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Study on the Effect of Coupling Materials on the Ultrasonic Signals Detection of Partial Discharge

Jie Li[1, a], Wei Shi[1, b], Pipei Zhang[1, c], Peng Wang[1, d], Jiangwei Wang[1, e], Shisong Yan[2, *] and Wenxu Si[2, f]

[1]Equipment Status Evaluation Center, State Grid Shandong Electric Power Research Institute, Jinan, China
[2]PDStars Electric Co., Ltd., Shanghai, China

*Corresponding author e-mail: yanshisong@pdstars.com, [a]dkylijie@126.com, [b]wshi@126.com, [c]ppzhang@qq.com, [d]269155508@qq.com, [e]1783142046@qq.com, [f]siwenxu@pdstars.com

Abstract. This paper studied the effect of different coupling agents on ultrasonic detection of partial discharge. Water-based ultrasonic coupling agents, medical coupling agents and silica gel coupling materials were compared with commonly used high-vacuum silicone greases to analyse the different response by using different coupling materials to detect the ultrasonic signals with different frequency and amplitude. It is found that the ultrasonic sensor has a better response when applied to medical coupling agents under the frequency 20kHz and 80kHz, the frequency response is better when applied to water-based ultrasonic coupling agents under the frequency 20kHz ,40kHz and 80kHz,but the both two coupling agents have the disadvantage of low viscosity. The frequency response under 40 kHz of sensor is better than other frequencies when applied to silica gel, but this material has the difficulty to achieve full coupling. The high-vacuum silicone gel with higher viscosity is preferred in the consideration of different application scenarios in the field. The silicone gel with the thickness of 0.5mm is also well recommended when the sensor is fixed by an external magnetic base and meet the test accuracy.

1. Introduction

In the insulation system of power equipment, discharge occurs only in part of the region, and there is no penetration between the applied voltage conductors, there is no breakdown, this phenomenon is called partial discharge. When the partial discharge signal is generated in the electrical equipment, it will produce shock vibration and sound. Ultrasonic wave is a kind of mechanical vibration wave. When the partial discharge occurs, there is a violent collision between the molecules in the area of the discharge, which is a kind of pressure at the macro level. Since the partial discharge is a series of pulses, the resulting pressure waves are also pulses, producing sound waves. It contains various frequency components with a wide frequency band of 101~107Hz. Sounds that exceed the 20 kHz range are called ultrasonic [1-3]. Ultrasonic method measures partial discharge signals by installing ultrasonic sensors on the outside wall of the equipment cavity. The characteristic of this method is that the sensor has no connection with the electrical circuit of the power equipment and is not affected by electrical interference, but is easily affected by ambient noise or mechanical vibration of the equipment when used in the field. Because the ultrasonic signal in the electrical equipment commonly used insulation material attenuation is large, ultrasonic detection method detection range is limited, but has the advantages of high positioning accuracy [4-6]. According to section 7.2.2 of "DL/T 1250-2013 application guidelines for charged gas-insulated metal-enclosure switchgear device partial discharge detection with ultrasonic method", during the local discharge detection of ultrasonic sensors, special coupling agents should be uniformly applied between the sensor and the measuring point to minimize the attenuation of detection signals [7].

Discharge during the process of ultrasonic testing, the scene of ultrasonic sensor and the testing point has a regulation, but no clear rules on the coupling agent, coupling agent is also varied. In the process of partial discharge intensive monitoring, because need a short-term fixed ultrasonic sensor monitoring, the coupling agent is easy to fall off with rain, the measuring data is error. This paper mainly studies the effects of different coupling agents and silica gel on partial discharge ultrasonic detection.

2. Coupling agent requirements

In ultrasonic detection, the air between the sensor and the surface of the test point will block the ultrasonic transmission between the two, and the coupling agent can play a good role in conducting. Generally, the coupling agent is a kind of water-soluble polymer colloid, which has no corrosion, no harm, is not easy to burn or pollute, and is easy to remove after the end of testing. Ultrasonic coupling agent has the following three functions in the process of local release detection:

(1) Fill the gap between the sensor and the surface of the measuring point to avoid the trace air between the gaps affecting the ultrasonic transmission.

(2) Reduce the acoustic impedance difference between the sensor and the measuring point, so that the acoustic energy loss of the detection interface reflection is small.

(3) The sensor is fixed at the measuring point to avoid the detection error caused by the hand immobilization of the inspector.

