ENGINEERING MEASUREMENTS ENTERPRISE LTD.

TECHNICAL REPORT

RESULTS OF DEVIATION MEASUREMENTS AND GEOMETRY OF ROTARY KILN

AT Geo Cement

GEOCEMENT PLANT

Period of survey: February 2012
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1. **SCOPE OF WORK:**

1. Setting up the surveying bases around the kiln.
3. Measurements of rollers axis position, rollers skewing, inclination and operating angles.
5. Measurements of rollers shafts deflection (indication of shell crank formation).
7. Measurements of tires and shell temperatures.
8. Measurements of tire migration (circumferential tire movement) and calculation of shell ovality.
9. Measurements of shell profile (circularity deviation and eccentricity of cross sections), preparation of shell polar diagrams and shell 3D animation model.
11. General mechanical inspection of drive mesh, bearings and shafts condition, lubrication efficiency, inlet and outlet sealing, thrust unit, adjustment bolts and housing.
12. Calculation of axial deviations in horizontal and vertical plane and the kiln slope.
13. Preparation of optimal version of adjustment program and schedule.
14. Supervision over adjustment procedure carried out by technicians of the Cement Plant.
15. Control survey of final kiln axis position and rollers skewing after the adjustment.
16. Preparation of completed report on measurement and adjustment.
17. Preparation of recommendation for future preventive maintenance actions, routines, necessary repairs and replacements.
18. Presentation and submission of the report to the Customer.
19. Optional 1: Shelltest elastic shell deformation survey, shell ovality check.
21. Optional 3: Recalculation of kiln mechanical parameters (current loads on piers, pressure on bearings, Hertz pressures, bending stress in the shell, stress in the tires, calculation of stiffness matrix, optimization of kiln vertical axis position considering load distribution).
II. **SURVEY OF THE ROTARY KILN No. 1**

1. All measurements have been taken by GEOSERVEX Hot Kiln Alignment Team - Bydgoszcz, Poland from February 21, 2012 to February 29, 2012.

2. After completing all measurements for the kiln, technical documentation has been presented to the cement plant representatives.

3. Coordinating system:
   - Piers are numbered from outlet to inlet side
   - Left and right sides are orientated, looking from inlet to outlet end
   - Starting point for all measurements is a reference line; shim placed on this line is shown as shim No. 1 (see page 7).

III. **RESULTS OF MEASUREMENTS**

1. **Kiln axis, tire migration.**

   Kiln axis position in horizontal plane is within the tolerance and does not require any correction at the moment, but the kiln axis in vertical plane is - 3.5 mm lower and requires some adjustment. Measurement data is shown on page 8 and kiln axes deviations are shown on pages 9 and 10.

   Under-tire clearance values are shown on pages 8 and 10, the clearance at tires No. III and No. I slightly exceeds recommended value, which is 3 to 6 mm. Kiln slope is 3.50 % and it is correct (See page 8 and 10).

2. **Rollers parameters and the kiln thrust**

   Skewing of rollers is not high. Rollers inclination is within the tolerance only for two rollers (see rollers inclination and rollers skewing correction drawings on pages 12 and 17).

   Rollers operating angles are correct for all stations (see page 8 and 10).

   No angle exceeds the tolerance (60°00’ +/- 1°30’).

   Rollers mechanical wear is quite low (see page 22). Also diameters of all rollers are not far from nominal values. The rollers low wear is a result of proper lubrication routine.

3. **Drive station**

   The drive system has been working with a lot of vibrations caused by improper girth gear and pinion meshing (the girth gear teeth are worn out). Gear wobbling is +/- 1.4 mm and slightly exceeds the tolerance (+/- 1 mm for a brand new kiln). Gear radial run-out is +/- 2.0 mm and is acceptable at the moment.
4. Kiln shell

Survey of shell deviation has been taken at 30 cross sections shown on page 52. Maximum shell eccentricity is 14 mm at section No. 1, second biggest eccentricity is 11 mm at cross-section No. 25 (The tolerance for shell eccentricity and shell local deformations given by most kiln producers is 12 mm for the eccentricity and 15 mm for local deformations).

