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Research Article

Exploration Method of Stone Statue Based on Nondestructive Testing Technology-Taking Xinchang Maitreya Statue as an Example

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Abstract

Non-destructive detection of cultural relics has always been a difficult issue. To effectively detect the degree of weathering in the superficial layer of the Maitreya statue in Xinchang grotto, the microwave humidity nondestructive testing technology was used to detect the humidity of 328 points of the Maitreya statue. For the internal materials of the irregular Maitreya statue, taking moisture detection as the object, the infrared thermography and the microwave humidity method were used to detect the calf parts of the statue respectively, and the weathering degree obtained was basically the same. Results show that the infrared thermography method and the microwave humidity method are suitable for the internal looseness detection of the irregular Maitreya statue and the result has a certain reliability. The conclusions obtained in the study are of the reference value to the similar engineering.

Keywords: Maitreya statue, Nondestructive testing, Infrared thermal imaging, Microwave humidity method.

1. Introduction

According to the principle of minimum intervention and authenticity integrity, how to rationally select the exploration method and improve the scientific diagnosis ability of the statue disease is the primary task of protecting the cultural relics.

With the development of modern science and technology, many advanced testing equipment and testing techniques have been applied in the field of stone cultural relics protection. Since the non-destructive testing technology has the characteristics of high detection resolution and no damage to the measured object [1], the non-destructive testing technology is introduced into the disease investigation work of the stone statue, making it a internal looseness detection method for the stone statue.

At present, the non-destructive or micro-loss detection instruments commonly used for the weathering degree of stone cultural relics are rebounding instruments, hardness testers, roughness meters and ultrasonic instruments. The rebound tester and hardness tester can only detect the surface strength of the stone, but can not do anything for the damage of the superficial layer. The roughness meter and the ultrasonic instrument have high requirements on the flatness and roughness of the tested body. Therefore, these instruments are obviously not suitable for detecting the degree of looseness in the superficial layer of the stone statue. As the seventh key cultural relics protection in China, the Maitreya statue of the Buddha Temple is the remains of the important statues of the Southern China, which is the largest and most ancient stone statue in the south of the Yangtze River [2]. So the operating characteristics and detection effects of infrared thermal imaging and microwave humidity detection methods are more suitable for the detection of the stone disease of the Maitreya statue.

2. State of the Art

Infrared thermography has been applied to the detection of cultural relics. For examples, Wu and Liu used infrared technology to detect the water seepage of the cliffs in Huashan rock paintings and they found that the infrared technology can not only effectively detect the water seepage of rock paintings, the location can also be determined by the amount of water seepage [3]. Zhang applied the infrared thermal imaging technology to detect the water seepage disease of stone cultural relics [4]. Su et al. found the obvious differences in the distribution of condensed water in different parts of the Avalokitesvara imagery area [5]. Zhou and Gao researched on the weathering indicators of stone cultural relics and also introduced the detection methods of common weathering diseases [6]. Zhou et al. analyzed the internal fissures and moisture of the post-stepstone of the Chengde Mountain Resort and they found that the infrared thermal image can measure the internal trend of the crack [7]. Avdelidis and Moropoulou conducted infrared detection before and after restoration of ancient buildings of Greek banks and evaluated the protective effects of different repair materials on the city wall [8]. Budrugeac et al. used infrared technology to apply to other cultural relics research [9].

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Tighe et al. detected different types of holes inside the sample by using the infrared detection technology [10].

There are few research and application cases on microwave moisture technology in the detection of stone cultural relics. Ye and Li used microwave moisture method, infrared thermal imaging, color difference detection, and other techniques to evaluate the repair effect of Hangzhou Baita grouting [11]. He et al. used the microwave humidity method to detect the stone artifacts of the Yangxin Temple in the Forbidden City of Beijing and they found that this method can be used for evaluating the degree of deterioration of stone artifacts [12]. Li used the microwave humidity test system to measure the moisture content of the wall and realized the quantitative measurement of the moisture content of the wall under non-destructive conditions [13]. Lu et al. used a microwave moisture meter to test the humidity of concrete lining [14].

Kaariainen et al. used a microwave detector to test concrete, wood, sand and other test pieces and they found that the moisture content error was between 0 and 2% [15]. Austin and Harris used microwave resonance sensors to monitor the bulk density and water content of fast flowing particles and obtained empirical correction models for simultaneous moisture content and effective bulk density [16]. Cataldo et al. embedded linear sensing probes in the wall and found that linear sensors based on time domain reflectometry can be applied to the monitoring of moisture in building structures [17]. Pavlík et al. applied the time domain reflectometry technique to the moisture distribution measurement of aerated concrete and determined the water diffusion coefficient of the samples based on the measured moisture content [18].