The viscosity of the coupling agent is an important index of its stability. The coupling agent should be easy to be coated and not easy to flow freely in the field test. The acoustic impedance of the coupling agent represents the loss of energy in the process of transmission. For the same test surface, the larger the acoustic impedance value of the coupling agent, the better the coupling effect. In this paper, several kinds of coupling agents are selected to analyze their influence on the detection of PD ultrasound. The parameters of each coupling agent are as follows:

Table 1. Coupling agent parameters

Coupling agent	Viscosity (Pa•s)	Sound velocity (m/s)	Acoustic impedance (Pa.s/m)
High vacuum silicone grease	5.1	2210	$3.1*10^5$
Medical couplant	1.5	1520-1620	$1.6*10^5$
Water based couplant	1.6	1780	$2.88*10^5$
Silicone	/	1055	$1.21*10^5$

3. Study on the Influence of Different Coupling Agents and Silica Gel on Partial Discharge Ultrasonic Detection

3.1. Test purposes

To study the influence of different coupling agents and silicone rubber on the detection of ultrasonic partial discharge, and to compare the change rules of signal waveform and spectrum characteristics.

Determine the ultrasonic couplant material with good performance.

3.2. Test program

According to the inspection plan of ultrasonic partial discharge detector of State Grid Corporation of China, the test environment is set up as shown in Figure 1. The acoustic emission system adopts N9320B signal generator, and the measurement system adopts DSO6104 oscilloscope. The two channels of the acoustic emission system and the measurement system are connected with the same type of ultrasonic sensor. The frequency band of the ultrasonic sensor is 20-80 kHz, and the distance between the three sensors is the same [8]. As shown in Figure 1, the red area is the sensor, the yellow area is the high vacuum silicone grease, as the standard coupling agent, and the blue area is the medical coupling agent, ultrasonic coupling agent and silica gel of different thickness. The acoustic emission system outputs different pulse signals, and their frequencies are 20 kHz, 40 kHz, 60 kHz, and 80 kHz, and the amplitudes are 100 mV, 200 mV, 500 mV, and 1000 mV. After receiving, the output signal 1, signal 2, is connected to the measurement system to record the difference between the two signals, and analyze the influence of different coupling agents and silica gel on the ultrasonic detection.

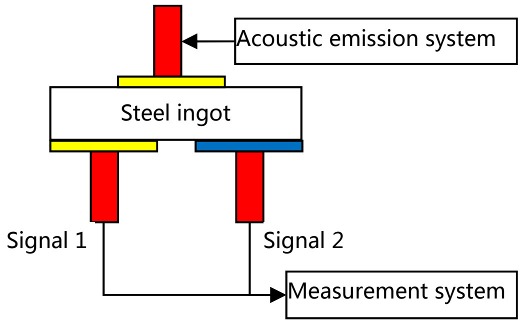


Figure 1. Testing wiring diagram.

3.3. Influence analysis of water-based ultrasonic couplant test

The water-based ultrasonic coupling agent is a kind of colorless viscous liquid without bubbles, soluble foreign matters and precipitation. Test as shown in Figure 1, and record the amplitude of ultrasonic signal under four frequencies as shown in Table 2.

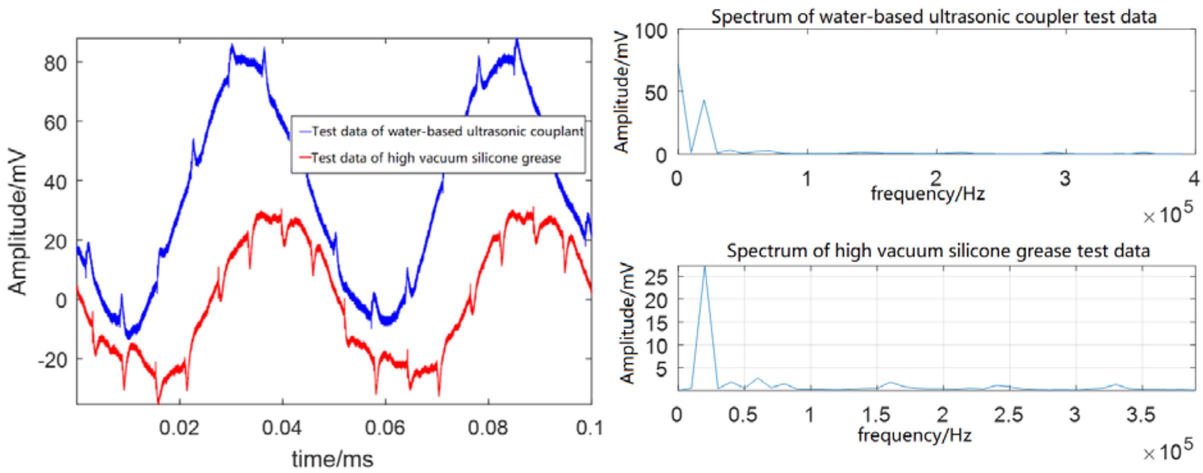
Table 2. Water-based coupling material comparision result.