Some shell cross-sections radial deformations are quite significant and they do exceed the acceptable range, take a look at sections No. 12, 13 and 14 in this report.

Tires wobbling is not high for stations No. II and III, but the tire wobbling at the first station exceeds the tolerance.

The kiln shell has been examined for mechanical and thermal hidden crank formation presence. Mechanical crank formation can be examined by measuring of roller shaft deflection change. The measurement results are shown on pages 29-34. None of roller shaft deflection exceeds the tolerance (0.30 mm for total deflection).

5. Shell-test measurement

The expected maximum ovality for a kiln of this diameter would be 0.58%. Summary graph is shown on page 39. For all measured piers ovality results are quite low. The measured ovality for pier No. I was 0.30%, creep value was approximately 20 mm. For pier No. II measured ovality was 0.32%, creep was around 12 mm. The ovality at pier No. III was 0.22%, creep value was 20 mm. All presented ovality values are perfectly within the tolerance. For more details see pages 39 – 45.

6. Mechanical inspection (visual)

The kiln is in satisfactory mechanical condition. All rollers bearing condition is good. Lubrication system is complete and works properly, there is proper oil film on all shafts. Rollers shaft condition is also good. Rollers housing and adjustment bolts are well maintained. Rollers and tires are in good condition, the graphite lubrication device works properly, shimming bolts and nuts were inspected and they are complete.

The contact between tires, supporting rollers and thrust roller is acceptable.

7. Adjustment

The adjustment has been carried out in stages within three days (February 25-27 2012). The above mentioned adjustment has been made due to the fact that the kiln axis in vertical plane required adjustment and the girth gear and pinion meshing was improper and it was necessary to decrease vibrations appearing at the inlet side pier. The whole adjustment has produced the desired result and the vibration level has been significantly reduced (please, see page 13 for more details).
IV. CONCLUSION

We have been informed about the kiln tendency for high amperage, especially during start-up, in our opinion the main reason for this was:
- kiln axis misalignment in vertical plane, improper girth gear and pinion meshing
- and also shell deformation - crank.

To prolong the life of shell and refractory lining is important to:
- correct tire clearance regularly,
- monitor tire creep, temperature of tire and shell,
- avoid rapid heating and cooling of kiln,
- check alignment of kiln every two years.

According to our measurements some geometrical parameters such as kiln axes in horizontal and vertical plane do not require any further correction, however, some actions should be performed in the future to improve the kiln operation.

Actions to be taken in the nearest future:
- skewing correction in vertical plane and bearing thickness check (page 17),
- repair works on outlet seal, a lot of material drops on pier No. 1, which has a bad influence on tire and rollers surface (page 51),
- thrust roller position correction (5 mm move towards the right side of the kiln viewing from inlet side - page 37).
- thrust correction (only if necessary) according to our proposal described on page 19,
- careful monitoring of under-tire clearances at all tires, the most recommended clearance value is 3 to 6 mm.

Actions to be taken later:
- take under consideration the girth gear reversal and centering,
- consider shell section replacement between cross-sections No.12 and 14, due to significantly big shell local deformations which may cause frequent lining problems.

Geoservex, Hot Kiln Alignment Team would like to thank the Plant Crew and Management for cooperation and assistance during our visit. In case of any problems with the kiln geometry do not hesitate to contact us.

GEOCEMENT Plant: 29th of February 2012.
Coordinating System, Symbols and Terms

Starting point for all measurements. Reference line.

