Structure and Conceptual Design of a Water-Hammering-Type *Honsang* for Restoration

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We analyzed the manufacturing procedure, specifications, repair history, and details of celestial movements of the water-hammering type *Honsang* (celestial globe). Results from our study on the remaining *Honsangs* in China and Japan and on the reconstruction models in Korea were applied to our conceptual design of the water-hammering type *Honsang*. A *Honui* (armillary sphere) and *Honsang* using the water-hammering method were manufactured in *Joseon* in 1435 (the 17th year of King *Sejong*). *Jang Yeong-Sil* developed the *Honsang* system based on the water-operation method of *Shui yün i hsiang t'ai* in China. Water-operation means driving water wheels using a water flow. The most important factor in this type of operation is the precision of the water clock and the control of the water wheel movement. The water-hammering type *Honsang* in *Joseon* probably adopted the *Cheonhyeong* (天衡; oriental escapement device) system of *Shui yün i hsiang t'ai* in China and the overflow mechanism of *Jagyeongnu* (striking clepsydra) in *Joseon*, etc. In addition to the *Cheonryun* system, more gear instruments were needed to stage the rotation of the *Honsang* globe and the sun's movement. In this study, the water-hammering mechanism is analyzed in the structure of a water clock, a water wheel, the *Cheonhyeong* system, and the *Giryun* system, as an organically working operation mechanism. We expect that this study will serve as an essential basis for studies on *Heumgyeonggaknu*, the water-operating astronomical clock, and other astronomical clocks in the middle and latter parts of the *Joseon* dynasty.

Keywords: *Honsang* (celestial globe), water-hammering method, astronomical clock

1. INTRODUCTION

Honsang (渾象; celestial globe) is an ancient model of the celestial sphere, which is now called a celestial globe or star globe. Various types of *Honsang* were manufactured across the ages both in the East and the West and formed an important category of astronomical instruments among the scientific artifacts of astronomy.

In China since the *Tang* dynasty, instruments for celestial observations had been called *Honui* (armillary sphere) and those for representing the movement of stars on the celestial sphere called *Honsang* (Hahn et al. 2001, Kim 2002).¹ The first records on *Honsang* in Korea are found in the *Sejong* era. A *Honsang* in that period was formed of a body of globe,

made rotate around a north-south polar axis, and operated by a water-hammering method using water power. The surface of the globe was marked by degree numbers in horizontal and vertical lines, and by the equator, the ecliptic, and positions of stars to track the stars on the sky. It was also used to show the sun's movement along time and seasons by having the position of the sun move on the ecliptic.

In this study, we describe historical facts on the water-hammering type *Honsang* in *Joseon* based on the literature and introduce the manufacturing procedure of our *Honsang* model which has already been restored. System components

¹In naming an armillary sphere, *Honui* and *Honsang* are distinguished today, but they were mixed to be *Honcheonui* in the past.

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Fig. 1. Two arrangement types of Honui and Honsang with respect to the power system.

of the water-hammering type *Honsang* are also analyzed.

2. MANUFACTURE HISTORY AND LITERATURE ON HONSANG

The very first literature in Korea regarding *Honsang* is the record in 1437 (the 19th year of King *Sejong*) found in *Sejong sillok* (世宗實錄; history book during the *Sejong* era). This record says about the material and size of *Honsang*, the marking of degree numbers, the equator and the ecliptic, the rotation of the celestial sphere, the sun's movement on the ecliptic, and the power by the water-hammering method. The record in *Sejong sillok* is as follows.

The 19th Year of King *Sejong* (1437) April 15th (*Gap Sul*)

The *Honui* and *Honsang* have been placed in a small house to the west of the gnomon, where the *Honui* is in the east and the *Honsang* in the west. The *Honui* system has been changing through the ages, and here we followed the descriptions in <*Ossiseochan* (吳氏書纂)> to craft one of lacquered wood. The *Honsang* system has a body of lacquered cloth which is shaped round like a cannonball with a circumference of 10 *Cheok* 8 *Chon* 6 *Bun*. The *Do* and *Bun* scales on the sky are marked in horizontal and vertical lines, with the equator in the middle and the ecliptic intersecting at an angle of a little less than 24 *Do*. A number of stars other than the five greatest stars are represented to make one revolution with one further degree per day. A sun model is hung on the ecliptic ring, which moves backward one degree per day to match the celestial movement. The automatic mechanism of the machine using the water is covered and hidden.²

According to this record, those *Honui* and *Honsang* were installed together, which might be explained in two different arrangements (Fig. 1); (a) with a power system in the leftmost position, (b) with a power system between the *Honui* and *Honsang*. We assume these two possibilities since the exact position of the power system remains unknown

with only the descriptions on the arrangement of *Honui* and *Honsang* in the record.

We concentrate on *Honsang* in this paper. The globe of *Honsang* was made of lacquered cloth. The shapes of supporting frame and axes are unknown regarding the inside structure of the globe. The outer circumference of the *Honsang* was 10 *Cheok* 8 *Chon* 6 *Bun*³. Since this perimeter is converted to 2,248.02 mm with a scaling factor of 1 *Cheok* = 207 mm (Nam 1995), the diameter of the globe is

$$2,248.02 / \pi = 715.56 \text{ mm} \approx 71.6 \text{ cm}.$$

The fact that the *Do* and *Bun* (度分) marks in horizontal and vertical lines represent the lines of longitude and latitude of the celestial sphere implies that those marks represent a concept of time zone and indicate *Do* and *Bun* (度分) for the equator and the ecliptic. However, it is unknown how 1 *Do* (度) split into a finer scale or how many ticks were grouped in the system of 365.25 degrees which was *Jucheondo* (周天度; circumference of celestial globe) at that time.⁴ There is no information about which star chart (celestial map) was referred to for the positions of stars, i.e. details on the constellations and the number of stars, either.

