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**Acoustics - High intensity focused ultrasound (HIFU)
measurements of acoustic power and field characteristics**

声学 高强度聚焦超声（HIFU）声功率和声场特性的测量

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Table of Contents

Foreword.....	3
Introduction.....	4
1 Scope	5
2 Normative references.....	5
3 Terms and definitions.....	5
4 General	10
5 Requirements of measurement system.....	11
5.1 Requirements for radiation force balance system	11
5.2 Requirements for hydrophone measurement system.....	11
5.3 Requirements for measurement water tank.....	13
5.4 Requirements for water and degassing.....	16
5.5 Requirements for high-intensity focusing system under test.....	16
5.6 Requirements for measuring instruments	16
6 Sound power measurement methods	17
6.1 Measurement of radiation force	17
6.2 Calculation of sound power	17
7 Measurement of sound field characteristics.....	20
7.1 Measurement preparations.....	20
7.2 Alignment of hydrophone.....	20
7.3 Measurement steps	20
References.....	25

Acoustics - High intensity focused ultrasound (HIFU)

measurements of acoustic power and field characteristics

1 Scope

This standard specifies the measurement conditions and methods, for sound power and sound field characteristic parameters of high-intensity focused ultrasound (HIFU) in water, within the frequency range of 0.5 MHz ~ 5 MHz.

This standard applies to high-intensity focused ultrasound systems.

Note 1: This standard uses SI units. In some parameter descriptions, such as the beam area parameter and the sound intensity parameter, it may be more convenient to use other units. For example: The unit of sound beam area can be cm^2 ; the unit of sound intensity can be W/cm^2 or kW/cm^2 .

Note 2: The measurement range specified in this standard: the power is not more than 500 W; the sound intensity is not more than $5000 \text{ W}/\text{cm}^2$.

2 Normative references

The provisions in following documents become the provisions of this Standard through reference in this Standard. For the dated references, the subsequent amendments (excluding corrections) or revisions do not apply to this Standard; however, parties who reach an agreement based on this Standard are encouraged to study if the latest versions of these documents are applicable. For undated references, the latest edition of the referenced document applies.

GB/T 3947-1996 Acoustical terminology

3 Terms and definitions

The terms and definitions, as determined in GB/T 3947-1996, as well as the following terms and definitions, apply to this standard.

3.1

High intensity focused ultrasound (HIFU)

Using methods such as acoustics and electronics, to converge the ultrasonic beam

5 Requirements of measurement system

5.1 Requirements for radiation force balance system

5.1.1 Target requirements

This standard recommends the use of an absorbing target: the sound pressure reflection coefficient is required to be $\leq 5\%$; the sound pressure transmission coefficient is less than 10%. The area of the target is large enough, that its diameter or minimum dimension is greater than 1.5 times the -26 dB beam width, in the intercepted plane.

5.1.2 Requirements for target support (or suspension) system

The support of the target shall have sufficient stability; the horizontal displacement of the target during the measurement shall be small enough, to not affect the measurement results. Keep the target surface perpendicular to the beam axis.

5.1.3 Force measuring system

The force measuring system can use an electronic balance or a force measuring sensor system. The measurement precision is required to be better than 10^{-3} N.

5.2 Requirements for hydrophone measurement system

5.2.1 Requirements for hydrophones

5.2.1.1 Requirements for hydrophone sensitivity

The free-field voltage sensitivity, at the end of the hydrophone cable, is not less than 10 nV/Pa.

5.2.1.2 Bandwidth requirements for hydrophones

The fluctuation of the hydrophone's sensitivity shall be within ± 6 dB, when changing in the 2-octave range of the acoustic operating frequency.

5.2.1.3 Directivity requirements for hydrophones

At the acoustic operating frequency, the main beam width of sound pressure -6 dB in the direction of the acoustic axis is $\geq 70^\circ$.

