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Maximum Current of the Suspension Actuator Coil

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1 ABSTRACT

We examined the maximum DC current of a coil used for the test mass actuating in the 40-meter interferometer. The 150mA DC current heated the coil head at 33 ^{o}C on its surface and at 42 ^{o}C inside it from the room temperature of 19 ^{o}C respectively. It was low enough not to damage an LED and a photodetector inside the coil head. The dominant molecules, that were H_2, H_2O, and N_2, emitted from the coil head heated with its 200mA DC current proved not to degrade the LIGO sensitivity of $h = 10^{-23}$ 1/rHz. The pressure of hydrocarbons emitted from it heated with its 150mA DC current also proved to be comparable with the LIGO requirement level of 10^{-12} torr.

2 INCREASE OF TEMPERATURE IN A COIL HEAD DUE TO ITS DC CURRENT

2.1. Purpose and Method

In order to examine that the increase of temperature in the coil head heated with its (over) expected DC current of ~150mA for the test mass actuating was not crucial and was less than the specified tolerable temperature of 80 ^{o}C for an LED and a photodetector inside the coil head, we loaded 100mA, 150mA and 200mA current to the coil and measured its surface temperature with a thermal couple in the vacuum.

2.2. Experiment Setup

Fig 1 shows the experiment setting. We set everything to reproduce as practical condition as possible. The coil head was the same one used in the 40-meter interferometer for the test mass actuating. It was fixed in a hole in a coil holder bar on a mirror suspension tower, which had dimensions of 16cm x 13cm x 44cm and was made of stainless. Only the end of the coil head sit on the two dips on the hole surface and it was fixed with one screw bolt on its top (Fig.2). It had only three tiny contactiong points with the bar. The whole tower was put in a vacuum chamber which had dimensions of ϕ0.45m x 0.5m and 0.08 m^3 volume. Two lead lines of the coil were connected with a 9-Pin D-sub connector and extended to terminals with a twist pair line which had about 50 cm in length to load current to the coil from outside the chamber. The thermal couple was glued on the coil directly with the “Vacseal“. Its volume was about 2 mm^3. The two lead lines of the thermal couple were fixed on the tower on the way to terminals not to stress the contacting point. Its length was about 40 cm. The chamber was evacuated by a rotary pump to more than 0.1 torr to prevent oil of the rotary pump from flowing back to the chamber.

Outside the chamber, the thermal couple lines were connected to a thermometer. One of coil lines was connected to a +15 V terminal of a voltage supply, while a proper external resistance was connected in series between the other line and the common terminal of the voltage supply to produce 100mA, 150mA and 200mA current. The +15 V terminal of the voltage supply and the upper reaches of the resistance were monitored to measure the change of coil resistance due to heating and to observe unexpected fluctuation of the voltage and the current. In the experiment using 200mA current, we monitored the current directly inserting a current meter between the +15 V terminal of the voltage supply and the terminal of one coil lines outside the chamber.