The intersection angle of the equator and the ecliptic was written as '24 *Do Yak* (二十四度弱)' in the record.⁵ According to the almanac data by Korea Astronomy and Space Science Institute (2011), the intersection angle of the ecliptic decreases by 0.00000036^d per day.⁶ Considering

²「*Sejong sillok*」 77:9b:line 11–line 16; 表西建小閣置渾儀渾象儀東象西渾儀之制歷代不同今依吳氏書纂所載漆木爲儀渾象之制漆布爲體圓如彈丸圍十尺八寸六分縱橫畫周天度分赤道居中黃道出入赤道內外各二十四度弱偏布列舍中外官星一日一周而過一度用綵絡於黃道每日却行一度與天行合其激水機運之巧隱不見。

³Hahn et al. (2001) regard this value as a typo of 10 *Cheok* 9 *Chon* 6 *Bun* where 3 *Bun* make 1 *Do* in the system by Wang *Bun* (王蕃). Divided by 3 *Bun*, 10 *Cheok* 9 *Chon* 6 *Bun* corresponds to approximately 365.33 which is almost the same as the length of one year and can be represented using the scale of 365.2575. With this value, the diameter of *Honsang* would be approximately 72.2 cm.

⁴In *Gukjoeoksanggo* and *Seowoongwanji* from the latter part of the *Joseon* dynasty, the descriptions on the scale of *Jeokdokyeongeuiui* (赤道經緯儀) determined the range by the 5 *Do* scale limit and the 10 *Do* scale limit.

⁵The expression of *Yak* (弱) is interpreted as an addition of 11/12 to 24 *Do* or as a subtraction of 1/12 from 24 *Do*. Ahn et al. (2006) argue for the latter opinion, and this results in approximately 23.91 *Do*. Then this value is converted into 23°.58 in the current system of 360 degrees. It would be 24°.56 by the former opinion..

⁶*d* = JD - 2455926.5 = elapsed days since midnight on January 0, 2012.

this fact, it is appreciated that the intersection angle on the *Honsang* is close to the mean value of $23^{\circ}.437719$ to the modern knowledge.

Stars on the celestial sphere make one revolution and move further by one degree in a day. This description on the celestial movement is from the point of view with the earth at the center of the reference frame. An exact astronomical explanation for this situation is that one rotation of the earth for a day takes 23 hours 54 minutes 4 seconds (1 sidereal day). Rotation during 24 hours would be a little bit more than one turn. This is owing to the fact that the earth revolves around the sun while it rotates.

The sun's movement on the ecliptic on the *Honsang* is controlled by a string, where the sun moves backward by one degree on the ecliptic every day. The stars on the *Honsang*, with respect to the horizon, rise in the east, pass through the culmination, and set to the west. During the daytime, the sun tracks on the ecliptic while the *Honsang* works. The backward motion of the sun on the ecliptic by one degree per day, however, means that the sun moves one degree on the ecliptic in the opposite direction to the stars. By these movements, the positions of celestial objects (the constellations) change when viewed from the earth at the same time every day.

The movement of *Honsang* was designed to represent the effective motion of the celestial sphere and the sun resulting from the combination of rotation and revolution of the earth. The power mechanism for this instrument operation was called 'Gyeoksugiwoon (激水機運)' in which water was used for power of water wheels. The water-hammering method was a typical system for power generation in *Joseon*. This method was adopted by *Heumgyeonggaknu* (欽敬閣漏, or *Ongnu*) in the early part of the *Joseon* dynasty, *Honcheonsigye* (渾天時計; armillary clocks) by *Choi Yu-Ji* and *Lee Min-Cheol* in the middle, and *Honsangui* (渾象儀) by *Hong Dae-Yong* in the latter period. *Shui yün i hsiang t'ai* (水運儀象臺; manufactured circa 1092) by *Su Song* (蘇頌) and *Han Gong-Lian* (韓公廉) in China is well known as a clock work using this water-hammering method.

The record in 'Sejong sillok' on the specifications of *Honsang* and the movement of the sun is also mentioned in *Sangwigo* (象緯考) of *Jeungbomunheonbigo* (增補文獻備考) in the latter part of the *Joseon* dynasty and *Gukjoyeoksanggo* (國朝曆象考) published by *Seo Ho-Su* (徐浩修, 1736-1799), *Seong Ju-Deok* (成周惠), and *Kim Yeong* (金泳) in the latter period.⁷ The records in 'Jeungbomunheonbigo' and 'Gukjoyeoksanggo' are brief versions with a few modifications from that in 'Sejong sillok', omitting the part on the use of a 'string (繩)' regarding the sun's movement. Other than these records, 'Jegayeoksangjip' (諸家曆象

集) by *Lee Sun-Ji* (李純之, 1406-1465) in the early period of the *Joseon* dynasty contains descriptions on *Honsang* in its record about the *Uisang* (儀象) system in the Chinese history.⁸ However, no such power system is mentioned there as in the record of 'Sejong sillok'.

