An Experimental Test To the High-Low-Voltage-Coupler Which Is Used In the Two-Sources-Driven Underwater Spark Acoustic Source

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Abstract. In this paper, a new type of two-sources-driven underwater spark acoustic source (TSD-USAS), is suggested. Then, the main mechanism and design principle of the high-low-voltage-coupler, which is the key part of TSD-USAS, is discussed. Finally, an experimental measurement to the backward voltage-penetration of the high-low-voltage-coupler, is implemented (at conditions of the HV capacitor: $C_H = 1 \mu F$, $U_0 = 15$ kV). The experimental results show that, when the HV discharge of the right-hand-side part (traditional USAS) leads to a non-breakdown, no apparent backward voltage-penetration will appear at the low voltage input terminal of the high-low-voltage-coupler; when leads to a breakdown, a backward voltage-penetration (peak value of +6200 V, pulse width of 17 $\mu$s) will arise.

1. Introduction
In 1938, Yutkin has found that, a 'water-hammer effect'[1], which finally leads to intense mechanical damage, will be generated when a HV-discharge is implemented in water. The underwater spark acoustic source, which bases on the 'water-hammer effect', has many applications, such as marine geological exploration [2], extracorporeal shockwave lithotripter [3], impulse forming [4], rock fragmentation [5], water purification [6].

According to our previous study [7, 8], in an environment of weak electric field (~10kV/cm), the breakdown of conductive water usually happens in an 'electro-thermal' mode, which means that, only by heating the gap water to a critical temperature, can the breakdown of gap water be realized. Based on this theory, a novel two-sources-driven underwater spark acoustic source [9] is provided, as shown in Figure 1.
In the left-hand-side of Figure 1, the low-voltage capacitor firstly provides a pre-breakdown heating pulse of low voltage, which is controlled by an IGBT module (6300V). When the gap water is heated to the critical temperature, the pre-breakdown heating pulse will be removed and then a following discharge pulse of high voltage will be provided by the high-voltage capacitor, which finally leads to an electro-thermal breakdown.

As shown in Figure 1, the kernel part of the TSD-USAS is the high-low-voltage-coupler, which is expected to allow the pre-breakdown heating pulse transfer to the right-hand-side (underwater discharge gap) and to be capable of preventing the HV discharge pulse to penetrate to the left-hand-side(IGBT module). The most important matter is that, in Figure 1, the diode itself can not achieve this goal because of its parasite capacitor. When a HV discharge happens in the right-hand-side, only if the parasite capacitor is charged to the discharge voltage, can the diode be capable of taking effect. As a result, the charging of the parasite capacitor usually leads to a backward voltage-penetration to the right-hand-side, which may finally destroy the expensive IGBT module. Therefore, besides of the diode, an additional high-low-voltage-coupler is very necessary to the TSD-USAS.

As shown in Figure 1, a ‘π’ type coupler, which consists of a left buffer resistor, an insulation inductor and a right buffer resistor, is provided. The main purpose of this paper, is to implement an experimental verification to this high-low-voltage-coupler.

2. Mechanism and design of the high-low-voltage-coupler

According to the typical discharge waveform of the traditional USAS, the high-low-voltage-coupler is expected to take a ‘blocking’ effect at two moment when HV discharge happens at the right-hand-side in Figure 1:

(1) When the gas gap in Figure 1 closes, a high discharge voltage will arise at the A point. Because of the existence of the junction capacitor, the high-low-voltage-coupler can not block the high voltage from the right hand side immediately. At this moment, the right buffer resistor will provide a charging routine with low resistance. In the meanwhile, the coupling inductor which appears high impedance at high frequency, and the left buffer resistor, form a voltage divider with high ratio, which means that the backward voltage-penetration at point C will be much lower than the value at point B.

(2) When the water gap in Figure 1 breakdown, an oscillating discharge voltage (seen in [10]), will finally arise at the A point, because of the existence of the parasite inductor in the discharge circuit. When the oscillating voltage at the A point turns negative, the diode itself will not be capable of blocking this negative high voltage, which is a great threat to the IGBT module. At this moment, the coupling inductor in Figure 1 becomes the key part to blocking this negative oscillating voltage.

