Application of Dual-frequency Identification Sonar to detection of visible damages of underwater hydraulic structures

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Abstract. Based on the limitation of the conventional methods to the detection of visible damages underwater to the hydraulic structures, along with the characteristics of the visible damages, we suggest the application of Dual-frequency Identification Sonar technology for its detection. This paper illustrates how Dual-frequency Identification Sonar technology works and puts forward the method of detection. The application of Dual-frequency Identification Sonar technology has been carried out in engineering practice and the result indicates that the technology performs well in the detection of visible damages underwater to the hydraulic structures.

1. Introduction
After long-term operation of hydraulic structures like water gates, pumping stations and locks, various diseases such as cracks, craters, erosion will occur, and cause serious damage. Since these diseases occur in the underwater parts of buildings, and they are in the blind spots of inspection of technical management work, the occurrence and expansion of diseases are concealed and difficult to find in time. The detection is also troublesome. The progress of underwater disease detection technology is slow for a long time, and the following operation methods are limited [1]. What is usually used today is still the conventional method of diving exploration.

Due to the low underwater visibility in most cases, especially when the water quality is turbid, the underwater visual inspection of the divers is generally difficult to implement, and an intuitive recording such as an image cannot be generated. At the same time, the method has high requirements for diving operation skills, the divers’ underwater operation experience, so the test results are not objective enough. Other methods, such as underwater robot ROV technology [2], also require higher turbidity of water; the technology of self-floating pneumatic caisson also has some shortcomings, such as small maintenance range of single cover, influence of water depth and net height [3].

Detection of underwater diseases is important in the safety inspection for hydraulic structures. How to effectively detect underwater diseases in hydraulic structures is very important. In this regard, the use of Dual-frequency Identification Sonar technology is proposed for underwater disease detection of hydraulic structures in this paper, and is applied in many large and medium-sized hydraulic projects.
2. Characteristics of the types of underwater diseases in hydraulic structures

Due to the long-term operation and frequent activation of hydraulic structures, buildings and ancillary facilities will continue to age. Especially in buildings with early construction, due to low design standards, construction and management levels, the risk rate is higher. Uneven settlement of foundation, improper control of seepage, aging of concrete structure, cavitation and wear of water flow will cause various underwater diseases in hydraulic structures [4].

Among the various types of underwater diseases, some of them are visible and detectable appearance diseases, such as cracks, abrasions, collapses [5], etc. Most of the underwater diseases are of this type; some are invisible but detectable. For example, water damage is difficult to judge whether it is damaged by visual alone, because it is located in the expansion joint, and it needs to be obtained by exploration; some are neither visible nor detectable, such as the base of the water gate bottom. When it is empty, it must be obtained by special means of detection. For underwater detection of hydraulic structures, it is possible to obtain underwater appearance diseases, which can basically meet the needs of safety identification and evaluation of hydraulic structures. Therefore, the detection of underwater appearance diseases should be the focus of underwater detection. In this paper, the main object of Dual-frequency Identification Sonar detection is also the underwater appearance disease.

3. Basic theory of Dual-frequency Identification Sonar

3.1 Working principle

Dual-frequency Identification Sonar is a device that uses ultrasound to obtain high-resolution and large range clear images. When the Dual-frequency Identification Sonar works, the transmitting system emits transmission signal with a certain acoustic information into the water medium, and if the signal encounters an obstacle when it propagates in the water, an echo signal is generated. The echo signal is converted into a corresponding electrical signal by the receiving transducer, which is processed by the processor and transmitted to the discriminator. It makes a decision on whether there is a target or not according to the pre-determined principle, and points out the distance, azimuth, velocity and some physical attributes of the target after making the decision on if there is a target. Finally, the result is displayed by indicator [6]. Table 1 is the DIDSON (300m standard type) Dual-frequency Identification Sonar performance parameters [7].

| Working mode | Working frequency | Horizontal beam width | Vertical beam width | Beam number | Horizontal view | Vertical view | Detection distance |
|--------------|-------------------|-----------------------|---------------------|-------------|----------------|-------------|-------------------|
| Identification mode | 1.8MHz  | 0.3°  | 14°  | 96   | 29°  | 14°  | 1-15m |
| Sniffer mode | 1.1 MHz  | 0.6°  | 14°  | 48   | 29°  | 14°  | 1-30m |

3.2 Imaging characteristics

Dual-frequency Identification Sonar uses acoustic lenses to compress and converge sound waves to form narrow beams to obtain high-definition image data. There are two important advantages of compressing beams with acoustic lenses: one is that the compressing beams do not need to consume energy, and the working power of the instrument is only 30W; the other is that it is easy to transmit and receive the same beams without confusion with other beams and receive the wrong beams [8], so the anti-interference ability is strong.