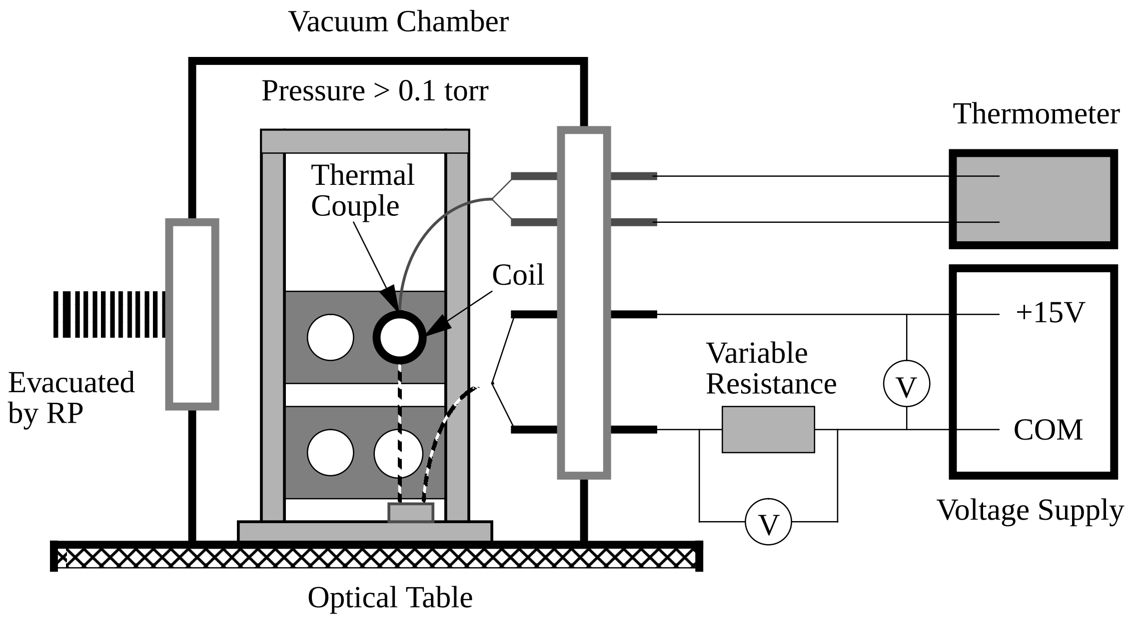

Figure 1: The setup for the measurement of the temperature increase of the coil head heated with its variable DC current.

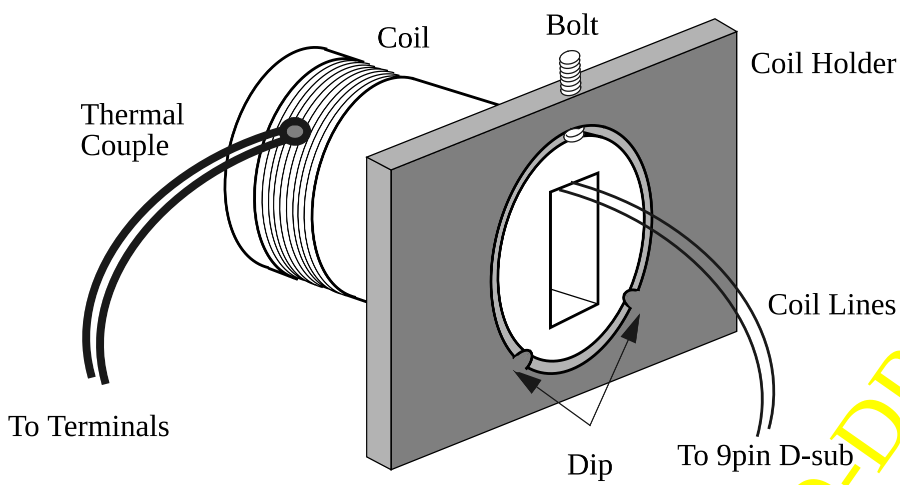

Figure 2: The coil head mounted on the holder bar in the suspension tower.

2.3. Results and Discussions

Fig.3 shows the increase of the surface temperature in the coil head. The black, dark gray and light gray curves show the difference of the starting load current of ~100mA, ~150mA and ~200mA respectively. Each DC current heated the coil head by 6 ^{o}C, 14 ^{o}C and 24 ^{o}C respectively from the room temperature of ~19 ^{o}C. It took more than 2 hours to reach thermal equilibrium state of 25.1 ^{o}C, 33.1 ^{o}C and 43.0 ^{o}C respectively.

Fig.4 shows the relation between its surface temperature and the coil resistance calculated from the change of current. The resistance of the coil increased in the rate of 0.11 Ω / ^{o}C. It corresponded to the temperature coefficient of 6.2 x 10^{-3} ^{o}C which was 1.5 times larger than the general temperature coefficient of copper of 3.8 x 10^{-3} ~ 3.9 x 10^{-3} ^{o}C. This reveals that the increase of temperature inside the coil head was about 1.5 times bigger than the increase of temperature of 14 ^{o}C on its surface. Fig.5 shows the expected temperature inside the coil head judging from the surface temperature when 150mA current was loaded to the coil. Thermal equilibrium state would reach 42 ^{o}C which was about a half of the specified tolerable temperature of 80 ^{o}C for the LED and the photodetector.

