A Study for the Restoration of Hong Dae-Yong *Honsangui* - Focusing on the structure and operating mechanism -

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Honsangui (celestial globe) which is a water-hammering method astronomical clock is recorded in 「*Juhaesuyong*」 which is Volume VI of supplement from 「*Damheonseo*」, written by *Hong Dae-Yong* (1731~1783). We made out the conceptual design of *Hong Dae-Yong's Honsangui* through the study on its structure and working mechanism. *Honsangui* consist of three rings and two layers, the structure of rings which correspond to outer layer is similar to his own *Tongcheonui* (armillary sphere) which is a kind of armillary sphere. *Honsang* sphere which correspond to inner layer depicts constellations and milky way and two beads hang on it as Sun and Moon respectively for realize the celestial motion. *Tongcheonui* is operated by the pendulum power but *Honsangui* is operated by water-hammering method mechanism. This *Honsangui's* working mechanism is the traditional way of *Joseon* and it was simplified the working mechanism of *Shui yün i hsiang t'ai* which is a representative astronomical clock of China. This record of *Honsangui* is the only historical record about the water-hammering method working mechanism of *Joseon* Era and it provide the study of water-hammering method mechanism with a vital clue.

Keywords: *Honsangui* (celestial globe), *Hong Dae-Yong*, astronomical instrument, water-hammering method

1. INTRODUCTION

The various Korean cultural heritages in the area of astronomical science include the records of making a variety of clock instruments. The representative relics existing in our time are the water clock in *Borugaknu* (*Borugaknu* is the No. 229 National Treasure, newly made in 1536, but only the water clock part is remaining.), and the armillary sphere made by *Song, I-Yeong* (1619~1692) designated as No. 230 National Treasure (called as an alarm clock or an armillary clock). In addition to these, many clock instruments have been known only in the literature, among which representative ones are the water-hammering method *Honui* (armillary sphere) and *Honsang* (celestial globe) or *Heumgyeonggakru* (automatic water clock) made during the reign (1418~1450) of King *Sejong*, the armillary clock produced by *Lee Min-Cheol* (1631~1715) in the tenth year of *Hyeonjong's* reign (1650~1674), and *Honsangui* made by

Hong Dae-Yong (1731~1783) in the 18th century. All the clock instruments mentioned previously are mechanical clocks made in an elaborate and scientific manner in order to not only actuate the clock by the water-hammering method action mechanism using water as the driving force, but also simultaneously reproduce the armillary sphere or celestial globe, the appearance of the sky, as well as the rise and fall of the sun on the celestial body in real time. However, most of the clock instruments do not exist currently, and only the *Borugaknu* was reconstructed recently (reconstructed in 2007, National Palace Museum of Korea)

Hahn (2003) studied the *Hong Dae-Yong Honsangui* the book entitled, "The Astronomical Clock at *Nongsugak*." Hahn (2003) investigated the structure of *Honsangui* through a detailed analysis of the literatures about *Honsangui* found in the books <*Nongsugak-uigiji* (籠水閣儀器志)> and <*Geonjeondong-pildamsok* (乾淨衝筆談續)> and also added detailed interpretation about the technical aspects

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comparable to the celestial globes of China.

This study about the restoration of the *Hong Dae-Yong Honsangui* was conducted to understand the level of the science and technology at that time when it was produced and to provide important information needed for construction of the restored model.

2. OUTWARD STRUCTURE AND WATER-HAMMERING SYSTEM OF HONSANGUI

The record about *Hong Dae-Yong Honsangui* is found in 「*Juhaesuyong* (籌解需用)<Nongsugak-uigiji>」¹ the Extra Collection Volume 6, and 「*Hangeoncheokdok* (杭傳尺牘)<*Geonjeongdong-pildamsok*>」² the Extra Collection Volume 3 of 「*Damheonseo*」.