The beam emitted by the Dual-frequency Identification Sonar passes through the surface of the object, and the image is displayed according to the intensity of the echo. When the frequency of the beam is high, an acoustic shadow appears on the image display. Dual-frequency Identification Sonar can automatically zoom the detection target within the effective range of sight to ensure the sharpness of the image.
3.3 Range and resolution of imaging

The imaging range of the Dual-frequency Identification Sonar is related to its working attitude angle and detection distance. Adjusting the working attitude angle of the sonar can adjust its imaging range and window length. When the detection distance is fixed, the working angle is inclined, the imaging range is smaller, and the window length is shorter. The imaging range of the sonar is also related to the detection distance. As shown in figure 1, the horizontal viewing angle of the sonar operation is 29° and the vertical viewing angle is 14°. Therefore, the longer the detection distance is, the larger the projection surface is when the sonar working attitude angle is fixed. The imaging range is also larger.

![Figure 1. DIDSON Dual-frequency Identification Sonar imaging perspective](image)

Dual-frequency Identification Sonar has 512 samples per beam. The imaging resolution perpendicular to the beam direction is half the distance of the target from the acoustic lens divided by the number of beams. The resolution of the beam direction is the window length divided by the number of sampling points 512 \[8\]. Taking the operation of the sonar in the recognition mode as an example, if the detection distance of the underwater disease target is 8m and the length of the observation window is 10m, the resolution of the object perpendicular to the beam direction is 4.2cm and the resolution of the beam direction is 1.95cm. It can be seen that the resolution of the Dual-frequency Identification Sonar is very high.

3.4 Detecting the adaptability of diseases in hydraulic structures underwater

Since the rivers and lakes in which most of the hydraulic structures are located have a certain degree of turbidity, underwater imaging systems based on optical principles such as underwater robot ROV are difficult to function. Because the Dual-frequency Identification Sonar is imaged by acoustic principle, it largely compensates for the defects of the optical imaging system, which is limited by the brightness of the ambient light source, the transparency of the water body and the contrast of the environment. It can obtain better image effects in the turbid water body, which can be applied in detection of hydraulic structures underwater; at the same time, the Dual-frequency Identification Sonar is small in size, light in weight, easy to install, and can be carried by ships and boats, easy to operate in the small hydraulic structures and narrow waters.

4. Detection methods and key technologies

4.1 Instrument installation and attitude control

Dual-frequency Identification Sonar probe is mounted on the side of the hull with a fixed bracket and the bracket is connected to the hull by sleeve rods, so that the sonar probe can be adjusted in two aspects according to the detection requirements: one is the vertical lifting of the sonar probe to adjust the lens and the distance of the detection target. The second is the rotation of the sonar probe to adjust the attitude angle and imaging range of the sonar work.

In the sonar working attitude angle control, according to the field detection experience, usually the sonar lens keeps tilting downward at an angle of 30° to the horizontal plane, then the ideal imaging
range and imaging effect will be obtained. Therefore, when designing the mounting bracket, the fixing plate of the sonar on the bracket and the vertical rod of the bracket are reserved at a fixed angle to facilitate the attitude control of the sonar during installation and detection. The installation of the Dual-frequency Identification Sonar is shown in figure 2.

4.2 Control of sonar movement speed
Since the beams emitted by the Dual-frequency Identification Sonar are not transmitted together, there is a certain interval, so that when the instrument is mounted on a moving object or the detected object is moving, and the speed is relatively fast, the outline of the image will appear serrated; when the speed is reduced, the zigzag features are improved significantly, as shown in figure 3. Therefore, in order to obtain high-quality images that meet the requirements for underwater disease detection, the sonar probe movement and rotation should be controlled at a slow speed. According to the experience of on-site inspection, in order to eliminate the serrated outline of the image, the translation speed of the sonar is usually not more than 3m/s, and the rotation speed should not exceed 10°/s.

4.3 Layout of survey lines
When using Dual-frequency Identification Sonar detection, the layout scheme of survey lines should be determined according to the structure and contour characteristics of buildings. For areas with uniform contours and large areas, such as sluice floor, sea overflow, guard, ship lock chamber, approach channel, etc., the survey line shall be arranged according to the longitudinal axis of the parallel building; for special parts with small contour, such as sluice gate slot, expansion joint, sluice sill, overhaul gate slot, corridor and so on, fixed point detection is carried out. In order to ensure that the detection area is not missing, it is required that the images of the detection scenes of different lines overlap. Since the imaging angle of the sonar is fixed, the imaging range is related to the detection...
distance. Therefore, the distance between the measurement line should be determined according to the distance between the sonar lens and the detection target before detection. The shorter the detection distance is, the smaller the line spacing will be. Usually for high-definition imaging, the Dual-frequency Identification Sonar should ensure that it works in high-frequency state and recognition mode. The distance between the detection target and the sonar lens is controlled within 15m. According to the horizontal working angle of the sonar 29°, the maximum spacing of the measurement line can be calculated which should be controlled within 8m. According to the experience of on-site inspection, the line spacing is usually controlled at 2~5m.