Fig.6 shows the thermal diffusion effect of the air. The gray and black curves represent the temperature increase in the coil head in the air pressure and in the pressure of 0.1 torr respectively. The heat corresponding to about 2 ^{o}C, which was 33% of the temperature increase of 6 ^{o}C in the case of 100mA current, was diffused through the air. We still don't know, however, the efficiency of the thermal diffusion through the thermal couple and the coil lines compared with radiation.

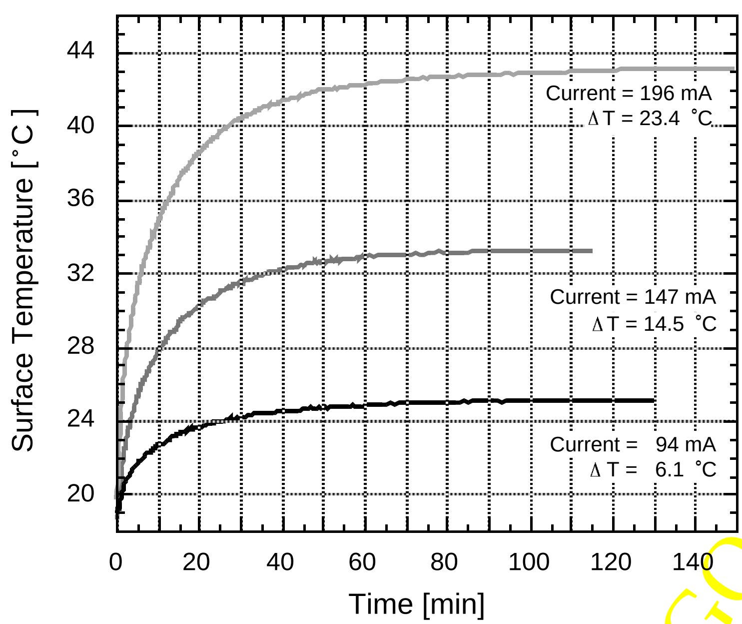

Figure 3: The temperature increase in the coil head heated with its variable DC current in the vacuum.

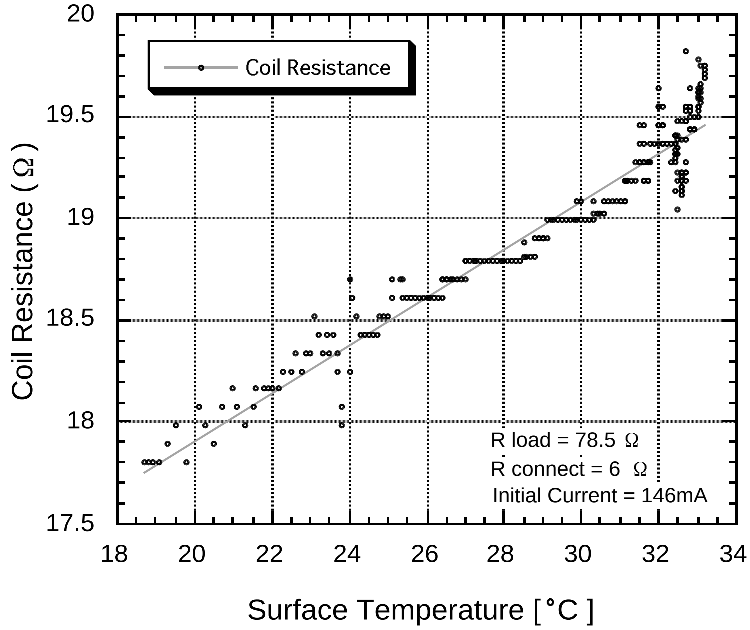

Figure 4: The increase of resistance of the coil head heated with its 150mA DC current.