In addition, according the basic operation routine of the TSD-USAS, before these two key moments, a rectangle-like pre-breakdown-heating pulse needs to pass the coupling inductor. When the pre-breakdown-heating pulse finishes, the left buffer resistor will play a role of continuing the current in the coupling inductor.
The value of these three key parts of the high-low-voltage-coupler (coupling inductor, left buffer resistor and right buffer resistor), must be chose properly. To the left and right buffer resistors, too much big resistance means that they will not be capable of blocking the backward voltage-penetration when the HV discharge happens, and too much small resistance means that they will waste more energy in the pre-breakdown-heating phase. To the coupling inductor, too much small inductance also means that it will not be capable of blocking the backward voltage-penetration, and too much big inductance means that a high negative voltage (also a great threat to IGBT) will arise when the pre-breakdown-heating phase finishes.

Through a lot of attempt and adjustment, the most reasonable and optimal values for these three key parts of the high-low-voltage-coupler, are finally found. Then, an experimental test to the practical effect of the high-low-voltage-coupler, is going to be performed. In this experiment, the voltage waveform of the input port (point C in Figure 1) at the moment when a HV discharge happens at the right hand side, is the kernel interest to us.

3. The experimental measurement to the backward voltage-penetration
Under a condition of discharge in which \( C_H = 1 \mu F, U_0 = 15 \text{ kV} \), by launching the trigger in Figure 1, a high-voltage discharge is performed. For the underwater discharge gap which lays in tap water with a conductance of \( G = 0.028 \text{ S/m} \), two different gap intervals \( (d = 5\text{mm} \text{ and } d = 2.5\text{mm}) \) are used, which respectively lead to non-breakdown discharge and breakdown discharge. By using a voltage divider with a ratio of 10000, the non-breakdown voltage waveforms of point ABC under the condition of \( (d = 5\text{mm}) \) are gathered and shown in Figure 2 to Figure 4:

![Figure 2. The non-breakdown waveform of the HV discharge (A).](image_url)
In Figure 2 to Figure 4, the peak values at the moment \((t = 0 \text{ s})\) reach \(20 \text{ kV}\) and exceed the charging voltage \((U_0 = 15 \text{ kV})\). Therefore, we can determine that these peak pulse is the electromagnetic interference caused by trigger, from which the origin signal is gathered by the voltage divider and multiplied by the division ratio (10000).

Then, the gap interval is reduced to \((d = 2.5 \text{ mm})\), the breakdown voltage waveforms of point ABC are gathered and shown in Figure 5 to Figure 7:
Figure 5. The breakdown waveform of the HV discharge (A).

Figure 6. The breakdown waveform of the right buffer-resistor (B).
From these experiment results (Figure 2 to Figure 7), we can make a preliminary judgement that, under the non-breakdown condition ($d = 2.5$ mm), no obvious backward voltage-penetration is observed at the input port of the high-low-voltage-coupler (point C in Figure 1), while under the breakdown condition ($d = 5$ mm), a backward voltage-penetration is observed, of which the peak value is $+6200$ V and the half-peak width is $17$ $\mu$s.

4. Conclusion
According to the mechanism and design principles of the high-low-voltage-coupler, the parameters of the left/right buffer resistors and the coupling inductor are optimized. Based on this, the waveforms of the backward voltage-penetration at three key points in the high-low-voltage-coupler, are measured, under two experiment conditions which lead to non-breakdown and breakdown respectively.

The experiment results show that, under the breakdown conditions ($U_0 = 15$ kV, $d = 2.5$ mm), a backward voltage-penetration is observed, of which the peak value is $+6200$ V and the half-peak width is $17$ $\mu$s. Such backward voltage-penetration can not lead to a damage to the $6300$ V IGBT which is used in our TSD-USAS described in Figure 1.

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