫院, the government office of inspection) and

Saheonbu (司憲府, the government office of advice) and the *Heumgyeonggak* was completed over a period of 1 year. As there were several records of correction during the reign of King *Gwanghaegun*, it is thought that the water clock was also made and operated in *Heumgyeonggak*. Since then, there was no record on *Heumgyeonggak* and *Heumgyeonggaknu*. In 1655 (the 6th year of the reign of King *Hyojong*), there was the record that King *Hyojong* constructed *Mansujeon* (萬壽殿) pavilion at the site of *Heumgyeonggak* to support the Queen Mother (Kim 2002).⁵

In 1770 (the 46th year of the reign of King *Yeongjo*), the *Heumgyeonggak* was again mentioned in the record for storing the carved-stone astronomical chart (天象列次分野之圖, *Cheonsang-yeolcha-bunya-jido*) discovered in *Gyeongbokgung*. However, as the *Heumgyeonggaknu* was not particularly mentioned in the historical records, it is thought that the *Heumgyeonggaknu* was not operated. When the *Gyeongbokgung* was rebuilt over 3 years from 1865 (the 2nd year of the reign of King *Gojong*) to 1868 (the 5th year of the reign of King *Gojong*), the *Heumgyeonggak* was also newly reconstructed, but there was no record on *Heumgyeonggaknu*. In 1876 (the 13th year of the reign of King *Gojong*), the *Heumgyeonggak* was again burned down when there was a

³Integrated Database of Korean Classics from the Institute for the Translation of Korean Classics was used.

⁴Ahn (2010) introduced that 「*Heumgyeonggak-yeonggeon-ugwe* (欽敬閣營建儀軌)」 records the reconstruction procedure and result of *Heumgyeonggak* in 1613, and reported that the *Uigwe* was kept in *Ogyujanggak* and burned in a fire by French Navy in 1866.

⁵Kim (2002) examined 「*Changdeokkung-mansujeon-suridogam-ugwe* (昌德宮萬壽殿修理都監儀軌)」, and reported that the *Changdeokkung Mansujeon Suridogam* was installed on August 4, 1656 (the 7th year of the reign of King *Hyojong*) and the *Heumgyeonggak* was pulled down on August 11, 1656.

Table 2. The external form and working mechanism of *Heumgyeonggaknu* in 『Chronicle of *Heumgyeonggaknu*』 (or 『*Heumgyeonggakgi*』) (『*Sejong Sillok*』 80:5a:line 5~6a:line 8).

No	Contents
1	Dimensions (7 foot height of <i>Gasam</i>) and Operating Principals (water-hammering method) of <i>Heumgyeonggaknu</i> .
2	Sun Movement Device runs in accordance with 4 Seasons (role of astronomical clock).
3	<i>Ongnyeo</i> (I) on the top of mountain ring a bell every hour and 4 gods (神) rotate 90 degree.
4	Operation Explanation of time signal puppets on <i>Sibodae</i> (時報臺).
5	<i>Ongnyeo</i> (II) on the ground come out with time signal card and the relevant god among 12 gods (神) stand up.
6	Explanation of Device and <i>Gwanin</i> on <i>Nusudae</i> (漏水臺): Bowl of <i>Uigi</i> gradually stands straight when the water fills the bowl and then the water in bowl flushes when it full.
7	4 seasons of <i>Binpungdo</i> (閏風圖) and puppets were expressed on the farm land of <i>Gasam</i> .

Fig. 1. Miniature of *Heumgyeonggaknu* (1/6 size, 80×60×45(h) cm). 1: Sun apparatus, 2: ecliptic ring and equatorial ring, 3: *Ongnyeo*(II) and four gods, 4: *Sibodae* (*Sasin* and *Musa*), 5: *Ongnyeo*(I) and twelve gods, 6: *Nusudae* (*Gwanin* and *Uigi*), 7: *Gasam*

fire at *Gyeongbokgung*. Based on the above historical records, the *Heumgyeonggaknu* which was operated following the tradition of King *Sejong*'s era is estimated to have been used until 1617 (the 9th year of the reign of *Gwanghaegun*).

