2.7 RESEARCH ON SCALE AND PRECISION OF THE WATER CLOCK IN ANCIENT CHINA

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The instruments of measuring time have been closely related to astronomy, especially to astrometry. In ancient China, before mechanical clocks were imported from European countries, accurate Water Clocks, main tools for measuring time, had been developed two thousand years ago.

In this paper the sizes (mainly the height) of five single vessel-type Clocks of Western Han Dynasty (206 B.C.-25 A.D.), which were either unearthed in recent years or recorded in some historical documents, are taken as a sample for studying the scaling of indicator-rods and precision of Clock.

I <u>WATER CLOCK OF THE HAN DYNASTY</u>

The Chinese Water Clock had been created long before the Qin and Han Dynasties. At the latest in Shang Dynasty (1711 B.C.-1066 B.C.) the 100-quarter system which could be used to divide a day equally into one hundred ke. In Zhou Dynasty (1066 B.C.-256 B.C.) the Clocks were used in daily life and work, in the imperial court and the army.

At early Western Han, the 100-quarter system was the only system which was used in the Clock. Up to the present, we have found neither any recorded historical documents or picture concerning the Clocks before Han Dynasty, nor any material object. As for the Clocks in Han Dynasty, there are the painting of "Cheng Xiang Fu Clock", the Clock possessed by Prof. Ronggeng, and three Clocks of Western Han Dynasty which were unearthed in recent 25 years from the tomb of Emperor Hanwu, from the tomb of Zhongshan Jing Emperor in the Western Han Dynasty, and from the Inner Mongolia. The type, the size and the structure of these five bronze Clocks are fundamentally similar (Table 1). They are sinking indicator-rods, i.e. outflow Clocks, the four of them are near 20 cm, and the other one is near 10 cm, all of which are smaller than any multivessel Clocks developed later.

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TABLE 1
MAIN SIZE OF THE WATER CLOCK IN WESTERN HAN DYNASTY

Name	Depth	Size diameter	Volume	Form
Cheng Xiang Fu	7.5 cun*	5.8 cun		cylindrical
Rong Geng	3.7 cun	1.8 cun		"
Shaanxi	23.5 cm	10.3 cm	2000 cm^3	"
Hebei	20 cm	8.6 cm		"
Inner Mongolia	24.2 cm	18.7 cm		"

*cun, a unit of length (≃1/3 decimeter)

II ANALYSIS OF SCALING OF INDICATOR-RODS &PRECISION

The precision of the Water Clock is mainly determined by the stability of outflow. Since the Eastern Han Dynasty (25-220 A.D.) in China, the Clock was developed into the multivessel, which made outflow more even. Since the rate of outflow in the cylindrical single vessel decreases as the water level reduced, so that the indicator-rods which measure time by means of measuring the height of water level should not be scaled with equal intervals.

Indicator-rods were made of materials such as bamboo, wood etc., and they were almost thoroughly rotten when unearthed. Since no historical records could be found, deduction have to be used for analysis. We will discuss on the depth (the height of water capacity) of a single vessel from the viewpoint of unequal scaling. In Fig.1, supose h_0 is the zero level of the water outlet, and

$$h_2 - h_1 = \Delta h_1$$

is the lowest scale in the indicator-rod (1 ke time) (this is a scale with the shortest interval of all the scalings), Δh_1 is reasonably selected in order for it to be able to distinguish by the observer in practical work. The selection of h_1 should not be too low, otherwise the cylinder would be very high (see Table 2)

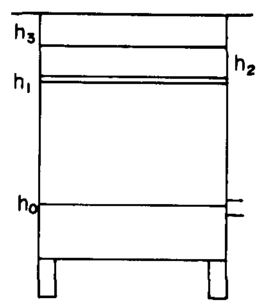

Fig.1

If the shape, the length and the caliber of the water outlet pipe are not considered, by means of fundamental principle of hydrostatics, from h_1, Δh_1 and h_2 the value of Δh_2, i.e., the value of water level reduction of the last but one ke can be calculated, then the water level reduction of the total N ke can be found also

$$\Delta h_2 = h_3 - h_2$$

$$h_3 = \frac{h_2^2}{h_1}$$

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since

$$\frac{\Delta h_2}{\Delta h_1} = \frac{\Delta h_3}{\Delta h_2} \; ..... = \frac{\Delta h_N}{\Delta h_{N-1}} = r$$

the formaula of a geometrical series can be used for calculating the water level reduction of the total N ke.

$$H_N = \frac{\Delta h_1 (rN-1)}{r-1}$$

In the Western Han period, like the earlier time, the 100-quarter system was used for time measuring. The lengths of the day time and the night were measured respectively from the instants corresponding to sunrise and sunset. The longest time of the day (night) in north of China was approximately above 60 ke. Let us take 100 ke or 70 ke as the whole scale and then calculate the total length of graduation respectively in order to estimate the depth of the Clock. The results are as follows (see Table 2).

Take Δh_1 = 1mm, 2mm
h_1 = 25,40,60,100,150,250 mm

we have the data listed in the Table.