- - - - - reference axis
----- real axis
----- adjustment axis

x   axial coordinates
y   horizontal coordinates
z   vertical coordinates
s   undertire clearance
α   rollers operating angle
η   slope of axis
dy  horizontal axis correction
dz  vertical axis correction
ds  skewing correction
c   root clearance
# Measurements Data

## Coordinates "x"

<table>
<thead>
<tr>
<th>Outlet</th>
<th>[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x_1)</td>
<td>54.15</td>
</tr>
<tr>
<td>(x_2)</td>
<td>29.08</td>
</tr>
<tr>
<td>(x_3)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet</th>
<th></th>
</tr>
</thead>
</table>

## Coordinates "y"

<table>
<thead>
<tr>
<th>Outlet</th>
<th>[mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(y_1)</td>
<td>0.0</td>
</tr>
<tr>
<td>(y_2)</td>
<td>-4.0</td>
</tr>
<tr>
<td>(y_3)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet</th>
<th></th>
</tr>
</thead>
</table>

## Coordinates "z"

<table>
<thead>
<tr>
<th>Outlet</th>
<th>[mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(z_1)</td>
<td>0.0</td>
</tr>
<tr>
<td>(z_2)</td>
<td>+5.0</td>
</tr>
<tr>
<td>(z_3)</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet</th>
<th></th>
</tr>
</thead>
</table>

## Undertire clearance "s"

<table>
<thead>
<tr>
<th>Outlet</th>
<th>[mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S_1)</td>
<td>7.0</td>
</tr>
<tr>
<td>(S_2)</td>
<td>4.0</td>
</tr>
<tr>
<td>(S_3)</td>
<td>7.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet</th>
<th>(Average)</th>
</tr>
</thead>
</table>

## Rollers operating angle "\(\alpha\)"

<table>
<thead>
<tr>
<th>Outlet</th>
<th>(^\circ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_1)</td>
<td>59° 47'</td>
</tr>
<tr>
<td>(\alpha_2)</td>
<td>59° 56'</td>
</tr>
<tr>
<td>(\alpha_3)</td>
<td>59° 48'</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inlet</th>
<th></th>
</tr>
</thead>
</table>

## Slope of axis

\(\eta = 3.50\%\)
Axial Deviations in Horizontal Plane

DEFORMATION SCALE: 1:1

0.0 mm

- 4.0 mm

0.0 mm

left side

right side

tolerance zone
+/- 1.5 mm

real axis

reference axis

Precision of finding kiln axis: +/- 1 mm

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012 (Hot condition)
Axial Deviations
in Vertical Plane

DEFORMATION SCALE: 1:1

$\alpha = 59^\circ 48'$
$s = 7.0$ mm

$\alpha = 59^\circ 56'$
$s = 4.0$ mm

$\alpha = 59^\circ 47'$
$s = 7.0$ mm

Precision of finding kiln axis: +/- 1 mm
Rollers Skewing
in Horizontal Plane

1.5 mm

0.0 mm

2.0 mm

left side

right side

klin_axis

Rollers skewing (Sh) are reduced for bolts distance
Rollers Skewing in Vertical Plane

Roller skewing (Sv) are reduced for bolts distance.

Caution! Roller skewing value is reduced for adjustment bolts distance.

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Adjustment Schedule

left side

right side

4.5 mm  4.5 mm

12.5 mm  12.5 mm

INLET

OUTLET

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Adjustment Schedule - Step by Step

The number of adjustment steps - in red colour

1st Day

12.5 mm 12.5 mm

2nd Day

4.5 mm 4.5 mm
Control Check - Axial Deviations in Horizontal Plane

DEFORMATION SCALE :  1 : 1

0.0 mm  - 0.5 mm  0.0 mm

left side

tolerance zone
+/- 1.5 mm

right side

real axis

reference axis

Precision of finding kiln axis: +/- 1 mm
Control Check - Axial Deviations
in Vertical Plane

DEFORMATION SCALE: 1:1

\[
\begin{align*}
\alpha &= 59^\circ 44' \\
s &= 7.0 \text{ mm} \\
\alpha &= 60^\circ 05' \\
s &= 4.0 \text{ mm} \\
\alpha &= 59^\circ 47' \\
s &= 7.0 \text{ mm}
\end{align*}
\]

Precision of finding kiln axis: +/- 1 mm
Base Plates Elevation

PIER No. I

-94.1 mm
(-93.8 mm)
-0.3 mm

PIER No. II

0.0 mm

PIER No. III

0.0 mm

-92.5 mm
(+93.8 mm)
-1.3 mm

-3.0 mm - measured elevation
(0.0 mm) - theoretical elevation
-3.0 mm - deviation

