Characteristics of the PVC rotor R4-14 for the O4 NCal system VIR-0851A-24

Florian Aubin, Eddy Dangelser, Benoit Mours,
Antoine Syx, Pierre Van Hove

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Contents

1 Introduction

This note discusses the metrology of a rotor machined at IPHC from the second batch of PVC material (VIR-0441A-24) and follows a similar discussion made on the PVC rotor R4-10 in VIR-0203A-24 and the aluminum rotors R4-01 in VIR-0591C-22 and R4-05 in VIR-0859A-22. The drawings and figures of the PVC rotor can be found at the end of the R4-10 technical note. The rotor has been engraved IPHC-R4-14 on one side and painted on the other side.

2 Measurement method

To determine the geometry of the rotor we use an improved method compared to R4-10. This method, shown in fig. 1, uses 17*2*2 = 68 points for the outer thickness of the sector (red and blue colored points), 16 points for the inner thickness (orange colored points) and 20 points for the diameter (pink colored points). We will use the drawing values for the inner diameter.

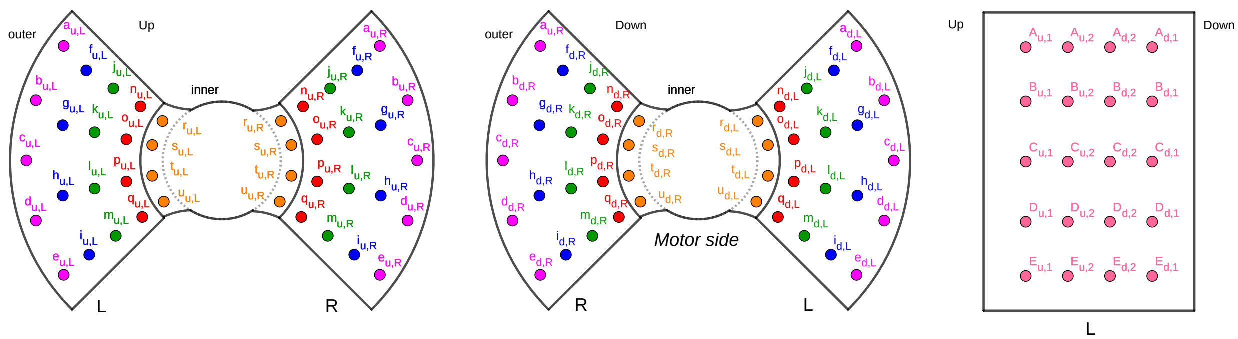

Figure 1: Outline of the faces of the rotor with the measurement points. Left is face up, center is face down and right is the side view of the left sector. Sectors have been labelled L for left sector and R for right sector.

The tool used to measure the thickness and the outer diameter is a measuring column "Garant 44 5350_600 HC1" (see VIR-0160A-22) with a given precision of 1.8+L/600 μm (L the measured length in mm). Steel reference blocks of 100.000 mm and 90.000 mm were used to check the accuracy of the measuring column, the standard deviation from the nominal values is of the order of the uncertainty of the measuring column (2 μm).

The measuring column was operated on a metrology table with surface defects ranging from 0 to 2 μm. The rms of the 16 values is 0.9 μm.

We measured the opening angles of the sectors using a video measuring microscope "Garant MM2" (see VIR-0591C-22) with a given precision of 2.9+L/100 μm at 95% CL (L the measured length in mm).

2.1 Thermal effects and density

As discussed in VIR-0441A-24, the thermal effects on the PVC must be taken into account (80 $\mu\mathrm{m/m/°C}$). As for the previous rotors the results will be expressed at a reference temperature of 23°C.

The temperature inside the NE building might fluctuate around $T_{\mathrm{build}} = 21.5$°C. The temperature of the motor can increase by up to several tens of degrees depending on the rotation speed. This will increase the rotor temperature. We expect to operate the rotors continuously at around 18 Hz, they have been operating since the beginning of O4b at this frequency and the temperature of the box is seen to be constant at around

23°C with less than 1.5°C of maximum deviation. The gravitational strain h is therefore computed assuming a reference temperature $T_{\text{ref}} = 23 \pm 1.5$°C.

