Density of the PVC used for the O4 NCal rotors
VIR-0193A-24

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Contents

1 Introduction

One of the issues encountered with the aluminum rotor is a magnetic coupling with the mirror when operating. This can be reduced by using a non magnetic material for the rotors such as PolyVinyl Chloride (PVC).

We decided to machine a new set of 4 rotors in PVC at IPHC issued from the same block. This note addresses the identical method described in VIR-0160A-22 for determining the density of the material used in the O4 rotors. The same measuring tools were used as for the first set of aluminum cylinders.

The technical data sheet of the PVC is provided at the end of this note.

2 Measurement of the four PVC cylinders

Figure 1 shows the four PVC cylinders machined and temporarily labelled 1, 2, 3 and 4 . The cylinders have been machined to be 211 mm of diameter and 114 mm of height.

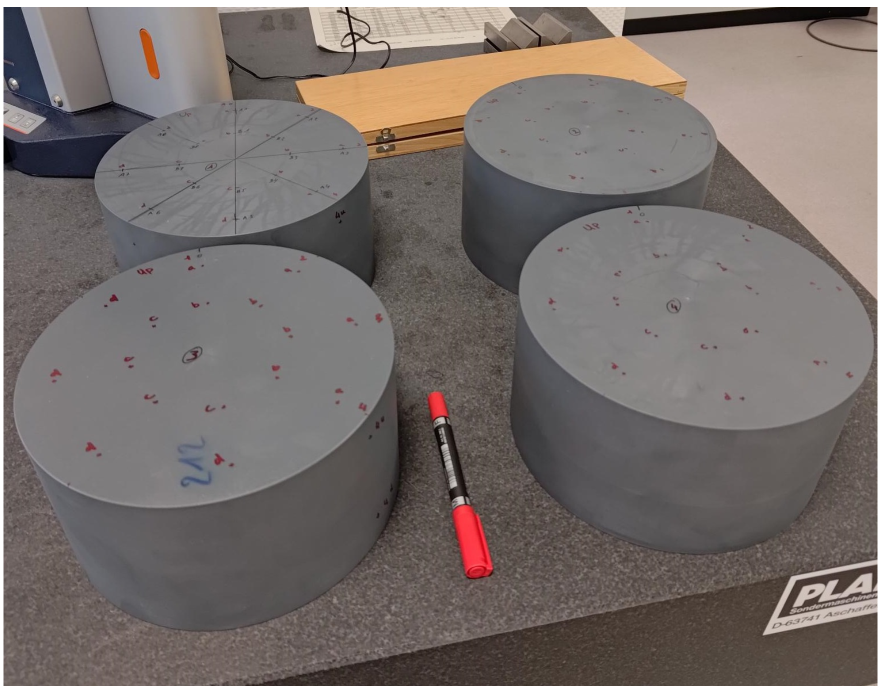

Figure 1: Picture of the four PVC cylinders machined at IPHC. The cylinders have been temporarily labelled 1, 2, 3 and 4.

As explained in section 1, the measurement method is identical as the aluminum cylinders previously machined at IPHC. Therefore there is a total of 40 measurement points on each cylinder to determine the volume. In addition we measured the mass of each cylinder 4 times (turning back the cylinder upside down between each measure) and took the average value.

One major concern was whether the material would produce uneven shapes after machining. Table 1 shows the dispersion of the measurements made on the diameter and height of each cylinder. The dispersion is usually below the hundredth of a millimeter. This result is comforting but we will check if the machined rotor will remain as even.

Parameter RMS	Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4
σ_D [μm]	4.9	15.4	15.3	9.8
σ_h [μm]	4.4	6.0	4.2	5.4

Table 1: Dispersion of the measurements made on the cylinders. Top row is the diameter and bottom row is the height.

3 Calibration of the scale

To determine the mass of the cylinders we used a scale (model KFB 36K0.1) given with an uncertainty of ± 0.3 g.

A reference aluminum cylinder R4-TEMOIN-2022 (see section 2.1 of VIR-0859A-22) was machined at IPHC to check the consistency of the scale, in September 2022 the measured mass was 10.6998 kg. In November 2023, a second set of measurements was made on this cylinder, the mass measured was 10.6992 kg or 0.6 g less than the previous year. In January 2024, a third set of measurements was made, the mass measured was 10.6983 kg or 0.9 g less than a few months earlier. But the scale was moved from the metrology room to another location for a few weeks then brought back between the second and third measurements.