5.2.1.4 Determination of effective radius of hydrophone

Measure $\theta_{-3\text{ dB}}$ and $\theta_{-6\text{ dB}}$. Use formulas (2) and (3), to calculate $\alpha_{-3\text{ dB}}$ and $\alpha_{-6\text{ dB}}$. Use formula (4), to calculate the arithmetic mean of the two, which is the effective radius α

Figure 4 -- Configuration of the HIFU sound field with beam down, as measured by the hydrophone method

5.4 Requirements for water and degassing

5.4.1 Water quality requirements

It is required to use purified water or tap water after purification.

5.4.2 Degassing requirements

The water in the water tank must be degassed, to meet the requirement of oxygen content ≤ 4 mg/L.

Note: The water after degassing shall be strictly prevented from shaking, stirring, spraying, or other operations, during the filling process, so as to avoid the re-dissolving of air causing the oxygen content to exceed the standard.

5.4.3 Water temperature requirements

The water in the water tank is kept at (23 ± 3) °C.

5.5 Requirements for high-intensity focusing system under test

5.5.1 Requirements for the frequency stability of the high-intensity focusing system under test

After preheating for 15 min, the frequency stability reaches $10^{-4}/4$ h.

5.5.2 Requirements for the electrical power stability of the high-intensity focusing system under test

After 15 min of preheating, the electrical power stability reaches $10\%/4$ h.

5.5.3 Requirements of the hydrophone method for the measurement working state of the high-intensity focusing system under test

In order to ensure the safety and service life of the measuring device, the device under test is required to have a dedicated pulse measurement working state. This state requires: the pulse duration is less than or equal to 100 μ s; the pulse repetition frequency is less than 1 kHz.

5.6 Requirements for measuring instruments

The frequency range of the oscilloscope shall be higher than 10 times the sound

operating frequency; the DC vertical gain accuracy shall be $\pm 2\%$ full scale. It has storage and spectrum analysis functions.

6 Sound power measurement methods

6.1 Measurement of radiation force

The radiation force is measured, using the devices as shown in Figures 1 and 2. In order to avoid the influence of nonlinearity and acoustic flow on the radiation force measurement, the axial position of the absorption target shall be set, near the sound source away from the sound focal point. The absorption target shall be perpendicular to the sound axis; the bullseye shall be aligned with the sound axis; the distance from the transducer or the center of the transducer surface should not be greater than 0.7 times the sound pressure focal length. Before measurement, the absorption target shall be soaked for 30 minutes; the instrument shall be preheated for 15 minutes.

In order to reduce the influence of thermal drift, it shall measure the short-term (within 2 ~ 3 s) stable value of the balance indication value, when ultrasonic waves are applied and when ultrasonic waves are interrupted; the difference between the two is the ratio m -- of the normal radiation force F on the absorption target TO the gravity of acceleration g . The unit is kg.

Note: When the lever mechanism is used, the force measured by the electronic balance shall be converted into the actual force on the absorption target, by calibrating the force arm ratio.

During the measurement, it shall observe the surface of the absorption target and the transducer at any time; remove the small bubbles appearing on it in time.

6.2 Calculation of sound power

6.2.1 Acoustic power calculation of spherical focusing unit transducer

$$P = \frac{2Fc}{1 + \cos\beta} e^{2\alpha \cdot d} \dots\dots\dots (6)$$

Where:

P - Sound power, in watts (W);

F - The normal radiation force on the absorption target, in Newton (N);

c - The speed of sound of water, in meters per second (m/s);

Position the hydrophone at the sound focal point, to measure the maximum positive sound pressure p_+ and the maximum negative sound pressure p_- :

$$p_+ = |U_{+\max}| / M_L$$

$$p_- = |U_{-\max}| / M_L$$

Where:

$U_{+\max}$ - The positive peak value of the output sound pressure signal voltage of the hydrophone, at the sound focus, in volts (V);

$U_{-\max}$ - The negative peak value of the output sound pressure signal voltage of the hydrophone, at the sound focal point, in volts (V);

M_L - The load sensitivity of the hydrophone at free-field cable end, in volts per pascal (V/Pa).