2.1 Outward structure of *Honsangui* (渾象儀)

The <*Nongsugak-uigiji*> contains the record about 3-Won (垣), five planets, 28-Su (宿), 360 constellations, and 11,520 celestial bodies (stars). The record is an explanation of the outline of the overall universe in addition to the explanation about the correlation between the universe and the human affairs. The record states that the positions of the celestial bodies and the angle of sun moving should be measured after measuring the polar altitude (latitude), indicating that the calendar may be established and the accurate time may be known through these measurements.

Regarding the structure of *Honsangui*, the record describes that *Honsangui* has dual layers and has a structure similar to that of *Tongcheonui* (統天儀, armillary sphere). *Honsangui* is composed of an inner layer covering *Honsanggu* (*Honsnag* sphere) and an outer layer which is *Honsanggu*. The structural similarity may mean that the structure of *Yukhapui* (六合儀, armillary fixed outer component) corresponding to

the outer layer is similar to that of *Tongcheonui*. Hence, there are three rings (*Jaogyu*, *Jipyonggyu*, and *Myoyugyu*) on the outer layer, and *Honsangu* finished with sized paper forms the inner layer.

A modern celestial globe is convenient to search and identify constellations by projecting the constellations in the night sky on the surface of the sphere. However, the structure of *Joseon's Honsang* enables to look at the inside from the outside of the sphere surface. *Hong Dae-Yong* stated about the constellations on the spheric surface of *Honsangui*, "The sky is merged and rotated to view it(并合天象 轉而望之). If a person's body stood on the nine celestial bodies, he would look down the celestial bodies(若人之身昇九霄俯臨天體也)." This statement can be confirmed by the constellations carved on the past celestial globes of China or Japan which are bilaterally symmetrical. The question is 'To view the stars carved on the sphere from the inside or from the outside?' It is understood that *Honsang* was an instrument in which the sphere was viewed from the outside of the sphere in order to observe and understand the universe.

2.2 Water-hammering system

The actuation of *Honsangui* is by the water-hammering method actuation of *Giryun* (機輪, mechanism wheel) at the outside. The Antarctic axis of *Honsangui* has 359-toothed gear which receives the driving force from the wheel apparatus to rotate *Honsangu*. The record of <*Nongsugak-uigiji*> about the water-hammering method actuation structure is as follows:

「*Juhaesuyong* <*Nongsugak-uigiji*>」 the Extra Collection Volume 6 of 「*Damheonseo*」

A ring was installed at the south pole at the southern part of the equator, and the ring had 359-teeth. A mechanism wheel was established at the outside. The mechanism wheel of the water-hammering system was produced in the following method. A *Mokgwe* (木櫃) is set up and its height is lower than the ground. A *Suu* (1) (水盂, *Pasuhō*) containing water is put on the *Mokgwe*. *Nuja* (漏箭) is suspted below the *Suu*(1). A pillar is placed in the south-north direction, and a round holes are perforated through the pillar. A wheel is included in the pillar, and the width of the wheel is 1-*Chon* and the diameter is 1-*Cheok*. The axis penetrates both holes, protrudes from the *Mokgwe* to the north, reaches the teeth of the ring. 8-teeths at the tip support 2-teeths to divide the wheel circumference into four and to fasten the *Suho* (水壺). The length of the bag is several *Chon*. The lowering, heightening, and balanceing are controlled through the weight, size, and gap of the four *Suhos*. An *Cheolcheok* (鐵尺) between two *Suhos* is installed, and it is long enough to protrude the *Suhos*. The tip is a little sharp so that it may be bent or stretched.

