Thermal resistance of ultrasound probe cable

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***Abstract*—Ultrasound probe cable must efficiently dissipate the heat of piezoelectric elements in a probe head. We evaluated the heat transfer by measuring thermal resistance with various conditions. By simply changing the braid shielding material inside the cable and by implementing a thermal connection method to the heat source, we found that at least 40% of the heat could be efficiently transferred to the cable.**

Keywords—Thermal resistance , Ultrasound probe cable, Cable design

I. INTRODUCTION

Ultrasound probe cable for 3D and 4D designs must efficiently dissipate the heat of piezoelectric elements in a probe head. A typical ultrasound probe cable consists of a few hundred micro-coaxial cables with an overall shield and jacket. By simply changing materials and termination methods, a significant reduction of heat can be transferred and dissipated through the cable. We will show our analysis of the ability of removing this heat through a redesigned thermal connection of the probe head to the shielding material.

II. METHOD

Heat paths of probe cable are roughly classified into two groups shown in Fig. 1. One is heat radiation via probe head and the other is heat radiation via the cable. In this study, we show an experimental setup and evaluation method for heat radiation from a cable.

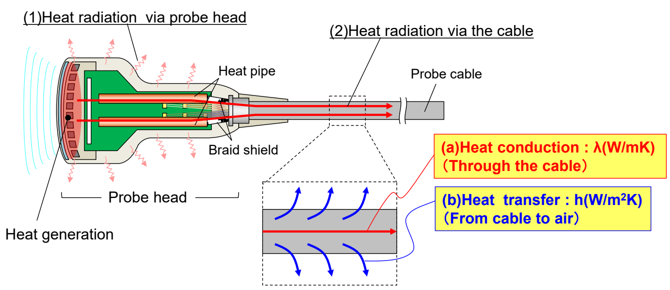


Fig. 1 Heat paths of probe cable

1. Thermal Resistance (R)

To evaluate the heat transfer, we measured the thermal resistance R value of the cable. We assumed that the probe cable was a kind of thermal fin, so we used the fin model to analyze the thermal resistance R of the cable shown in (1).

$$R = \frac{1}{\eta h \pi D L} \quad \left(\eta = \frac{\tanh u}{u} \ , \quad u = 2L\sqrt{\frac{h}{\lambda D}} \ \right) \quad \text{(K/W)} \qquad (1)$$

η is the fin efficiency, h is the heat transfer coefficient, D is the cable diameter, L is the cable length and λ is the heat conduction coefficient. The thermal resistance R depends on the cable length and the surrounding environment, therefore we also evaluated the heat conduction coefficient λ and the heat transfer coefficient h that are not dependent on cable length.

2. Heat conduction coefficient (λ)

Fig. 2 shows an experimental setup for measuring the heat conduction coefficient λ value shown in (2)

$$\lambda = \frac{Q_{cable} L}{s(T_B - T_C)} \quad \text{(W/mK)} \qquad (2)$$

Q_{cable} is heat quantity through the cable, L is the cable length, s is surface area of cable, T_B and T_C are temperature at each point B and C in Fig. 2. We connected a copper rod to both sides of the shield inside the probe cable with solder (for the thermal connection), and applied heat to one-side of the copper rod and kept the other side at a constant temperature (10 (deg C)). We measured the temperature of each point from A to D in Fig. 2 by using thermocouples.

We defined Q_{cable} as the average value of the heat quantity through both copper rods, Q_{AB} and Q_{CD}. We used tough pitch copper for the copper rods which has a known value of heat conduction coefficient λ_{cu}=391 (W/mK). Then, we calculated Q_{AB} and Q_{CD} by using λ_{cu} and measured temperature of each point A to D.

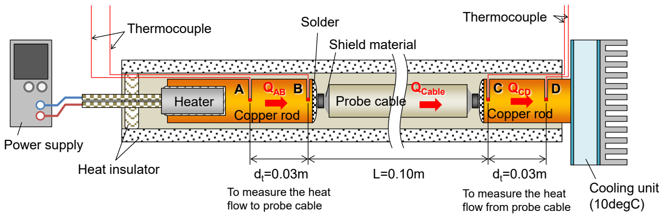


Fig. 2 Experimental setup for measuring the λ value

3. Heat transfer coefficient h

Fig. 3 shows experimental setup for measuring the heat transfer coefficient h value shown in (3)

$$h = \frac{Q_h}{A(T_w - T_a)} \quad \text{(W/m}^2\text{K)} \tag{3}$$

Q_h is heat quantity from the braid shielding to the air, A is surface area of braid shield, T_w is the shield layer temperature, T_a is the ambient temperature.

