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The Role of *‘Ilm al-Mīqāt* in the Progress of Making Sundials in the Islamic Civilization

Pouyan REZVANI

Abstract

Timekeeping (*‘Ilm al-Mīqāt*) was one of the applied astronomical disciplines from the Islamic period in which one deals with determination of the Muslim's prayer times using the shadow of sundial gnomons. According to the Islamic religious sources, such as *ḥadīth* and legal elaborations, *ẓuhr* and *‘aṣr* praying times should be determined based on the shadow length of gnomon. Indeed the sundial has historically been used as an astronomical instrument by which determining the time based on the shadow length of gnomon is possible; as a matter of fact, in Islamic societies (particularly in Syria and Egypt) some institutions were formed in mosques which were dedicated to such activities officially and they used reckoning methods for this purpose. At the same time, the methods for making sundials were developed as well. Some *Muwaqqits*, (people who were expert in *‘Ilm al-Mīqāt* and worked for mosques), compiled major works which played important role in this evolution. It is noteworthy that these activities promoted some fields such as mathematical astronomy, particularly spherical trigonometry. Because of the importance of *‘Ilm al-Mīqāt*, it prevailed in Islamic territories very soon. This research provides a survey of the formation and development of timekeeping methods from the Islamic period (between 11th and 16th c. CE) and their roles in the development of sundial designs and constructions. It also comprises various traditions of timekeeping, the most important astronomers who contributed to this field, and their works. The transmission of timekeeping methods in Egypt, Syria, Yemen and Turkey is also discussed.

Keywords: Timekeeping, *‘Ilm al-Mīqāt*, Prayer Time, Sundial, Gnomon, *Muwaqqit*.

Introduction

Astronomical timekeeping (*ʿIlm al-Mīqāt*) that is also called "*ʿIlm al-Mawāqīt*", was a discipline which was particularly dedicated to determining the prayer times based on the position of the sun across the sky according to the Islamic religion sources such as *Qurʾān* and *ḥadīth*. This generated in Islamic civilization, in 11th century¹ and developed after 1250 CE and included spherical astronomy, determination of time, the making of astronomical instruments, and determination of *qibla*, chronology and lunar crescent visibility. Timekeeping also comprised all of the applied aspects of astronomy and became proficiency for persons who were called "*Muwaqqit*", during 13th century. These persons worked in the mosques and schools for regulating the prayer times, determination of *qibla* and making the astronomical instruments such as sundials.²

Since permitted times of Muslims' prayers, according to Islamic religious sources, depends on the position of the sun at the sky, official institutes was established in mosques to determine the prayer times by astronomical instruments specially sundials. For instance, according to religious standards, Islamic day and permitted interval for the *Maghrib* prayer begins when the disc of the sun is set over the horizon. Permitted intervals for *ʿIshā* and *ḥajr* prayers begin at the nightfall and daybreak. But definition of the time of *zuhr* was different for different legal schools. This time, begins either when the sun crosses the meridian, or when the shadow of any object such as the sundial's gnomon, is observed to increase.³ According to *Kitāb al-Mughnī*, permitted time for *zuhr*, begins when the shadow of the gnomon, is equals its length.⁴ In medieval Andalusia and in *Maghrib*, this time, began when the shadow of gnomon has increased over its midday minimum by one-quarter of its length.⁵ The permitted interval for the *ʿaṣr* prayer begins when the shadow of the gnomon increase equals the length of the gnomon and ends either when the shadow increase is twice the length of the gnomon or at sunset.⁶ In *Ḥanafī* legal

¹ Saliba, 2007, pp. 38, 103

² Charette, 2003, p. 6

³ King, 1993, p. 28

⁴ Ibn Qudāma, pp. 378-379

⁵ Calvo, p. 160

⁶ King, 1993, p. 28

school, permitted time for *‘aṣr* prayer begins, when the shadow of the gnomon increase is twice the length of the gnomon.⁷