2.2 Structure and Water-hammering Method of *Heumgyeonggaknu*

The external form of *Heumgyeonggaknu* and the operation of time signal puppets are described in 『*Sejong Sillok* (世宗實錄)』.⁶ The historical records include the specification and working principle of *Heumgyeonggaknu*, Sun movement device, and the detailed operation mechanisms such as the operation of 4 *Ongnyeo* I (玉女, jade female immortals) and four gods (神; 青龍-Blue Dragon, 白虎-White Tiger, 朱雀-Red Bird, and 玄武-Black Tortoise) at the top of the mountain, the operation of *Sibodae* (時報臺, time signal platform) and time signal puppets at the foot of the mountain, the operation of 12 *Ongnyeo* II and twelve gods (神; 子, 丑, 寅, 卯, 辰, 巳, 午, 未, 申, 酉, 戌, and 亥) on the flatland, and the operation of *Nusudae* (漏水臺, platform of *Uigi*) (Table 2).⁷ The 1/6 scale model of *Heumgyeonggaknu* was recently restored based on the our detailed analysis regarding the external structure of *Heumgyeonggaknu* (Fig. 1).⁸

The fixed quantity supply of water and constant speed operating of the water wheel is most important to the water-hammering type water clock. Kim et al. (2011) suggested that a fixed quantity water in *Uigi* (欽器, inclining vessel) which is supplied from southern *Gwanin* (官人, government official)'s golden bottle spilled into *Nusudae* as time passed and this water move into a small vessel which is hanging from the water wheel in *Heumgyeonggaknu* and then this water-filled device is operating *Cheonhyeong system* (天衡, oriental escapement device).

However, a fixed quantity water is already supplied to *Sususang* (授水箱, water receiving small vessel) from the water clock with the overflow function which is installed inside *Gasam* (假山, imitation mountain). Therefore, it is hard to be regarded as a mechanism which again connects *Nusudae* and *Sususang* with *Cheonhyeong system*.⁹ Regarding the operation mechanism of water-hammering type *Honsang*, Lee & Kim (2012) recently introduced a mechanism which is controlled by *Cheonhyeong system* when the water of water clock is contained in *Sususang*. The water wheel control method of *Heumgyeonggaknu* (made in 1438) is thought to be similar to the water wheel control method of *Honui* (渾儀, armillary sphere) and *Honsang* (渾象, celestial globe) (made in 1435) as they were produced in the same period. Kim (2012) suggested that the motif of operation mechanism for this water wheel control is the control method of Chinese water-driven astronomical clock tower (水運儀象臺, *Shui yün i hsiang t'ai*).

⁶*Sejong sillok*, 80:5a:line 5~6a:line 8; 欽敬閣成。大護軍蔣英實經營之。其規模制度之妙。皆出睿裁。閣在景福宮燕寢之傍。上命右承旨金敬。作記曰。若稽帝王發政成務。必先於明曆授時。而授時之要。在於觀天察候。此環儀儀表所由設也。然考驗之方。極精至密。非一器一象所能取正。我主上殿下命攸司制諸儀象。若大小簡儀渾儀渾象仰釜日晷日星定時圭表禁漏等器。皆極精巧。寬越前規。猶慮制度未精。……閣既成。命臣書其事。謹述梗概。拜手稽首以獻。

⁷For the expression and meaning of four gods and twelve gods, refer to pp. 81~82 of Kim et al. (2011).

⁸In the case of 12 puppets on the flatland in *Heumgyeonggaknu*, only the puppet which corresponds to the specific time is standing up, and other puppets are lying face down. The scale model in Fig. 1 was made so that every puppet is standing up.