A *Honsang* was newly built in 1526 (the 21st year of King *Jungjong*). The record on the new *Honsang* in 'Jungjong sillok' (中宗實錄) is as follows.

The 20th Year of King Jungjong (1525) October 19th (Gap Jin)

Jeong Won said, "Lee Sun, Saseong (司成) at Seonggyungwan (成均館) had obtained a new book in China on the weather variability, which is about observation of celestial objects and titled <Mokryun (目輪)>. Lee Sun offered today what he had crafted before referring to the descriptions in <Mokryun> when he was at Gwansanggam (觀象監) as a Gamsugwan (監修官) for Honui (渾儀) and Honsang (渾儀). As this is a new and highly sophisticated instrument, could we make another set and test it at Gwansanggam?," then the king gave the order, "Execute as you suggested."⁹

The 21st Year of King Jungjong (1526) May 11th (Gye Sa)

The Gwansanggam (觀象監) said, "The Ganui (簡儀) and Honsang (渾儀) was manufactured in the period of *Sejong*, and having only one instrument for astronomical observations is not so much convenient. We cannot repair it either without a replacement for climate observations. Thus, we made a request to craft another one, and now it is completed. But, the current instrument is so old that some stars are missing and some lacquer has been peeled off. How would you think of fixing its displaced parts and letting a craftsman repair it? Also, I would like to ask you where to keep the old instrument," then the king gave the order, "Execute as you suggested. Keep the fixed old instrument at Nae-Gwansanggam (內觀象監)."¹⁰

The *Honsang* made in 1526 was probably a system of water-hammering method since the record was the first one

⁷ 'Jeungbomunheonbigo', Sangeugo 2:24a:line 9-b:line 2; 渾儀渾象之制渾儀則依元儒吳澄書纂言所載漆木爲之渾象前漆布爲體圓如彈丸圍十尺八寸六分縱橫畫周天度分赤道居中黃道出入赤道內外各二十四度弱徧列中外官星一日一周而過一度綴日於黃道每日却行一度與天行合激水機輪藏而不見. 'Gukjoyeoksanggo', 3:13b: line 10-14a: line 5; the same record is in Sangeugo of 'Jeungbomunheonbigo' (Sangeugo 2:24a:line 9-b:line 2) with the only difference of writing '藏' instead of '藏' which has the same meaning.

⁸ 'Jegayeoksangjip', Uisang vol.2.

⁹ 'Jungjong sillok', 55:41a:line 10-line 13; 政院啓曰成均館司成李純得革象新書於中原其書爲觀天之器名曰目輪李純向以渾儀渾象監修官在觀象監因目輪之制而造作今日進上矣此器極爲新巧請加作一件以置觀象監驗之何如傳曰依啓; Mokryun (目輪) mentioned in the record is considered to indicate an astronomical instrument.

¹⁰ 'Jungjong sillok', 57:5b:line 5-line 9; 觀象監啓曰簡儀渾象世宗朝所造也觀天之器只有一件未便若又修補則無測候之具故前日請加造一件而今又畢造但舊象排置星辰及着漆處今或剝落請以新象排設校正其差違而令匠人仍修補何如且一象藏之何所竝棄傳曰依啓修補一件置于內觀象監可也.

(a) Dosanseowon's Honsang

(b) Restoration product

Fig. 2. Artifacts of Honsang in Korea.

after the manufacturing record of the water-hammering type *Honsang* in 1435 and it mentioned that there had been only one instrument from the period of *Sejong*. Here, it is interpreted that the *Honsang* was manufactured together with *Honui*. Considering that the title of *Lee Sun* (李純) around 1525 was *Gamsugwan* (監修官) who was in charge of supervising the repair work for *Honui* and *Honsang*, and that the *Honsang* was built in the following year, 1526, the name, *Honsang*, at that time was presumably used for both *Honui* and *Honsang* together. Jeon (1994) deduced that ‘*Ganui*’ in the phrase of ‘*Ganui-Honsang* (簡儀渾象)’ in the record on May 11th (*Gye Sa*) in 1526 (the 21st year of King *Jungjong*) should have meant *Honui*. The reason is thought to be the expression of ‘*Uisang* (儀象)’ instead of ‘*Ganui-Honsang*’ in the record of ‘*Jeungbomunheonbigo*’ regarding the 21st year of King *Jungjong*.¹¹ The important fact seen in these two records in ‘*Jungjong sillok*’ is that a new *Honsang* was manufactured in 1526 and the old *Honsang* from the *Sejong* era was repaired and moved to *Gwansanggam* in the palace. It is highly probable that the new *Honsang* was a water-hammering type system of *Honui-Honsang*.