As we mentioned, permitted intervals for prayers depend on seasonal hours directly, as well as the beginning of the permitted intervals for *ẓuhr* and *‘aṣr* prayers, are coincide with the sixth and ninth seasonal hours. Ibn al-Raḥīq has mentioned that this coincidence is because of ‘Alī's (the forth caliph of Muslims) authority.⁸ In addition to these five prayer times, Islamic sources mentioned to another time called *duḥa*, which almost coincides with third seasonal time and the interval which is between this time and midday equals the interval that is between *‘aṣr* and midday but, *duḥa* is before midday. According to these passages and since sundials show seasonal hours, they play an important role in determination of the prayer times. As we know, 'Umar bin ‘Abd al-‘Azīz used a Greaco-roman sundial for regulating his prayers.⁹

⁷ King, 1987 (a), p. 193

⁸ Ibid, p. 194

⁹ King, 1993, p. 28

Muwaqqit's official institutes in mosques

At least, before 13th century, the regulating of the prayer times was the duty of Mu'ezzins, who had some information about rudiments of folk astronomy such as the shadow length of gnomon at *ẓuhr* and *ʿaṣr* prayer times. But they didn't use any astronomical instrument or mathematical method.¹⁰

According to D. A. King, a new development occurred in the 13th century in the field of *ʿIlm al-Mīqāt*, that its origins are obscure.¹¹ But George Saliba believes that *ʿIlm al-Mīqāt* was a reaction by astronomers to the attacks against astrology during the past centuries.¹² In fact astronomy primarily because of its association with astrology was maligned. *Muwaqqits*, by showing the practical aspects of astronomy and its role in religion, reclaim and developed it in that time. By accepting this opinion, we can trace the first attempts for the making of this discipline back to 11th century, when Islamic astronomers tried to be known distinguished from astrologers, although we can find some mentions to determining the Muslim's prayer times in earlier works, for example in a treatise which is attributed to al-Khwarizmi.¹³

The first mention of the institution of *Muwaqqits* is found in Egypt at 13th century.¹⁴ Also, in western part of Islamic world, we can find the first mention of *Muwaqqit* at the great mosque of Granada by the end of this century.¹⁵ There were two groups of people who specialized in regulation of the times of prayers. One of them, were not necessarily associated with any religious institution and called *Mīqātī*, and another were employed and supported by mosques and called *Muwaqqits*.¹⁶ We can mention to Ibn al-Shāṭir and Khalīlī as important *Muwaqqits* who worked in Damascus and had an important role in the development of astronomy in that time. Also there are many technical treatises on sundials from Mamlūks and Ottomans era, which were written by *Muwaqqits*.¹⁷

¹⁰ King, 1987 (b), p. 44

¹¹ Ibid, p. 44

¹² Saliba, 1994, pp. 61, 65, 78- 79

¹³ Ahmedov, p. 163

¹⁴ King, 1987 (b), p. 44

¹⁵ Calvo, Suhayl, p. 161

¹⁶ King, 2004, Vol. 1, p. 631

¹⁷ Charette, p. 181

The regulating of prayer times based on calculation

The using of calculation for determination of elapsed time widespread in the Islamic civilization gradually, although some of Muslim lawyers such as Aṣbahī who was one of the Yemeni lawyers in 13th century, were contrary to the determination of prayer times based on calculation primarily.¹⁸

The most popular formula that was used for finding seasonal hours after or before sunset (at $T < 6$) is:¹⁹

$$T = \frac{6n}{\Delta S + n}$$

Where (n) is the length of the gnomon and ΔS is the increase of the shadow over its midday minimum.

In this formula, when $\Delta S = \infty$ (the sun is over horizon), we will have $T = 0$. Now, if we assume that the length of the gnomon is 6.5 units, we will obtain $\Delta S = 6.5, 3.25, 1.3$ for third, fourth and fifth seasonal hours, respectively.