⁹For the study of Kim et al. (2011), it is hard to be regarded as the key device related with water-hammering type control considering that the *Uigi* is installed separately as stated in the literature record (*Myeongjong Sillok* 10:92a:10 ~ 14). (*Myeongjong Sillok* 10:92a:10 ~ 14; 領觀象監事李己啓曰 前者。以欽敬閣欽器。虛而不欽。故今改造而進。然此器。非但置諸欽敬閣。乃古聖人勸戒之器。常置諸左右。可注水而觀省也。荀子畫此器。而且。有臺。故具臺而進。傳曰 知道。此乃聖人勸戒之器。當置諸坐側而觀省焉。其貯水器及注水器。並造入之。)

3. ANALYSIS OF INTERNAL COMPOSITION

3.1 Haeja and Jujeon

『*Seongjong Sillok*』(May 10, 1493) introduced *Haeja* (海子, water containing large vessel) which is a vessel that supplies water in *Heumgyeonggaknu*. The *Haeja* is made of copper (銅) and iron (鐵). Lead is commonly used for repairing *Haeja*, but the lead is damaged when exposed to water for a long time. In that case, the plank at the bottom decays due to leaking water which causes problem in maintenance.¹⁰ The water contained in *Haeja* is also supplied to pond which is shown in the operation of *Giryun* (機輪, mechanism wheel) and exterior of *Gasam*, *waterfall*, and *Ugi*.¹¹

The water in *Haeja* is used to induce an automatic striking by triggering *Jujeon* (籌箭, calculating apparatus of stick) of *Heumgyeonggaknu*.¹² The role of *Jujeon* seems to be similar to the rod (hereinafter, '*Bujeon* (浮箭, float-rod)') in *Borugaknu* (報漏閣漏, alias '*Jagyeongnu*'). The *Bujeon* of *Borugaknu* rises when the water flows into *Susuho*. The rising *Bujeon* touches the ball that corresponds to 12-*Si* (時, 1-*Si*; double hours in modern time), 5-*Gyeong* (更, 1-*Gyeong*; divide night into five equal parts), and 5-*Jeom* (點, 1-*Jeom*; divide *Gyeong* into five equal parts), which generates the signal for striking the bell, drum, and gong.

No clear explanation exists for the operation of *Jujeon* in *Heumgyeonggaknu*, but it can be summarized as two kinds of views. One hypothesis is that the water inflow from *Haeja* raises the device of *Jujeon*, similar to the *Bujeon* of *Borugaknu*. The inflow of water operates *Jujeon*, and the corresponding ball controls 37 time signal puppets which are located at the top of the mountain, at the foot of the mountain, and on the flatland, and strikes the bell, drum, and gong. However, in this case, there is no need for '*Ongnu-giryun* (玉漏機輪)' to be operated in contact with water, and a complicated mechanism would be required which has independent operation device for each floor.

The other hypothesis is that the water from *Haeja* is supplied to the water clock and this water operates the water wheel, and this power is transferred to *Giryun* and raises the device of *Jujeon*. In the power system of *Borugaknu*, the water clock and time signal system operate independently, and these two operation mechanisms are connected by a device called *Bangmok* (方木, narrow wooden casing). The *Bangmok* plays a role in converting the analog flow of water clock to digital signal (Nam 2002). When the water

in *Haeja* is sent to the water wheel in *Heumgyeonggaknu*, the digital signal is generated with the use of *Sususang* and *Cheonhyeong* system. The operation of water wheel is not continuous, and plays a role in generating a constant signal. Therefore, the motion of *Giryun* and the rise of *Jujeon* can transfer the power through the rotation of *Giryun* even though there is no inflow of water.

To further add to the above discussion, the reason that the inflow of water supplied from *Haeja* is not likely to move *Jujeon* directly is as follows. First, it is because of the explanation on the operation mechanism called '*Ongnu-giryun-sugyeokji* (玉漏機輪水激之)'. For *Gasam*, using a single column as the rotation axis (*Giryun*) is efficient for making the time signal puppets at the top of the mountain, at the foot of the mountain, and on the flatland have a unified motion and signal system. This rotation axis has a constant speed by the constant water wheel torque. In addition, if the movement of *Sibodae* at the foot of the mountain which strikes the bell, drum, and gong is designed to use extra inflow of water, it is difficult to exactly match the motion of time signal puppets at the top of the mountain and on the flatland at the same time. Therefore, in order to accomplish a systematic motion of time signal puppets at the top of the mountain (relevant to the operation of four gods and *Ongnyeo* I), at the foot of the mountain (relevant to the operation of *Sasin*, *Jongin*, *Goin*, and *Jeongin*), and on the flatland (relevant to the operation of twelve gods and *Ongnyeo* II) by rotating *Giryun* with the torque generated from the water wheel, it is best to operate a single *Giryun*.