3.51 % - measured slope
(3.50 %) - theoretical slope

INLET

OUTLET

-78.8 mm
(+83.3 mm)
-4.5 mm

+82.8 mm
(+83.3 mm)
-0.5 mm

Geo Cement
EXEMPLARY CEMENT PLANT
Rotary Kiln Inspection
February 2012
(Heat condition)
Skewing Correction in Vertical Plane

0.5 mm

3.50 %

adjustment bolts distance

Caution!
Roller skewing value is reduced for adjustment bolts distance

4.0 mm

3 mm shim to be placed under housing

left side

right side

Rollers skewing (Sv) are reduced for bolts distance

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Position of Supporting Rollers (up - down)
Distance between Trust Collars and Retaining Blocks
Perform only if necessary
Recommendation for Future Thrust Correction

Perform only if necessary

kiln down

left side

right side

kiln axis

0.5 mm

kiln down

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Tires and Shell Temperature

Unit: [°C]

Emission factor: 0.95

<table>
<thead>
<tr>
<th>PIER III</th>
<th>inlet side</th>
<th>outlet side</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>222</td>
<td>235</td>
</tr>
<tr>
<td>maximum</td>
<td>272</td>
<td>270</td>
</tr>
<tr>
<td>difference</td>
<td>50</td>
<td>35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PIER II</th>
<th>inlet side</th>
<th>outlet side</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>216</td>
<td>257</td>
</tr>
<tr>
<td>maximum</td>
<td>250</td>
<td>272</td>
</tr>
<tr>
<td>difference</td>
<td>34</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PIER I</th>
<th>inlet side</th>
<th>outlet side</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum</td>
<td>299</td>
<td>309</td>
</tr>
<tr>
<td>maximum</td>
<td>336</td>
<td>342</td>
</tr>
<tr>
<td>difference</td>
<td>37</td>
<td>33</td>
</tr>
</tbody>
</table>

Date: February 23, 2012
Diameters of Tires and Rollers
in Normal Physical Conditions (20 °C)

\[ \phi = 1994 \]
\[ \phi = 2298 \]
\[ \phi = 2000 \]

\[ \phi = 1996 \]
\[ \phi = 2300 \]
\[ \phi = 1999 \]
Rollers Mechanical Wear

OUTLET

Deviation [mm]

- 1.0
- 1.0
- 0.5
- 0.5
0.0
0.0

Max. radius = 1002.0 mm

Max. radius = 1001.0 mm

DEFORMATION SCALE 1:1

P - I

P - II

P - III

INLET

Deviation [mm]

- 1.0
- 1.0
- 0.5
- 0.5
0.0
0.0

Max. radius = 1150.0 mm

Max. radius = 1151.0 mm

Max. radius = 998.0 mm

Max. radius = 999.0 mm

Accuracy of measurements +/− 0.5 mm
Tire Wobbling

Tire No. III
(VIEWING FROM INLET SIDE)

Caution: reference line describing kiln position - at the bottom

TIRE No. III

INLET

0.4 mm
(Point No. 12)

0.4 mm
(Point No. 28)

OUTLET

TIRE No. II

TIRE No. I

Geo Cement
EXEMPLARY CEMENT PLANT

Rotary Kiln
Inspection
February 2012
(Hot condition)
Page 24
Tire Wobbling

Tire No. II
(VIEWING FROM INLET SIDE)

Caution: reference line describing kiln position
- at the bottom

TIRE No. III

INLET

0.9 mm
(Point No. 2)

0.9 mm
(Point No. 18)

OUTLET

TIRE No. II

TIRE No. I

EXEMPLARY CEMENT PLANT

GeoCement

Rotary Kiln Inspection

February 2012
(Hot condition)

Page 25
Tire Wobbling

Tire No. I
(VIEWING FROM INLET SIDE)

Caution: reference line describing kiln position - at the bottom

TIRE No. III

TIRE No. II

TIRE No. I

2.2 mm
(Point No. 20)