In February 2024 we checked the scale calibration using reference weights. Two 5 kg reference weights were used and are shown in fig. 2. The weight on the left of fig. 2 will be labelled test weight 1 (TW1) and the weight on the right will be labelled test weight 2 (TW2). The weights were given with a maximum tolerance of 0.25 g, the calibration certificates are provided at the end of this note. Since both weights come from different providers we assume that their calibration process is uncorrelated, the uncertainty is then $0.25/\sqrt{2} = 0.18$ g.

A set of 10 measurements was made on both weights (see table 2) and R4-TEMOIN-2022. The measurements on R4-TEMOIN-2022 gave an average value of 10.6983 kg with a rms of 1.6×10^{-4} kg. This value is compatible with the January measurement. The measurements on TW1 and TW2 gave a deviation of respectively -0.55 g and -0.38 g from the 5 kg theoretical value. If we consider a linear sum of the scale uncertainty (0.3 g) and the weights uncertainty (0.18 g) the 0.48 g total uncertainty barely covers the differences measured. We point out that when measuring both test weights at the same time (TW1 + TW2 in table 2) we observe an even larger -0.83 g deviation from the 10 kg theoretical value. It seems that for 5 kg the scale suffers an offset of about $(0.55 + 0.38)/2 = 0.47$ g. The measured mass of the PVC cylinders will be increased by the latter when computing the density.

Object	Mean measurement [kg]	RMS [g]	Difference from gauge [g]
TW1	4.99945	<0.1	-0.55
TW2	4.99962	<0.1	-0.38
TW1 + TW2	9.99917	0.2	-0.83

Table 2: Measurements made on both test weights TW1 and TW2. The TW1 + TW2 measurements were made with both test weights on the scale.

Figure 2: Reference weights used to calibrate the weighing scale. Left is from *Gram Precision*, right is from *AE Adam*.

4 Uncertainties

To determine the mass of the cylinders we used a scale (model KFB 36K0.1) given with an uncertainty of ± 0.3 g. To measure the diameter and the height of the cylinders, we used a measuring column located in the metrology room at IPHC (model Garant 44 5350_600 HC1) with a given error of $1.8{+}\mathrm{L}/600$ μm at 95% CL (L being the measured length in mm).

To compute the relative density uncertainty we assume that the uncertainty on the mass and the lengths are uncorrelated. Therefore we add the relative uncertainties quadratically. However the diameter and height values are correlated since we used the same measuring tool. The systematic uncertainty on the density is then expressed in eq. (1).

$$\left(\frac{\delta_\rho}{\rho}\right)_{\text{syst}} = \sqrt{\left(\frac{\delta_m}{m}\right)^2 + \left(\frac{2\delta_D}{D} + \frac{\delta_h}{h}\right)^2} \tag{1}$$

Additionally, we take into account the maximum dispersion in diameter and height from table 1 to consider the use of average values in the calculation of density. We chose to not divide by the square root of the number of measurement points to remain conservative. The statistical uncertainty on the density is then expressed in eq. (2).

$$\left(\frac{\delta_\rho}{\rho}\right)_{\text{stat}} = \sqrt{\left(\frac{2\sigma_D}{D}\right)^2 + \left(\frac{\sigma_h}{h}\right)^2} \tag{2}$$

Finally to compute the total uncertainty on the density we add quadratically the systematic and statistical uncertainty (eqs. (1) and (2)). Since we consider four cylinders in our analysis we divide the statistical uncertainty by the square root of the number of cylinder. The total uncertainty is then expressed in eq. (3).

$$\left(\frac{\delta_\rho}{\rho}\right)_{\text{tot}} = \sqrt{\left(\frac{\delta_\rho}{\rho}\right)^2_{\text{syst}} + \frac{1}{\sqrt{4}}\left(\frac{\delta_\rho}{\rho}\right)^2_{\text{stat}}} \tag{3}$$

In eqs. (1) and (2), the following parameters are used:

- D the measured diameter of the cylinder : 211 mm.
- h the measured height of the cylinder : 114 mm.
- m the measured mass of the cylinder : 5.75 kg.
- δ_D the uncertainty on the diameter from the column : 2.2×10^{-3} mm.
- σ_D the maximum RMS of the first row of table 1 : 1.54×10^{-2} mm.
- δ_h the uncertainty on the height from the column : 2.0×10^{-3} mm.
- σ_h the maximum RMS of the last row of table 1 : 5.98×10^{-3} mm.
- δ_m the uncertainty on the mass of the cylinder being the uncertainty of the scale : 3×10^{-4} kg.