Amplitude		Frequency			
		20kHz	40kHz	60kHz	80kHz
100mV	Signal 1	43.1	30.6	239	20.6
	Signal 2	61.9	36.9	69	27.8
200mV	Signal 1	60.6	49.4	456	25.3
	Signal 2	106.9	62.5	109	27.5
500mV	Signal 1	150.6	92.5	1190	50.6
	Signal 2	283	118	209	65
1000mV	Signal 1	547	177	1800	74.4
	Signal 2	588	245	313	136.3
Average percentage of difference		53.8%	28.3%	-78.1%	38.8%

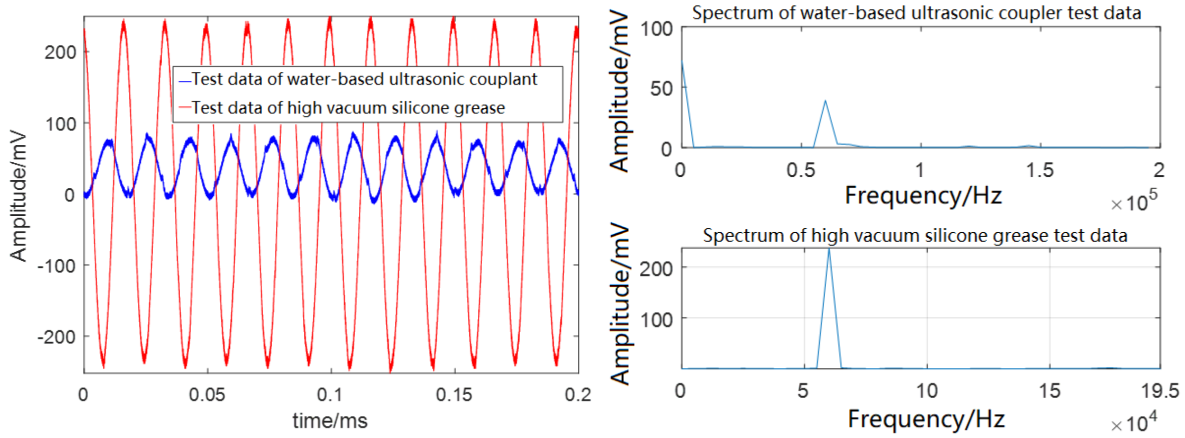
It can be seen from the above table that the water-based ultrasonic coupling agent responds well at 20 kHz, 40 kHz, and 80 kHz, and the ultrasonic amplitude is compared with the standard couplant (high vacuum silicone grease), and the response increases by 53.8%, 28.3%, and 38.8%; The standard couplant responded well and the water-based ultrasonic couplant response decreased by 78.1%.

In terms of coupling effect, due to the small density and viscosity of the coupling agent, the surface of the sensor coated with coupling agent cannot be fully coupled with the surface of the measuring point for adsorption, and the horizontal direction is easy to slide, which is not conducive to the stable field test.

Analyze the frequency spectrum of the signal when the frequency is 20 kHz and 60 kHz, as shown in Figure 2 below.



a. Test signal spectrum under frequency 20 kHz.



b. Test signal spectrum under frequency 60 kHz.

Figure 2. Test signal spectrum under frequency 20 kHz and 60 kHz by applied to water-base coupling agent.

It can be seen from Figure 2 that when the input signal frequency is 20kHz, the frequency components of signal 1 and signal 2 are 20kHz, but the amplitude of signal 2 is greater than signal 1, and the amplitude of corresponding time domain signal is greater than signal 1, which is consistent with the data trend in Table 1, indicating that the response of water-based ultrasonic couplant in this frequency band should be better than that of standard couplant; when the input signal frequency is 60kHz, the frequency components of signal 1 and signal 2 are both 60kHz, but the amplitude of signal 2 is obviously smaller than that of signal 1, and the amplitude of corresponding time domain signal is smaller than that of signal 1, which is consistent with the data trend in Table 2. Under this frequency band, the response of standard coupling agent is better than that of water-based coupling agent.

