Xenon Photon Detector

Cryostat Design Summary

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Introduction

This note describes summary of cryostat design for the photon detector done by Japanese group in collaboration with a design/construction company, SAAN* in Japan. Information described in this note can be found also at the project web site http://meg.web.psi.ch/subprojects/calorimeter/calorimeter.html.

*Taiyo Toyo Sanso Co., Ltd. http://www.saan.co.jp/english/index.html

Overview of the cryostat

The cryostat consists of two layers, outer vessel and inner vessel. The inner vessel is supported from the outer vessel by G10 supports so that heat conduction can be reduced as small as possible. There are three large nozzles on the top of the cryostat where equipments can be mounted like a vacuum pump, feed-through connectors for temperature readout; HV supply and PMT signal readout, pressure/vacuum gauges, and various kinds of valves for xenon transfer. A pulse-tube refrigerator will be mounted on one of the nozzle for cooling. A liquid nitrogen-cooling pipe is planned to be attached on the cover as done in the large prototype[1,2]. An overview of the cryostat can be found in Fig. 1.

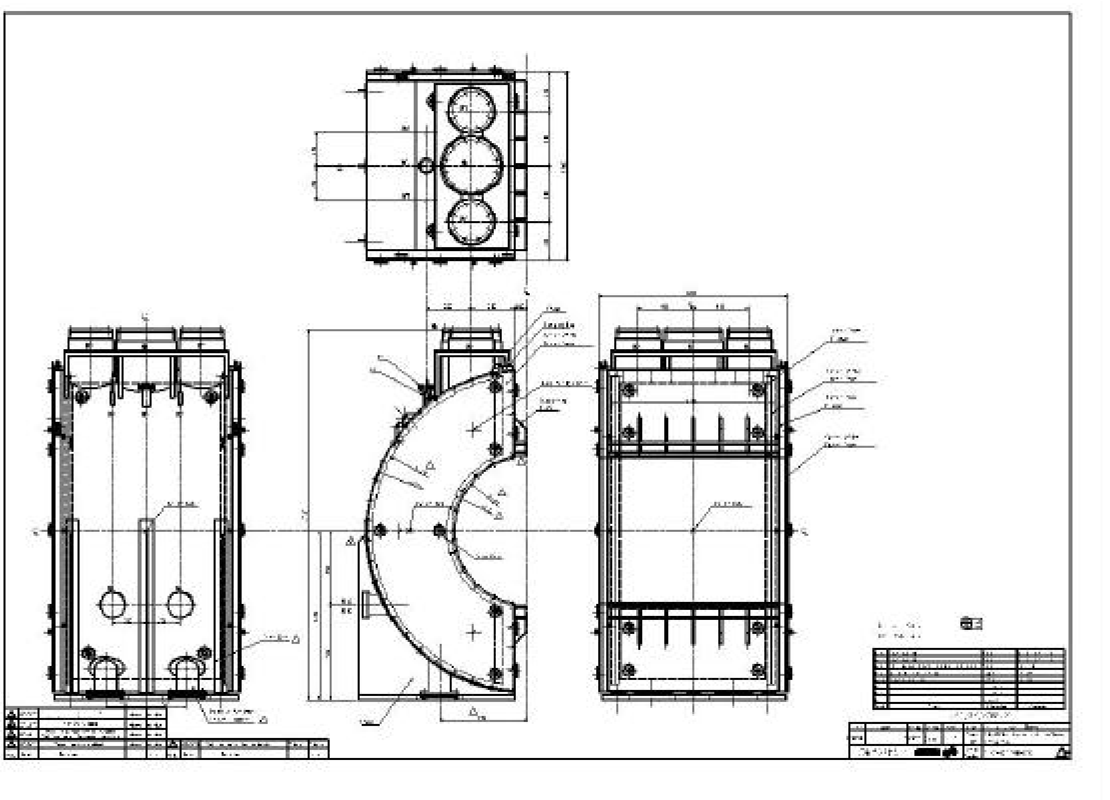

Fig. 1 Overview of the cryostat. The drawing can be found at http://meg.web.psi.ch/subprojects/calorimeter/drawings/210overview.dwg

Important Parameters

Strength Calculation for the walls

Design values of wall thickness were determined based on the following calculations. Details are shown in separate tables from Table 1 to Table 4 and are summarized in

Table 5.

There are in principle 12 walls on the cryostat,

- Inner vessel
  - Inner wall, Outer wall (cylindrical)
  - 2 Covers at both ends (plate)
  - 2 front walls at top and bottom of the cryostat (plate)
- Outer Vessel
  - Inner wall, Outer wall (cylindrical)
  - 2 Covers at both ends (plate)
  - 2 front walls at top and bottom of the cryostat (plate)

The minimum thickness of each wall was calculated under the condition of vacuum in the insulation layer and 0.3MPa in the inner vessel. Detector operation will be done in principle around 0.1MPa. During liquefaction of xenon the pressure can reach 0.2MPa but never above that except for emergency like refrigerator operation failure due to power cut (even in this case we have liquid nitrogen cooling system for avoiding the disaster). Thus 0.3MPa design still has some margin of pressure tolerance.