2.2 mm
(Point No. 4)
Girth Gear Wobbling

Girth Gear
(VIEWING FROM INLET SIDE)

Caution: reference line describing kiln position
- at the bottom
TIRE No. III  GIRTH GEAR

TIRE No. II

TIRE No. I

1.4 mm
(Point No. 3)

1.4 mm
(Point No. 19)
Girth Gear Runout

Girth Gear
(VIEWING FROM INLET SIDE)

Caution: reference line describing kiln position - at the bottom

GEOMETRIC CENTRE COORDINATES

| Coordinate Y | - 2.0 mm |
| Coordinate Z | 0.0 mm   |
| ECCENTRICITY | 2.0 mm   |
Roller Shaft Deflection Value Change

PIER No. III
LEFT ROLLER

Eccentricity: 0.28 mm (tolerance 0.15 mm)
Total deflection value: 0.58 mm
Maximum deflection at point No.: 28
Roller Shaft Deflection Value Change

PIER No. III
RIGHT ROLLER

Eccentricity: 0.26 mm (tolerance 0.15 mm)
Total deflection value: 0.53 mm
Maximum deflection at point No.: 32
Roller Shaft Deflection Value Change

PIER No. II

LEFT ROLLER

Measurement Method

View from inlet side

Eccentricity: 0.29 mm (tolerance 0.15 mm)

Total deflection value: 0.58 mm

Maximum deflection at point No.: 14
Roller Shaft Deflection Value Change

PIER No. II

RIGHT ROLLER

Eccentricity: 0.46 mm (tolerance 0.15 mm)

Total deflection value: 0.92 mm

Maximum deflection at point No.: 15
Roller Shaft Deflection Value Change

PIER No. I

LEFT ROLLER

Eccentricity: 0.08 mm (tolerance 0.15 mm)

Total deflection value: 0.15 mm

Maximum deflection at point No.: 30
Roller Shaft Deflection Value Change

PIER No. I

RIGHT ROLLER

Measurement Method

View from inlet side

Eccentricity: 0.08 mm (tolerance 0.15 mm)

Total deflection value: 0.17 mm

Maximum deflection at point No.: 28
Axial Deviations of Drive
in Horizontal Plane

Precision of finding Drive misalignment: +/- 0.5 mm
Axial Deviations of Drive
in Vertical Plane

- 2.0 mm
- 1.0 mm
- 0.5 mm
+ 1.0 mm
+ 0.0 mm

Precision of finding Drive misalignment: +/- 0.5 mm
Thrust Roller Position in Horizontal Plane

OUTLET

3 mm
thrust roller slope 3.47%

incorrect
klin axis
thrust roller axis

3 mm

TIRE No. III

INLET
SHELLTEST Measurements results
SHELLTEST Measurements results
Date of measurement: 10.02.2012

<table>
<thead>
<tr>
<th>No. of the Tire and side of measurement</th>
<th>Mean ovality from three measurements</th>
<th>Distance from the ring center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire III Inlet side</td>
<td>0.23 %</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Tire III Outlet side</td>
<td>0.22 %</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Tire II Inlet side</td>
<td>0.29 %</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Tire II Outlet side</td>
<td>0.34 %</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Tire I Inlet side</td>
<td>0.32 %</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Tire I Outlet side</td>
<td>0.27 %</td>
<td>1.3 m</td>
</tr>
</tbody>
</table>

Ovality limits as a function of the kiln diameter

![Graph](image-url)
SHELLTEST - MEASUREMENT

PIER No. III INLET SIDE

Average ovality = 0.23 %
Shell diameter = 4830 mm
Creep = 20 mm

\( \omega_r = 0.22\% \)

\( \omega_r = 0.26\% \)

\( \omega_r = 0.22\% \)
PIER No. III  OUTLET SIDE

Average ovality = 0.22 %
Shell diameter = 4830 mm
Creep = 20 mm

ωr = 0.30 %
7.0 mm

ωr = 0.13 %
3.0 mm

ωr = 0.22 %
5.0 mm
SHELLTEST - MEASUREMENT

PIER No. II  INLET SIDE

Average ovality = 0.29 %
Shell diameter = 4830 mm
Creep = 12 mm
SHELLTEST - MEASUREMENT