Table 3 shows the relative uncertainties on the measurements.

Relative uncertainty	Value
δ_m/m	5.22×10^{-5}
δ_D/D	1.90×10^{-5}
δ_h/h	2.63×10^{-5}
σ_D/D	7.30×10^{-5}
σ_h/h	5.25×10^{-5}
$(\delta_\rho/\rho)_{\text{tot}}$	1.37×10^{-4}

Table 3: Relative uncertainties associated to the measurement tools.

5 Density of the PVC

Table 4 shows the average measured values for the diameter, height and rescaled mass (see section 3) as well as the associated computed density for each cylinder. We point out that a weight of 0.5 is applied on the inner points when computing the height. Since the measurements were taken in the metrology room at IPHC at a temperature of $21°$C we must take into account the thermal expansion of the material. The material used is labelled as "PVC - U GREY" (the provided technical data sheet is available at the end of this note) and the coefficient of linear thermal expansion given is 80 μm/m/°C. This is taken into account when computing the density at the reference operating temperature of the rotors of $23°$C (see last row of table 4).

Average value		Cylinder 1	Cylinder 2	Cylinder 3	Cylinder 4
D [mm]		211.040	211.047	211.029	211.034
h (weighted) [mm]		114.021	113.987	114.042	114.028
m_{rescaled} [kg]		5.7554	5.7535	5.7562	5.7554
ρ [kg.m^{-3}]	21°C	1443.0	1442.9	1443.1	1443.0
	23°C	1442.3	1442.2	1442.4	1442.3

Table 4: Average measurements made at IPHC on the four PVC cylinders. From top to bottom: the diameter, the height, the mass and the density. A weight of 0.5 is applied on the inner points for the height. The densities at 23°C are highlighted in yellow.

Using table 4 we compute the mean density of the PVC at $23°$C with the associated uncertainty using last row of table 3 (rounded up to 0.2 kg.m^{-3}). The density of the material for the first set of O4 PVC rotors is then $\rho_{\text{PVC}} = 1442.3 \ \pm \ 0.2$ kg.m^{-3}.

CERTIFICADO DE CALIBRACIÓN

Certificate of Calibration

Número **C- 6825**
Number

INSTRUMENTO *Instrument*: **Masa / Juego de Masas**

FABRICANTE *Manufacturer*: **Gram Precision**

MODELO *Model*: **M1 OIML R-111**

PETICIONARIO *Customer*: **CNRS IPHC**
23 rue du Loess - BP28
67037 STRASBOURG CEDEX 2

FECHA DE CALIBRACIÓN *Date of Calibration*: **08/02/2024**

Signatario/s autorizado/s
Authorized signatory/ies

Fecha de emisión 08/02/2024
Date of issue

Inma Guerro Rodriguez
Responsable de Ensayos

Francesc Fuentes i Linares
Responsable del Laboratorio

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ISO 9001

GRAM

GRAM PRECISION SL

Laboratorio de Calibración

Barcelona

Nº C- 6825

CERTIFICADO DE CALIBRACIÓN

Peticionario: **CNRS IPHC**

23 rue du Loess - BP28

67037 STRASBOURG CEDEX 2

Elemento calibrado

Masa/Juego de masas

Clase de Precisión: M1 OIML R111

Fabricante: Gram Precision

Fecha de recepción: 08/02/2024

Fecha de calibración: 08/02/2024

Condiciones ambientales y procedimientos

Temperatura de medición: 21 ºC

Humedad relativa: 60 %

Presion atmosférica: 1012 hPa

Procedimiento calibración: PR-7/02

Equipos y patrones utilizados

Equipos patrón	*Identificación*	*Trazabilidad*	*Nº certificado*
Comparador C-06.5000	C-06	ENAC	2020-C6
Masa de 5000 g	A-5000F1	ENAC	00533889

ISO 9001

ANEXO DE RESULTADOS

Nº: C- 6825

RESULTADOS

Nº SERIE	VALOR NOMINAL	MASA CONVENCIONAL		INCERTIDUMBRE	ERROR MAXIMO TOLERADO
39805	5000 g	5000 g	-11,90mg	83,33 mg	± 250 mg

El error máximo tolerado que figura en la tabla de resultados, a título indicativo, es el establecido por OIML R111 (2004) para la clase de precisión **M1**

Observaciones: *Se adjunta una etiqueta indicativa de este certificado*

(1) El valor de la masa convencional se ha calculado conforme a la R.I. nº 33 de la OIML.