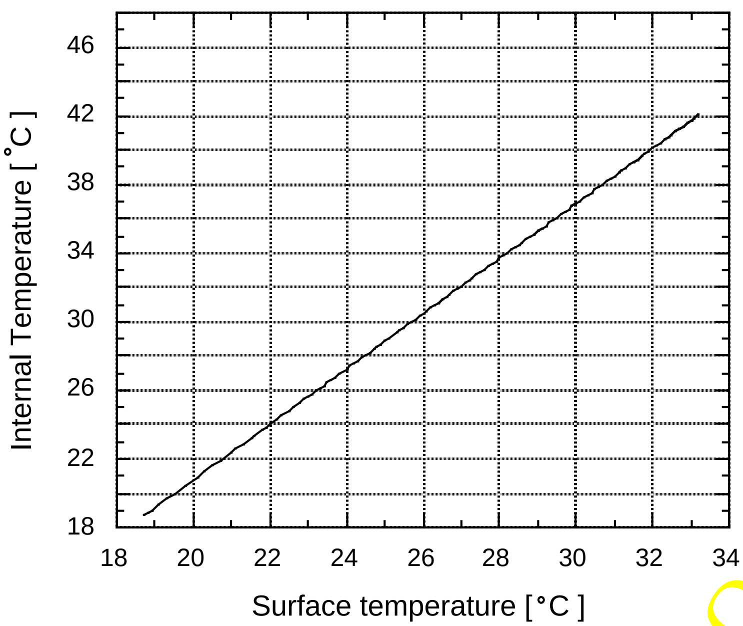

Figure 5: The relation between the temperature inside and outside the coil head when it was heated with its 150mA current

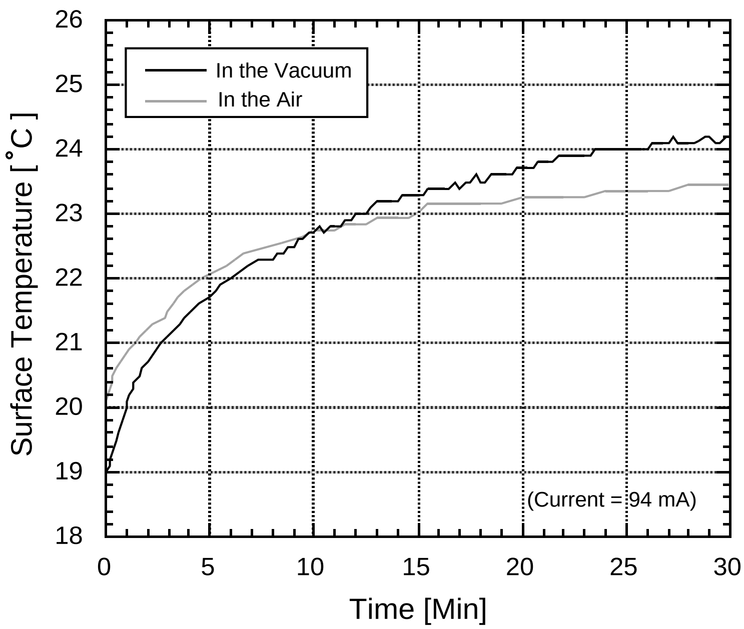

Figure 6: The effect of the air for the thermal diffusion from the coil head heated with its 100mA current.

3 OUTGAS EMITTED FROM THE COIL HEAD HEATED WITH ITS DC CURRENT

3.1. Purpose and Method

In order to examine the maximum DC current to keep the pressure of the hydrocarbons emitted from the coil head heated with it less than the LIGO requirement level of 10^{-12} torr in pressure, we observed it with an RGA detector before and after heating the coil head with its DC current.