This study was carried out to detect the degree of weathering in the superficial layer of the Maitreya statue in Xinchang grotto by using the nondestructive testing technology. The rest of this study is organized as follows. Section 3 describes the two test methods. Section 4 gives the results analysis and discussion, and finally, the conclusions are summarized in Section 5.

3. Methodology

3.1 Engineering background

The Maitreya Grotto is located in Xinchang County, Zhejiang Province, China. It was built in the third year of Qiyongming (485) in the Southern Dynasties. The height of the cave is 17.13 m, its width is 15.65 m, and its depth is 10.69 m. The plane of the grotto is horizontal elliptical, open top and open the front wall, and which is connect the five-story pavilion in front of the grotto. The Maitreya statue is 2 m high and which sits at a height of 14.05 m. The partial repair of the Maitreya Grottoes since 1991, it has been discovered that Maitreya statue has some flaky damages, some stones falling from the top of the grotto, and some water seepage in the grotto. Maitreya statue had micro cracks on the left and right shoulders and it has been slowly expanding since 2006.

3.2 The followed principle

Non-destructive testing is adopted by infrared thermal imaging and microwave humidity method, and high-resolution photo archiving is performed for detection points and detection processes. This inspection work is based on the repair of the Maitreya statue in the Xinchang Grotto. The following principles must be followed:

This work must strictly implement the relevant principles of the cultural relics protection. The testing work itself must not have a new destructive effect on the cultural relics. Try to choose non-destructive technology. This work should be carried out by using advanced and mature scientific and technological means, which is different from the manual observation and empirical judgment of traditional survey work. The adoption technology must be objective and rigorous, and more mature and reliable technologies. When detecting the operation of the device, it is necessary to avoid mistakes and reduce data errors.

3.3 Microwave humidity method

The microwave hygrometer emits microwaves, the internal humidity of the object can be measured by absorbing the reflected waves. The microwave humidity method can be used to accurately measure the liquid water inside the measured object. According to the activity of the internal liquid water, it is judged whether there is pore inside the stone cultural relic. Therefore, the degree of weathering of the Maitreya statue can be detected using microwave humidity.

The MOIST 300B is an instrument that measures the moisture content of materials at different depths (Fig. 1). The probe is placed on the tested surface, and the water content can be measured according to the principle that water molecules move under the action of microwaves. The water content at different depths can be measured by different probes, and the water distribution from 3 cm to 11 cm deep inside the stone can be inferred.

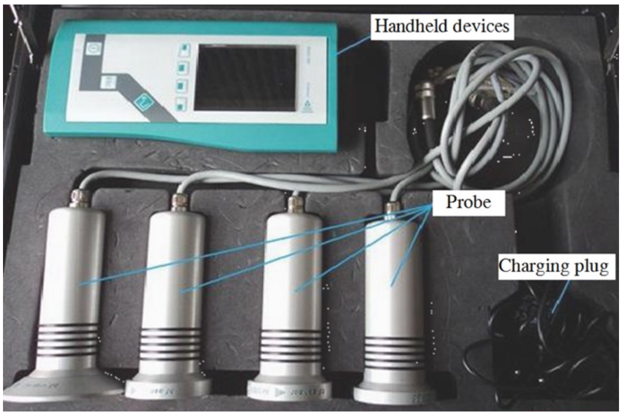

Fig. 1. Microwave hygrometer.

The interval between the two points is about 0.4 - 0.6 m, average 0.5 m, and the distance between the two groups is about 0.6 - 0.8 m, average 0.7 m. Since the shape of the stone statue is irregular, the number of groups of each detection point will be greatly different. The microwave humidity detection value characterizes the moisture content of the measured stone in the form of humidity index, and compares it with the humidity index of the rock sample of different weathering control groups.

The control rock samples were firstly placed in the Maitreya Cave for more than one month, so that the humidity environment was basically the same as that of the Maitreya statue. Then the microwave humidity was measured at the Maitreya statue, and the humidity index of the control samples was measured. So, this as a criterion for judging the degree of weathering of the Maitreya statue.