Cylindrical Body Wall			
	Formula	t=P*Di/(2*σ_a* η -1.2*P)	
		Outer Vessel Inner Wall	Inner Vessel Outer Wall
Input Parameter	Design Pressure (MPa)	0.1	0.3
	Design Temp (deg C)	40	40
	Material	SUS316L	SUS316L
	σ_a at the design Temp (N/mm2)	109	109
	Welding efficiency η	1	1
	Inner Radius of the body Di (mm)	1100	2218
Result	(I) 2* σ_a* η	218	218
	(II) 1.2*P	0.12	0.36
	(III) (I)-(II)	217.88	217.64
	(IV) P*Di	110	665.4
	T=(IV)/(III)	0.5	3.1
	Minimum thickness (mm)	0.5	3.1
	Actual thickness (mm)	0.5	7.0

Table 1 Wall thickness calculation of Outer-Vessel Inner wall and Inner-Vessel Outer wall where pressure direction is from the center to the outside.

Cylindrical Body Wall			
	Formula	t1 = 3*P*D0/(4*B*C) for t1>=t0	
		t2 = 3*P*D0/(4*A*E*C) for t2>=t0	
		Outer Vessel Outer Wall	Inner Vessel Inner Wall
Input Parameter	Design Pressure (MPa)	0.1	0.3
	Design Temp (deg C)	40	40
	Material	SUS316L	SUS316L
	Breakdown point (N/mm2)	154	154
	Outer diam of the body D0(mm)	2400	1232
	Coeff. depending on welding C	1	1
	Length of the body L(mm)	1270	1086
	Supposed minimum thickness t0(mm)	5	5
Result	L/D0	0.52916667	0.88149351
	D0/t0	480	246.4
	Coeff. determined by the shape A	0.00025	0.00052
	Coeff. depending on the material B	24	51
	(I) 4*B*C	96.0	204.0
	(II) 3*P*D0	720.0	1108.8
	t1 = (II)/(I)	7.5	5.4
	t1 >= t0 ?	OK	OK
	Minimum thickness (mm)	7.5	5.4
	Actual thickness (mm)	8	7

Table 2 Wall thickness calculation of Outer-Vessel Outer wall and Inner-Vessel Inner wall where pressure direction is from the outside to the center.

Plates fixed to a cylindrical body with bolts			
	formula	t=G*sqrt(0.3*Z*P/σ_a + 6*W*hG/σ_a*L*G^2)	
		Inner Vessel Cover	Outer Vessel Cover
Input Parameters	Design Pressure P(MPa)	0.3	0.1
	Design Temp T(deg C)	40	40
	Material	SUS316L	SUS316L
	σ_a at the design Temp (N/mm2)	109	109
	G of Gasket G(mm)	494	580
	Moment Arm hG(mm)	18	20
	Weight on bolt W(N)	61054	27326
	Peripheral length of bolt hole L(mm)	5881	6750
	Diameter or minimal span d (mm)	560	660
	Maximum span D(mm)	2365	2373
Result	Z=3.4-2.4*G/D, Z<=2.5	2.5	2.5
	(I) 0.3*Z*P	0.225	0.075
	(II) (I)/σ_a	0.00206422	0.00068807
	(III) 6*W*hG	6593832	3279120
	(IV) σ_a*L*G^2	1.5643E+11	2.4751E+11
	(V) (III)/(IV)	4.2151E-05	1.3249E-05
	(VI) sqrt((II)+(V))	0.04589522	0.02648249
	T=G*(VI)	22.6722377	15.3598415
	Minimum thickness (mm)	22.6722377	15.3598415
	Actual thickness (mm)	30	20

Table 3 Wall thickness calculation for the Inner-Vessel and Outer-Vessel covers.

Plates			
	formula	t=d*sqrt(Z*C*P/σ_a*η)	
		Inner Vessel Front Wall	Outer Vessel Front Wall
Input Parameters	Design Pressure P(MPa)	0.3	0.1
	Design Temp T(deg C)	40	40
	Material	SUS316L	SUS316L
	σ_a at the design Temp (N/mm2)	109	109
	Welding efficiency η	1	1
	Coeff. depending on attachment C	0.33	0.33
	Diameter or minimal span d (mm)	504	650
	Maximum span D(mm)	1086	1270
Result	(I) σ_a*η	109	109
	(II) Z=3.4-2.4*d/D	2.28618785	2.17165354
	(III) Z*C*P	0.2263326	0.07166457
	(IV) sqrt((III)/(I))	0.04556804	0.02564124
	t=d*(IV)	22.9662898	16.6668048
	Minimum thickness (mm)	22.9662898	16.6668048
	Actual thickness (mm)	24	20

Table 4 Wall thickness calculation for the front plates of the inner and outer vessel.

Walls/Cover	Material	Dimension	Pressure Direction	Design P [MPa]	Design T [degree C]	Thickness Calc [mm]	Thickness Act [mm]
Inner Vessel Inner Wall	SUS316L	R623 x L1086	Outer	0.3	-108~ 4	5.4	7.0
Inner Vessel Outer Wall	SUS316L	R1116 x L1086	Inner	0.3	-108~ 4	3.0	7.0
Inner Vessel Front Wall	SUS316L	min504 x max1086	Inner	0.3	-108~ 4	23.0	24.0
Inner Vessel Cover	SUS316L	R1148 x R588	Inner	0.3	-108~ 4	22.7	24.0
Outer Vessel Inner Wall	SUS316L	R550 x L1260	Inner	0.1	40.0	0.5	0.5
Outer Vessel Outer Wall	SUS316L	R1200 x L1270	Outer	0.1	40.0	7.5	8.0
Outer Vessel Front Wall	SUS316L	min650 x max1270	Outer	0.1	40.0	16.7	20.0
Outer Vessel Cover	SUS316L	R1200 x R540	Outer	0.1	40.0	15.4	20.0

Table 5 Summary of wall thickness calculations

Strength calculation for the G10 support

Strength calculation for the G10 support is summarized in Table 6.