The uncertainty on the strain h is the following:

$$\begin{aligned} h &\propto \rho_{rot}\, b\, r_{max}^4 \\ &\propto \frac{m\, r_{max}^2}{\pi} \end{aligned} \tag{1}$$

Using $r(T) = r(1 + \alpha_T)$ (with the temperature factor $\alpha_T = C_T(T_{\text{build}} - T_{\text{ref}})$) we have:

$$\begin{aligned} h(T) &\propto r_{max}^2(T) \\ &\propto r_{max}^2(1 + \alpha_T)^2 \end{aligned} \tag{2}$$

We compute the relative uncertainty of h on the temperature T:

$$\left|\frac{\partial h}{\partial T}\right| \frac{\Delta T}{h} = \frac{2C_T}{1 + C_T(T_{\text{build}} - T_{\text{ref}})} \Delta T \tag{3}$$

3 Raw measurements of the rotor

This section presents the raw measurements made on the rotor at the ambient temperature of 22.7°C for the thickness and 22.9°C for the diameter. Table 1 shows the thickness measurements according to the measurement points defined in fig. 1. The rotor is laying on the table. The rotor surface as well as the table are not perfectly flat. Some space could be present in between that should be substracted when computing the rotor thickness as discussed later.

Measurement point	L sector		R sector	
	Up	Down	Up	Down
a	104.429	104.436	104.425	104.437
b	104.428	104.437	104.432	104.442
c	104.429	104.440	104.440	104.449
d	104.434	104.449	104.442	104.454
e	104.441	104.454	104.428	104.451
f	104.434	104.441	104.434	104.445
g	104.436	104.443	104.443	104.448
h	104.438	104.451	104.448	104.454
i	104.444	104.456	104.447	104.456
j	104.443	104.448	104.443	104.451
k	104.443	104.448	104.447	104.452
l	104.445	104.452	104.451	104.456
m	104.450	104.457	104.452	104.459
n	104.448	104.453	104.452	104.455
o	104.449	104.453	104.454	104.456
p	104.452	104.457	104.456	104.458
q	104.455	104.459	104.457	104.461
r	101.544	101.423	101.548	101.424
s	101.546	101.423	101.550	101.424
t	101.548	101.425	101.555	101.425
u	101.551	101.427	101.557	101.432

Table 1: Raw measurements of the height in mm for each point at 22.7°C on L and R sectors of R4-14.

Table 2 displays the diameter measurements. The measurements were made on 4*3 diameters (three parts of each diameter, the up, middle and down sides of the rotor).

Measurement point	Up 1	Up 2	Down 2	Down 1
1	208.108	208.111	208.120	208.125
2	208.109	208.110	208.119	208.125
3	208.109	208.113	208.120	208.124
4	208.208	208.113	208.120	208.128
5	208.107	208.112	208.123	208.125

Table 2: Raw measurements of the diameter in mm for each point at 22.9°C on R4-14.

Theoretical values were taken for the inner radius r_{min} = 29 mm and the radius for the counterweight $r_{\text{counterweight}}$ = 40 mm.

4 Extracting the geometrical parameters

4.1 Thickness

We need to correct the possible gap between the rotor and the measuring table. Assuming that the table is flatter than the rotor surface we can extract the gap from the measurement of the top surface considering the plane tangents to the highest points (asking them to be on both sectors). Using the measurements in table 1 we can compute a plane equation for each side of the rotor in cartesian coordinates:

$$\text{Up plane equation} : z = 3.477 \times 10^{-5}x - 1.085 \times 10^{-4}y + 104.454 \quad (4)$$

$$\text{Down plane equation} : z = 2.503 \times 10^{-5}x - 1.127 \times 10^{-4}y + 104.457 \quad (5)$$

Using eqs. (4) and (5) the gap can be determined, see table 3. The maximum rms of the gap for a sector is 8.1 μm.

Measurement point	L sector		R sector	
	Up	Down	Up	Down
a	16	13	26	16
b	20	14	22	14
c	22	15	17	10
d	20	9	18	9
e	16	7	35	14
f	13	9	18	9
g	13	10	12	9
h	15	6	11	7
i	12	4	14	8
j	5	4	9	3
k	7	6	8	5
l	8	5	7	4
m	6	3	8	3
n	2	0	0	0
o	2	2	0	1
p	2	0	1	1
q	1	0	1	0

Table 3: Gap computed in μm on up and down sides of both sectors of R4-14.