3.4. Effect analysis of medical ultrasonic coupling agent

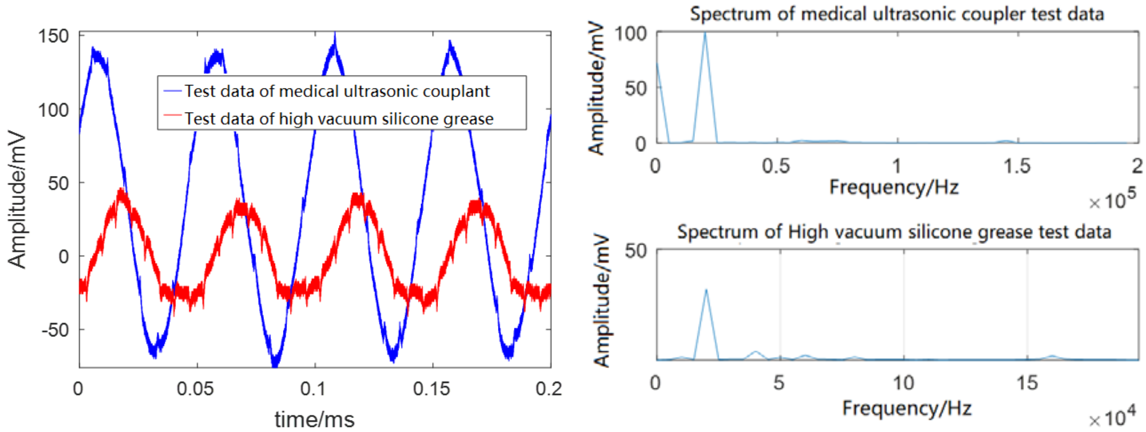
Medical ultrasonic coupling agent takes water as solvent and forms a colorless transparent gelatinous form after dissolution or swelling, with a small amount of bubbles inside, no soluble foreign matter and precipitation. It is tested as shown in figure 1, and ultrasonic signal amplitude at four frequencies is recorded as shown in table 3.

Table 3. Water-based coupling material comparision result.

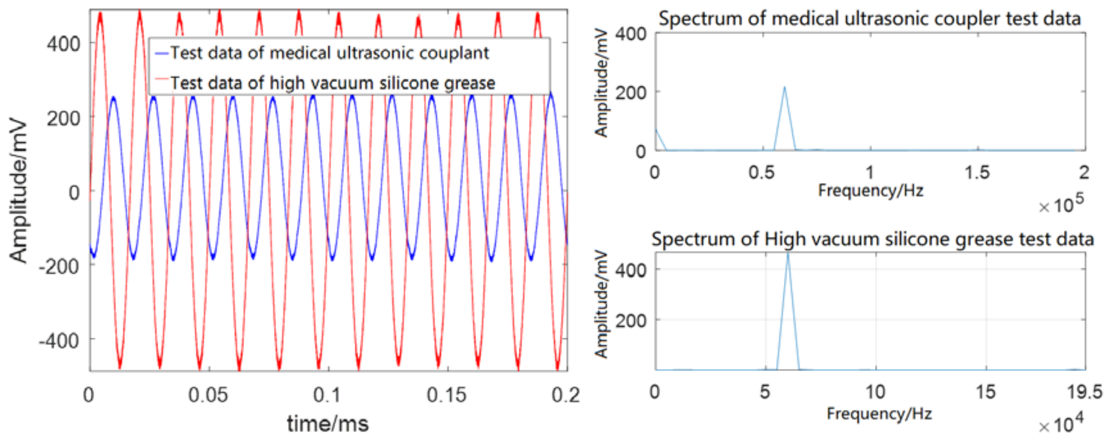
Amplitude		Frequency			
		20kHz	40kHz	60kHz	80kHz
100mV	Signal 1	50	36.9	206	22.2
	Signal 2	81	29.4	86.9	23.1
200mV	Signal 1	80	70.6	394	18.4
	Signal 2	241	45	211	28.1
500mV	Signal 1	139	140	888	32.5
	Signal 2	538	77	488	47.8
1000mV	Signal 1	519	291	1630	65
	Signal 2	594	118.1	925	88.8
Average percentage of difference		141.2%	-40.3%	-48.10	35.1%

It can be seen from the above table that the response of the medical ultrasonic coupling agent is good at 20 kHz and 80 kHz, and the response amplitude is increased by 141.2% and 35.1% compared with the standard couplant. In terms of coupling effect, the density and viscosity of the couplant are higher. Small, the surface of the sensor is not fully coupled with the surface of the measuring point after applying the coupling agent, and the horizontal direction is easy to slip, which is not conducive to stable testing at the site.