3.4 Infrared thermal imaging method

Infrared thermal imaging technology is completely safe for the surface of cultural relics. An infrared thermal imager converts invisible infrared energy emitted by an object into a visible thermal image. The different colors on the thermal image represent the different temperatures of the measured object. By looking at the thermal image, people can observe the overall temperature distribution of the target being measured. This test uses the Fluke Tis40 portable infrared thermal imager (Fig. 2).

Fig. 2. Infrared thermal imaging technology.

If there is loose or empty drum inside the Maitreya statue, the deviation of the specific heat value of the part will be larger, and the uneven temperature range is reflected in the infrared thermography image. According to the above principle, infrared thermal imaging can be used to detect the uniformity of the temperature variation inside the Maitreya statue, and to find the loose and hollow parts in the rock.

Due to the complexity of the degradation of stone artifacts, the multi-solution of non-destructive testing methods is necessary. It is necessary to adopt two suitable detection methods to verify and supplement each other, and improve the accuracy and reliability of the non-destructive testing of the Maitreya statue. Considering that the infrared thermal imager has a certain limitation in the Xichang Maitreya Grotto, only the infrared thermal imaging of the parts of the calf is performed as a verification of the results of the microwave humidity detection.

4. Results Analysis and Discussion

4.1 Microwave humidity test

The basic rock samples were taken from the falling stones from the top of the grotto (Fig. 3a) and the fresh rock samples from the nearby mountains (Fig. 3b). The falling stones at the top of the grotto were microscopically examined by X-ray diffractometer and scanning electron microscopy, and it was judged that the weathering erosion of the rock sample was serious (Fig. 4).

According to the design scheme, the microwave humidity was carried out on the two groups of the falling rock and the fresh rock samples of the mountain. For the same depth 7 cm, the average humidity index of the weathered rock blocks was 2564 and that of the fresh rock samples was 435. According to this, it can be approximated that the stone statue with a humidity index of less than 1000 is denser, the degree of looseness of the body with a humidity index of 1000-2000 is lighter, the degree of porosity of the body with a humidity index of 2000-3000 is moderate empty drum phenomenon, and the humidity index is 3000 indicate the rock mass is severely loose (empty drum phenomenon serious).

(a) Falling stones at the top of the grotto

(b) The fresh rock samples on site

Fig. 3. The collecting rock samples.

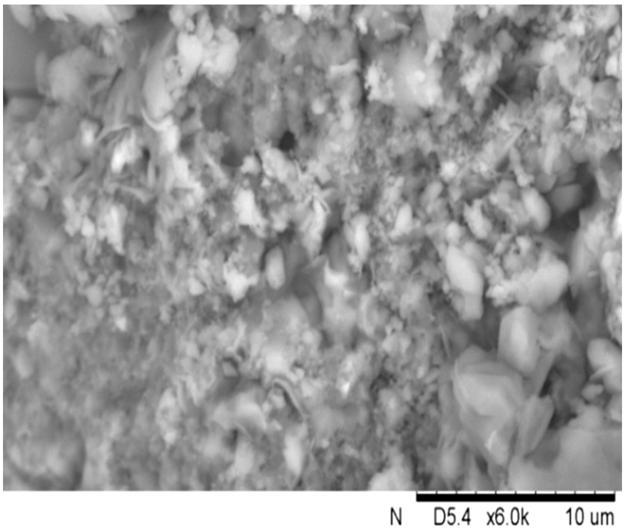

Fig. 4. SEM photo of rock sample (magnification 6000 times).

The following microwave humidity tests were selected from the position of the 3 cm depth of the Maitreya calf, the 3 cm, 7 cm, and 11 cm depth of the knee on the west side, and 11 cm depth of the upper body of the Maitreya statue. The test number and the related information are shown in Tables 1-4 and Fig. 5.

Table 1. Microwave humidity index detection point number at 3 cm depth of stone statue.

Body parts	West side calf		East side calf		West knee		
Point number	1	2	3	4	5	6	7

Table 2. Microwave humidity index detection point number at 7 cm depth of stone statue.

Body parts	West knee		
Point number	5	6	7

Table 3. Microwave humidity index detection point number at 11 cm depth of lower stone statue.

Body parts	West knee			Torso										
Point number	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Table. 4. Microwave humidity index detection point number at 11 cm depth of upper stone statue.