We can then compute the rotor thickness for each point by removing these gaps. If one of the raw values is lower than the corrected thickness we take this lowest value. The thickness of the inner part is computed by taking into account the air between the closest measurement point on the sector and the measurement point on this part, the average value between up and down is taken as our final value. The value of each point is shown in table 4 at 23°C.

Measurement point	L sector	R sector
a	104.432	104.428
b	104.431	104.435
c	104.432	104.443
d	104.437	104.445
e	104.444	104.431
f	104.437	104.437
g	104.439	104.446
h	104.441	104.451
i	104.447	104.450
j	104.446	104.446
k	104.446	104.450
l	104.448	104.454
m	104.453	104.455
n	104.451	104.455
o	104.452	104.457
p	104.455	104.459
q	104.458	104.460
r	98.519	98.521
s	98.520	98.521
t	98.521	98.525
u	98.523	98.532

Table 4: Measurements of the thickness in mm for each point at 23°C on L and R sectors of R4-14.

4.2 Radius

Using the measuring column while the rotor is rotating on its axis we can determine the deformation on both sectors and compute different radii values. Table 5 shows the raw measurements on L and R sectors. The measurements were made on the Up 1, Up 2, Down 2 and Down 1 sides of L and R sectors for a total of 5*4*2=40 points (the first and last points are near the edge of the sectors).

Measurement point	L sector				R sector			
	Up 1	Up 2	Down 2	Down 1	Up 1	Up 2	Down 2	Down 1
1	0	0	0	0	25	21	24	26
2	3	-2	0	0	26	22	26	29
3	4	-1	0	0	26	23	28	30
4	5	-1	1	0	24	22	26	29
5	7	0	3	1	22	20	25	27

Table 5: Raw measurements in μm of the column on the radius for the L and R sectors of R4-14.

The zeroing of the column was made arbitrarily close to the edge of the sector. The offsets shown in table 5 are measured relative to this reference.

To compute the radius per measurement point we use the following process: First we compute the mean deformation for one side (for example Up 1). Then we remove this mean deformation to each measurement of this side. The corrected shift value is added to the mean of the associated Up 1, Up 2, Down 2 or Down 1 diameter computed using table 2 at 22.9°C. This process is repeated for each side. The final radius for each point are shown in table 6.

Measurement point	L sector				R sector			
	Up 1	Up 2	Down 2	Down 1	Up 1	Up 2	Down 2	Down 1
A	104.040	104.045	104.047	104.048	104.065	104.066	104.071	104.074
B	104.043	104.043	104.047	104.048	104.066	104.067	104.073	104.077
C	104.044	104.044	104.047	104.048	104.066	104.068	104.075	104.078
D	104.044	104.044	104.048	104.048	104.064	104.067	104.073	104.077
E	104.047	104.046	104.050	104.049	104.062	104.065	104.072	104.075

Table 6: Radius measurements in mm at 22.9°C for the L and R sectors of R4-14.

5 Characterization of the rotor using an advanced model

5.1 Thickness

An advanced model can be used considering the deformations on the surfaces of the sectors for increased accuracy. Each measurement point of table 4 can be considered as a sub-sector with its own thickness.

The uncertainty on this value is more complex to evaluate. As a conservative approach we use the maximum rms of the deviation to a plane for each sector (8.1 μm see section 4.1) to which we add linearly the uncertainty on the flatness of the measurement table (0.9 μm) as well as the measurement tool (2.0 μm). The total uncertainty on the thickness is 10.9 μm.

5.2 Radius

On fig. 1 we divided the external sectors in 4 sub-sectors for each sector (blue points). We convert the point of table 6 to the grid of fig. 1 by averaging the two closest values and converting them to 23°C. The results are shown in table 7. We notice that the R sector is on average 24 μm larger than the L sector.

Radius	L sector				R sector			
	Up 1	Up 2	Down 2	Down 1	Up 1	Up 2	Down 2	Down 1
1	104.041	104.046	104.048	104.049	104.066	104.067	104.072	104.075
2	104.044	104.044	104.048	104.049	104.067	104.068	104.074	104.078
3	104.045	104.045	104.048	104.049	104.067	104.069	104.076	104.079
4	104.045	104.045	104.049	104.049	104.065	104.068	104.074	104.078
5	104.048	104.047	104.051	104.050	104.063	104.066	104.073	104.076

Table 7: Radius measurements (in mm at 23°C) for the L and R sectors of R4-14.