¹「*Juhaesuyong*」, the Extra Collection Vol. 6 of 「*Damheonseo*」; 22b: line 6 ~ 23a: line 10; 積氣寥廓 列曜森布 無情無朕 不可得以名狀也 乃若三垣五星二十八宿 三百六十之官 萬有一千五百二十之數 參之人事 象以物形 割裂牽合 以占祥眚 吾不知其何說也 惟辰次分然後天可步也 躔度明然後曆可治也 昏中定然後時可協也 不有定界 測候何據 此列曜之所以不能無名而所由來久矣 今立一儀 名曰渾象 三環兩層 制同統天 糊紙正圓 剖而合之 全覆內層 成一大球也 經緯分度 六等周羅 中外星官 燦然備載 銅絲懸珠 以象日月銀河起沒 并合天象 轉而望之 若人之身昇九霄俯臨天體也 赤道之南中南極而設一環 亦為三百五十九牙 外設機輪 以水激之 機輪之制 設一木櫃 高出地平 上安水盂 漏箭下垂 南北有柱 并鑽圓竅 內藏一輪 廣寸徑尺 軸貫兩竅 北出櫃外 至于牙環 末施八牙 兩牙相受 四分輪周 繫以水壺 柄長數寸 四壺之輕重大小 遠近低昂 務其均齊 兩壺之間 各設鐵尺 長出壺外 稍銳其端 可以屈伸 一壺受水數勺之後 便欲旋瀉 則上有橫槓 以拒鐵尺 壺水漸滿 鐵尺漸屈 水滿尺脫 壺傾而輪旋 次壺皆受 次尺見拒 櫃底有盂 以受壺水 傍有曲機 盂水逆行 上有小盂 以受機箭 如是累層 復注于櫃上之盂 一盂之水 互相輪瀉 日添數勺 任其周流 袖手傍觀 允是壺中之一天也. Source: The National Library of Korea, Book Number 古3648-文93-31, published in 1939.

²「*Hangeoncheokdok* <*Geonjeongdong-pildamsok*>」, the Extra Collection Volume 3 of 「*Damheonseo*」; 13b: line 12 ~ 14a: line 2; 別設一儀兩層 如原制糊紙 虛中而正圓 中分之 合于內儀之上而固其縫 成鷄卵之形 上圓周天星宿及黃赤日月之道 其北極之環 自轉之法 十字之機 皆同原儀 此制雖無日月之真象而星宿度數 粲然可考 又原儀之所不及也. Source: The National Library of Korea, Book Number 古3648-文93-31, published in 1939.

Table 1. Structural features of Honsangui (<Nongsugak-ugiji (籠水閣儀器志)>).

Component parts	Structural features	Remarks
<i>Jipyonggyu</i> (地平規)	- Labeled in <i>Jipyonggyu</i> : 24-direction, four seasons, long and short of Sun movement - Fixed under the framework of the cross-shaped	
<i>Jaogyu</i> (子午規)	- <i>Jaogyu</i> erected north-south direction in <i>Jipyonggyu</i> 's vertically - Polar axis: 36 degrees	Outer layer (六合儀)
<i>Myoyugyu</i> (卯酉規)	- <i>Myoyugyu</i> erected east-west (vernal equinox-autumnal equinox) direction in <i>Jipyonggyu</i> 's vertically - Or may be a description of the celestial equator	
<i>Honsanggu</i> (渾象球)	- <i>Honsang</i> sphere: Starched paper - Latitude and longitude into six equal installments, around the constellation - bead stringing copper-thread: Sun, Moom <i>Sun- Ilgyu</i> (日規, Ecliptic), <i>Moon-Wolgyu</i> (月規, Moon's path) - <i>Honsang</i> sphere's constellation: real constellation's symmetrical structure(left-right) - Antarctic gear: 359-toothed wheel	Inner layer
Water-hammering system	- Water wheel diameter: 1- <i>Cheok</i> (20.7 cm), width 1- <i>Chon</i> (2.07 cm) - <i>Suho</i> (水壺, <i>Sususang</i> , small size water jar) 4 ea	Water wheel
	- <i>Sue</i> (1) (水盂, <i>Pasuho</i> , water supply jar) - <i>Nuja</i> (漏觔, water supply valve)	Water clock
	- <i>Cheolcheok</i> (鐵尺, iron measure, delay apparatus): between two <i>Suhos</i> - <i>Geolteok</i> (threshold)	Escapement
	- <i>Suu</i> (2) (水盂, <i>Toesuho</i> , waste water barket) - <i>Gokgi</i> (曲機, water pumping apparatus) - <i>Gija</i> (機觔, <i>Gokgi</i> 's water supply valve)	<i>Toesuho</i> (退水壺)
<i>Mokgwe</i> (木櫃)	- Installed above the horizon: <i>Suu</i> (1) installed on <i>Mokgwe</i> (木櫃; wooden crate)	