Body parts	West shoulder		East shoulder			Head			
Point number	19	20	21	22	23	24	25	26	27	28

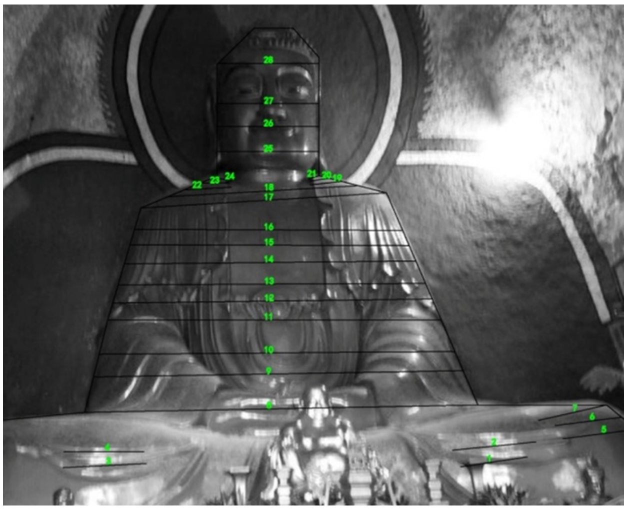

Fig. 5. Measurement points of microwave humidity.

As seen from Tables 1-4 and Fig. 6-12, there is a big difference in the degree of relaxation between different parts of the stone statue. There is less empty drum at the depth of 3 cm on the west side of the stone statue, a partial empty drum at the depth of 7 cm, and a large area empty drum at the depth of 11 cm. Due to the limitation of on-site detection conditions, the upper part of the stone statue is mainly detected. According to the total number of detection points and the humidity value of each point, the area with a lighter degree of looseness accounts for about 35%, the area with a common loose degree accounts for about 60% of the total tested area. The area with a large degree of looseness is not found. Therefore, it can be judged that there is a loose phenomenon in the stone statue, but it is not serious.

The test results are shown in Fig. 13, where the symbl ● indicate the area with a common loose degree of looseness, but the symbl ○ indicate the area with a lighter degree of looseness.

4.2 Infrared thermal imaging test

To verify the accuracy and reliability of the micro-humidity method to determine the looseness of the stone statue, the infrared calorigraphy method was used to test looseness of the calf parts of the stone statue.

As seen from Fig. 14, there are three obvious empty drums in the calf parts of the stone statue. The measured area of the calf parts of stone statue is about 1.46% of that of the total test area. Since the surface of the stone statue is covered with two layers of gold foil, the inside of the gold foil is a layer of mantle composed of a mud layer and a gauze. These materials are different and the specific heats of two materials are different. The thermal conductivity of metallic materials is better than that of shale materials, so the temperature of that area is higher on the thermographic image. On the left side of Fig. 14, there are two smaller detached hollow drum zones, while on the right side of the Fig. 14 is a larger but less detached hollow drum zone.