The rms of the radii is 12.8 μm. The tool uncertainty is 2.2 μm. Like for the thickness we use a linear sum and find the uncertainty on both radii to be 15 μm.

5.3 Counterweights

This rotor needed no balancing, we then used two full PVC disks of density $\rho_{\text{PVC}} = 1442.3$ kg.m^{-3} (see section 6.3 of VIR-0203A-24).

5.4 Opening angles and asymmetry

The opening angles of the full and empty sectors have been measured using a video microscope with the same method as for R4-01.

The measurements are shown in table 8. The center value corresponds to the mean of up and down measurements.

Opening angle	Up	Center	Down
L	1.57101	1.57110	1.57120
R	1.57098	1.57100	1.57102
L-R	1.57066	1.57055	1.57043
R-L	1.57054	1.57053	1.57053

Table 8: Opening angle measurements in rad for the L, R full sectors and L-R, R-L empty sectors of R4-14.

The opening angle α contributes as $\sin(\alpha)$ on the amplitude of the rotor. Adding a small opening angle uncertainty $\delta\alpha$, the strain varies as:

$$\delta h(\alpha + \delta\alpha) = -\frac{\delta\alpha^2}{2} + \frac{\delta\alpha}{\tan(\alpha)} \tag{6}$$

The largest opening angle defect from a rotors is 2.01 mrad (for R4-13 in VIR-0311A-24). Using this value as our $\delta\alpha$ value, the strain varies of $2 \times 10^{-5}\%$.

The asymmetry η contributes as $\cos(2\eta)$ on the amplitude of the rotor. Adding a small opening angle uncertainty $\delta\eta$, the strain varies as:

$$\delta h(\eta + \delta\eta) = -\frac{\delta\eta^2}{2} - \delta\eta \tan(2\eta) \tag{7}$$

The largest mean symmetry defect of a rotor is 1.40 mrad (also R4-13). Using this value as our $\delta\eta$ value, the strain varies of $4 \times 10^{-5}\%$.

5.5 Expected NCal signals and uncertainties

5.5.1 Advanced geometry including chamfers and counterweight

The geometry used to describe the rotor as an advanced model is represented in fig. 2. The external parts of the sectors are divided in 5 sub-sectors each to correspond to the different radii determined. In addition we include the counterweight, the opening angles and asymmetry of the sectors. The screws and screw holes are not taken into account since they are placed symmetrical they should not impact the 2f signal.

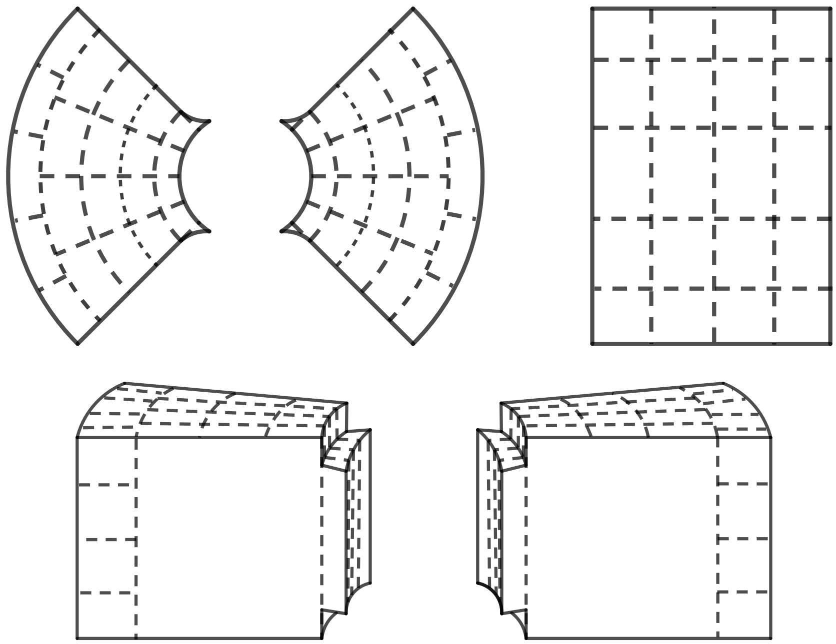

Figure 2: Advanced model geometry used to describe the rotor. Top left is a front view, top right is a side view (external sub-sectors) and bottom is a tilted view of the sectors. Only the 4 external part sectors are divided in 3 sub-sectors each. The chamfers are visible on the inner radius.