Hence, the meaning of 'The water in *Haeja* induces an automatic striking by triggering *Jujeon*.' stated in the historical records seems to indicate that the water supplied from *Haeja* operates the water wheel, and the water wheel transfers the physical power (mechanical power) to *Giryun*. Accordingly, the power transferred from *Giryun* is transferred from the top of the mountain to the flatland, and it is expected that there existed a device in *Sibodae* at the foot of the mountain that corresponds to the *Bujeon* and *Bangmok* of *Borugaknu*, which automatically regulates the striking number and order. Therefore, the water in *Haeja* stated in the historical records can be understood as the fundamental power which triggers *Jujeon*.

3.2 Internal Ball Mechanism and *Suho*

『*Gwanhaegun Ilgi*』(July 9, 1614) mentioned the operation and trigger of ball that is occurring in *Heumgyeonggaknu*, the contents of large · medium · small bronze vessels, the material for *Japsang* (雜像) at the top of *Gasam*, and the

¹⁰*Seongjong sillok*, 277:9b:line 8 ~ 10; 海子用銅鐵而罅隙補以鐵, 鐵久沈於水則必消鑠, 若每令貯水, 則滲漏其下, 板子腐朽, 隨後改板, 勢亦甚難矣.

¹¹*Seongjong sillok*, 277:9b:line 7 ~ 8; 此閣則有蓮池有欹器又有瀑布, 故常貯水於海子.

¹²*Seongjong sillok*, 277:9b:line 13; 貯水流注激籌箭, 使之自擊.

information on the rise and set of the Sun and the Moon.¹³ First, regarding the operation and trigger of ball, a connecting medium was mentioned which was not presented in the previous explanation of *Haeja* and *Jujeon*. In other words, it presented important contents which reveal the existence and role of ball. The sentence, 'The vessel is filled with water, the water moves the ball, and the ball strikes the machine (以器盛水, 以水運鈴, 以鈴觸動機械).' indicates that the water contained in *Sususang* of water wheel is the driving force which operates the ball. This ball triggers a mechanical device, and the mechanical device is thought to be related with *Jujeon*. In addition, it was presented that the tube for the movement of water and ball is made of copper.

For the size of *Suho* which constitutes the water clock, 3 kinds were mentioned as large, medium, and small. The big *Ho* (壺) is thought to be the water supply device, and the medium *Ho* and small *Ho* seem to be the *Suho* which has the overflow function and *Pyesuho* (廢水壺) which receives the overflowed water. Regarding the large, medium, and small *Suho*, Hahn et al. (2000) considered that the medium *Ho* has the overflow function with 3-stage arrangement, and that the *Suho* was located outside *Gasan* due to the size of this 3-stage arrangement. Though the possibility that the water clock was located outside *Gasan* cannot be completely ruled out, the exact position of water clock is not explained in the record of 『*Heumgyeonggakgi*』(『*Seongjong Sillok*』 January 7, 1438) of King *Sejong*'s era.

In the study of the internal water-hammering type mechanism of *Lee Min-Cheol*'s armillary clock, through the caparison with the Chinese water-driven astronomical clock tower, Park (2011) estimated that the diameter of water wheel was 82.8cm, the number of *Sususang* was 12 or 16, and the size of *Suho* was less than 2-*cheok* which are smaller than the Chinese water-driven astronomical clock tower, and that the water wheel rotated 45 times per day. However, the historical record of *Heumgyeonggaknu* stated that '5,000 to 6,000 *geun* (斤) of bronze' was used for the water clock, indicating that the size is not small. In this study, the structure was estimated considering both of the two possibilities that the water clock is located inside or outside *Gasan*. In addition, regarding the water clock configuration of *Borugaknu*, Nam (2002) placed a large water pot at the top, arranged 2-stage (upper and lower, 2 pieces) *Suho* below the pot which has an overflow device at the lower *Suho*, and positioned 1-stage (1 piece) *Pyesuho* which receives the overflowed water. It is expected that this