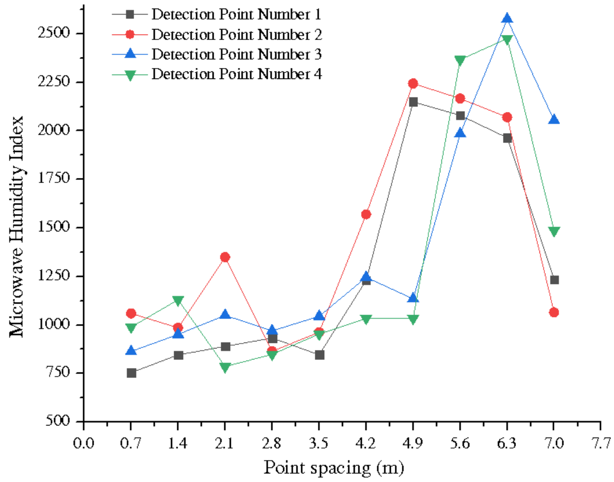

Fig. 6. Humidity values at depth 3 cm of calf

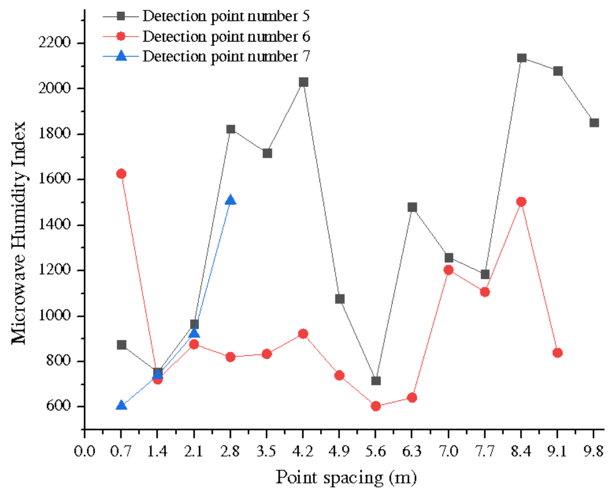

Fig. 7. Humidity values at depth 3 cm of west knee

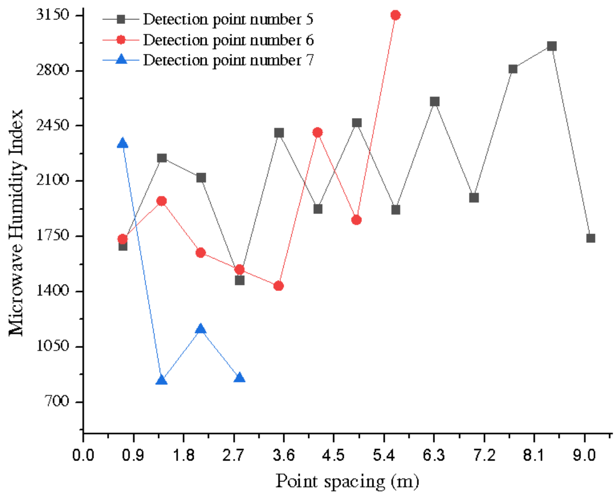

Fig. 8. Humidity values at depth 7 cm of west knee

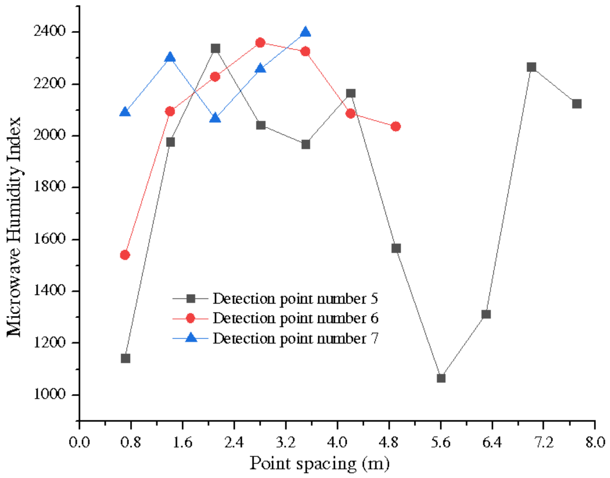

Fig. 9. Humidity values at depth 11 cm of west knee

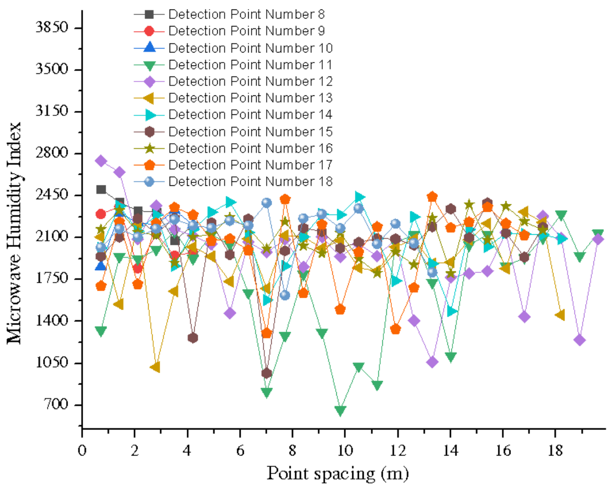

Fig. 10. Humidity values at depth 11 cm of torso

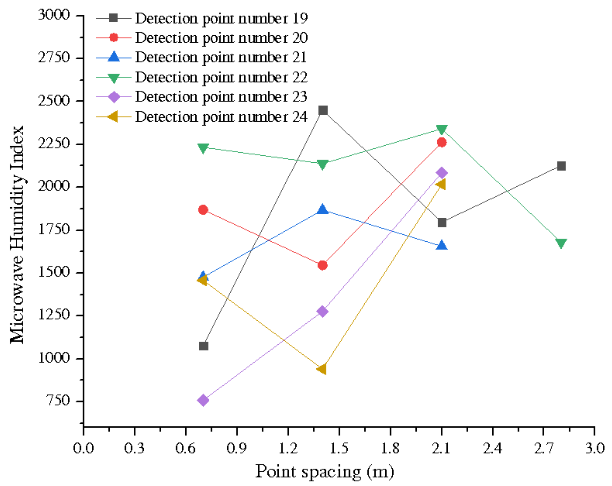

Fig. 11. Humidity values at depth 11 cm of shoulder

It can be seen from the comparison between Figs. 14 and 15 that the results obtained by the two non-destructive testing methods for the calf parts of the stone statue are relatively close, which not only verify each other, but also indicates that two non-destructive testing techniques, namely infrared thermal imaging and microwave humidity method, are suitable to detect the looseness of the stone statue.