After a *Suho* receives water, it starts to pour the water out. A horizontal *Geolteok* (threshold) is installed over the *Mokgwe*, and its *Cheolcheok* is supported. As the amount of water contained in the bottle is increased gradually, the *Cheolcheok* is gradually bend. When the *Suho* is full of water, the *Cheolcheok* falls out and the *Suho* is inclined. Then, the wheel rotates, and the next *Suho* starts to receive water. The next *Cheolcheok* supports the *Mokgwe*. The *Suu*(2)(水盂, *Toesuho*) at the bottom receives the water from the *Suho*, and the nearby *Gokgi* (曲機) turns the water in the *Suu*(2) in the reverse direction. A small *Suu*(1) in the back receives *Gija* (機觔, *Gokgi*'s water supply valve). The structure consists of multiple layers, and water is supposed to be injected to the *Suu*(1) upon the *Mokgwe*. Water in one bowl moves from one bowl to another by being poured. Several cups of water is added each day to make the flow. In this way, the system reproduces 'a universe in bottles' without any intervention.³

A *Suu*(1) (水盂; *Pasuho*, water supply jar) supplying water is installed upon the *Mokgwe* (木櫃; wooden crate), the water is provided through a *Nuja* (漏觔; water supply valve) with a water wheel. The water wheel is installed as it is supported by a pillar. The water wheel is very small; the width is 1-*Chon*

(寸, 2.07 cm) and the diameter is 1-*Cheok* (尺, 20.7 cm). Both axes of the wheel have eight toothed gears. Four *Suhos* (水壺; small size water jar) are installed to receive the water flowing through the *Nuja*. A sharp-end *Cheolcheok* (iron measure, delay apparatus) is installed between two *Suhos*, and the material is flexible. The *Cheolcheok* is longer than the *Suho*. A horizontal *Geolteok* (threshold) on the *Mokgwe* is in contact with the *Cheolcheok*. As the amount of the water contained in the *Suho* is increased, the *Cheolcheok* is bent gradually. After a certain time, the *Suho* is inclined and the water wheel rotates. The water contained in the *Suho* is poured into the *Suu*(2) (水盂; *Toesuho*, waste water barket) below the water wheel. At that time, the *Cheolcheok* is supported by the *Geolteok* of the *Mokgwe*, and water is started to be contained in the next *Suho*. The water contained in the *Suu*(2) is pumped up to the *Suu*(1) on the *Mokgwe* by the *Gokgi* (曲機, water pumping apparatus). The water-hammering system of *Hong Dae-Yong* repeats these actions. Because both of the axes of the water wheel have 8-toothed gears, as the wheel rotates 45 times a day (32 minutes for one rotation), *Honsanggu* rotates once (one day) since it is interlocked with the 359-toothed gears at the southern part of *Honsangui*.

<Geonjeongdong-pildamsok> also states that *Honsanggu* rotates around the polar axis, and indicates that the ecliptic, the equator, and the cross support were prepared according to the regulations, discussing the constellations on

³The translation of 『Juhaesuyong』, the Extra Collection Vol. 6 of 『Damheonseo』 was quoted from the material available at the website of Database of Korean Classics (<http://db.itkc.or.kr>).

Fig. 1. Star chart of plane representation (『Sinbeopsanseong』).