configuration could also be applied to the water clock of *Heumgyeonggaknu*. As for *Heumgyeonggaknu*, considering that the water in *Haeja* is supplied to water clock, it is thought that the *Haeja* corresponds to the large water pot of *Borugaknu*, and there may have been 2-stage *Suho* below *Haeja*. When a fixed amount of water by the overflow device is combined with *Cheonhyeong* system, the water wheel can be controlled at a constant time interval. For example, if the flow speed of water supplied from *Suho* gets slower, the operating time of *Cheonhyeong* also gets slower, and if the flow speed gets faster, the operating time also gets faster. Therefore, it is expected that the water-hammering type water clock which consists of water wheel and *Cheonhyeong* system is generally composed of 2-stage *Suho* with an overflow function and 1-stage *Pyesuho*.

The following is mentioned regarding *Japsang* at the top of *Gasan* and the Sun and the Moon. It was stated that 'Among the statues such as the mountain shape of *Gasan*, the form of trees and plants, and *Sasin* (司辰, hour-jack), those made of wood should be wrapped with hemp cloth and lacquered (至於假山山形, 草木之形, 司神等人像物像, 以木造作者, 必須裹布着漆)'. This is the part that showed the material and durability of *Gasan* and *Japsang*. With regard to the movement of celestial bodies, it was stated that 'The Sun and the Moon rise and set (日月出入)'. However, the presence of Moon is not mentioned in 『*Heumgyeonggakgi*』. The *Heumgyeonggaknu* of King *Sejong*'s era was burned down in 1553 when there was a fire at *Gyeongbokkung*. The *Heumgyeonggak* was reconstructed in 1554, but it was again destroyed during Japanese Invasion of Korea in 1592. It is thought that the Moon movement function was later added to the *Heumgyeonggaknu* that was newly made in 1614.

4. CONCEPTUAL DESIGN OF OPERATION MECHANISM

4.1 Power Mechanism

Needham et al. (1986) regarded the power which is applied to *Heumgyeonggaknu* as the buoyancy from the inflow of water. In other words, it was considered that the force generated when a buoy is raised acts as torque. This method is characteristic of the water clock devised by Al-Jajari in the 13th century in Islam (Hill 1989). By analyzing the record of 『*Sejong Sillok*』, Kim (2012) suggested that it is more likely to be the water wheel power which rotates at a constant speed, similar to the Chinese water-driven astronomical clock tower that was developed earlier than the one made in Islam. The internal power transmission

¹³Gwanghaegun ilgi, 80:7b:line 9 ~ 14; 閣內凡日月出入、晝夜刻漏遲速, 皆以機械爲之。以器盛水, 以水運鈴, 以鈴觸動機械, 故鈴路水道, 皆以熟銅鐵爲之, 已爲鑄成大小銅器者, 不啻五六千斤。皆自臣曹, 拮据辦出, 一應采色、銅鐵之價, 不敢別定於外方, 以貽民弊。至於假山山形, 草木之形, 司神等人像物像, 以木造作者, 必須裹布着漆, 然後可保經難不壞, 以至永久。

Fig. 2. Internal Structure of *Heumgyeonggaknu*. (a) Keys map of *Heumgyeonggaknu*'s inside. WC: water clock, WW: water wheel, E: escapement, WWS: waste water system, W1: wheel 1 (base), W2: wheel 2 (time signal platform), W3: wheel 3 (top of a mountain). (b) Power supply mechanism of *Heumgyeonggaknu* (Lee & Kim 2012).

system of *Heumgyeonggaknu* is shown in Fig. 2.