PIER No. II  OUTLET SIDE

Average ovality = 0.34 %
Shell diameter = 4830 mm
Creep = 12 mm

\[\omega_r = 0.43\%\]
\[\omega_r = 0.26\%\]
\[\omega_r = 0.34\%\]
SHELLTEST - MEASUREMENT

PIER No. I INLET SIDE

Average ovality = 0.32 %
Shell diameter = 4830 mm
Creep = 20 mm

A $\omega_r = 0.30 \%$
B $\omega_r = 0.32 \%$
C $\omega_r = 0.34 \%$

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012 (Hot condition)
SHELLTEST - MEASUREMENT

PIER No. I  OUTLET SIDE

Average ovality = 0.27 %
Shell diameter = 4830 mm
Creep = 20 mm

\[ \omega_r = 0.26 \% \]

\[ \omega_r = 0.30 \% \]

\[ \omega_r = 0.24 \% \]

**EXEMPLARY CEMENT PLANT**

**Rotary Kiln Inspection**

February 2012 (Hot condition)
Mechanical Inspection
(Visual)

Girth Gear and Pinion
(Teeth inspection)

The Girth Gear Teeth - worn out at a point of contact
The Pinion Teeth - good condition
Mechanical Inspection
(Visual)

Pier No. III

Tire - running surface
in good condition

Running surface of both rollers
- satisfying condition

Left Roller

Right Roller
Mechanical Inspection

(Visual)

Thrust Roller

Running surface - good condition

Pressure around 40 Bar
Mechanical Inspection
(Visual)

Pier No. II

Tire - running surface
in good condition

Running surface of both rollers
- satisfying condition
Mechanical Inspection
(Visual)

Pier No. I

Tire running surface
- good condition

Gap between
The Tire and Left Roller

Running surface
of both rollers
- good condition

Left Roller

Right Roller
Inlet

Inlet sealing works properly

Outlet

Outlet sealing does not work properly
Sections Position Diagram
for Kiln Shell Deviation Survey (layout)

P - III DRIVE

P - II

P - I

reference line describing kiln position
- at the bottom
Shell Profile
Axonometric View
Starting point at bottom - 0°
Shell Profile
Axonometric View
Starting point at 90°
Shell Profile
Axonometric View
Starting point at 180°
Shell Profile
Axonometric View
Starting point at 270°
Radial Diagram of Shell Deformation
(Circular Deviations)

**CROSS SECTION No. 1**
Deformation Scale - 1 : 1

**GEOMETRIC CENTRE COORDINATES**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Y</td>
<td>- 7 mm</td>
</tr>
<tr>
<td>Coordinate Z</td>
<td>+ 12 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>14 mm</td>
</tr>
</tbody>
</table>

**Caution:**
Hatch Line describing kiln position at the bottom

VIEWING FROM INLET SIDE

**Geo Cement**
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 2
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>- 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>+ 6 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>7 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012
(Hot condition)
Radial Diagram of Shell Deformation (Circular Deviations)

CROSS SECTION No. 3
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>- 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>+ 3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012 (Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 4
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

| Coordinate Y | - 1 mm |
| Coordinate Z | + 1 mm |
| ECCENTRIC    | 1 mm   |
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 5
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>0 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>0 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 6
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>-2 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>2 mm</td>
</tr>
</tbody>
</table>
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 7
Deformation Scale - 1 : 1

axis of rotation
geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
Radial Diagram of Shell Deformation  
(Circular Deviations)

CROSS SECTION No. 8  
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom  
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

GeoCement  
EXEMPLARY CEMENT PLANT  
Rotary Kiln Inspection  
February 2012  
(Hot condition)
Radial Diagram of Shell Deformation  
(Circular Deviations)

CROSS SECTION No. 9
Deformation Scale - 1 : 1

axis of rotation

geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

<table>
<thead>
<tr>
<th>GEOMETRIC CENTRE COORDINATES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Y</td>
<td>+ 1 mm</td>
</tr>
<tr>
<td>Coordinate Z</td>
<td>-2 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