Strength Calculation for the G10 support		Unit	Formula	Value
W1	Inner Vessel weight	kg		1200
W2	Liquid xenon weight	kg		2400
W3	PMT weight	kg		400
W	total weight	kg	W1+W2+W3	4000
n	number of support			2
w	weight/support	kg	W/n	2000
d1	outer diameter of the support	mm		115
d2	inner diameter of the support	mm		95
s	allowed strength of G10	kg/mm2		10
A	cross section	mm2	pi/4(d1^2-d2^2)	3298.672
Wr	allowed weight		s*A	32986.72
Wr-w	never negative	kg	Wr-W	30986.72

Table 6 Strength calculation for the G10 support.

Estimation of the total weight

Current estimation of the weight is summarized in Table 7.

		Material	Dimension	Qty	kg	kg
Inner Vessel	Inner Wall	Honeycomb	0.94g/cm2	1	15.0	15.0
	Outer Wall	SUS	307.8x108.6x0.7cm3	1	185.0	185.0
	Front Wall	SUS	107x50.8x2.4cm3	2	103.0	206.0
	Flange	SUS	see the drawing	2	60.0	120.0
	Cover	SUS	see the drawing	2	265.0	530.0
Outer Vessel	Inner Wall (thick)	SUS	126x18.5x2.0cm3	2	36.9	73.7
	Inner Wall (thin)	SUS	127x115x0.05cm3	1	5.8	5.8
	Outer Wall	SUS	354x127x0.8cm3	1	285.0	285.0
	Front Wall	SUS	126x65x2.0cm3	2	129.5	259.0
	Flange	SUS	see the drawing	2	111.0	222.0
	Cover	SUS	see the drawing	2	260.0	520.0

Legs	Plate	SUS	see the drawing	1	327.7	327.7
	Legs	SUS	see the drawing	3	24.5	73.5
Subtotal						2822.7
PMT	500 g/PMT including holder			800	0.5	400.0
Subtotal						400.0
Scintillator		xenon		800	3.0	2384.0
Subtotal						2384.0
Total						**5606.7**

Table 7 Estimation of the weight of the detector.

Heat load calculation

Heat load calculation is summarized in Table 8. In this calculation it is supposed that 30 layers of super insulators are placed on the inner vessel. Most of heat load is from PMTs bleeder circuit and conduction through cables. We can expect 150W cooling power of the refrigerator is realistic which is sufficient to compensate this static heat load.

Heat load calculation for the xenon photon detector vessel			
			Unit
Radiation	Outer Vessel -> Inner Vessel (30 Mylar layers)	3.1	W
Conduction	Nozzle (N1-N3) via xenon gas	0.2	W
Conduction	Nozzle (N1-N3) via bellows	4.6	W
Conduction	Support (brace and supporting pipe)	6.3	W
Heat generation	PMT (65mW/PMT)	52	W
Conduction	PMT HV and Signal Cables	50	W
total		116.2	W

Table 8 Heat load calculation done based on the current design.

Bolts for fixing the covers

Number of bolts and their positions for fixing the covers are determined based on **JIS B8273:1993 "Bolted flange for pressure vessels"**. Location of the groove for the metal seal is also determined based on this standard. The shape for the groove is determined by following recommendation from a possible metal gasket producer USUI[3]. Stress calculation is performed to check that the actual stress caused by moment of force is less than the allowed stress of the material. The results are summarized in Table 9.

Symbol	Description	Unit	Inner Vessel Flange	Outer Vessel Flange
P	Design Pressure	MPa	0.3	0.1
σf	Allowable Tensile Stress	N/mm2	115	115
A	Outer Radius	mm	2296	2400
B	Inner Radius (Outer)	mm	2204	2160
B1	Inner Radius (Inner)	mm	1276	1190
K	A/B		1.042	1.111
Y	Coefficient from A		47.0	18.4
g0	Thickness of the leading edge	mm	7	16
b0	Basic width	mm	0.7	0
b	Effective width	mm	0.7	0
G	Basic width of gasket（outer）	mm	2,225	2,330
G1	Basic width of gasket（inner）	mm	1239	1,170
m	Gasket Coefficient		4.5	0.0
y	Minimum tightening stress	N/mm2	150	0
σb	Allowable Tensile Stress of Bolts	N/mm2	102	102
C	Radius of bolt center	mm	2266.0	2370.0
	Bolt Size		M20	M20
D	Core Diameter	mm	17.294	17.294
N	Number of Bolts		70	41
tm	Groove Depth	mm	4.5	7.0
H	Area of G x P		377,446	153,208
Hp	$\pi b(G + G1)mP$		10,279	0
$H + H_p$			387,725	153,208
$W_{m1} = W_0$	$H + H_p$		387,725	153,208
πbGy	$\pi b(G + G1)y/2$		571,040	0
W_{m2}	πbGy		571,040	0
A_{m1}	$W_{m1}/\sigma b$		3,801	1,502
A_{m2}	$W_{m2}/\sigma a$		5,598	0
A_m	Larger one between A_{m1} and A_{m2}		5,598	463

