CONFIRMATION OF LEAK TIGHTNESS OF THE MO SEALING IN SUPERFLUID HELIUM

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Abstract

In SRF cavity application, super-fluid helium leak is a issue. Development of highly reliable and cost effective seal method is very important. We have successfully applied MO seal to SRF cavities. We have found out a leak rate limit: 1*E-10 Pam^3/s with super-fluid helium. When the helium leak rate is smaller than this value, the cavity gradient is expected to be higher than 25MV/m from vacuum point of view. MO seal satisfies well this level. Tightening torque: 15Nm works to get such a small leak rate. As the flange material, SUS316L and Titanium are useable. Copper gasket looks reliable as seal material.

MO SEAL

Concept of MO sealing has been originally developed at the S-band accelerator design at DESY [1]. Matsumoto and Otsuka successfully applied it widely for high peak power normal conducting accelerators [2]. This sealing mechanism is similar to ICF conflate seal but has no gap between the connected flanges, which can produce the zero RF impedance. We made small modifications from their original and applied it to the SRF cavity operated under the super-fluid environment [3]. The principle demonstration of leak tightness on the MO seal has been done and reported in the last IPAC10 in Kyoto [3]. However, on its application to the real SRF cavities small leak after warm-up and high sensitivity of leak on the flange surface were further issues in that stage. After the IPAC10, we continued R&D and finally confirmed the leak tightness even after the warm-up. We have tested two types of MO seal: "Old type" (Fig.1 a) and "New type" (Fig.1 b).

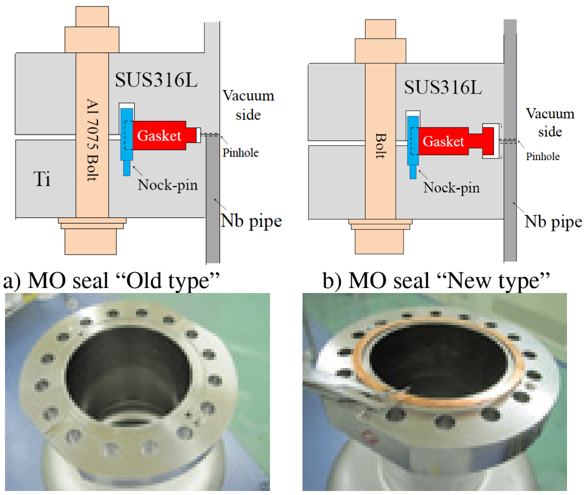

Figure 1: MO seal mechanism and Pictures of real MOF.

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ACCUMULATED SUCCESSFUL 2K VERTICAL TEST RESULTS

Fig.2 shows one of L-band superconducting single cell RF cavities used in this experiment, which has MO flange (MOF) on the top. After vacuum evacuation, it is sealed the vacuum at the bottom metal valve and demounted from the vacuum system, then immediately cold tested at 2K. During the test, it has no vacuum evacuation. After the last IPAC10, we have accumulated cavity test results with successful leak tightess at 2K in both MO types. Some examples are shown in Fig.3 and 4.

These cavities were surface treated initially by buffered cheminical polish-ing (BCP). Just HPR and short baking took place for the successive cold tests. Gradients were most likely limited by Q-slope or field emission.

Figure 2: One L-band SRF cavity used in this study.

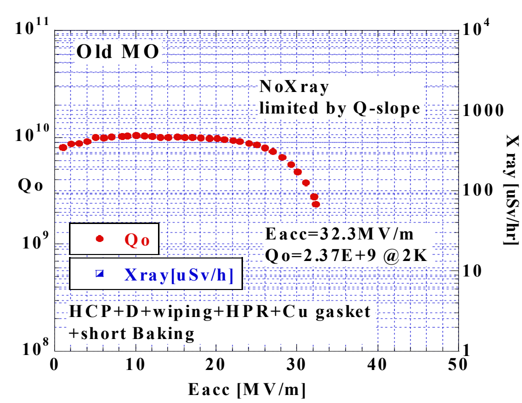

Figure 3: Cavity test result with "Old MO seal".