Using FROMAGE at a distance of 1.7 m, an angle of $34.7°$ and a twist of $12°$ on this geometry gives the following strains:

- strain(1f) $= \dfrac{1.1205 \times 10^{-20}}{(1f_{rot})^2}$
- strain(2f) $= \dfrac{1.1434 \times 10^{-18}}{(2f_{rot})^2}$

5.5.2 Remaining geometry uncertainty

Other geometrical defects are probed by the remaining 1f signal computed with the advanced geometry as described for the rotor R4-01 (see section 7.5.4 of VIR-0591C-22). For this rotor the 1f signal is 2 times smaller than for R4-01. Nevertheless we will use the $5 \times 10^{-4}\%$ R4-01 remaining geometry uncertainty as a conservative approach.

5.5.3 Uncertainties

To set an uncertainty on the strain(2f) from the description of the geometry use the method described in VIR-0854A-24. This method gives a value of 0.023% and is reported in table 9 as modelling uncertainty.

The uncertainties considered for this full model are displayed in table 9. We point out that the elongation of the material caused by the rotation is not taken into account in this technical note.

R4-14 rotor parameter advanced model (23°C)	2f signal uncertainty [%]
Density ρ	0.014
Temperature T	0.024
Opening angle and sector asymmetry	$<4 \times 10^{-5}$
Rotor flat surfaces offsets	$<5 \times 10^{-4}$
Modelling Uncertainty	0.023
FROMAGE grid uncertainty	0.005
Gravitational constant G	0.002
Total uncertainty from the rotor (quadratic sum)	0.036

Table 9: Uncertainties on the amplitude of the calibration signal at 2f from the R4-14 rotor advanced model geometry at 23°C.

A Appendix

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### This is a cfg file for a more realistic geometry of the mirror and the Virgo NCal R4-14 (2024)

### ALL THE OBJECTS ARE DEFINED IN THE MIRROR'S FRAME (O,x,y,z),
### with O the center of the mirror, x axis along the ITF's beam toward the beam-splitter,
### y axis orthogonal to x in the plane of the ITF,
### z axis orthogonal to the plane of the ITF upward

### MIRROR DEFINITION

GRID_SIZE 12 30 8

CYLINDER 2202. 0 0.175 0.2 360 0 0 0

GRID_SIZE 1 1 1

# Defining the flats on the edge of the mirror
CUT_CYL 2202. 0.175 0.2 0.05 0 0
CUT_CYL 2202. 0.175 0.2 0.05 0 180

# Defining the ears and anchors of the mirror
CUBOID 2202. 0.090 0.010 0.015  0     0.1782 -0.0125
CUBOID 2202. 0.090 0.010 0.015  0    -0.1782 -0.0125
CUBOID 2202. 0.039 0.008 0.008 -0.02 -0.1772 -0.024
CUBOID 2202. 0.039 0.008 0.008 -0.02  0.1772 -0.024
CUBOID 2202. 0.039 0.008 0.008  0.02 -0.1772 -0.024
CUBOID 2202. 0.039 0.008 0.008  0.02  0.1772 -0.024

### ROTOR DEFINITION: CYLINDER DENSITY INNER_RADIUS OUTER_RADIUS THICKNESS OPEN_ANGLE r z theta

ROTOR_CYLINDRICAL 1.7 34.7 0 0 12

### COUNTERWEIGHT AXLE
GRID_SIZE 4 17 10
CYLINDER 1442.3 0.010 0.040 0.003 360 0 0.05077012356 0

### COUNTERWEIGHT MOTOR
GRID_SIZE 4 17 10
CYLINDER 1442.3 0.02175 0.040 0.003 360 0 -0.05077012356 0

### L sector
## Inner part
GRID_SIZE 8 17 10

OUTER_FILLET 1442.2 0.029 0.098519 0 0.01 -11.2522 146.2434
CYLINDER 1442.2 0.029 0.04 0.098519 22.5044 0 0 146.2434
CYLINDER 1442.2 0.029 0.04 0.098520 22.5044 0 0 168.7478
CYLINDER 1442.2 0.029 0.04 0.098521 22.5044 0 0 191.2522
CYLINDER 1442.2 0.029 0.04 0.098523 22.5044 0 0 213.7566
OUTER_FILLET 1442.2 0.029 0.098523 0 0.01 11.2522 213.7566