A_b	π/4 x d^2 x n		16,435	9,626
A_b - A_m	Never negative		10,837	9,163
W_g	(A_b + A_m) / 2 x σb		1,123,662	514,537
H_D	Area of B x P		333,935	116,121
H_G	W_o - H		10,279	0
H_T	H - H_D		43,511	37,087
h D	(C - B) / 2		31	105
h G	(C - G) / 2		20.5	20
h T	(h D + hG) / 2		25.75	62.5
M_D	H_D x hD		10,351,992	12,192,718
M_G	H_G x hG		210,714	0
M_T	H_T x hT		1,120,402	2,317,958
M_o	M_D+M_G+M_T		11,683,108	14,510,676
M_g	W_g x hG		23,035,062	10,290,748
T	Thickness	mm	30.0	40.0
t0	Design thickness	mm	25.5	33.0
h			8.0	10.0
h0	sqrt (Bg0)		124.2	185.9
h / h0			0.06	0.05
g 1			7.00	16.00
G1/g0			1.00	1.00
F			1.00	1.00
F			0.91	0.91
E	F / h0		0.01	0.00
T			1.90	1.90
U			52.00	23.00
V			0.55	0.55
D	U/V x h0 x g0^2		575,429	1,990,178
L	(t0e+1)/T + t0^3 / d		0.65	0.63
σH	Stress along hub spindle	N/mm2	166	42
1.5σa - σH	Never negative	N/mm2	7	131
			OK	OK
σR	Radial direction stress	N/mm2	31	8
σa - σR	Never negative	N/mm2	84	107
			OK	OK

Z		N/mm2	26.00	2.20
σT	Hoop stress	N/mm2	-43	62
σa - σT	Never negative	N/mm2	158	53
			OK	OK
(σH + σR)/2		N/mm2	98.13	25.07
σa - (σH + σR) / 2	Never negative	N/mm2	16.87	89.93
			OK	OK
(σH + σT)/2		N/mm2	-6.25	35.20
σa - (σH+σR) / 2	Never negative	N/mm2	121.25	79.80
			OK	OK

Table 9 Results of stress calculations for the flanges.

Finite Element Analysis Results

Finite element analysis is performed based on the design described above to check the maximum deformation and stress distribution. The results are shown in Fig. 2 and Fig. 3. Maximum deformation (5.3mm) occurs on the outer-vessel inner wall (0.5mmt steel) where the deformation is along the radial direction. Maximum stress appears along the welded line on the outer-vessel inner wall, but this is less than the allowed pressure of the material.

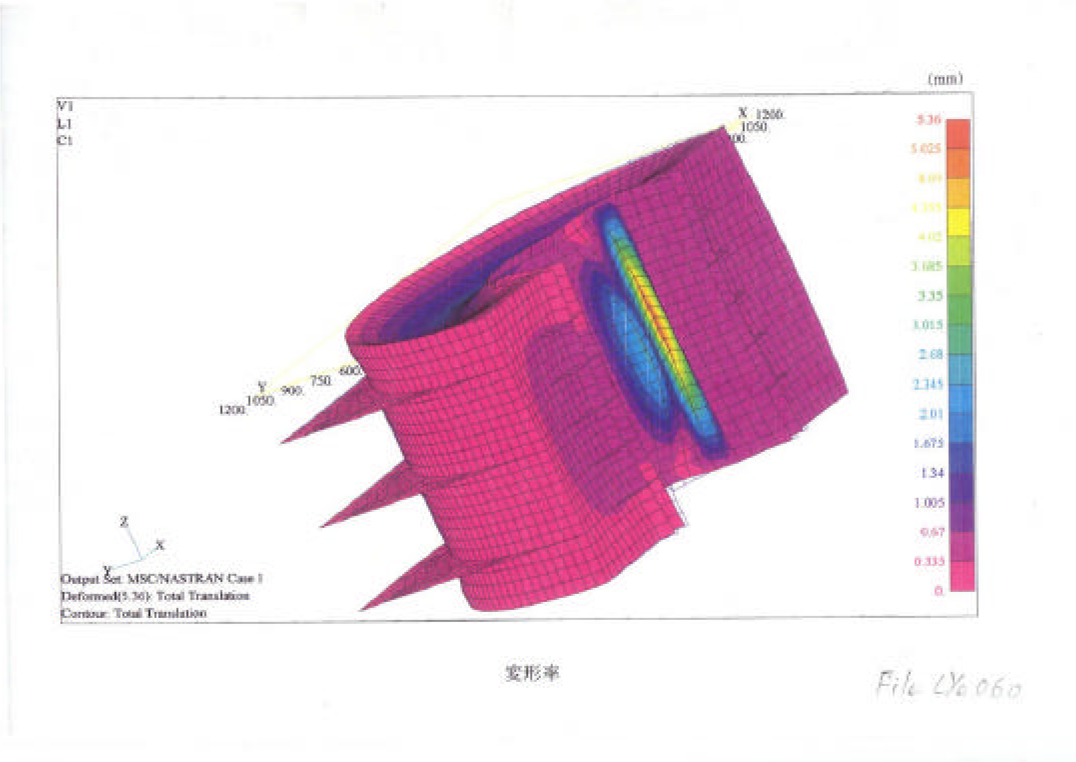

Fig. 2 Result of finite element analysis (deformation).