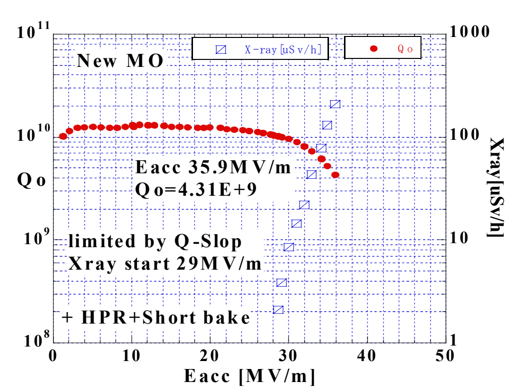

Figure 4: Cavity test result with "New MO seal".

MESUREMENT OF HELIUM LEAK RATE

In the vertical cold test, cavity is immersed in super-fluid helium lower than 2K for 3 hours. After test, it is warmed-up to room temperature in one night and connected again to the vacuum evacuation system. Confirming the leak tight at the connect flange by helium leak detector, the metal valve at the cavity bottom is slowly opened and the partial helium pressure and the time are measured. An example of the output is shown in Fig.5. The output is integrated. We regard as that the amount of the integrated helium gas would enter the cavity during the cold test. So the integrated value is divided by 1080 seconds (3hrs) in order to calculate the super-fluid helium leak rate. Cavity has three vacuum seals: MO seal at top flange, indium seal at bottom flange, and the metal valve seal. The calculated leak rate gives the maximum leak rate for MO seal.

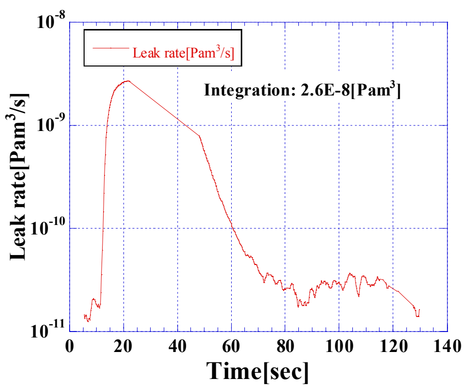

Figure 5: Typical output data from helium leak rate measurement.

EXPERIMENTAL RESULTS

All experimental results are listed in Table 1 for “Old MO” and Table 2 for “New MO”. Cavity beam pipe (BP) flange material is titanium for “Old MO”. SUS316L is used for “New MO”. Top pick-up flange is SUS316L in both cases. In these experiment, we tested pure aluminium and copper gaskets 1mm thick for “Old MO”, aluminium and copper gaskets 1.5 mm thick for “New MO”. These gaskets were well annealed. Vickers hardness (Hv) was 37 for aluminium gasket and 40 for copper gasket. M8-aluminium alloy bolts (Al) and M8-stainless bolts (SUS304) were tested in bolt tightening. The tightened torque is 15Nm in every experiment.

Second column of Tables 1 and 2 shows these combinations. As seen in Table 1, combination of BP titanium flange and aluminium gasket works fine as long as leak tightness needed for stable PLL (Phase Locked Loop) operation in the vertical cold test. Combination of copper gasket and SUS bolts also well works in “NEW MO”. Small leak after warmed-up happens sometimes with aluminium gasket. Copper gasket looks more reliable than aluminium. Third column shows residual surface resistance (Rres) in nΩ unit. In Table2, a remarkable increase in Rres is observed with chemically heavily etched copper gaskets. In fourth column, Eacc,max means the achieved maximum gradient in the cold test. Qo is the unloaded Q value at the Eacc,max. 6th column is helium partial pressure calculated from the integrated data. Both MO flanges are designed so that gasket is bitten 0.5mm thick and has no gap at the inside seal however a small gap remains depending on the

Table 1: All Experimental Results for “ Old MO”