(2) La incertidumbre expandida ha sido calculada según EAL-R2 con un factor de cobertura de k = **2** *, correspondiente a una probabilidad de cobertura de aprox. el 95%, en una distribución t de student.*
Para su determinación se han tenido en cuenta las contribuciones debidas a los patrones, al método de calibración empleado y al propio elemento calibrado.

GRAM PRECISION S.L.

ISO 9001

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IN HOUSE CALIBRATION WEIGHT STATEMENT

Adam Equipment hereby declares that the following weights listed below are calibrated within the OIML class tolerance permitted.

Location:	Adam GmbH Germany Weight & Balance test room
Description:	5kg OIML Cast Iron Weights
Serial number:	**AE909231935**
Calibrated to OIML Class:	M1
OIML Class tolerances:	250mg

The weights were tested at a temperature of 20˚C using standards reference weights with a hypothetical density of 7.9 g/cm³.

Reference weights used (UKAS or equivalent):

ID	Master Weight set	Class	Tolerance		Calibration certificate no	Date
176754	5kg	F1	25mg		132322	31/08/2021

Signed by:

A.C.

Andrej Cernakov
Dated: 14.12.2023

Technical Data Sheet

PVC - U GREY

Typical characteristics

- Flame retardant, self-extinguishing after removal of flame
- High rigidity
- Very good electrical insulation properties
- High resistance to acids, lyes and salt solutions
- Easy processing by welding, thermoforming and glueing
- Excellent printability
- Chemical resistance

Typical industries

- Construction de réservoirs et d'installations chimiques
- Industrie électronique
- Réservoirs de stockage

	Test method	Unit	Guideline value
General properties			
Density	DIN EN ISO 1183-1	g / cm^3	1,45
Flammability (Thickness 3 mm / 6 mm)	UL 94		V0 / V0
Mechanical properties			
Yield stress	DIN EN ISO 527	MPa	45
Elongation at break	DIN EN ISO 527	%	15
Tensile modulus of elasticity	DIN EN ISO 527	MPa	3000
Notched impact strength	DIN EN ISO 179	kJ / m^2	2
Shore hardness	DIN EN ISO 868	scale D	79
Thermal properties			
Thermal conductivity	DIN 52612-1	W / (m * K)	0,2
Coefficient of linear thermal expansion	DIN 53752	10^{-6} / K	80
Service temperature, long term	Average	°C	0 ... 60
Service temperature, short term (max.)	Average	°C	70
Electrical properties			
Dielectric constant	IEC 60250		3

	Test method	Unit	Guideline value
Dielectric dissipation factor (10^6 Hz)	IEC 60250		0,02
Volume resistivity	DIN EN 62631-3-1	Ohm * cm	10^{15}
Surface resistivity	DIN EN 62631-3-2	Ohm	10^{13}

The short-term maximum application temperature only applies to very low mechanical stress for a few hours. The long-term maximum application temperature is based on the thermal ageing of plastics by oxidation, resulting in a decrease of the mechanical properties. This applies to an exposure to temperatures for at least 5.000 hours causing a 50% loss of the tensile strength from the original value (measured at room temperature). This value says nothing about the mechanical strength of the material at high application temperatures. In case of thick-walled parts, only the surface layer is affected by oxidation from high temperatures. With the addition of antioxidants, a better protection of the surface layer is achieved. In any case, the center area of the material remains unaffected. The minimum application temperature is basically influenced by possible stress factors like impact and/or shock under application. The values stated refer to an minimum degree of impact stress. The electrical properties as stated result from measurements on natural, dry material. With other colours (in particular black) or saturated material, there may be clear differences in the electrical properties. The data stated above are average values ascertained by statistical tests on a regular basis. They are in accordance with DIN EN 15860. They serve as information about our products and are presented as a guide to choose from our range of materials. This, however, does not include an assurance of specific properties or the suitability for particular application purposes that are legally binding. Since the properties also depend on the dimension of the semi-finished products and the degree of crystallization (e.g. nucleating by pigments), the actual values of the properties of a particular product may differ from the indicated values.