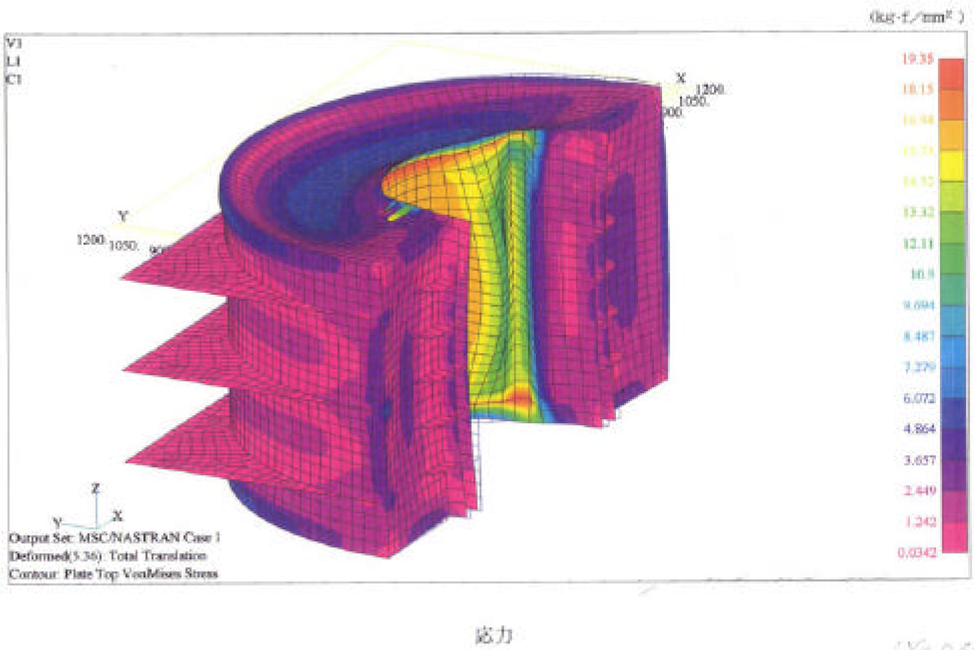

Fig. 3 Result of finite element analysis (stress distribution).

Drawings

All the drawing can be found in the MEG web site[4]. These drawings are only for the vessel. These do not include the followings; Liquid nitrogen cooling pipe, feedthrough connectors, vacuum pump system, any port for sensors/gauges, gas inlet/outlet, drain for liquid phase purification. These must be included into the design before construction.

Detector Components

Followings are detector components currently considered to be used in the cryostat although they can be substituted by any kind of better components available now. So please consider each of them as one of the candidates that fulfill the minimum requirement.

U-tight seal

A special kind of metal gasket is required for the inner vessel covers because they face liquid xenon whose temperature is –108 degree C. Currently "U-tight seal[4]" is considered to be used for the cryostat. Followings are the specification of it. The shape of the groove on the flange is determined by recommendation for using this metal gasket.

- Usage condition
  - Pressure: Vacuum - 0.3 MPa
  - Temperature: –110 ~ 100 degree C
  - Fluid: Liquid xenon
  - Frange and bolt: SUS316L
- U-tight seal dimension
  - Cross section: 5.5 mm diam
  - Material: Aluminum(outer), Stainless(Inner), Spring(Inconel)

Vacuum pumping system

Two vacuum pumping system are considered to be used for the cryostat. One is for evacuating the inner vessel before filling xenon and the other is for the insulation vacuum layer which has to be evacuated continuously during the operation.

- ALCATEL ATP400[5] for evacuating the inner vessel. 400 liter ceramic bearing turbo pump. The inlet flange type is DN 160 CF.
- PFEIFFER TMU 261[6] for evacuating the outer vessel. 210 liter turbo pump. The inlet flange type is DN100 CF.

Both will be connected to the cryostat with gate valves.

Refrigerator/Liquid nitrogen cooling pipe

A pulse tube refrigerator is equipped on the central nozzle on the top of the cryostat. The refrigerator works for pre-cooling the cryostat, liquefaction and re-condensation of xenon. The flange shape of the refrigerator is the same one used in the large prototype. Part of the drawing of the large prototype top cover is shown in Fig. 4 as a reference.

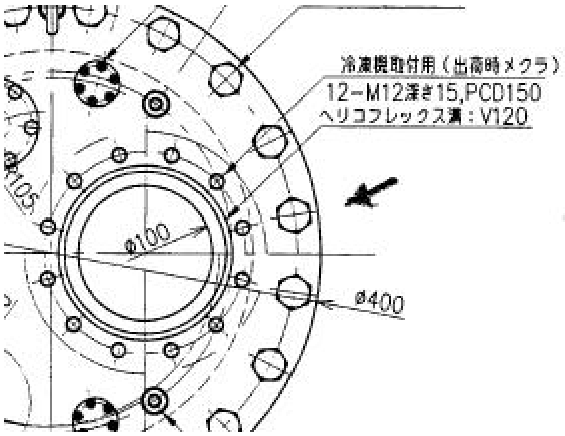

Fig. 4 Part of the drawing of the large prototype. The pulse tube refrigerator is installed in the 100mm diameter hole and fixed on the cover with twelve M12 bolts. Depth of the screw hole is 15mm. The groove for the metal gasket (helicoflex) is V120.