GeoCement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012  (Hot condition)
CROSS SECTION No. 10
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 4 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 4 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>6 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

**CROSS SECTION No. 11**
Deformation Scale - 1 : 1

**Caution:**
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

<table>
<thead>
<tr>
<th>GEOMETRIC CENTRE COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Y</td>
</tr>
<tr>
<td>Coordinate Z</td>
</tr>
<tr>
<td>ECCENTRIC</td>
</tr>
</tbody>
</table>
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 12
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>Coordinate Z</th>
<th>ECCENTRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 3 mm</td>
<td>- 3 mm</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE
CROSS SECTION No. 13
Deformation Scale - 1 : 1

Radial Diagram of Shell Deformation
(Circular Deviations)

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>-3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
Radial Diagram of Shell Deformation (Circular Deviations)

CROSS SECTION No. 14
Deformation Scale - 1 : 1

GEOMETRIC CENTRE
COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>- 1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 15
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>Coordinate Z</th>
<th>ECCENTRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1 mm</td>
<td>- 2 mm</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012  (Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 16
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>-3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 17
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>0 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 2 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom

VIEWING FROM INLET SIDE
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 18
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 2 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

EXEMPLARY CEMENT PLANT    Rotary Kiln Inspection
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 19
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 3 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>4 mm</td>
</tr>
</tbody>
</table>
Radial Diagram of Shell Deformation
(Circular Deviations)

**CROSS SECTION No. 20**
Deformation Scale - 1 : 1

![Diagrampic](image)

**GEOMETRIC CENTRE COORDINATES**

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 4 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>5 mm</td>
</tr>
</tbody>
</table>

**Caution:**
Hatch Line describing kiln position at the bottom

VIEWING FROM INLET SIDE

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012  (Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 21
Deformation Scale - 1 : 1

axis of rotation

geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>- 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>+ 4 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>5 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 22
Deformation Scale - 1 : 1

axis of rotation

geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>+ 2 mm</td>
</tr>
<tr>
<td>Z</td>
<td>- 6 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>6 mm</td>
</tr>
</tbody>
</table>

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
CROSS SECTION No. 23
Deformation Scale - 1 : 1

axis of rotation
geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 6 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>8 mm</td>
</tr>
</tbody>
</table>
Radial Diagram of Shell Deformation (Circular Deviations)

CROSS SECTION No. 24
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 10 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>10 mm</td>
</tr>
</tbody>
</table>

Geo Cement
EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 25
Deformation Scale - 1 : 1

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
Geo Cement
February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 26
Deformation Scale - 1 : 1

axis of rotation

geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 4 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 6 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>7 mm</td>
</tr>
</tbody>
</table>

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection  February 2012
(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 27
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 4 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>5 mm</td>
</tr>
</tbody>
</table>

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 28
Deformation Scale - 1 : 1

axis of rotation

geometric centre

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

GEOMETRIC CENTRE COORDINATES

<table>
<thead>
<tr>
<th>Coordinate Y</th>
<th>+ 1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinate Z</td>
<td>- 1 mm</td>
</tr>
<tr>
<td>ECCENTRIC</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
February 2012
(Hot condition)
**Radial Diagram of Shell Deformation**

**(Circular Deviations)**

**CROSS SECTION No. 29**

Deformation Scale - 1 : 1

---

**Caution:**

Hatch Line describing kiln position at the bottom

VIEWING FROM INLET SIDE

---

**EXEMPLARY CEMENT PLANT**

**Rotary Kiln Inspection**

February 2012

(Hot condition)
Radial Diagram of Shell Deformation
(Circular Deviations)

CROSS SECTION No. 30
Deformation Scale - 1 : 1

GEOMETRIC CENTRE COORDINATES
- Coordinate Y: -3 mm
- Coordinate Z: +4 mm
- ECCENTRIC: 5 mm

Caution:
Hatch Line describing kiln position at the bottom
VIEWING FROM INLET SIDE

EXEMPLARY CEMENT PLANT
Rotary Kiln Inspection
February 2012
(Hot condition)
Kiln Mechanical Parameters

The kiln mechanical parameters has been calculated with consideration of actual thickness and weight of kiln shell, refractory lining, coating, material flow, as well as all dimensions of kiln components. All results represents the case of kiln straight axis. To illustrate consequences for the kiln we calculate load capacity utilization of particular parameter referring to its design limit.