3.2. Experiment Setup

One coil head held in the small stainless bar (Fig.2) which was a part of the suspension tower was put in the vacuum chamber after they were washed with acetone and methanol. To minimize the outgas from other sources except for the coil head, they were baked at 70 ^{o}C for 65 hours. The setup of the coil lead lines and the thermal couple lines were same with that of the previous experiment except that we adjusted the current with not the external resistance but the loading voltage. The external resistance was 78.5Ω consisting of six parallel 470 Ω (1/2 W) resistances. The coil resistance was ~18Ω at the room temperature of ~25 ^{o}C. The lead lines and terminals resistance was about ~6Ω totally. Hence, the total resistance was ~103Ω. The current of ~150mA and ~200mA were obtained with the +15V and +20V load voltage respectively. The chamber was evacuated with the pumping speed of 25 *l*/sec by a turbo pump to less than 10^{-7} torr.

3.3. Results and Discussions

Fig.6 and Fig.7 shows the amount of the emitted molecules distinguished with their atomic masses when the coil head was heated with its DC current of 150mA and 200mA respectively. Most of molecules under 80u were emitted more as the temperature of the coil increased, while the emission level of molecules over 80u was kept except several kinds of molecules. The characteristic conspicuous emission due to heating was not observed. The thermal diffusion through the residual air of 10^{-1} torr in the previous experiment was verified to be negligible because the increase of the temperature of 24 ^{o}C and 14 ^{o}C for the 200mA and 150mA current respectively was same in spite of the difference of the pressure between 10^{-7} torr and 10^{-1} torr.

Table.1 shows the pressure of the dominant residual molecules which are H_2, H_2O, and N_2. We used 3000 *l*/sec as a pumping speed for one test mass tank in LIGO and six coil heads were assumed to be used for one test mass actuating in one tank. According to the reference[1], none of them degrades the LIGO sensitivity of 10^{-23} 1/rHz even if the coil head was heated with its 200mA DC current.

Table.2 shows the total pressure of the dominant hydrocarbons, which have 41u, 43u, 53u, 55u and 57u mass respectively. We also used 3000 *l*/sec as a pumping speed and six coil heads were assumed to be used for one test mass actuating in one tank. It shows that 150mA is the maximum current to keep the pressure of the hydrocarbons less than the LIGO requirement level of 10^{-12} torr.

Table 1: The expected pressure of the dominant molecules emitted from the six coil heads heated with their DC current in one test mass tank for LIGO

Surface Temperature	25 ^{o}C (0mA)	39^{o}C (150mA)	49 ^{o}C (200mA)
H_2 [torr]	1×10^{-11}	2×10^{-11}	3×10^{-11}
H_2O [torr]	2×10^{-10}	3×10^{-10}	1×10^{-9}
N_2 [torr]	1×10^{-11}	5×10^{-11}	8×10^{-11}

Table 2: The expected pressure of the dominant hydrocarbons emitted from the six coil heads heated with their DC current in one test mass tank for LIGO

Surface Temperature	25 ^{o}C (0mA)	39^{o}C (150mA)	49 ^{o}C (200mA)
Pressure [torr]	4.9×10^{-13}	1.0×10^{-12}	1.7×10^{-12}

1. Proposal to the National Science Foundation. " A Laser Interferometer Gravitational-Wave Observatory (LIGO) " Volume 1. LIGO Science and Concepts. December 1989. B-13 page, Figure B-4.