## Middle part
CYLINDER 1442.2 0.04 0.056 0.104451 22.5044 0 0 146.2434
CYLINDER 1442.2 0.04 0.056 0.104452 22.5044 0 0 168.7478
CYLINDER 1442.2 0.04 0.056 0.104455 22.5044 0 0 191.2522
```

```
CYLINDER 1442.2 0.04 0.056 0.104458 22.5044 0 0 213.7566

CYLINDER 1442.2 0.056 0.072 0.104446 22.5044 0 0 146.2434
CYLINDER 1442.2 0.056 0.072 0.104446 22.5044 0 0 168.7478
CYLINDER 1442.2 0.056 0.072 0.104448 22.5044 0 0 191.2522
CYLINDER 1442.2 0.056 0.072 0.104453 22.5044 0 0 213.7566

CYLINDER 1442.2 0.072 0.088 0.104437 22.5044 0 0 146.2434
CYLINDER 1442.2 0.072 0.088 0.104439 22.5044 0 0 168.7478
CYLINDER 1442.2 0.072 0.088 0.104441 22.5044 0 0 191.2522
CYLINDER 1442.2 0.072 0.088 0.104447 22.5044 0 0 213.7566

## Outer part
GRID_SIZE 2 13 10

CYLINDER 1442.2 0.088 0.104041 0.026107876574 18.0024 0 0.039161814861 143.9952
CYLINDER 1442.2 0.088 0.104046 0.026107876574 18.0031 0 0.013053938287 143.9937
CYLINDER 1442.2 0.088 0.104048 0.026107876574 18.0039 0 -0.013053938287 143.9923
CYLINDER 1442.2 0.088 0.104049 0.026107876574 18.0046 0 -0.039161814861 143.9908

CYLINDER 1442.2 0.088 0.104044 0.026107626568 18.0024 0 0.039161439852 161.9976
CYLINDER 1442.2 0.088 0.104044 0.026107626568 18.0031 0 0.013053813284 161.9969
CYLINDER 1442.2 0.088 0.104048 0.026107626568 18.0039 0 -0.013053813284 161.9961
CYLINDER 1442.2 0.088 0.104049 0.026107626568 18.0046 0 -0.039161439852 161.9954

CYLINDER 1442.2 0.088 0.104045 0.026107876574 18.0024 0 0.039161814861 180.0000
CYLINDER 1442.2 0.088 0.104045 0.026107876574 18.0031 0 0.013053938287 180.0000
CYLINDER 1442.2 0.088 0.104048 0.026107876574 18.0039 0 -0.013053938287 180.0000
CYLINDER 1442.2 0.088 0.104049 0.026107876574 18.0046 0 -0.039161814861 180.0000

CYLINDER 1442.2 0.088 0.104045 0.026109126604 18.0024 0 0.039163689906 198.0024
CYLINDER 1442.2 0.088 0.104045 0.026109126604 18.0031 0 0.013054563302 198.0031
CYLINDER 1442.2 0.088 0.104049 0.026109126604 18.0039 0 -0.013054563302 198.0039
CYLINDER 1442.2 0.088 0.104049 0.026109126604 18.0046 0 -0.039163689906 198.0046

CYLINDER 1442.2 0.088 0.104048 0.026110876646 18.0024 0 0.039166314969 216.0048
CYLINDER 1442.2 0.088 0.104047 0.026110876646 18.0031 0 0.013055438323 216.0063
CYLINDER 1442.2 0.088 0.104051 0.026110876646 18.0039 0 -0.013055438323 216.0077
CYLINDER 1442.2 0.088 0.104050 0.026110876646 18.0046 0 -0.039166314969 216.0092