Fig. 2a schematically shows the interior of *Gasam* in *Heumgyeonggaknu*. The water supplied from the water clock (WC) operates the water wheel (WW), and the power generated from the water wheel operates *Giryun* and rotation wheels (W1, W2, and W3). The water used for the operation of water wheel is contained in *Pyesuho* system (WWS) below the water wheel, and this water is again supplied to the water clock. In Fig. 2a, the dashed arrow represents the flow of water, and the solid arrow represents the flow of power. The position of water clock is shown considering both the exterior of *Gasam* (WC(out) position) and the interior of *Gasam* (WC(in) position). Fig. 2b shows the *Cheonhyeong* system (天衡裝置) which has the escapement device that generates constant power for the water-hammering type operation.¹⁴ The water is supplied from the water clock to *Sususang* of water wheel. In order to let *Sususang* contain a fixed amount of water, a balance device was attached where a weight is hung. Therefore, the water is contained as much as the mass of weight, and the generated power is transferred to the water wheel.

4.2 Internal Structure of the Time Signal System

The power transferred to the water wheel rotates the *Giryun* of *Heumgyeonggaknu* once per day. The *Giryun* consists of rotating wheels which constitute the 1st, 2nd, and 3rd floors. The 1st floor rotation wheel (W1) transfers

Fig. 3. Keys map of *Heumgyeonggaknu*'s wheel 1.

power to the 12 *Ongnyeo* (II) and twelve gods on the flatland. The 2nd floor rotation wheel (W2) transfers the power to the time signal puppet device of *Sibodae*. The 3rd floor rotation wheel (W3) transfers the power to the 4 *Ongnyeo* (I) and four gods. In the uppermost floor, the power is transferred to the Sun movement device.

The 1st floor rotation wheel transfers the operating signal to the *Ongnyeo* (II) and twelve gods (Fig. 3). On top of the rotation wheel, the sliding rail and *Geolteok* (raised spot) were installed. The sliding rail is a device which was also used in *Borugaknu*¹⁵ and armillary clock (渾天時計) (Kim 2012). Also, the *Geolteok* which has the shape of horizontal rod('■■■■' shape) was developed based on the fact that the *Sipae* of armillary clock is raised to the time-announcing window and is shown continuously. The *Ongnyeo* (II) and twelve gods were installed at the end of the rods having the shape of umbrella ribs which extend from the central axis so that they can be coupled with the sliding rail and *Geolteok*. For example, at *O-Si* (午時), the *Ongnyeo* is raised with the corresponding *Sipae* by the motion of rotation wheel.

¹⁴Regarding this part, Kim et al. (2011) stated that "by the working mechanism of *Nusudae* that had the escapement system" (Kim et al. 2011, p.84). However, in the following research, the *Nusudae* was analyzed as the space which simply accommodates *Uigi*. Thus, a fixed quantity of water is directly supplied to *Sususang* of water wheel.

¹⁵*Sejong sillok*, 65:2b:line 12; 則足端鐵輪，順轉銅板而下。

Fig. 4. Keys map of Heumgyeonggaknu's wheel 2.

Among the twelve gods, the *Osin* (午神) which was lying face down stands up at this moment. This posture is maintained until it gets out of *Geolteok* which is on top of the rotation wheel (The *Geolteok* is installed in 30° range from the central axis of rotation wheel).

The 2nd floor rotation wheel transfers the signal to the *Sasin* and 3 *Musa* (武士, warrior) (Fig. 4). On top of the rotation wheel, the pin-shaped ('|' shape) *Geolteok* is installed at the position of 12-Si, 5-Gyeong, and 5-Jeom. When the rotation wheel passes *Sibodae*, the 12 *Geolteok* which are spaced at an interval of 30° send the operating signal to *Sasin* and *Jongin* (鐘人, striking bell puppet). The *Sasin* and *Jongin* face each other, and the *Jongin* strikes the bell. At night, the 25 *Geolteok* which express the 5-Gyeong and 5-Jeom send the signal to *Goin* (鼓人, striking drum puppet) and *Jeongin* (鉦人, striking gong puppet). The *Goin* strikes the drum, and the *Jeongin* strikes the gong. The *Sasin* and *Goin* face each other when striking the drum, and the *Sasin* and *Jeongin* face each other when striking the gong. The *Geolteok* signal of 12-Si, 5-Gyeong, and 5-Jeom generates a ball signal which facilitates the striking system that is similar to *Borugaknu*.