When cooling power of the refrigerator is not sufficient in such cases like fast liquefaction, power failure, or insulation vacuum break, liquid nitrogen cooling system will help to compensate the additional heat load. For this purpose a liquid nitrogen cooling pipe will be equipped on the cover of the central top nozzle as was done in the large prototype. A valve to control the nitrogen flow should be opened/closed automatically when needed. The system operating method is established in large prototype studies and proved to work in a safe manner.

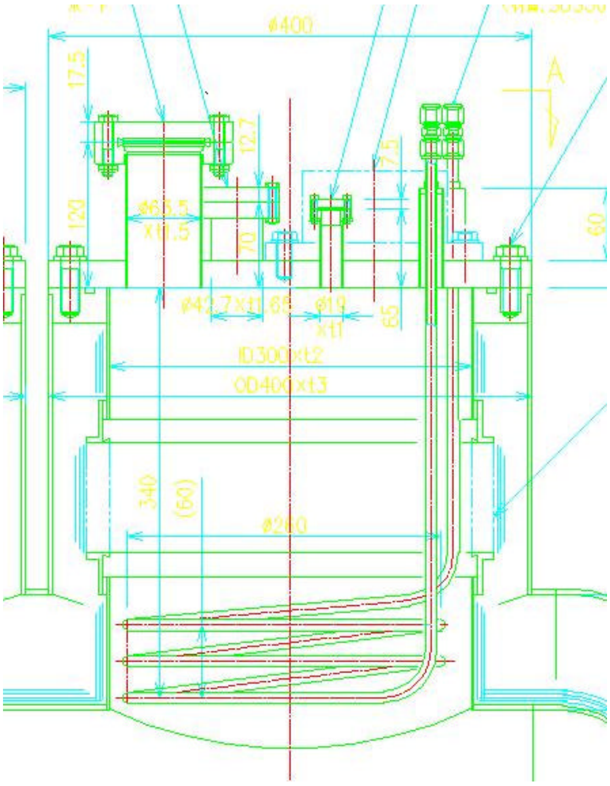

Fig. 5 Part of the drawing of the large prototype to show how the liquid nitrogen cooling pipe is equipped. Details can be found in its drawing[1].

Feedthrough connectors

We will use about 800 PMTs in the cryostat. Two coaxial cables of HV and signal are needed for each of them. Requirements to the feedthrough are different between signal and HV. Feedthrough connectors for HV supply must be tolerant, at least, up to 2.0kV but do not need to transmit fast signal while for signal transmission of fast PMT signal is truly important. In Fig. 6 and Fig. 7 feedthrough connectors currently used in the large prototype are shown. The HV feedtrough is mounted on the top cover and fixed by cramps with o-rings between the flange and cover. The signal feedthrough is welded on a steal cover with is mounted on a flange. When constructing the cryostat for the final photon detector, we should pay attention to reduce difficult welding part in order to avoid unexpected leakage.