This formula is very similar to which of Ibn al- Raḥīq. He discussed a way for determination seasonal hours in a day by using the shadow of a gnomon in his treatise which is written in 11th century in Yemen or Hejaz.²⁰

As we mentioned, this formula, probably is the first one that used by Muslim astronomers in the regulating of time. Ibrāhīm al-Fazārī (c. 777 CE) who was one of the first Muslim astronomers has used this formula in this way:²¹

$$T = \frac{72}{\Delta S + 12}$$

In this formula, al- Fazārī has used 12 for the length of the gnomon that is similar to Indian way for dividing the length of gnomon to 12 units.²² So maybe it is an evidence to tell that al- Fazārī was influenced by Indian astronomy in this field.

¹⁸ King, 1987 (a), p. 193

¹⁹ King, 1993, p. 28

²⁰ King, 1987 (b), p. 193

²¹ Ibid, p. 200

²² Rosenfeld, p. 2052

Ibn al-Shāṭir (1304-1375) has also used this formula, but he has used 7 for the length of gnomon. So his formula will be as the following:

$$T = \frac{42}{\Delta S + 7}$$

Using 7 units in the divination of a gnomon length was common between Muslim astronomers.²³

Furthermore, there are many tables in a *zīj* compiled by Qāsim ibn Maḥfūz Baghdadī which are dedicated to regulate the prayer times. These tables are prepared for Baghdad latitude.²⁴

***ʿIlm al-Mīqāt* in different regions of Islamic civilization**

After Baghdad, Egypt, Syria and Ottoman territory were very effective in *ʿIlm al-Mīqāt*. Now we want to introduce the most famous astronomers who worked in these regions, with their works.

Egypt

As we mentioned, Egypt, was one of the earliest regions in the Islamic civilization whose astronomers worked on *ʿIlm al-Mīqāt*. In this part, we can mention to some of these scholars.

Al-Marākushī:

The most important work on spherical astronomy and astronomical instruments which is compiled in Mamluks era in the Islamic civilization is Marākushī's book: *Djāmiʿ al Mabādī wa al-Ghāyāt fī ʿIlm al-Mīqāt*. Sharaf al-Dīn abū ʿAlī Hasan ibn ʿAlī ibn ʿOmar al-Marākushī (c. 1262 CE) worked in Cairo. As we know, he was an independent scholar without institutional affiliation so he was a *Mīqātī*.²⁵ In fact, his great work is a comprehensive reference work of intermediate to advanced level, not an introductory work on timekeeping. This work that is compiled probably between 1276-1282 CE²⁶ comprises four books on the following topics:

²³ Ibid, p. 2052

²⁴ King, 1993, p. 29

²⁵ Charette, p. 12

²⁶ Ibid, p. 10

On calculations, in 67 chapters (*faṣl*). This book is dedicated to chronology, trigonometry, geography, spherical astronomy, determination of prayer times, the solar motion, the fixed stars and sundials. There are computing methods for these subjects in this book, but there are not any proofs.

On the construction of instruments, in 7 parts (*qis*). The first part is about spherical astronomy and gnomonics. The second to seventh parts includes these topics: 2. Portable dials, 3. Fixed sundials, 4. Trigonometric and horary quadrants, 5. Spherical instruments, 6. Instruments based on projection 7. Observational and planetary instruments.

On the usage of selected instruments, in 14 chapters (*bāb*).

The last book comprises a series of questions and answers in 4 chapters (*bāb*), which are for training the mental abilities of the students. The first chapter includes 21 questions and answers requiring no calculation, the second one has 40 questions and answers requiring mental calculation, the third one has 18 questions and answers requiring geometrical methods, and the last one has 22 question and answers requiring algebraic methods.²⁷

Shihāb al-Dīn al-Maqsī

Al-Maqsī, who was a contemporary of al-Marākushī, inaugurated the very practical Mamluk tradition of compiling a set of tables for constructing various sundials for Cairo.²⁸

These tables probably were based on an earlier set by Ibn Yunus,²⁹ and displaying the time since sunrise as a function of solar altitude and solar longitude. They expended and developed into a new set of tables containing over 30,000 entries in the 14th c. CE.³⁰ One of the Mamluks astronomers whose name is Muhammad al-Kattānī (14th c. CE) compiled several tables based on al-Maqsī.³¹ Also Ibn al-Majdī (15th c. CE) wrote a recension of al-Maqsī's work and added tables for Damascus.³²