Analyze the frequency spectrum of the signal when the frequency is 20 kHz and 60 kHz, as shown in Figure 3 below.



a. Test signal spectrum under frequency 20 kHz.



b. Test signal spectrum under frequency 60 kHz.

Figure 3. Test signal spectrum under frequency 20 kHz and 60 kHz by applied to medical coupling agent.

It can be seen from the above spectrum that when the input signal frequency is 20kHz, the frequency components of signal 1 and signal 2 are 20kHz, but the amplitude of signal 2 is greater than that of signal 1, and the amplitude of corresponding time domain signal is greater than that of signal 1, which is consistent with the data trend in Table 3, indicating that the response of medical coupling agent is better than that of standard coupling agent in this frequency band; When the input signal frequency is 60 kHz, the frequency components of signal 1 and signal 2 are both 60 kHz, but the amplitude of signal 2 is significantly smaller than that of signal 1, and the amplitude of the corresponding time domain signal is smaller than that of signal 1, which is consistent with the data trend in Table 2. The standard couplant response in this band is superior to medical couplants.

3.5. Silica gel impact analysis

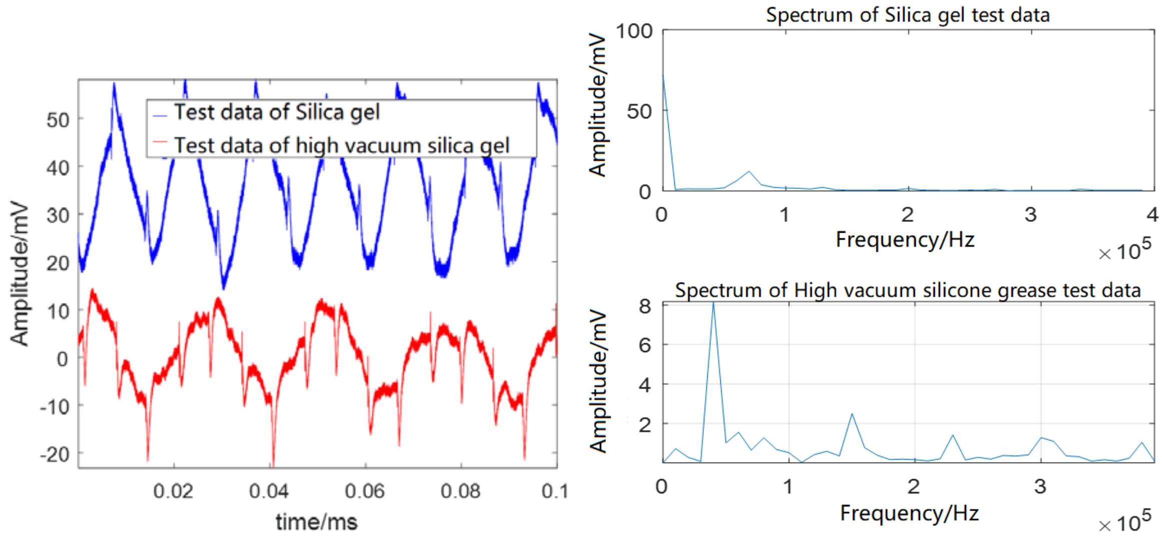
Use 0.5mm-thick silica gel, wipe the surface with alcohol, place the rubber gasket between the sensor and the test block, compress and exhaust the air, test as shown in Figure 1, and record the amplitude of ultrasonic signal under four frequencies as shown in Table 4.

Table 4. Test data of silicone gel with the thickness of 0.5mm.