We assumed that Q_h is equivalent to the power supplied to heating the wire inside the cable. Then we measured the shield layer temperature T_w by using the temperature dependence of the electrical resistance of the shield layer.

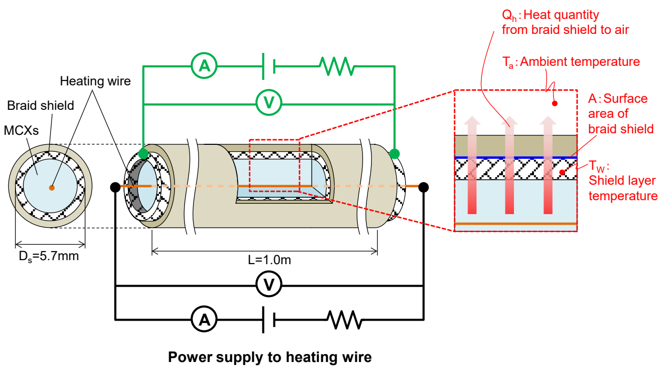


Fig. 3 Experimental setup for measuring the h value

4. Shielding materials

We used and compared two types of braid shielding material called SX and SB shown in Fig. 4. SX braid shielding is composed of nylon fibers round by thin copper foil and SB braid shielding uses tinned copper alloys. We conventionally used SX braid shielding for probe cable.

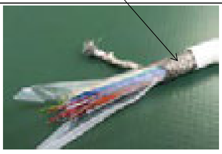
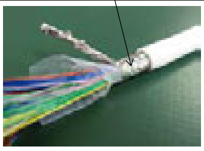
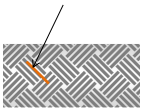
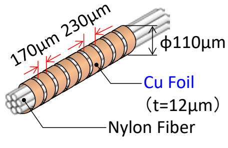
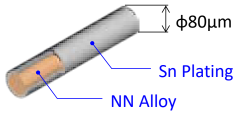
Tested cable	#1 (SX shield)	#2 (SB shield)
Photo of probe cable		
Braid shield material	**SX Braid shield**	**SB braid shield**
	Using tinsel wire	Using tinned copper alloy
Wire material 	 (Strand Number : 208)	 (Strand Number : 256)

Fig. 4 Braid shielding materials

III. Result and Discussion

Fig. 5 shows the measurement results by comparing the thermal resistance. We connected the copper rod to the shielding materials inside the cable using two patterns, one with solder (for the thermal connection) and one with an epoxy resin (for the non-thermal connection comparison).

The SB braid shielding when compared to the SX braid shielding, which our conventional probe cables use, showed a 10% reduction in the thermal resistance of the cable. By providing a soldered thermal connection between the cable and the heat source, there is a greater than 30% reduction in thermal resistance as compared to the non-thermal connection.

In total, at least 40% of the heat could be efficiently transferred into the cable simply by changing the braid shielding material and by implementing a thermal connection method to the heat source. Further, we expect even higher thermal transfer effects by altering the thermal connection structure and method.

	Without thermal connection of shield material		With thermal connection of shield material	
	Setup of λ measurement 		Setup of λ measurement 	
	SX	SB	SX	SB
Heat conduction coef λ [W/mK]	6.1	7.0	18.5	34.1
Heat transfer coef h [W/m²K]	17.6	18.9	17.6	17.6
Thermal resistance[K/W] @cable length 1m				

Fig. 5 Measured thermal resistance

IV. Conclusion

We evaluated the heat transfer by measuring the thermal resistance of the cable with various conditions. We found that the braid shielding material and its connection method to the heat source have significant effects on lowering the thermal resistance, which leads to higher heat transfer from the probe head through the cable. In this study, at least 40% of the heat could be efficiently transferred to the cable.

In the future, for higher thermal dissipation, we will develop new braid shielding that offers lower thermal resistance and a novel connection method for increased thermal dissipation.