²⁷ Ibid, pp. 12-13

²⁸ Ibid, p. 183

²⁹ King, 2004, VolI, p. 44

³⁰ King, 1993, p. 29

³¹ King, 1983, p. 541

³² Charette, p. 183

Najm al-Dīn al-Misrī

Najm al-Dīn al-Misrī was one of the Egyptian astronomers who was contemporary of al-Marakushī and Maqsī and compiled several tables for timekeeping. These tables had two important traits:

1. They were compiled for all latitudes,
2. By use of them, timekeeping base on position of fixed stars in the night was possible.³³

Najm al-Dīn also has several tables for constructing the sundials, which are for both of seasonal and equal hours. Also, there is a manuscript of a table which giving the horizontal and vertical shadows as functions of the altitude for each 5° or 6° of argument which was compiled by Najm al-Dīn.

Najm al-Dīn's method for drawing the hour lines on the sundial is very similar to Al-Battani's method. First, he draws a circle on a plane and determines the line of meridian. Then, he graduates this circle and determines the values of azimuth and shadow length for each seasonal hour of solstices. Then, he joins these points and draws corresponded hyperbolas for solstices. Furthermore, he draws a line that indicates 'aṣr prayer time. Also, Najm al-Dīn introduces a sundial, which in addition to these standard markings bears circles indicating the altitude of the sun.³⁴

The Cairo corpus of tables for timekeeping was used for several centuries and survives in numerous copies. They displaying the time since sunrise, hour-angle, and solar azimuth for each degree of solar altitude. Also, there are other tables displaying the solar altitude and hour angle as the 'aṣr, the solar altitude and hour angle when the sun is in the direction of the qibla, and the duration of morning and evening twilight.³⁵

Ibn al-Majdī

Shihāb al-Dīn abū al-‘Abbās Ahmed ibn Rajab ibn Tībūghā ibn Majdī (1365-1447 CE) was one of the well known astronomers of Cairo who was worked on *‘Ilm al-Mīqāt* too. According to Ibn al-‘Attār, a fifteenth century specialist on instruments, Ibn al-Majdī taught him the elements of astronomy, and Ibn al-

³³ King, 1993, p. 29

³⁴ Charette, pp. 188- 189

³⁵ King, 1993, p. 29

‘Attār read under his supervision about the construction of instruments such as declining sundials.³⁶

Sirāj al-Dīn (fl. Ca. 1200)

In a unique copy of a treatise entitled *Maṣābīh al-Anwār wa-Mafātīḥ al Asrār fi A‘māl al-Layl wa-l-Nahār* which is preserved in Cairo (Tal‘at Mīqāt 127s) Sirāj al-Dīn mentioned that the author of a book entitled *Kitāb Ḥall al-Mushkilāt fi Ma‘rifat al-Daqā‘iq wa-l-Daraj wa-l-Sā‘āt* devised a sundial called al-basīṭa al-sab‘īniya because it bore seventy (sab‘īn) lines for regulating time of day.³⁷

The influence of the Cairo *Muwaqqits* on Yemen

One of the regions in the Islamic civilization which was influenced by the Cairo *Muwaqqits*, is Yemen. In the Rasūlīds era, mathematical astronomy was practiced and patronized. Sultan al-Ashraf (1295-6) compiled a treatise on instrumentation base on that of al-Marākushī. Another Yemeni astronomer was Abū al-‘Uqūl who worked for the sultan al-Mu‘ayyad in Ta‘iz, compiled a corpus of tables for timekeeping which contains over 100000 entries.³⁸

Syria

Maybe the most important activities in *‘Ilm al-Mīqāt* were done in this region of the Islamic civilization. Large number of the first astronomers, who worked in this region, was students of Egyptian *Muwaqqits* which have come back to Syria and continued their activities. Now, we mention to some of these astronomers, in this section.