TABLE 2 unit: mm

Δh_1	The lowest level used h_1	Water depth of 70 ke H70	Water Clock depth H70+h_1	Water depth of 100 ke H100	Water Clock depth H100+h_1
1	25	365	390	1240	1265
1	40	180	225 Δ	430	470
1	60	130	190 Δ	250	310
1	100	100	200 Δ	170	270
1	150	85	235 Δ	135	285
1	250	80	330	120	370
2	25	5440	5465	55000	55025
2	40	1180	1220	5220	5260
2	60	525	585	1540	1600
2	100	300	400	625	725
2	150	240	390	565	715
2	250	185	435	305	555

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From the above results we can see that if we take $\Delta h_1 = 1$ mm, the values with Δ in the Table are all roughly similar to the depth of the unearthed Clocks of the West Han period. If the value of h_1 is increased by a bit, the depth of the Clock would dramatically increase . The scale of 1 mm is easily distinguished with naked eyes. Because of the continuous moving of the indicator-rod and its nonlinear variation of rate, the scale reading of the single vessel may be set with precision (between half ke and one ke). In the Eastern Han period, the precision of determination of the length of the day or night was merely of 1 ke or so, and so was precision for time measuring. It is not necessary to increase the minimum value of h_1 and to enlarge the depth of the Water Clock.

The values deducted from the unequally scalled indicator-rods show that the sizes of Clocks of the Western Han period known at present are much smaller than any of the multivessel. This is why the single vessel discovered are all with small size. (Table 3).

TABLE 3

Name of multivessel-type Water Clock	Size of Water Clock
Yansu (Song Dynasty)	2.15 chi*
Shen Kuo (Song Dynasty)	3.5 chi
Among the people in the Song Dynasty	3 chi
Yanyou (Yuan Dynasty)	75 cm
Qianlong (Qing Dynasty)	97 cm

*chi $\simeq$ 1/3 m

Because of the low precision of the single vessel, the length of the apparent solar day is used as the standard of the length of a day. The length between two successive apparent solar days varies by less than 0.5 sec, and therefore it is impossible for a low precision single vessel to run for a long time with high precision. Thus it is necessary to check it daily or frequently with the apparent Sun, and hence the time scale measured with a Clock is the time of the apparent Sun. Measuring the length of the day-time and night separately is one of the distinguishing features in time measuring in China, since sunrise was taken as a standard of time measuring at ancient ceremony and sacrifice.

In the calendars of ancient dynasties graduations of the day and night in different seasons are given. For instance, graduations for the middle of China are: on the Winter solstice the length of night is 60 ke and on the Summer solstice 40 ke. Accordingly there are more than 180 days between the Winter and Summer solstices, and the difference between the days or nights is equal to 20 ke, that means there is an increasing or decreasing of one ke every nine days. This was the method used in the Qin dynasty. In the early years of the Han dynasty, the Qin's method was still adopted. As variation of the length of the day-time and night at

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any place is related with declination, an increasing or decreasing of one ke every nine days is approximate. Until Eastern Han Dynasty, in the year 102 B.C., Huo Rong pointed out that this method would not be strict, with which there would be so great a difference as 2-1/2 ke in a year. He suggested a method with which the variation of the length of the day-time and night is changed according to declination, i.e., one ke every 2.4^0 of declination. The value of 2.5 ke must be determined by time measurement with an error, so that the precision of the Water Clock in the Western Han Dynasty would not be higher than one ke everyday. In Eastern Han dynasty, more than two vessel types appeared. To compare the lengths of the day-time and night in different seasons recorded in Si Fen Calendars in Lu Li Zhi (律历志,) of the Book of Hou-Han-History with corresponding values it is known that the error given at that time is about half ke. The precision of Clock reached a standard which was worse one ke. In China, the 100-quarter system appeared in a comparatively early period. Comparing the Clock in the Western Han Dynasty with that used in earlier periods, we find that there was no obvious improvement in structure, and therefore the accuracy had not been obviously raised than those before the Qin Dynasty. In China, the Decimal calculating system had an early development history. This was the foundation on which the 100-quarter system was based. The 100-quarter system fulfilled the social activities for a quite long period, but since the Han and Tang feudal societies developed rapidly, more precise time measuring instrument was required in many respects, and that promoted its continuous development. The double-vessel Water Clock was first discovered in the Eastern Han dynasty and after Jin and Tang, the multi-vessel type appeared. This is a different stage of the development of Clock. Until Song dynasty, the multi-vessel typed Clock with steady water level and dividing flows was developed. This is the climax of Water Clock development in China.

DISCUSSION

A.K. Bag : From what time do the most ancient literary evidence on the Water-Clock in China date?

Quan Hejun : They date from the Zhou dynasty.

K.V.Sarma : What were the shapes of the Chinese Water-Clocks?

Quan Hejun : They were cubic, single and composite. In the latter, water flowed from one to the others which were placed lower.

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Olaf Pedersen and Mrs. Pedersen
at the Oriental Astronomy exhibition

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