7.3.1.2 Measurement of acoustic operating frequency (f_{awf})

Input the instantaneous sound pressure waveform signal, which is measured by the hydrophone, into the oscilloscope. Use the oscilloscope or other spectrum analyzer, to measure the sound operating frequency.

7.3.1.3 Measurement of spatial peak intensity (I_{sp})

Calculate and derive the sound intensity I_{sp} , from the root mean square value of the sound pressure, during the pulse duration, which is measured at the sound focus:

$$I_{\text{sp}} = \frac{U_{\text{rms, max}}^2}{\rho c M_L^2} \dots\dots\dots (11)$$

Where:

$U_{\text{rms, max}}$ - The root mean square value of the output voltage of the hydrophone, for the duration of the pulse, at the sound focal point, in volts (V);

ρ - The density of water, in kilograms per cubic meter (kg/m^3);

c - Speed of sound in water, in meters per second (m/s).

7.3.1.4 Temporal average intensity spatially averaged over the -6 dB beam area

Let the hydrophone perform a two-dimensional linear step scanning, at a step $\Delta x = \Delta y \leq 0.1 \lambda_{\text{awf}}$, in the sound pressure focal plane. The measured sound pressure RMS in the plane is greater than or equal to half of the sound pressure RMS P_{rms6i} , for all points which is half of maximum sound pressure RMS $P_{\text{rms, max}}$. It shall calculate I_{sal} , using the following formula:

$$I_{\text{sal}} = \frac{\sum_{i=1}^N p_{\text{rms}6i}^2(x_i, y_i, F_{\text{pres}})}{\rho c N} = \frac{\sum_{i=1}^N U_{\text{rms}6i}^2(x_i, y_i, F_{\text{pres}})}{\rho c N M_L^2} \dots\dots\dots (12)$$

Where:

$U_{\text{rms}6i}$ - The rms value of the output voltage, at the spatial point, where the rms voltage of the i^{th} sound pressure signal as measured by the hydrophone, in the sound pressure focal plane, is greater than or equal to half the rms value of the maximum sound pressure signal voltage, in volts (V);

N - The number of all points in the sound pressure focal plane, where the rms sound pressure measured by the hydrophone is greater than or equal to half of the maximum sound pressure rms value.

7.3.2 Measurement of focus parameters

7.3.2.1 Measurement of full width at half (pressure) maximum, FWHM

In the process of measuring I_{sal} , the $U_{\text{rms}}(x_i, y_i, F_{\text{pres}})$ distribution in the sound pressure focal plane is determined by the method of hydrophone scanning and the coordinate positioning system; the maximum size Δd_r of the -6 dB focal region is taken.

Scan the hydrophone on the main sound axis (z-axis), to measure the distance Δd_z , between two points whose sound pressure RMS is equal to half the maximum sound pressure RMS, before and after the sound pressure focal point.

7.3.2.2 Measurement of maximum side lobe level (L_{sm})

Use a method similar to measuring Δd_r , to find the second maximum (sub-maximum) $P_{\text{rms,sm}}$ of the sound pressure RMS value, in the distribution of $U_{\text{rms}}(x_i, y_i, F_{\text{pres}})$ in the sound pressure focal plane. Use the following formula, to calculate the maximum side lobe level L_{sm} :

$$L_{\text{sm}} = 20 \lg \frac{p_{\text{rms, sm}}}{p_{\text{rms, max}}} \dots\dots\dots (13)$$

7.3.2.3 Measurement of axial secondary maximum level (L_{asm})

In a similar way to measuring Δd_z , scan the hydrophone along the z-axis, to measure the second maximum sound pressure rms on the z-axis, $P_{\text{rms,asm}}$. Calculate the axial secondary maximum level, by the following formula:

$$L_{\text{asm}} = 20 \lg \frac{p_{\text{rms, asm}}}{p_{\text{rms, max}}} \dots\dots\dots (14)$$

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