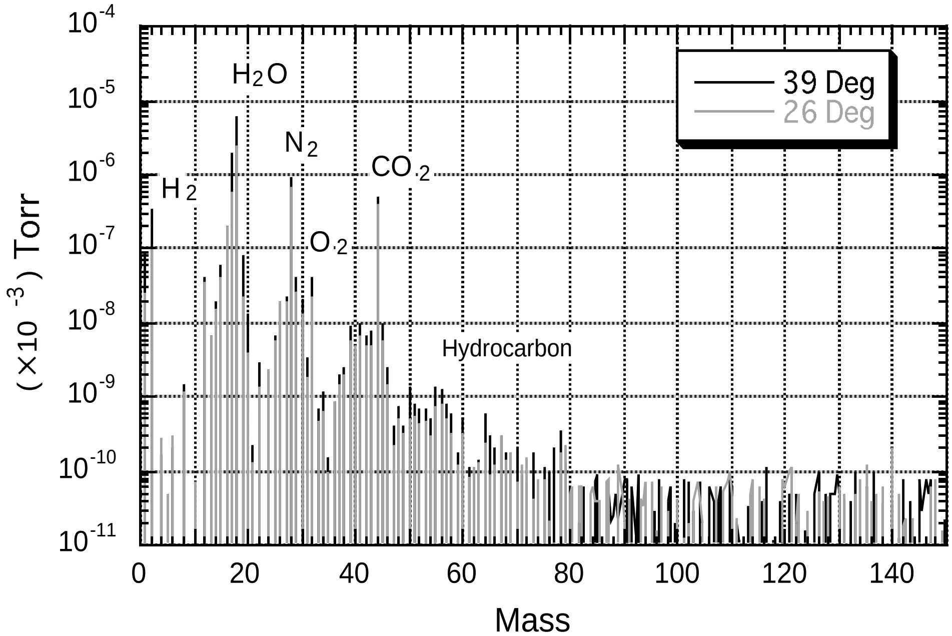

Figure 7: The amount of molecules emitted from the coil head heated with its 150mA DC current. (RGA detector data)

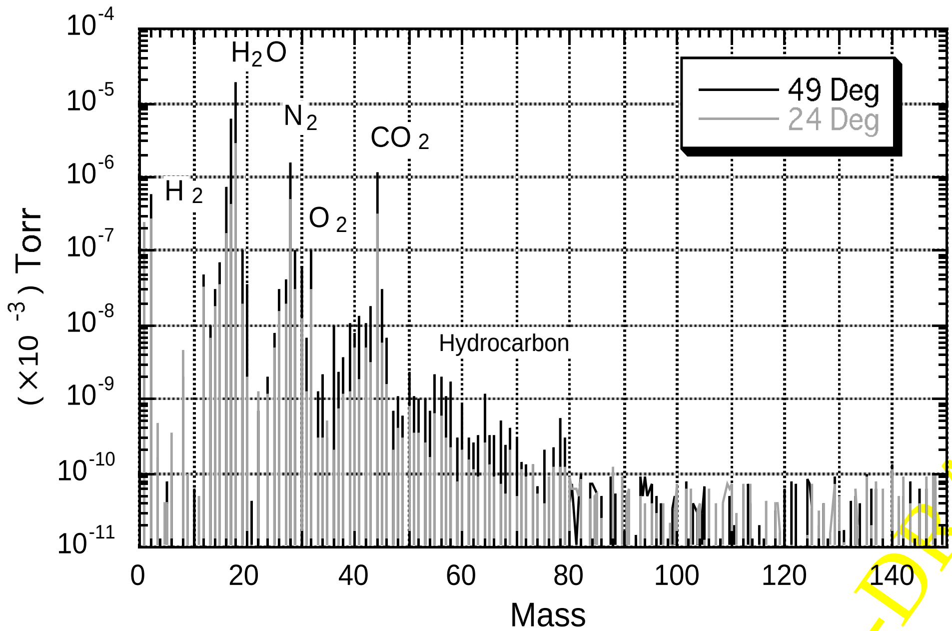

Figure 8: The amount of molecules emitted from the coil head heated with its 200mA DC current. (RGA detector data)

4 CONCLUSION

The expected temperature of 42 ^{o}C inside the coil head heated with its 150mA DC current proved to be low enough not to damage the LED and the photodetector inside the coil head. The equivalent phase noise due to statistical fluctuations in the index of refraction of the dominant molecules which were H_2, H_2O, and N_2 proved not to degrade the LIGO sensitivity of $h = 10^{-23}$ 1/rHz even if it was heated at 49 ^{o}C on its surface with 200mA DC current. The hydrocarbons emitted from the coil head heated with its 150mA DC current mainly for the alignment of the pitch position proved to be comparable with the LIGO requirement level of 10^{-12} torr in pressure.

It was proved that 150mA was the maximum current to use the 40-meter test mass suspension actuator coil for LIGO.