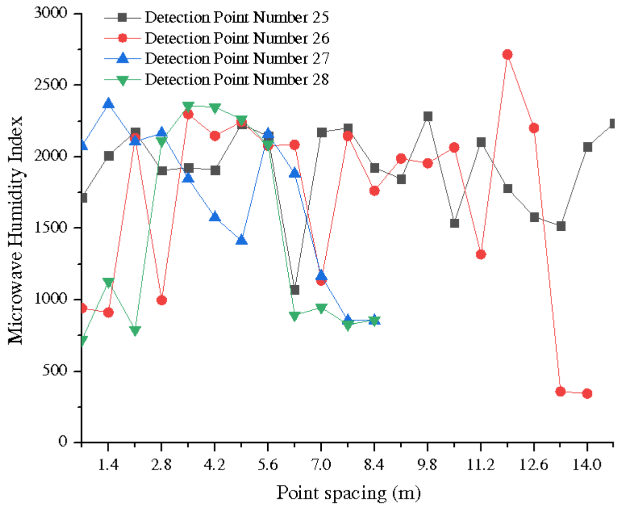

Fig. 12. Humidity values at depth 11 cm of head

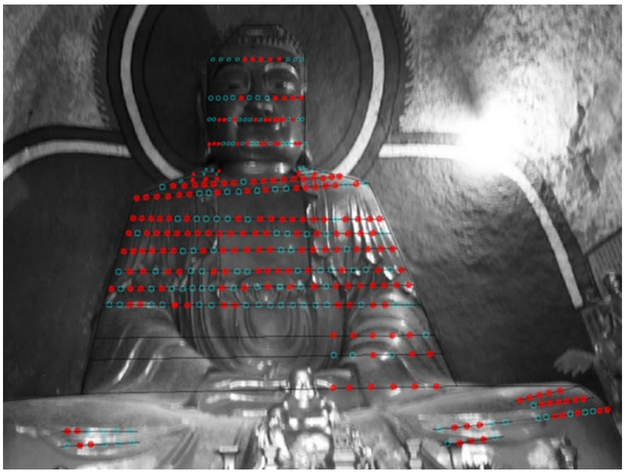

Fig. 13. Test results of microwave humidity.

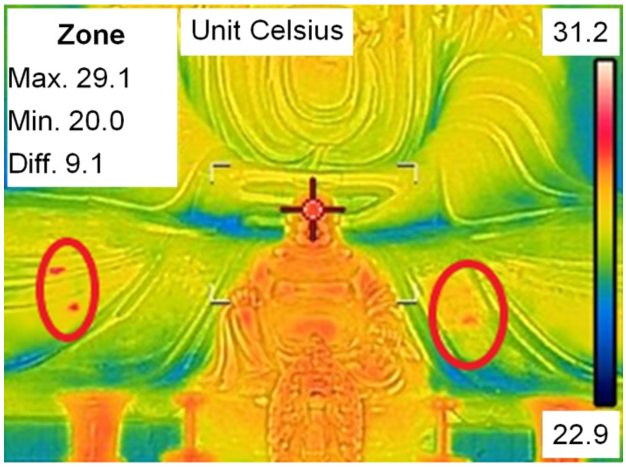

Fig. 14. Empty drum schematic of calf parts of stone statue.

5. Conclusions

To effectively detect the degree of weathering in the superficial layer of the Maitreya statue, the microwave humidity and infrared thermal imaging methods were used to detect the looseness of the stone statue. The main conclusions are as following.

Due to the high humidity all the year round, taking moisture detection as the object, the microwave moisture detection and infrared thermal imaging methods are suitable for non-destructive testing of the degree of weathering of stone cave.

For the internal materials of the irregular Maitreya statue, the results of infrared thermal imaging and microwave humidity method can be used as a basis reference for judging the degree of looseness of the stone statue.

In this study, it is the preliminary exploration for the microwave humidity and infrared thermography methods being applied to the investigation of grotto disease. The next step is to use the data of temperature and humidity monitoring in the grotto to bulid the prediction models to provide quantitative judgment for the detection of grotto weathering degree.

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