Ibn Sarrādī

Abu bakr Muhammad ibn al-Sarrādī (14th c. CE) was one of the Syrian astronomers who worked in Aleppo and he had visited Egypt. Addition to make the universal Quadrants and Astrolabes,³⁹ he designed several sundials.⁴⁰ Ibn al-Majdī has mentioned to a treatise on sundials which was compiled by Ibn al-Sarrādī that is not exist unfortunately.⁴¹

³⁶ Charette, p. 7

³⁷ King, Shadow Schemes, p. 233

³⁸ King, 1993, p. 30

³⁹ Ibid, p. 30

⁴⁰ Ibid, p. 210

⁴¹ Charette, p. 184

al-Mizzī and Ibn al-Shāṭir

Two major Syrian astronomers were al-Mizzī and Ibn al-Shāṭir who studied under astronomy in Egypt under Ibn al-Akfānī and others. Al-Mizzī returned to Syria and compiled a set of hour-angle tables and prayer tables for Damascus. Also he compiled some treatises on astronomical instruments.⁴²

Ibn al-Shāṭir was the chief *Muwaqqit* in great Umayyad mosque of Damascus. He compiled a corpus of prayer tables for an unspecified locality with latitude 34°. Despite to this fact that Ibn al-Shāṭir unlike al-Mizzī concerned to theoretical aspects of sundials, he constructed a noble horizontal sundial in the southern *minaret* of Damascus great mosque which size is 2 m × 1 m. The fragment of this sundial is preserved in Damascus archeology museum. This sundial indicated seasonal and equal hours, *zuhr* and *‘aṣr* prayer times. Maybe the most noticeable thing in Ibn al-Shāṭir's sundial is its inclined gnomon with a trapezoid shape. The inclination angle of this style is equal to the latitude of Damascus.⁴³ As we know, the horizontal sundials which were made in early Islamic period had vertical gnomon. According to Ibn al-Shāṭir's sundial, we can claim that inclined style in horizontal sundials was known for Muslims in 14th century.⁴⁴ We can find an interesting text in Ibrāhīm bin Sinān's work on shadow instruments, in which he has mentioned to the inclination of gnomon in horizontal sundials, although he didn't mention to the angle of this inclination. In this text he wrote that if we install the style of the horizontal sundial with an inclination, there would be no deference in the design of hour lines with the case of vertical gnomon.⁴⁵

"When the inclined gnomons are set on the plates [of the sundials], the lines that are casted on these plates by [the inclined gnomon] shadows, are

⁴² King, 1993, p. 30

⁴³ Janin, p. 287

⁴⁴ Ibid, p. 287

⁴⁵ Sezgin, 1999, p. 122. Here is the Original Arabic text:

«وأما متى وضعت المقاييس المائلة على السطوح فالذى يرسمه الظل مثل ما ترسمه المقاييس القائمة. وذلك أن طرف الظل إنما يحدث من طرف المقياس المائل مقياساً قائماً على السطح لأنّ الظل الحادث من طرفه هو الظل الذى قد بينا أصنافه وطرفه هو طرف المقياس المائل فالذى يحدث من المائل هو ما يحدث من القائم.»

similar to ones that are casted by the vertical gnomon [shadows] on [these plates]. In this case, the end point of the shadow that is corresponding to the top of the inclined gnomon, [is similar to the end point of the shadow] of a vertical gnomon, because the shadow that is corresponding to the top [of the inclined gnomon], is the same shadow which we mentioned its types, and the top of the [vertical gnomon], is the same with the top of the inclined gnomon, so the shadow that is casted [on the sundial plate] from [the top of] the inclined [gnomon], is the same with the shadow that is casted [there] from [the top of] the vertical gnomon."

Despite to this mention to inclined style for horizontal sundials in 9th century CE, we don't know of any horizontal sundial with inclined style in Islamic civilization until 14th century (in Ibn al-Shāṭir's sundial).