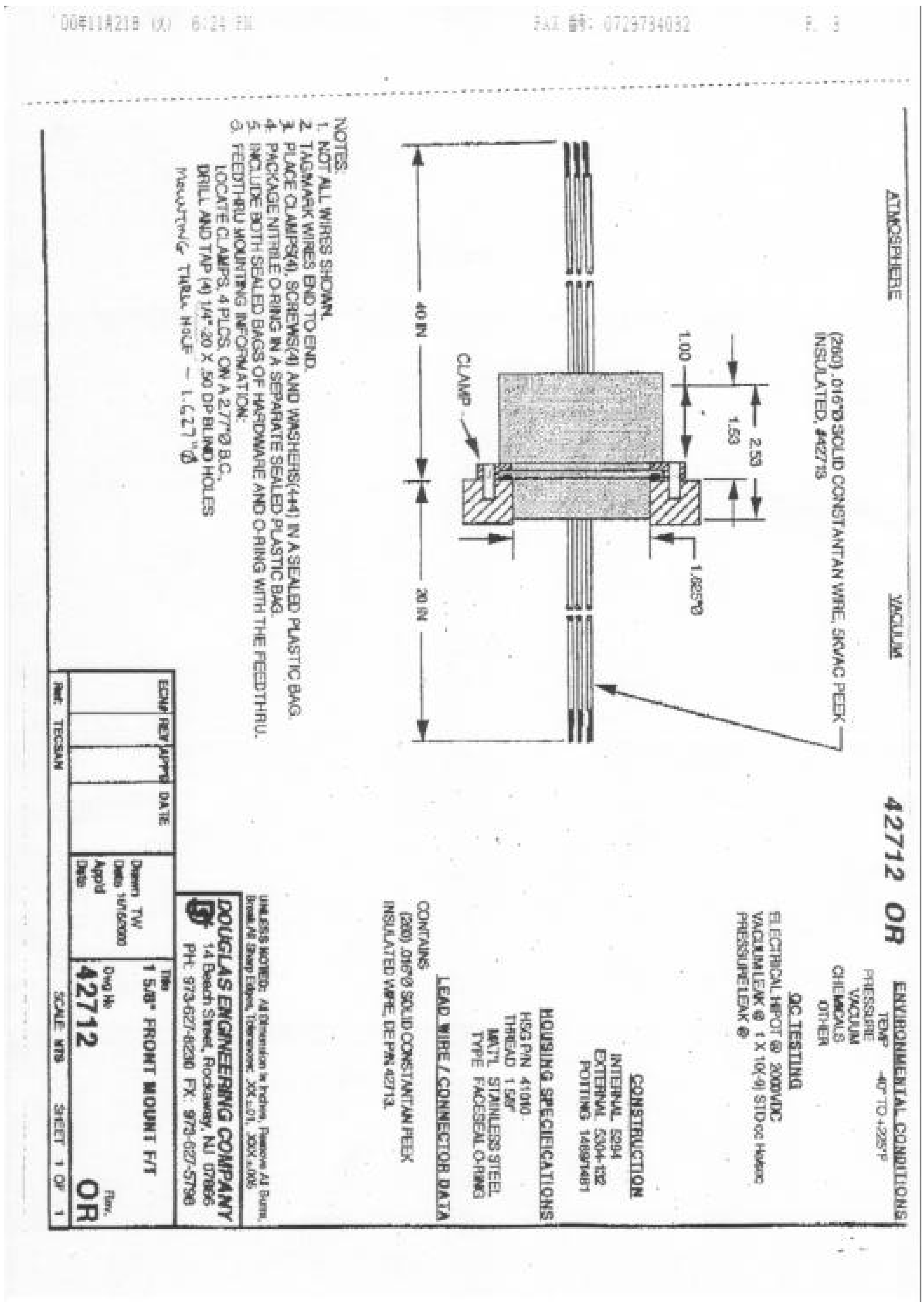

Fig. 6 HV feedthrough connector used in the large prototype. 260 wires in total.

Fig. 7 Signal feedthrough connector used in the large prototype. 256 channel in total.

Sensors

Sensors to measure environmental variables like temperature and pressure in the cryostat will be located inside (temperature sensors, surface level meter) or mounted on the cryostat (pressure and vacuum gauges).

For reading out the sensors located in the cryostat we need feedthrough connectors although the number of channel is not quite large. Currently we are considering to use a commercially available feedthrogh connectors mounted on CF flanges. Flange type for the pressure and vacuum gauges will be also CF type.

For mounting them we have to prepare several ports on the top cover with CF flanges. Details have not been determined yet. A list of sensors is shown in Table 10.

Purification system

In this design liquid phase purification is not considered. Only gas phase purification is taken into account. For implementing liquid phase purification we need a drain at the bottom of the cryostat and liquid xenon inlet port on the top. These must be newly added into the design.

Flow sheet of the system

Whole system is schematically shown in . However as mentioned above, liquid phase purification scheme is not included into this figure. This must be included in future.

Sensors

Section	Discription	Control	Mark		Sensor	Range	
Photon Detector	Inner Vessel TEMP(Bot)		TI-101		PT100	77K~ 327K	
	Inner Vessel TEMP(Middle)		TI-102		PT100	77K~ 327K	
	Inner Vessel TEMP(Top)		TI-103		PT100	77K~ 327K	
	Vac. Vessel TEMP(Top)		TI-104		PT100	77K~ 327K	
	LN2 Cooling Pipe TEMP(In)		TI-105		PT100	77K~ 327K	
	LN2 Cooling Pipe TEMP(Out)	O	TIC-106		PT100	77K~ 327K	
	LN2 Pipe VAC Vessel TEMP(In)		TI-107		PT100	77K~ 327K	
	LN2 Pipe VAC Vessel TEMP(Out)	O	TIC-108		PT100	77K~ 327K	
	LXe Level	O	LIA-101				
	LXe Pressure	O	PI-101	PT-101		-0.1~ 0.5MPa	
	Inner Vessel VAC Gauge		PI-102			10^-5~ 0.1MPa	
	Vac. Vessel VAC Gauge		PI-110			10^-5~ 0.1MPa	
	Vac. Vessel Pressure		PI-112	PT-112		-0.1~ 0.5Mpa	
Refrigerator/	Cold Head TEMP	O	TIC-201		PT100	77K~ 327K	
Compressor	Top Flange TEMP		TI-202		PT100	77K~ 327K	
	Heater Power W(Vxl)						
	Compressor Delivery Pressure		PI-211	PT-211		0~ 3.5MPa	
	Compressor Suction Pressure		PI-212	PT-212		0~ 3.5MPa	
	Cooling Water Flow Meter		FIA-211			~ 10L/min	
	Cooling Water TEMP(In)		TIA-211			-20~ 50 degreeC	
	Cooling Water TEMP(Out)		TI-212			-20~ 50 degreeC	
	On/Off Status						
	Interlock INFO(Overload)						
	Interlock INFO(TEMP)						
	Interlock INFO(Pressure)						
Purification	Getter Purifier Pressure (In)		PI-301	PT-301		-0.1~ 0.5MPa	
(Gas Phase)	Getter TEMP		TI-301			0~ 500	