4.4 Target image positioning
Using Dual-frequency Identification Sonar to detect hydraulic structures underwater requires not only the target image, but also the location of the detection target image for large areas such as floodgates and lock chambers where the background characteristics of the detection target are not obvious. In order to realize the position of sonar images, our institute introduced GPS positioning technology in the application practice, and combined the Dual-frequency Identification Sonar with the GPS. First, the layout of the survey network was carried out through the GPS, and the GPS-RTK mode was used for navigation and positioning in the detection to accurately control the motion trajectory of sonar; Secondly, the GPS was marked when the sonar appeared the characteristic image, and the coordinates were recorded in real time. The position information of the scanning target image was converted according to the detection depth, sonar underwater working depth and scanning angle. The location of sonar detection image can provide more sufficient basis for the safety evaluation of hydraulic structures.

5. Application examples and effects
In order to test the effect of Dual-frequency Identification Sonar technology in detection of hydraulic structures underwater, the application tests were carried out in Jianbi control gate and Sanhe lock. Jianbi control gate is the backbone water conservancy project in the west basin of Taihu Lake. It was built in August 1959. The upper reach of the gate is connected with the Grand Canal of Southern Jiangsu and the lower reach is connected with the Yangtze River. There are 15 holes with a net width of 3.8 m per hole and a total net width of 57 M. In April 2009, it was identified as "four types of gates" after safety identification and needed to be demolished and rebuilt. The Sanhe lock project is a dike-piercing structure of the Hongze Lake embankment. The upper lock head cuts the Hongze Lake embankment into the Hongze Lake. The lower reach of the project passes through the Shigang Lock, the Jinbao Channel and the South-to-West Lock to the Grand Canal to connect the Sanhe reach of the Huaihe River,. The project was completed in March 1970 with a designed annual navigation capacity of 1.8 million tons. After construction, it has been repaired and reinforced many times. Both the Jianbi control gate and the Sanhe sluice are large and medium-sized hydraulic structures with a long history of construction and frequent operation. At the same time, the turbidity of the water body in the locks is obvious, which has a certain representativeness.
Figure 4. Part of underwater detection images of Jian Bi control gate

Figure 5. Part of underwater detection images of Sanhe lock

When the Jianbi control gate was detected, the tide level of the Yangtze River was 4.70m, the water depth of the chamber was about 5.1m, the underwater working depth of the sonar probe was 3.0m, the detection target distance was controlled within 5m, and the line spacing was 2m. When the Sanhe lock was detected, the water depth of the sluice chamber and the downstream overflow section is about 3.0m, the working depth of the sonar probe was 1.0m, the detection target distance was controlled within 5m, and the distance between the lines was 2m. The scene detection photos are shown in figure 3. The detection image of the Dual-frequency Identification Sonar is shown in figure 4 and figure 5 above.
From the figure above, damage and siltation of the underwater construction of hydraulic structures can be clearly seen, which provides intuitive and recordable image data for underwater detection of hydraulic structures. Especially for the narrow space of the lock corridor and difficult implementation of the diving exploration, Dual-frequency Identification Sonar detection can fully utilize its advantages of small size and flexible operation. DIDSON acquisition software also provides measure function that can obtain the target range size of the image. As shown in the figure above, the damage size of the bottom floor of the Jianbi lock chamber was about 0.3 x 0.27 m, and the damage size of the Sanhe Ship Lock Corridor was about 0.64×0.58m. After the detection was completed, according to the GPS coordinates of the real-time marking recorded in the sonar detection, as well as the water depth, the sonar working depth and the scanning angle during the detection, position information of the scanning target image was obtained by conversion, thereby realizing the positioning of the underwater target.

6. Conclusion
1. Dual-frequency Identification Sonar technology has obvious technical advantages. It compensates for the defects of the optical imaging system by the brightness of the ambient light source, the transparency of the water body and the contrast of the environment through the imaging of the acoustic principle. It can work at high frequency and identification mode to obtain resolution and can obtain high, clear image in turbid and dim water;
2. Dual-frequency Identification Sonar technology can provide intuitive, continuous and recordable image data for underwater appearance disease detection of hydraulic structures;
3. The operation of the Dual-frequency Identification Sonar is simple and flexible, especially for the effective detection of difficult space and difficult parts for diving exploration, and it has high work efficiency and low detection cost;
4. Dual-frequency Identification Sonar can be used in conjunction with the GPS to achieve positioning of underwater detection target images.

Although the Dual-frequency Identification Sonar has better effect on underwater detection, the diseases of hydraulic structures underwater have various forms and distribution ranges, and the imaging effect of Dual-frequency Identification Sonar has higher requirements on its working attitude and shooting distance. At present, the so-called sonar probes are mostly simple fixed brackets. The control is inconvenient and the control of the sonar working posture and angle is extensive, and the accuracy of underwater target image positioning is also affected, which needs further research and improvement.

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