The specialists, who have studied on the relationship between Islam and Western Europe through the intermediary of the Caliphs in Spain, discussed about dissemination of inclined style of horizontal sundials. According to these researches, one can think of an influence of Islam on Europe or the reverse influence, or parallel progress.⁴⁶

Although Ibn al-Shāṭir who never forgot to praise his own, has written several books outlining the use and usefulness of the devices he has made, we didn't find a document written on sundials.⁴⁷ It is not clear to us that were the inclined gnomons a new thing for Ibn al-Shāṭir's contemporaries.

Furthermore, Ibn al-Shāṭir devised another astronomical instrument whose name is "Sanduq al-Yawāqīt li ma'rifat al-Mawāqīt" which is preserved in the museum of Aleppo. This instrument has a movable hole that by moving it, one can fine hour- angle of sun and if it has a suitable angle with horizon, can use it as a polar sundial. In fact this instrument has two universal sundials: one polar, the other equatorial.⁴⁸ Invention of this instrument can be another evidence for progress of design of sundials parallel with the culmination of *ʿIlm al-Mīqāt*.

We can also find the impacts of *ʿIlm al-Mīqāt* on the design of latest sundials which are made for religious aims in Egypt. A series of five vertical sundials which are made in a castle in Cairo can be good evidence. This castle

⁴⁶ Janin p. 288

⁴⁷ Ibid, p. 288

⁴⁸ Janin and King, pp. 187- 219

which is made in 12th/18th century is located in the front of the mosque of Mohammad ‘Ali and these five vertical sundials are made on one of the castle’s walls which has a curved surface. In fact, this surface is a part of a cylinder and so we can enumerate these sundials as cylindrical type. This series of sundials are designed based on the sophisticated mathematical calculations and include some hour lines for showing the Muslims’ prayer times.⁴⁹

Shams al-Dīn al-Khalīlī

Khalīlī (c. 14, 15 CE) was one of the colleagues of al- Mizzī and Ibn al-Shāṭir's and was cause of many progresses in timekeeping. He recalculated al-Mizzī's tables by Ibn al-Shāṭir's values for solar declination and altitude. His timekeeping tables for the latitude of Damascus were used until 19th century.⁵⁰ Also, he compiled a corpus of tables which include some trigonometric functions that were used for solving all of the spherical astronomy problems for any latitude.⁵¹

Other astronomers who worked in late Mamluks era were Muhallabī, Karādīsī, Sibṭ al-Maridīnī and Ibn abī al-Faṭḥ Ṣūfī.

Tīzīnī

Tīzīnī (c. 15th CE) was one of the *Muwaqqits* of Umayyad Mosque of Damascus who compiled several tables for drawing hour lines on vertical sundials for Cairo, Damascus and Aleppo. These tables are based on al-Maqsī.⁵²

The influence of Syria on Tunes

The activities of Damascus astronomers were known in Tunes in 14th and 15th centuries which led to compile several timekeeping tables for the latitudes of Tunes and Morocco. Compilers of these tables are unknown to us.⁵³

Ottoman territories

Istanbul was influenced the most by Cairo and Damascus after 16th century in timekeeping. A corpus of tables was compiled by Turkish astronomers for Istanbul and other cities of the modern Turkey based on Cairo and Damascus

⁴⁹ Savoie, p. 71-83

⁵⁰ King, 1983, p. 543

⁵¹ King, 1993, p. 30

⁵² King, 1983, p. 547

⁵³ King, 1993, p. 30

astronomers, although Cairo and Damascus astronomers compiled several timekeeping tables for Istanbul and other cities such as Jerusalem, Mecca and Aleppo.⁵⁴

Taqī al-Dīn Ibn al-Ma‘rūf and Sāliḥ Efendī

Taqī al-Dīn Ibn al-Ma‘rūf (c. 16th CE) was one of other Istanbul astronomers who compiled a corpus of tables for timekeeping. He was the director of an observatory in Istanbul in the late of his life duration. But we can mention to Sāliḥ Efendī (c. 18th CE) who was one of the famous *Muwaqqits* in Istanbul and compiled several tables for timekeeping. The most important trait of Ottoman sundials is that in these sundials the time of sunset coincides with the hour 12. This trait, distinguishes Ottoman sundials from Egyptian and Syrian ones. May be this contract was based on this fact that in lunar calendar, day begins at sunset. This contract was used in timekeeping tables too.⁵⁵

The use of trigonometric functions in the calculating of daytime

One of the mathematical subjects which are developed simultaneously by the development of sundials in Islamic civilization was trigonometry. Now, we want to mention to some of trigonometric functions were used by Muslims for first time.