### R sector
## Inner part
GRID_SIZE 8 17 10

OUTER_FILLET 1442.2 0.029 0.098529 0 0.01 11.2515 33.7541
CYLINDER 1442.2 0.029 0.04 0.098529 22.5029 0 0 33.7541
CYLINDER 1442.2 0.029 0.04 0.098529 22.5029 0 0 11.2512
CYLINDER 1442.2 0.029 0.04 0.098533 22.5029 0 0 348.7482
CYLINDER 1442.2 0.029 0.04 0.098540 22.5029 0 0 326.2453
OUTER_FILLET 1442.2 0.029 0.098540 0 0.01 -11.2515 326.2453

## Middle part
CYLINDER 1442.2 0.04 0.056 0.104455 22.5029 0 0 33.7541
CYLINDER 1442.2 0.04 0.056 0.104457 22.5029 0 0 11.2512
CYLINDER 1442.2 0.04 0.056 0.104459 22.5029 0 0 348.7482
CYLINDER 1442.2 0.04 0.056 0.104460 22.5029 0 0 326.2453
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CYLINDER 1442.2 0.056 0.072 0.104446 22.5029 0 0 33.7541
CYLINDER 1442.2 0.056 0.072 0.104450 22.5029 0 0 11.2512
CYLINDER 1442.2 0.056 0.072 0.104454 22.5029 0 0 348.7482
CYLINDER 1442.2 0.056 0.072 0.104455 22.5029 0 0 326.2453

CYLINDER 1442.2 0.072 0.088 0.104437 22.5029 0 0 33.7541
CYLINDER 1442.2 0.072 0.088 0.104446 22.5029 0 0 11.2512
CYLINDER 1442.2 0.072 0.088 0.104451 22.5029 0 0 348.7482
CYLINDER 1442.2 0.072 0.088 0.104450 22.5029 0 0 326.2453

## Outer part
GRID_SIZE 2 13 10

CYLINDER 1442.2 0.088 0.104066 0.02610687655 18.0024 0 0.039160314825 36.0039
CYLINDER 1442.2 0.088 0.104067 0.02610687655 18.0031 0 0.013053438275 36.0042
CYLINDER 1442.2 0.088 0.104072 0.02610687655 18.0039 0 -0.013053438275 36.0045
CYLINDER 1442.2 0.088 0.104075 0.02610687655 18.0046 0 -0.039160314825 36.0048

CYLINDER 1442.2 0.088 0.104067 0.026108626592 18.0024 0 0.039162939888 18.0018
CYLINDER 1442.2 0.088 0.104068 0.026108626592 18.0031 0 0.013054313296 18.0020
CYLINDER 1442.2 0.088 0.104074 0.026108626592 18.0039 0 -0.013054313296 18.0021
CYLINDER 1442.2 0.088 0.104078 0.026108626592 18.0046 0 -0.039162939888 18.0022

CYLINDER 1442.2 0.088 0.104067 0.02611062664 18.0024 0 0.03916593996 359.9997
CYLINDER 1442.2 0.088 0.104069 0.02611062664 18.0031 0 0.01305531332 359.9997
CYLINDER 1442.2 0.088 0.104076 0.02611062664 18.0039 0 -0.01305531332 359.9997
CYLINDER 1442.2 0.088 0.104079 0.02611062664 18.0046 0 -0.03916593996 359.9997

CYLINDER 1442.2 0.088 0.104065 0.026111126652 18.0024 0 0.039166689978 341.9976
CYLINDER 1442.2 0.088 0.104068 0.026111126652 18.0031 0 0.013055563326 341.9974
CYLINDER 1442.2 0.088 0.104074 0.026111126652 18.0039 0 -0.013055563326 341.9973
CYLINDER 1442.2 0.088 0.104078 0.026111126652 18.0046 0 -0.039166689978 341.9971

CYLINDER 1442.2 0.088 0.104063 0.026107626568 18.0024 0 0.039161439852 323.9955
CYLINDER 1442.2 0.088 0.104066 0.026107626568 18.0031 0 0.013053813284 323.9952
CYLINDER 1442.2 0.088 0.104073 0.026107626568 18.0039 0 -0.013053813284 323.9949
CYLINDER 1442.2 0.088 0.104076 0.026107626568 18.0046 0 -0.039161439852 323.9946

### GENERAL PARAMETERS

STEP 22.5 16

ARM_LENGTH 3000

SIGNAL 2
```