Regarding the method which expresses the *Geolteok* of 5-Gyeong and 5-Jeom, it seems that the 25 *Geolteok* were put in so that they match the seasons or the part of rotation wheel where the *Geolteok* of 5-Gyeong and 5-Jeom are located was replaced as a package. In addition, it is thought that the *Jujeon* mentioned in 『*Seongjong Sillok*』 is installed in *Sibodae*, strikes the bell-drum-gong using the *Cho* (初, beginnings double hours)-*Jeong* (正, mid-points double hours) signal of wheel 2 and the 5-Gyeong and 5-Jeom signal, and is involved in the detailed motion of time signal puppets. The mechanism of *Jujeon* seems to have scaled

Fig. 5. Keys map of Heumgyeonggaknu's wheel 3.

down and improved the mechanism of *Bujeon* and *Bangmok* in *Borugaknu*.

The 3rd floor rotation wheel transfers the operating signal to the *Ongnyeo* (I) and four gods (Fig. 5). On top of the rotation wheel is the 5 pin-shaped *Geolteok* which shows *Cho* and *Jeong* every hour, and 4 pin-shaped *Geolteok* device which rotates the four gods. This *Geolteok* device moves the gear device of *Ongnyeo* and four gods which are located in the north, south, east, and west. The *Ongnyeo* shakes a small bell in the hand at *Cho* and *Jeong* every hour, and the four gods rotate 90° every hour. The *Geolteok* of rotation wheel is located in 90° range of rotation wheel so that it operates only at the corresponding time.

5. CONCLUSIONS

Heumgyeonggaknu is an automatic water clock which was installed in *Heumgyeonggak*. *Heumgyeong* (欽敬) is quoted an expression from *Seogyong* (書經) *Yojeon* (堯典), 'Admire as high as the sky, and let the people know the subdivisions of the seasons'.¹⁶ In the 4 directions of *Gasam* in *Heumgyeonggaknu*, the *Binpungdo* (飢風圖, landscape of hard farming work scene) of the 4 seasons and the model of *Japsang* are manufactured. King *Sejong* fulfilled the meaning of *Heumgyeong* by reminding the people's difficulty in farming through *Binpungdo* and the model of *Japsang*.

In this study, the internal structure of *Heumgyeonggaknu* was inferred as follows. First, the water clock is thought to consist of the *Suho* equipped with 2-stage overflow and the 1-stage *Pyesuho*. Second, the two possibilities that the water clock is located inside or outside *Gasam* need to be considered. Third, in terms of systematic motion, it is efficient to use a single *Giryun* to operate the time

¹⁶*Sejong sillok*, 80:5b:line 13; 欽若昊天, 敬授人時.

signal puppets at the top of the mountain, at the foot of the mountain, and on the flatland. Fourth, the time signal puppets on *Sibodae* receive the ball signal through *Jujeon* and inform the 12-Si and *Gyeong-Jeom* time, which is thought to be an improvement of *Bangmok* and rod in *Borugaknu*.

In the conceptual diagram for each floor, emphasis was placed on the signal generation system for the design of detailed operation mechanism. For the operation of *Ongnyeo* (II) and twelve gods on the flatland of Gasan, the 1st floor rotation wheel was equipped with the device which has the shape of umbrella ribs, sliding rail, and the *Geolteok* structure which has the shape of rod. For the motion of *Sasin* and *Musa* on *Sibodae*, the 2nd floor rotation wheel was made so that the 12-Si signal, *Gyeong-Jeom* signal, and the operation of *Jujeon* are coupled together. For the operation of *Ongnyeo* (I) and four gods at the top of the mountain, the 3rd floor rotation wheel was made to be the pin-shaped *Geolteok* structure. Based on the above information, this study is expected to provide basic data for the detailed design of the internal structure of *Heumgyeonggaknu*.

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