No. (Date)	Gasket-bolt	Rres [nΩ]	Eacc,max[MV/m], Qo	Leak rate[Pam³/s]	Pressure[Pa] in the cavity (after VT)	Gap length at inside seal [mm]	Comment
1 (4/27,2010)	Al-Al	19.0	8.3, 2.0E+9	<3.6E-7	9.9E-2	0.032 ± 0.007	
2 (4/29,2010)	Al-Al	18.5	10.9, 8.7E+9	<2.7E-8	7.4E-3	0.006 ± 0.005	Made a gap 0.05mm outside TOP flange
3 (5/21,2010)	Cu-Al	19.5	32.3, 2.4E+9	<2.6E-11	7.1E-6	0.150 ± 0.100	Without knock-pin
4 (6/5,2010)	Cu-Al	27.0	17.7, 6.6E+8	<9.1E-9	2.5E-3	0.250 ± 0.020	
5 (6/9,2010)	Cu-Al	23.0	14.3, 6.8E+8	<1.2E-10	3.2E-5	0.230 ± 0.013	Gasket without surface oxide film
6 (6/15,2010)	Cu-Al	19.0	28.6, 3.3E+9	<9.2E-12	2.5E-6	0.280 ± 0.011	Input coupler change
7 (6/19,2010)	Al/In-Al	15.0	14.5, 3.4E+9	Large leak after VT	>2.8E+3	0.006 ± 0.012	Used In plated Al gasket To see the Qo change
8 (7/10,2010)	Cu-SUS	25.0	Cold Leak	>6.5E-4	>1.8E+2	0.230 ± 0.011	HPR with Top flange

Table 2: All Experimental Results for “New MO”

No. (Date)	Gasket-bolt	Rres [nΩ]	Eacc[MV/m], Qo	Leak rate[Pam³/s]	Pressure[Pa] in the cavity (after VT)	Gap length at inside seal [mm]	Comment
1	Al –Al	-	Cannot Meas.	Large leak			
2	Al-Al	18.5	10.2, 3.9E+8	<2.6E-8	0.71		Made a gap 0.05mm outside TOP flange
3	Cu-Al	19.5	33.7, 2.7E+9	<1.4E-11	4.1E-6	0.230 ± 0.014	Cu gasket none etched
4 (6/28,2010)	Cu-SUS	17.9	35.9, 4.3E+9	<4.4E-11	1.2E-5	0.230 ± 0.014	Used SUS bolts Cu gasket none etched
5 (7/1,2010)	Cu-SUS	29.3	21.5, 7.3E+9	<6.6E-12	1.8E-6	0.080 ± 0.005	Cu gasket etched by 0.15mm
6 (7/10,2010)	Cu-SUS	24.9	27.8, 5.9E+9	<1.7E-9	4.5E-4	0.020 ± 0.003	Cu gasket etched by 0.21mm
7 (7/19,2010)	Cu-SUS	27.6	Cold Leak	>2.8E-3	>30	0.130 ± 0.078	Cu gasket etched by 0.10mm
8 (8/14,2010)	Cu-SUS	29.9	11.6, 3.9E+8	<3.9E-10	1.1E-4	0.230 ± 0.014	Cavity EP’ed Cu gasket none etched

tightening condition. 7th column in Tables is the gap length. Aluminium gasket is almost no gap but copper gasket remains a gap 0.23mm thick at the torque 15Nm, of which hardness could be related.

DISCUSSION AND SUMMARY

Zero RF Impedance

As seen in Fig.7, Rres is large by 8-13nΩ in both MO cases (small gap cases) compared to the baseline SRF cavity performance, of which cavity BP length is 115mm. In this experiment, cavities were reused. The original BP flange at the 80ϕ beam pipe was cut down and replaced MO flange. As the result, the BP length became 105mm. This increases Rres about 8nΩ by RF simulation. 15± 3nΩ is the expected value for these MO sealed cavities. This value is obtained only for the indium plated aluminium gasket but other cases look large about 3-4nΩ. The tight contact might be a problem but we have not yet understood exactly. The gap at inside seal increases Rres and the limitation is more likely around 0.2mm. The heavy chemical etched copper gasket enhanced Rres rather. In this case, the gap is smaller than none etched case (0.23mm) and the Rres could decrease, while the results are opposite. Surface roughness of the gasket might relate to this. Zero RF impedance of MO seal is still further study issue.