Hongsanggu.⁴ It is understood that *Hongsangui* seemed to be installed at the center of a pond together with *Tongcheonui* and *Hujong* (候鍾, an alarm clock) to demonstrate the traditional *Honui* and *Hongsang* system.

On the basis of the record in <*Nongsugak-uigiji*> presented above, the structural characteristics of *Hongsangui* were identified as shown in Table 1. With respect to *Ukhapui* which was not directly mentioned in the dual layer structure of *Hongsangui*, the structure of *Tongcheonui* was included in the description.

3. CONCEPT DESIGN OF HONGSANGUI

Hongsangui is divided into the *Hongsanggu* part with which the constellations in the sky are viewed, and the water-hammering system that actuates the *Hongsanggu* part and generates driving force so that the *Hongsanggu* part can be consistent with the revolution of the celestial bodies. Ham (2013) applied the original drawings of the constellations in the <*Honcheonuiseol* (渾天儀說)> of 『*Sinbeopsanseong*』⁵ to the reconstruction of *Hongsang* of late Joseon Dynasty. In 『*Sinbeopsanseong*』, the constellations are expressed by attaching a planar astronomical chart divided into 12 pieces, each piece covering 30°, to *Hongsanggu* (Fig. 1). It is assumed that *Hong Dae-Yong Hongsangui* also expressed the stars on the sphere in the same manner.

Fig. 2 shows the driving force apparatus model of *Hong*

Fig. 2. Power model of *Hongsangui*. a. Suu(1)(Pasuho, 播水壺), b. overflow, c. Suho (水壺), d. Cheolcheok (鐵尺), e. Geolteok, f. water wheel, g. Suu(2)(Toesuho, 退水壺), h. mechanism wheel tooth (機輪牙)

Dae-Yong Hongsangui. The water-hammering system that transmits driving force to *Hongsangui* described in <*Nongsugak-uigiji*> is composed of a water wheel, a water clock, an escapement, and a *Toesuho* (waste water basket). The size of the *Suho* suspending from the water wheel might have been as small as a few *Chon*, considering that the diameter and the width of the water wheel was 1-Cheok and 1-Chon, respectively.⁶ In the study by Park (2011), an *Cheolcheok* was installed at the bottom of the *Suho*,

⁴ <*Geonjeondong-pildamsok*> contains the statement, "There is no true image of the sun and the moon." In contrast, <*Nongsugak-uigiji*> mentions the existence of the sun and the moon.

⁵ 『*Sinbeopsanseong*』 Source: *Munyeongaksagojeonseo* (文淵閣四庫全書), Vol. 788: pp.306-308.

⁶ The *Suho* bottle in this study had the inner volume of about 7.9 cm × 1.2 cm × 6 cm (h), containing about 57 cm³ of water. Considering the size of the *Suho*, the water wheel might have been operated with a very small amount of water, and the *Cheolcheok* might have been very flexible.

Fig. 3. Keys map (a) and 359-toothed wheel (b) of Honsangui.

Fig. 4. Water-hammering system (a) and water power connection (b) of Honsangui.

referring to the actuating structure of the *Cheonhyeong* (天衡, escapement) apparatus which is the escapement of *Shui yün i hsiang t'ai* (a representative astronomical clock of China). However, the literature indicates that the *Cheolcheok* is between two *Suhos*, and thus an improvement has to be made in this regard. By specifying the model studied by Park (2011), the conceptual drawing of *Hong Dae-Yong Honsangui* and the fundamental design plan of the water-hammering system were completed (Figs. 3 and 4).