The 8th Year of King *Myeongjong* (1553) May 7th (*Im Ja*)

Sim Yeon-Won, *An Hyeon*, and others were awarded and the grades of *Heo Yeop*, *Kim Yeo-Bu*, and others were raised. The king gave the order to *Jeong Won*. “Award *Dojejo* (都提調) *Sim Yeon-Won* (沈連源), *Jejo An Hyeon* (安玟), *Bujejo Yun Chun-Nyeon* (尹春年), and others at *Honsang Gyojeongcheong* (渾象校正廳) well-tamed steeds, raise the grades of *Nangcheong* (郎廳) *Heo Yeop* (許嘩), *Bak Min-Heon* (朴民獻), *Kim Yeo-Bu* (金汝浮), *Bak Yeong* (朴詠) and others, and reestablish *Jo Seong* (趙晟) to *Jubu* at *Dongban* (東班).”¹²

According to *Myeongjong sillok* (明宗實錄), the staff at *Honsang Gyojeongcheong* (校正廳; repair agency) received awards. The instrument which was fixed at *Gyojeongcheong* is highly probably the new *Honsang* that had been made in 1526. The old *Honsang* was repaired when they crafted the new *Honsang* in 1526. Considering that the old, fixed *Honsang* was sent to *Nae-Gwansanggam*, it is thought that they sent only the *Honsang* itself without the water-hammering mechanism. Thus, we suppose that its level of trouble or repair should have been much lower than in the case of a water-hammering type *Honsang* which was coupled with a mechanical device. On the contrary, the repair at *Honsang Gyojeongcheong* must have been a large scale work considering that they had even established a specialized agency for that repair. Therefore, we conclude that it should be the new *Honsang* made in 1526 and all of its mechanical parts what was repaired at *Honsang Gyojeongcheong* in 1553.

¹¹ ‘*Jeungbomunheonbigo*’, *Sangeuigo* 2:33b:line 2~b:line 5; 二十一年重修舊儀象更製副件。觀象監上言曰今儀象諸器皆。世宗朝所期星辰位置間或剝落請修補又言諸儀象皆單件故若值修補時則無他測候之具請更造副件。上竝從之又命副件置于內觀象監。

¹² ‘*Myeongjong sillok*’, 14:50b:line 3~line 5; 傳于政院曰渾象校正都提調沈連源提調安玟副提調尹春年賞熟馬。郎廳許嘩朴民獻金汝浮朴詠陸品趙晟東班主簿敘用。

3. ARTIFACTS IN KOREA AND OTHER COUNTRIES

3.1 Artifacts of *Honsang* in Korea and *Honsang* Modelling

The only remaining *Honsang* in Korea is the artifact at *Dosanseowon* (*Dosan* Confucian Academy). We conducted a scientific investigation (2006) on it, and measured the relic

Fig. 3. The Silla Arts and Science Museum (in Gyeongju-si).

and restored it (Fig. 2).

A number of efforts have been made in Korea to restore the *Honsang* in the *Sejong* era. Most of them analyzed the manufacturing technic referring to Chinese artifacts. The first model among them is the *Honsang* crafted by the Silla Arts and Science Museum (modeled by Prof. Nha Il-Seong, made in 1994; Fig. 3). *Cheonsang Yeolcha Bunyajido* was used to determine the positions of constellations. Stars were represented using cubic, in different sizes depending on the brightness of star. This model was operated by electric power using a stepping motor.

Other models after that were manufactured mainly for outdoor exhibitions (Fig. 4). Starting from the *Honsang* installed at the Korean Studies Advancement Center (in *Andong-si*, made in 2000, for the outside), several *Honsang* models were crafted in slightly different sizes and shapes.

Bronze models of *Honsang* were built at *Yeongreung* (in *Yeoju-gun*, made in 2004, for the outside), the *Gwacheon* National Science Museum (in *Gwacheon-si*, made in 2008, for the inside), *Jang Yeong-Sil* Science Garden (*Busan* metropolitan city, made in 2010, for the outside), and the Museum of *Silhak* (in *Namyangju-si*, made in 2011, for both the inside and the outside).¹³

The slightly different appearances of the *Honsang* models are considered to originate from that there is no extant artifact and they had to refer to Chinese relics with creating an aesthetic appearance using Korean motives. Thus, it is important to analyze the manufacturing method of each model and derive a standard model.

3.2 A Variety of *Honsang* Artifacts in China and Japan

3.2.1 *Honsang* in China

Shui yün i hsiang t'ai in China was completed by *Su Song* and *Han Gong-Lian* in North Song (北宋) circa 1092.¹⁴ In this facility, *Honui* and *Honsang* were driven by a co-operation of power devices such as water clocks, water wheels, and gear mechanism. It seems that such a system was introduced to *Joseon* and influenced the operating mechanism of the *Honui* and *Honsang* (made in 1435) installed to the west of *Ganuidae* (Kim 2007).

Shui yün i hsiang t'ai is a 3-story facility with a height of about 12 m and a length and width of 7 m each (Fig. 5).

¹³The constellation coordinates of *Cheonsang Yeolcha Bunyajido* were applied to the *Honsang* models at the Korean Studies Advancement Center, Yungneung, and Jang Yeong-sil Science Garden, while the model at the Museum of *Silhak* is based on the constellation coordinates from *Seongkyeong* (星鏡), by Nam Byeong-Gil (南秉吉, 1820~1869).

(a) The Korean Studies Advancement Center (in *Andong-si*)

(b) Yeongreung (in *Yeoju-gun*)

Fig. 4. Restored models of *Honsang* for outdoor exhibitions.