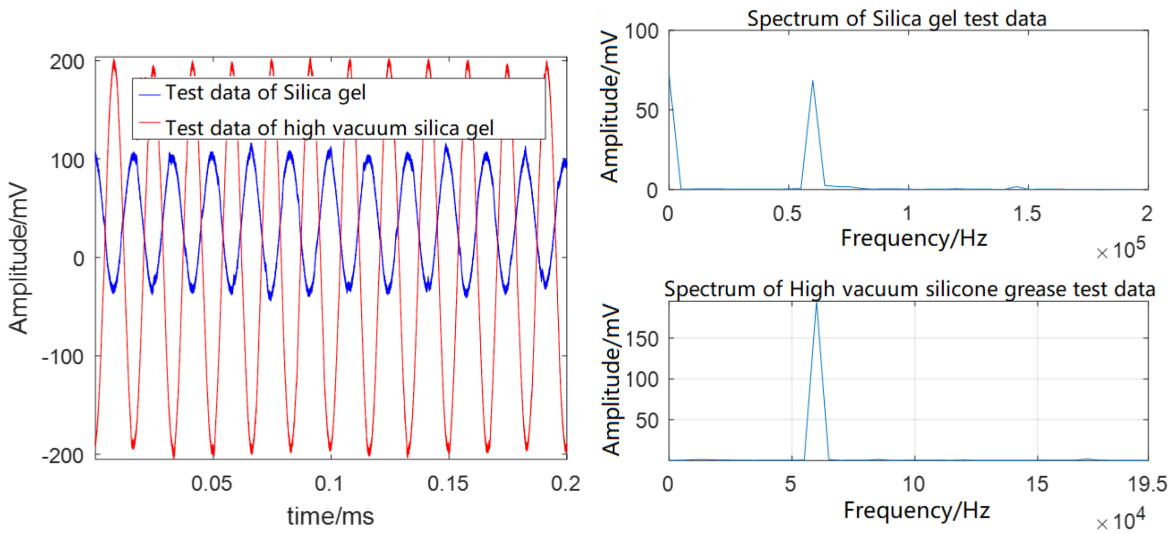
Amplitude		Frequency			
		20kHz	40kHz	60kHz	80kHz
100mV	Signal 1	36.9	28.8	106	34
	Signal 2	37.5	38.1	52.5	29.7
200mV	Signal 1	50	41	194	36.3
	Signal 2	48.8	53	76.9	31.9
500mV	Signal 1	100	56	444	53.8
	Signal 2	84	83	153	34.7
1000mV	Signal 1	281	88	880	106
	Signal 2	17	127	281	50.6
Average percentage of difference		-0.28%	0.39%	-61%	-28.1%

It can be seen from the above table that the response of silicone grease used at 40 kHz is similar to that of standard couplant, and the response of standard couplant at other frequencies is better than that of silicone grease. From the perspective of coupling effect, the thickness of 0.5mm rubber pad and sensor coated with standard couplant on the surface of measuring point is the closest, but the effect of coupling with sensor surface is not as good as that of other couplants.

Analyze the frequency spectrum of the signal when the frequency is 40 kHz and 60 kHz, as shown in Figure 4 below.



a. Test signal spectrum under frequency 20 kHz.



b. Test signal spectrum under frequency 60 kHz.

Figure 4. Test signal spectrum under frequency 20 kHz and 60 kHz by silicone gel with the thickness of 0.5mm.

It can be seen from the above spectrogram that when the input signal frequency is 20 kHz, the frequency component of the signal 1 is 20 kHz, but the component amplitude is small and there is a low frequency component, the signal 2 contains more harmonic components, and the amplitude is smaller than the component of the signal 1. When the input signal frequency is 60 kHz, the frequency components of the two channels are both 60 kHz. At this time, the amplitude of the frequency component of the signal 2 is smaller than the amplitude of the frequency component of the signal 1, indicating that the standard couplant response is better than 0.5 mm silica gel in the two frequency bands.

4. Test summary

The test results are shown in table 5.

Table 5. Test statistics.

Coupling agent	Frequency				Coupling evaluation
	20kHz	40kHz	60kHz	80kHz	
medical couplant	+	-	-	+	Small viscosity, easy to slide
water-based ultrasonic couplant	+	+	-	+	Small viscosity, easy to slide
Silicone 0.5mm	-	+	-	-	Complete coupling is difficult to achieve

In the test process, the effect of medical coupling agent is better at 20kHz and 80kHz, but the viscosity is small; the effect of water-based coupling agent is good at 20kHz, 40KHz and 80kHz, but the viscosity is small; the effect of silica gel is equivalent at 40KHz, and other frequencies are not as good as standard coupling agent, and it is difficult to achieve complete coupling.

5. Conclusion

The order of viscosity of different coupling agents is high vacuum silicone grease, water-based ultrasonic coupling agent, medical coupling agent and silica gel. The order of acoustic impedance value is high vacuum silicone grease, water-based ultrasonic coupling agent, medical coupling agent and silica gel.

In the process of field application, high vacuum silicone grease with high viscosity is preferred. If the external force is fixed and the test accuracy is satisfied, 0.5mm silica gel can be used as the coupling material.

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