Instead of *Jeokdogyu* (赤道規; equatorial ring) previously known to the conventional armillary sphere, *Myoyugyu* (卯酉規) was introduced as *Yukhapui* of *Hong Dae-Yong*

Honsangui. *Myoyugyu* might have been mentioned as *Myoyugyu* because *Jeokdogyu* was assembled in the *Myo* (卯, east) direction and the *Yu* (酉, west) direction on the horizontal plane. Referring to the description about such *Myoyugyu* in the Western armillary sphere and the conceptual description about *Myoyugyu* in Chinese literature, Hahn (2003) asserted that *Myoyugyu* is different from the configuration of *Yukhapui* located at the outer layer of the conventional armillary sphere. Considering the statement in the literature, 'The top and the bottom of *Myoyugyu* are connected with the top and the bottom of *Jaogyu* (爲卯酉規 與子午規 上下相結)' it seems appropriate

to consider that *Myoyugyu* penetrates the zenith of *Jaogyu*.

In general, a water wheel accompanies a *Pasuho* of a water clock having the function of overflow in order to supply a predetermined quantity of water. *Shui yün i hsiang t'ai* of 11th century and *Borugaknu* of 15th century had such a function. Kim *et al.* (2011) and Lee & Kim (2012) presumed that the overflow method was also applied to *Heumgyeonggaknu* and the water-hammering type celestial globe. The generation and control of the driving force using the alarm clock *Tongcheonui*, which is another instrument in the *Nongsugak*, the personal observatory of *Hong Dae-Yong*, is by a weight and a foliot type escapement system. These correspond to the overflow and the *Cheonhyeong* apparatus (the system controlling the water wheel by measuring a predetermined quantity of water by measuring it with a balance). Thus, *Hong Dae-yong* might have realized the function of driving force control by water wheel and *Suho* by combining the overflow which supplies a predetermined quantity of water with the *Cheolcheok* (the apparatus having a sharp and flexible tip). Four *Cheolcheoks* were installed between a *Suho* and another. A *Geolteok* was installed under the *Suho* so that the *Cheolcheok* could be stopped.

The water contained in the *Toesuho* under the water wheel was re-supplied to the *Pasuho* upon the *Mokgwe* through *Gokgi*. *Gokgi* was not included in this conceptual design. <*Nongsugak-uigiji*> does not provide a detailed description about the *Gokgi*, whether the water was automatically pumped up as being interlocked with the water wheel or the water was manual pumped up. Considering that the water-hammering system of *Hong Dae-Yong* is a small-scale experimental apparatus, contrary to the *Shui yün i hsiang t'ai* of China or the water-hammering type armillary clock of *Lee Min-Cheol*, there is a bare possibility that *Gokgi* is an automated apparatus.

4. CONCLUSIONS

Honsangui is a water-hammering type celestial globe which *Hong Dae-Yong* installed at *Nongsugak*, his personal observatory. <*Nongsugakuigiji*> is the only literature explaining the water-hammering system of *Joseon*. Through the study on the structure and action mechanism of *Hongsangui*, we present following structural features.

First, *Honsangui* comprises the celestial globe where constellations were carved on the spheric surface and the water-hammering system that actuate the celestial globe. Second, *Yukhapui* in *Honsangui* is beyond the traditional form of *Joseon*, perhaps being affected by the Western armillary spheres. Third, the escapement of the water-

hammering system was realized with a *Pasuho* having the apparatus for overflow and a *Cheolcheok*. Application of the *Cheolcheok* is beyond the traditional form of *Joseon*. Fourth, a very small quantity of water should be supplied to the *Suho* installed at the water wheel, and the *Cheolcheok* should be highly flexible. Fifth, the *Hong Dae-Yong* water-hammering system was a small-scale experimental apparatus for private research.

Hong Dae-Yong's Nongsugak Honsangui succeeded the traditions of the astronomical clocks that had been operated from the early *Joseon* Dynasty, and was partially improved to have the unique ring structure and water-hammering system. Through the analysis of the records in <*Nongsugak-uigiji*> and <*Geonjeondong-pildamsok*>, we had a better understanding of the structure of the *Hongsangui*, and performed a basic conceptual design on the basis of the structure. An experimental analysis may be needed in the future study for the restoration of the *Hong Dae-Yong's* astronomical instruments. We hope that an improved restoration model of the celestial globes can be constructed through the experimental analysis.

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