Fig. 5. *Shui yün i hsiang t'ai*'s outward view (『Xinyixiang Fayao』) and sectional view (Pan 2003). 1: *Honui* (渾儀), 2: *Oun and Gyupyo* (熬雲, 圭表), 3: *Cheonju* (天柱), 4: *Honsang and Jigeo* (渾象, 地柜), 5: *Ju-Ya Giryun* (晝夜機輪), 6: *Churyun* (樞輪), 7: *Cheonghyeong and Cheonswae* (天衡, 天鎖), 8: *Pyeongsohu* (平水壺), 9: *Cheonji* (天地), 10: *Hacha, Cheonha and Seungsusangryun* (河車, 天河, 乘水上輪)

『Xinyixiang Fayao』 presents the outward appearance of *Shui yün i hsiang t'ai* and its part designs. Pan (2003) shows main parts of *Shui yün i hsiang t'ai* in a sectional view. In this diagram, a time-signal device and a power device are installed on the lower floor of *Shui yün i hsiang t'ai*, the *Honsang* on the middle floor, and the *Honcheonui* (armillary sphere) on the upper floor. The automatic mechanism was powered by water at the water clock and connected through complicated mechanical wheels to the *Honui*, the *Honsang*, and the time-signal device.

There remain artifacts since 17th century for other than the water-hammering systems. There are 8 sets of astronomical instruments at the *Beijing Ancient Observatory* in China which were manufactured by western missionaries in 17th. This observatory keeps a *Honsang* which was made in 1673 in the *Qing* dynasty (Fig. 6). This *Honsang* is composed of several rings. A horizontal ring and a meridian ring are cross attached, and there is a polar ring (with a 96-Gak timescale engraved) at the position of the north pole. A uniquely shaped rod is hung on the ceiling, to which a device for measuring altitude is connected.

The horizontal ring has a water groove on it for leveling and various patterns on its side. There are four dragon-

Fig. 6. Ferdinand Verbiest (1623~1688)'s *Honsang* (The *Beijing Ancient Observatory*).

pillars under the horizontal ring and a meridian ring going north-south through the horizontal ring. The meridian ring has a scale with diagonal lines at 1 degree interval, which enables a precise measurement. Marks of stars were crafted in different sizes depending on the brightness of star. A mark of the Milky Way and scales of the equator and the ecliptic are engraved on the surface of the globe. Under the meridian ring of this *Honsang*, there is a gear mechanism to adjust the altitude of the north pole on the *Honsang* globe.

There is another *Honsang* manufactured in the *Qing* dynasty at the *Purple Golden Mountain Observatory* (Fig. 7). Its appearance is similar to the artifact at the *Beijing Ancient Observatory*. However, it has neither a polar ring at the north pole position nor a polar rod on the ceiling. The horizontal ring has a water groove, and engraved marks

¹⁴蘇頌,『新儀象法要』,四庫全書,宋.; *Shui yün i hsiang t'ai* is thought to have been built in 1088 or 1089 or 1092, where 1092 is mostly accepted. Hong-sen Yan and Tsung-Yi Lin, "A study on ancient Chinese time law and the time-telling system of Su Song's clock tower," *Mechanism and Machine Theory*, 37, 1(2002), p. 15; this paper supposes that *Shui yün i hsiang t'ai* was built in 1088. Gao Xuan, "Principle Research and Reconstruction Experiment on the Astronomical Clock in Ancient China," *Proceedings of the 11th World Congress in Mechanism and Machine Science*, August 18~21(2003); This paper considers that *Shui yün i hsiang t'ai* was built on January 16th, 1089 but completed in 1092 since it states that technology for all the components was not complete until 1093 when the book 『*Sinuisangbeobyō*』 was finished. The operation of *Shui yün i hsiang t'ai* lasted only 35 years owing to a war.

Fig. 7. *Honsang*, at the end of the *Qing* Dynasty (1905) (The Purple Golden Mountain Observatory).

such as a 360-degree scale and a 96-Gak scale on it. An equator ring and an ecliptic ring are engraved on the globe surface. The equator, ecliptic, and horizontal rings have 1-degree diagonal lines engraved on them, each line of which is divided into 6 parts.

3.2.2 *Honsang* in Japan

There remain relatively various artifacts of *Honsang* in Japan. Nha et al. (1994) introduce 14 sets of Japanese *Honsang*. Most of them have a horizontal ring and a meridian ring, and constellations drawn on a paper surface. In most cases, the celestial globe is composed of a wooden frame and paper on it. Considering their portable sizes, it seems that they were manufactured for academic or educational purposes. Here, we introduce the most typical 4

sets of *Honsang* among those presented by Nha et al. (1994), with some descriptions (Fig. 8).

4. STUDY ON THE STRUCTURE OF THE WATER-HAMMERING TYPE *HONSANG* FOR RESTORATION: CONCEPTUAL DESIGN

As there is no remaining artifact in Korea of the water-hammering type *Honsang*, our study here is based on the literature in Korea and the existing artifacts and records in China and Japan.

4.1 Discussion on the Components and Manufacturing Methods of *Honsang*

The power device of water-hammering method developed in 1435 operated *Honui* and *Honsang* together. Hahn et al. (2001) consider that this power system was in a parallel structure with *Honui* and *Honsang* arranged in a line. In this study, we discuss mainly on *Honsang* and the driving device of water-hammering method, excluding *Honui*.