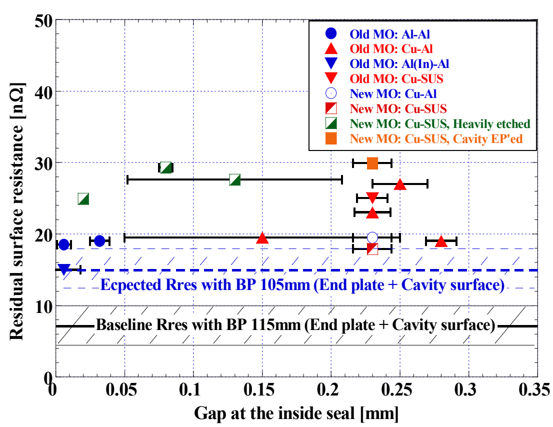

Figure 7: Relationship between gap length and residual surface resistance.

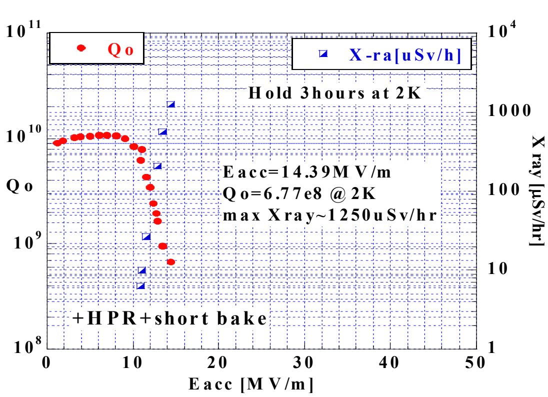

Figure 8: Typical field emission result seen on MO sealed cavity.

Leak Rate Limit Against Field Emission

In these experiments, we often observed field emission (FE) result. A typical example is shown in Fig.8. FE onset is less than 10MV/m and serious X-ray accompanies. We plotted Eacc,max and helium leak rate in Fig.9. One can see a correlation. This figure suggests a helium leak rate limit. 1*E-9 Pam^3/s is yellow zone to get high gradient, and safely saying 1*E-10 Pam^3/s is the leak rate limit, where no helium discharge happen at the high gradient higher than 10MV/m and results in no FE. We have not yet known wheatear these FE relates to any particle contamination from seal materials. This is another study issue.

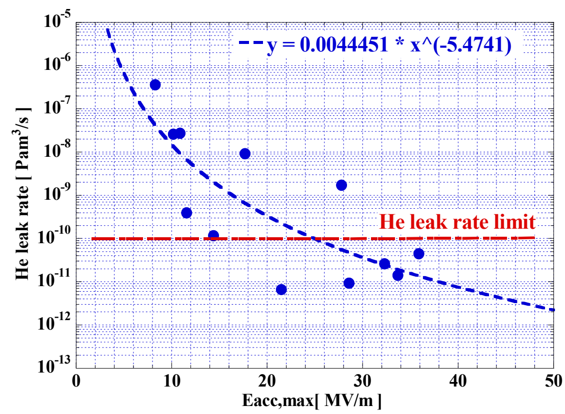

Figure 9: Relationship between Eacc,max and He leak rate.

Care of MO Seal Surface

Our MO design has small channels inside of the flange in order to well evacuate vacuum at the air pocket. During cavity preparation, acid enters these channels and makes corrosion on the MO seal surface, if no protection takes place. The left picture in Fig.10 shows such a case. Such corrosion happens vacuum leak. One has to care of the MO seal surface. We have solved this kind of problem developing a simple masking method, which is shown in Fig.10 right. Thin Teflon tape works fine as the surface protection.

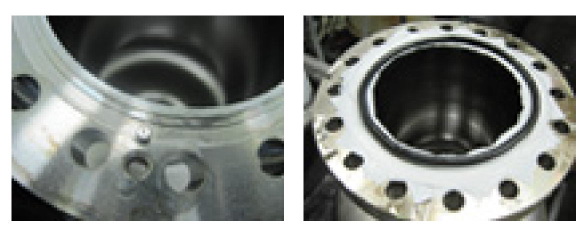

Figure 10: Corroded MO seal surface during BCP (left), and well developed protecting mask against the chemical corrosion (right).

REFERENCES

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[2] H.Matsomoto et al., Proc. in the PAC97. pp.530-532.
[3] K.Saito et al., Proc. in the IPAC10, WEPE009, pp. 3359-3361.