						degreeC	
	Getter Status (Stanby/Purify)						not shown in the diagram
	Circulator Pump On/Off Status						
Storage Tank	#1 Vessel TEMP		TI-401		PT100	77K~ 327K	
	#2 Vessel TEMP		TI-402		PT100	77K~ 327K	
	#3 Vessel TEMP		TI-403		PT100	77K~ 327K	
	#4 Vessel TEMP		TI-404		PT100	77K~ 327K	
	#5 Vessel TEMP		TI-405		PT100	77K~ 327K	
	#6 Vessel TEMP		TI-406		PT100	77K~ 327K	
	#7 Vessel TEMP		TI-407		PT100	77K~ 327K	
	#8 Vessel TEMP		TI-408		PT100	77K~ 327K	
	#1 Vessel Pressure		PI-401	PT-401		-0.1~ 10MPa	
	#2 Vessel Pressure		PI-402	PT-402		-0.1~ 10MPa	
	#3 Vessel Pressure		PI-403	PT-403		-0.1~ 10MPa	
	#4 Vessel Pressure		PI-404	PT-404		-0.1~ 10MPa	
	#5 Vessel Pressure		PI-405	PT-405		-0.1~ 10MPa	
	#6 Vessel Pressure		PI-406	PT-406		-0.1~ 10MPa	
	#7 Vessel Pressure		PI-407	PT-407		-0.1~ 10MPa	
	#8 Vessel Pressure		PI-408	PT-408		-0.1~ 10MPa	
	Liquefy Line Pressure	O	PI-421	PT-421		-0.1~ 10MPa	
	Liquefy Regulator TEMP	O	TIC-421		PT100	77K~ 327K	
	Liquefy Line Flow Meter		FI-421			0~ 60L/min	
	Recovery Flow Meter		FIQ-435			0~ 60L/min	
	UNIT A LN2 Level	O	LIA-431			0~ FULL	
	UNIT A Weight					0~ 2000kg	not shown in the diagram
	UNIT B LN2 Level	O	LIA-432			0~ FULL	
	UNIT B Weight					0~ 2000kg	not shown in the diagram
	UNIT C LN2 Level	O	LIA-433			0~ FULL	
	UNIT C Weight					0~ 2000kg	not shown in the diagram
	UNIT D LN2 Level	O	LIA-434			0~ FULL	
	UNIT D Weight					0~ 2000kg	not shown in the diagram
LN2 System	#1 LN2 Dewer Pressure		PI-501			0~ 1Mpa	

	#1 LN2 Dewer Level		LIA-501			0~ FULL	
	#2 LN2 Dewer Pressure		PI-502			0~ 1Mpa	
	#2 LN2 Dewer Level		LIA-502			0~ FULL	
	#3 LN2 Dewer Pressure		PI-503			0~ 1Mpa	
	#3 LN2 Dewer Level		LIA-503			0~ FULL	

Table 10 List of sensors planned to be used.

<u>Pipe dimension for xenon and nitrogen transfer</u>

Pipe dimension for xenon and nitrogen transfer was investigated. Results are summarized in Table 11 and pressure drop calculation result is summarized in Table 12 for two typical xenon flow rates.

		Material	Size	Flow rate	Gas	Press MPa	Temp degree C	Comments
1	xenon gas supply/recovery	SUS304	12.7 diam. x t1	6Nm3/hr	GXe	0.1	30	34mm diam.
2	Purified gas	SUS304	9.53 diam. x t1	1.5Nm3/hr	GXe	0.15	30	
3	gas recovery from the vacuum layer	SUS304	25A sch5S	30Nm3/hr	GXe	0	30	
4	liquid xenon recovery	SUS304	9.53 diam. x t1	52L/hr	LXe	0.1	-108~ 30	
5	LN2 supply (cooling)	SUS304	9.53 diam. x t1	10L/hr	LN2	0.5	-196	
6	LN2 supply (tank)	SUS304	15A sch5S	500L/hr	LN2	0.5	-196	21.7mm diam.

Table 11 Dimension of pipes for liquid nitrogen and xenon transfer.

Pressure Drop Calculation	Unit		
Gas		Xenon	xenon
flow rate	Nm3/Hr	3	6
Temperature	degree C	25	25
Pressure Drop Calculation	kg/cm2G	1	1
outer dimension of the pipe	mm	9.53	12.7
thickness of the pipe	mm	1	1
density of the gas	kg/Nm3	5.391	5.391
Viscosity	kg/ms	0.0000231	0.0000231
length of the pipe	mm	10	10

number of elbows		10	2
number of Ts		2	2
number of valves		2	2
Pressure drop (smooth pipe)	kg/cm2	0.296	0.224
Pressure drop (rough pipe)	kg/cm2	0.678	0.498
Flow speed	m/sec	10.4	10.3
Inner diameter	m	0.00753	0.0107
Density	kg/m3	9.719698016	9.719698
corresponding length of the pipe	m	18.1324	21.556
Reynolds		32884.50041	46284.166
friction coefficient (smooth pipe)		0.005750842	0.0053154
friction coefficient (rough pipe)		0.01318011	0.0118034

Table 12 Estimation of pressure drop in xenon transfer pipe for two typical flow rate.

References

[1] Drawing of the large prototype can be found at http://meg.web.psi.ch/subprojects/calorimeter/prototype.html

[2] Photograph of the cooling pipe in the large prototype cryostat can be found at http://meg.web.psi.ch/subprojects/calorimeter/photos/vessel/tn/photo10.jpg.html

[3] http://www.usui.co.jp/eng/products/12_u-tight_seal.html

[4] http://meg.web.psi.ch/subprojects/calorimeter/drawings/PD_vessel.html

[5] http://www.lesker.com/cfdocs/newweb/Vacuum_Pumps/Individual_Pumps/Turbo_and_Drag_Pumps/TurboMolecular_CeramicBearing_Alcatel_ATP400_ATP900.cfm

[6] http://www.pfeiffer-vacuum.de/shop/frontend/product.php3?productID=PMP02825