The *Honsang* globe is composed of marks of constellations, their names, the Milky Way, the equator, the ecliptic, and a sun device and a movement device. Four pillars and a horizontal part support *Honsang*. The inside of the *Honsang* globe is made by attaching several layers of clothes on a wooden frame and applying lacquer on it. Nha et al. (1994) sand papered the surface since that resulting from the traditional method was rough. A disadvantage of the *Honsang* globe made of the wooden frame and lacquered clothes is its heavy weight, but it is not a trouble to make it rotate as long as the entire globe is kept in balance. If restoring a *Honsang* globe now, fiber glass reinforced plastic

Fig. 8. Artifacts of *Honsang* in Japan (Nha et al. 1994). (a) The celestial equator and the longitude lines are shown on a 3 cm in diameter white celestial globe and names of fixed stars and constellations are also shown on. Meridian ring is attached on the pedestals and the material of pedestals is unidentified. (b) It was made of plaster and made by Murayamateiji (村山禎治, 1832~1922). The graduations at intervals of 5 degrees are marked on the meridian ring and the graduations at intervals of 30 degrees are marked on horizontal ring. (c) The 24 directions are shown on wide horizontal ring as the Chinese character instead of angles. The specific diameter is ascertained. (d) Its maker and age are unidentified. The silver inlaid celestial equator, ecliptic and constellations are shown elaborately on a 27.4 cm in diameter wooden celestial globe.

Fig. 9. The outline of Honsang and internal Cheonryun device (『Xinyixiang Fayao』).

or bronze can be considered for the material to enhance its durability and minimize any deformation. The *Honsang* models manufactured for outdoor exhibitions in Korea are mostly made of bronze and, although have no driving system, can be turned by hand.

The *Honsang* globe is supported by the combination of a horizontal plane and the meridian ring. The structure of the horizontal plane can be designed as either such a horizontal ring type as in Honcheonui or a plane type as in the model (made in 1994) displayed at the Silla Arts and Science Museum. A basic configuration of this horizontal plane is placing a *Honsang* globe on a box as presented in 『Xinyixiang Fayao』 (Fig. 9). Inside the box, there is a *Cheonryun* System which makes *Honsang* rotate one turn a day. The scene of rising and setting stars on *Honsang* was created by hiding such a mechanical system. *Liang Lingzan* (梁令瓚) in the *Tang* dynasty installed rings for tracking the sun and the

moon on his *Honsang* (made in 724) and *Zhang Sixun* (張思訓) in the *Song* dynasty made the shapes of the sun and the moon be seen on his *Honsang* (made in 979) (Hahn et al. 2000). However, *Shui yün i hsiang t'ai* in the period of North *Song* (北宋) included no parts for the sun's movement.

Lines of longitude and latitude (more exactly, the right ascension and declination) are drawn on the *Honsang* globe as a coordinate system for constellation drawings. Those lines are seen also on the existing artifacts in China and Japan even with slightly different formats. Most of the *Honsang* artifacts existing in Japan use 28-*Su* for the longitudinal lines. On the *Honsang* at the Beijing Ancient Observatory (made in 1673), traditional 28-*Su* lines of longitude are omitted and 24 longitudinal lines are drawn instead around the ecliptic pole at every 15°. And 13 latitudinal lines are drawn in parallel to the ecliptic line. On the *Honsang* made around the end of the *Qing* dynasty (1905), only 24 longitudinal lines at 15° interval are marked. There are no latitudinal lines drawn on this *Honsang*. The *Honsang* in 『*Sinuisangbeobyo*』 presents 28 longitudinal lines, and constellations around the north pole and the south pole, separately (Fig. 10). No latitudinal lines are marked here, either. It is considered that they were omitted since the scale on the meridian ring can substitute the latitudinal lines.

Considering when the *Honsang* in the early period of *Joseon* was manufactured, it seems clear that they adopted the 28-*Su* lines of longitude from *Cheonsang Yeolcha Bunyajido* (made in 1435). It is not certain, however, whether they drew latitudinal lines or not. According to the record in 『*Sejong sillok*』, degree numbers were marked on the *Honsang* globe in horizontal and vertical lines. Considering the expression, it seems that the horizontal direction represent the equator line and the vertical direction the

Fig. 10. Constellations around the north pole and south pole (『Xinyixiang Fayao』).

Fig. 11. Water-hammering power transmission system.

28-Su line. Although there is no record on a meridian ring, the ring must have been installed since the rotation axis of *Honsang* for its automatic operation should pass through the north and south poles of a meridian ring. Such a meridian ring is seen also on the *Honsang* presented in 「*Xinyixiang Fayao*」. Thus, it is considered that positions of celestial objects could be marked on the water-hammering type *Honsang* in the early period of *Joseon* using the scale of the meridian ring, even without latitudinal lines.

Besides the meridian ring, the equator should be represented on the *Honsang* globe. The equator can be drawn on the globe or formed in a ring; the equator ring. In the Chinese and Japanese artifacts, equator lines were drawn on the globes without any equator ring. The equator lines on the Chinese *Honsang* globes are presented as the scales of diagonal lines. Drawings of lines or small circles were used for the equators on the Japanese globes. The same formats were applied also for the ecliptic. Regarding the expression of the ecliptic on the Korean *Honsang*, it is not likely that a line was drawn on the globe considering the method of moving the sun. The sun model was actually moving along the ecliptic by one degree per day. Thus, it must be in a form of rail either in contact with or just above the globe surface. Such an example is the ecliptic ring of the existing artifact of *Honcheonsigye* (armillary clock; National Treasure of Korea No. 230). There is a ring for the sun's movement in the outer part of the ecliptic ring, where the sun is moved by pulling a string (Needham et al. 1986, Lee & Kim 2007). Thus, it can be concluded that there was a part of the ecliptic ring for tracking the sun on the globe of the water-hammering type *Honsang* in *Joseon*. On the other hand, the equator is thought to have been expressed by a drawing on the globe as in the Chinese and Japanese cases.