The formula that Alī ibn Amājūr (c. 9th CE) used for timekeeping for all of latitudes is the following:

$$T = \frac{1}{15} \text{arcSin} \left[\frac{\text{Sin}(h)}{\text{Sin}(H)} \right]$$

Where T is seasonal hours after sunrise or before sunset, h is the observed altitude and H is the meridian altitude. But this formula is true only when the sun is in the equinoxes. Ibn Amājūr tabulated all degrees of T (h, H) for the latitude of Baghdad.⁵⁶

In the *Zījes* from the 9th century onwards, We find descriptions of an accurate method for finding $T(h, H)$ that involve the semi-diurnal arc d and the use of the versed sine function ($\text{Vers}\theta = 1 - \text{Cos}\theta$). Modern notation of this formula is:

⁵⁴ King, 2004, Vol. 1, p. 18

⁵⁵ King, 1993, p. 30

⁵⁶ Ibid, pp. 28-29

$$\text{Vers}(d - T) = \text{Vers}d - \frac{\text{Sin}(h).\text{vers}(d)}{\text{Sin}(H)}$$

This formula was adopted by Muslim astronomers from Indian sources.⁵⁷

A new formula was used by late Muslim astronomers such as al-Khalīlī that determines hour angle $t = (d - T)$. We can write this formula in this way:

$$\text{Cos}(t) = \frac{\text{sin}(h) - \text{Sin}(\delta).\text{Sin}(\varphi)}{\text{Cos}(\delta).\text{Cos}(\varphi)}$$

Where δ is solar declination and φ is the local altitude.⁵⁸ We can calculate H (meridian altitude) via the following formula:

$$H = 90^\circ - \varphi + \delta$$

So, we can claim that Muslim activities on sundials which required the knowledge of the motion of the sun and also mathematical and geometrical methods, led them to their progress in spherical astronomy and trigonometric functions.

⁵⁷ Ibid, p. 29

⁵⁸ Ibid, p. 29

Conclusion

Although the Islamic timekeeping played an important role in the religious aspects of Muslims' life, it had crucial effects on Islamic instrumentation. The spreading of the timekeeping through the Islamic civilization after 11th century CE caused important progresses in the design and making Islamic sundials. One of the most significant changes which were occurred in the design of Islamic sundials is changing the position of the style of horizontal sundials from vertical to inclined mode (with respect to the local latitude). Although according to a treatise which is written by Ibrāhīm bin Sinān in 9th century CE maybe the Muslim astronomers knew the theoretical aspects of this subject, it seems that the oldest practical evidence for using the inclined style for a horizontal sundial is the sundial of Damascus great mosque which was made by Ibn al-Shāṭir in 14th century CE.

In addition, some of the sundials which are made near (or in) the mosques after the spreading of the Islamic timekeeping, are more complex than the other ones which were made before 11th century CE. One of the latest examples of these sundials can be found near the mosque of Mohammad 'Alī in Cairo.

Furthermore, Muslim *Muwaqqits*, such as al-Khalīlī, improved some mathematical formulas for determining the solar parameters and some trigonometric functions which were used for calculating the daytime. This progress is an evidence for the important role of ' *Ilm al-Mīqāt* in Islamic mathematical astronomy. Besides, The great number of Muslim *Muwaqqits* who compiled extended works on theoretical and practical aspects of sundials, such as *Djāmi' al Mabādī wa al-Ghāyāt fī 'Ilm al-Mīqāt*, show the important impact of ' *Ilm al-Mīqāt* on the improvement of theoretical foundations of Islamic sundials.

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