It is highly probable that the constellation drawings on the *Honsang* globe reflect the observational measurements at that time. *Cheonsang Yeolcha Bunyajido*, crafted in 1395 (the 4th year of *Taejo*), contains constellations of two different ages. The constellations engraved within the circumpolar ring reflect the observational results at that time, while the constellations out of the ring are those seen around the 1st century (Park 1998). Thus, constellations

at that time can be reproduced using the constellation positions in *Cheonsang Yeolcha Bunyajido*. Fortunately, *Cheonsang Yeolcha Bunyajido* was 3D scanned by the Korea Astronomy and Space Science Institute in 2008.¹⁵ Using such data, exact positions of constellations and sizes of stars can be reflected to a restoration of *Honsang*. There is no clear description on lines of constellations or shapes of stars. In the cases of existing artifacts, they were drawn or made of the same material and attached, depending on the material. The decision can vary depending on the location where the restored *Honsang* would be installed.

4.2 Configuration and Operation of the Power System of Water-Hammering Method

The power system of water-hammering method consists of a water clock, a water wheel, the *Cheonhyeong* system, the *Giryun* System, *Cheonryun*, etc. (Fig. 11). The water clock supplies a constant amount of water to *Sususangs* (small bowls) on the water wheel. *Sususangs* are connected to *Cheonhyeong* which is a kind of balance with weights and controls the water wheel. Power from the water wheel is sent through *Giryun* to *Honsang* for operation.

The role of the water clock is to supply water at a steady rate (refer to Water Clock in Fig. 12). Water clocks in the *Silla* era were 4-level compensating system (Lee et al. 2008). For *Jagyeongnu* (striking clepsydra) in the early period of *Joseon*, they used a water clock in a 3-level serial structure with one *Dae-Pasuho* (large-sized water supplying vessel) and two *Jung-Pasuho*s (medium-sized water supplying vessel) (Nam et al. 1998). The technology of the Three Kingdom Period was advanced considerably by the overflow device in *Jagyeongnu*. Among the water supplying *Pasuho*s, the lowest *Pasuho* has an overflow device at a certain height which keeps the amount of water constant. The water from the last *Pasuho* ('A' in Water Clock in Fig. 12) fills *Sususangs*, the

¹⁵Yang Hong-Jin (Korea Astronomy and Space Science Institute) measured the coordinates of stars on *Cheonsang Yeolcha Bunyajido*, National Treasure of Korea No. 230, accurately by 3D scanning, from 2008 to 2010 through the "study on the scientific features of *Cheonsang Yeolcha Bunyajido*, the National Treasure astronomical chart."

Fig. 12. Keys map of water wheel, Cheonhyeong system and water clock.

small bowls, on the water wheel.

The water wheel is turned by the weight of water in *Sususangs*, which are attached to the outer rim of the water wheel (refer to Water Wheel in Fig. 12). Park (2011) estimates the number of *Sususangs* as 12 or 16 in the water-hammering system of *Honcheonsigye* by Lee Min-Cheol in 1669. This result is from their comparison with the scale of water wheel of *Shui yün i hsiang t'ai* in China. In *Jeungbomunheonbigo*, there is a record on the manufacturing details of the water-hammering type *Honcheonsigye* in 1669, which says that it was to restore the old system of *Heumgyeonggak* in the *Sejong* era.¹⁶ This implies that the water-hammering system in 1669 inherited the manufacturing technology from *Heumgyeonggaknu* in 1438. Based on this, Kim (2007) considers that the *Honsang* system of water-hammering method in 1435 was in a similar form as the power systems of *Heumgyeonggaknu* in 1438 and the water-hammering type *Honcheonsigye* in 1669. In conclusion, it is probable that the water wheel mechanism by Lee Min-Cheol is similar to the water wheel system in the water-hammering type *Honsang*.

The function of the *Cheonhyeong* system is to turn the water wheel when the weight of water in a *Sususang* reaches a certain level and to hold the water wheel steady while water is filling the next *Sususang* (refer to *Cheonhyeong* System in Fig. 12). This is similar to the function of foliots in mechanical clocks in Europe in 14th century. In a mechanical clock powered by weights, a foliot was an essential device controlling the falling speed of a weight to enable precise measurement of time. In China, the *Cheonhyeong* systems, with the concept of foliot, were used to control water wheels already in 11th century. When a certain amount of water ('A' in Fig. 11) filled a *Sususang*, the balance measuring weight of the *Sususang* (to which

Weight 1 is hung) is pushed down. Then, it pulls the upper balance for water wheel control (to which Weight 2 is hung) down, which release the locks holding the water wheel by pulling the '∩'-shaped lock and the '—'-shaped lock up. Now the water wheel moves down. After a while, the water wheel is stopped by the '∩'-shaped lock and the '—'-shaped lock, and a repeating operation of this process generates a constant power of rotation at the water wheel. Then the rotational power is transferred to the *Giryun* system.

The role of the *Giryun* system is to receive power from the water wheel and to transfer it to *Honsang* (refer to *Giryun* system in Fig. 13). In *Shui yün i hsiang t'ai* in China, the force load on each gear device was probably large since it had to operate *Honui* and *Honsang* together including the time-signal device in a 5-level (floor) structure. On the contrary, in *Joseon*, *Honui* and *Honsang* formed an independent system, which was installed in a small house. Also the time-signal device and a part of the celestial movement were separated to become the *Heumgyeonggaknu* system. Thus it can be considered that the *Giryun* system, which was used only to drive *Honui* and *Honsang*, should have been operated with less power than that for *Shui yün i hsiang t'ai*. In the water-hammering type *Honsang* in *Joseon*, more gear parts and power were added to drive the device for the sun's movement.

The *Honsang* globe makes about one revolution per day (refer to *Honsang* in Fig. 13). The *Honsang* of *Shui yün i hsiang t'ai* was turned by the gear device named *Cheonryun*. The *Honsang* globe had a toothed wheel at the equator and received power from *Cheonryun* located under it. The *Honsang* in *Joseon* was turned by a device with a similar function as *Cheonryun*. The existing *Honcheonsigye* receives the driving power from the axis of the north pole, and the remaining *Honcheonui* at the Korean Christian Museum at Soongsil University also receives its power from the northern part (Kim 2007). However, it seems reasonable to operate the *Honsang* using a gear device connected to the equator

¹⁶ *Jeungbomunheonbigo*, Sangeuigo 3:2a:line7; 祭酒宋浚吉請復欽閣古制.

Fig. 13. Keys map of Giryun system and Honsang.

or the axis of the south pole. As 「*Sejong sillok*」 describes on the operation of the *Honsang* as “The automatic mechanism of the machine is covered and hidden,” it is more likely in a form of hidden gears in the south rather than a prominent device to the north.

5. CONCLUSIONS

The *Honui* and *Honsang* systems of water-hammering method in *Joseon* were installed together in *Sogak* (small house) to the west of *Ganuidae* in 1435. Later in 1526, new systems of *Honui* and *Honsang* were manufactured, and the previous systems were repaired and sent to *Gwansanggam*. There is a record on another repair of *Honsang* in 1553. However, this record mentions nothing about *Honui*. No record on the repair of *Honui* is found any more in the later literature (Kim 2007). Based on the records, it is considered that the tradition of operating *Honui* and *Honsang* of the water-hammering method together changed at that point.

The reconstruction models of *Honsang* in Korea have been built mainly for outdoor exhibitions. However, they can be sources of important technical information to refer to for manufacturing a restoration model of the water-hammering method, such as the marks of 28-*Su* longitudinal lines on the *Honsang* globe, the forms of the meridian ring and the horizontal ring, etc. Also, the 3D scanned data of *Cheonsang Yeolcha Bunyajido*, crafted in 1395, are expected to enable more accurate marking of the positions of constellations.

Shui yün i hsiang t'ai, built in China in 1092, is composed of a giant water wheel and a variety of gear devices. A set of *Honui* and *Honsang* was located on the 5-level structure of time-signal device. Unlike the tower-style *Shui yün i hsiang t'ai*, it is more likely that the *Honui* and *Honsang* in *Joseon* were positioned side by side in a parallel arrangement. Without a separate device for time-announcing, there

seems to be no particular reason to locate them on a high place. Furthermore, considering the typical scale of *Sogak* in *Gyeongbok* palace, it is supposed that the water wheel was connected from one side of both the *Honui* and *Honsang* or located in the middle to distribute power to both sides.

The most important factor in the power system of water-hammering method is to control the water clock to have a constant water flow and consequently to make the rotational power of the water wheel constant. The use of the overflow devices and the development of the *Cheonhyeong* system enabled the precise operation of the water wheel. It seems that *Jang Yeong-Sil* adopted an idea for developing the water-hammering system in *Joseon* from *Shui yün i hsiang t'ai* by *Su Song* and *Han Gong-Lian* (Nam 2002). *Jang Yeong-Sil* modified the structure of *Shui yün i hsiang t'ai* to meet our conditions. He separated the *Honui* and *Honsang* and placed them in *Sogak*, and installed *Ongnu* (jade clepsydra) in *Heumgyeonggak* which was a completely new type of astronomical clock with a time-signal device in a form of *Gasam* (imitation mountain). Also, he included the moving mechanism for the sun, which was not in the *Honsang* of *Shui yün i hsiang t'ai*, in the *Honsang* and *Ongnu* to automatically reproduce the sun's movement on the ecliptic.

Through the analysis on the structure of the water-hammering type *Honsang*, we investigated the water clock, the water wheel, the *Cheonhyeong* system, the *Giryun* system, the operation of *Honsang*, etc. Our study on such individual parts helped us understand the device of water-hammering method as an organically operating system. We established a basis for studies on the structure and operation of the water-hammering type system of *Honui* and *Honsang* for its reconstruction as well as studies on the structure of the water-hammering type *Honcheonui* in the future. Such studies on water-hammering type devices would achieve important results for restoration of various astronomical clocks in the entire period of *Joseon*.

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