<table>
<thead>
<tr>
<th>LOAD DISTRIBUTION FOR ROLLERS AND TIRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEARINGS</td>
</tr>
<tr>
<td>Specific load</td>
</tr>
<tr>
<td>Support No. 1</td>
</tr>
<tr>
<td>Support No. 2</td>
</tr>
<tr>
<td>Support No. 3</td>
</tr>
</tbody>
</table>

All above parameters, particularly specific load of bearings, tires’ bending stress and Hertz pressure between tires and rollers are within tolerance. Utilization of design limit is close to 100% for support No. 1 what is related with mass concentration in this zone (coating). The kiln is not overloaded but support No. 1 is close to upper tolerance limit for bearing load and Hertz pressure between tire and rollers. Therefore we recommend to pay special attention on coating accumulation. In case of high thickness of coating or coating ring formation support No. 1 may be temporarily overloaded.

<table>
<thead>
<tr>
<th>STIFFNESS MATRIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of reaction in [%] by lowering particular support by 10 mm</td>
</tr>
<tr>
<td>No. 1</td>
</tr>
<tr>
<td>Support No. 1</td>
</tr>
<tr>
<td>Support No. 2</td>
</tr>
<tr>
<td>Support No. 3</td>
</tr>
</tbody>
</table>

The stiffness matrix illustrates kiln shell characteristics. The result illustrates change of reaction of all supports when particular support is lowering by 10 mm. Considering maximum reaction value of 18% the kiln is classified as flexible. It means the kiln is not very much sensitive for change of kiln axis position and reactions on supports do not change drastically. Anyway, it is recommended to pay attention on the kiln alignment and under-tire clearance’s changes to avoid overload in the future.
Kiln shell bending stress reaches 16 MPa and it is within designed limits (25 MPa). It looks there is large spare limit for shell bending stress. However, it has to be considered that above result represent straight kiln in static condition without any shell deformation or crank formation. All above results lead to conclusion the kiln should be aligned for straight axis, there is no need to optimize loads and stresses by changing axis position.

<table>
<thead>
<tr>
<th>TIRE MIGRATION, SHELL RELATIVE OVALITY, NIES OVALITY FOR TIRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHELL Rel. ovality (design limit 0.30%) Utilization [% ]</td>
</tr>
<tr>
<td>Support No. 1</td>
</tr>
<tr>
<td>Support No. 2</td>
</tr>
<tr>
<td>Support No. 3</td>
</tr>
</tbody>
</table>

Tires’ migration is almost within tolerance (10-20 mm/rev) for all supports. Therefore relative ovality of kiln shell is also within design limit. Nies’ ovality for tires are within tolerance and the utilization is below 100%. However, the migration and ovality is just at the tolerance limit and it is recommended to pay attention on tire migration in the future. In case it increases, shimming should be considered.

Generally, the kiln mechanical parameters are within design limits. The kiln is definitely not overloaded in terms of support loads, bearing pressures, tire stress and Hertz pressures between tires and rollers. Also the kiln shell bending stress is within designed limit. However, it should be considered that all the design limits correspond to static condition and in fact all parameters are frequently much higher due to cyclical load change during kiln operation (crank effect). It is recommended to monitor the bearings condition and temperatures frequently.

Technical drawings of calculation results are attached at the end of this report.
Kiln Mechanical Parameters

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Kiln Mechanical Parameters

Tires & gear
Shell
Lining
Coating

EXEMPLARY CEMENT PLANT  Rotary Kiln Inspection
Weight distribution $[t/m]$
Vertical Displacement of the Kiln Shell [mm]

Vertical displacement for $E = 182.536$

Hot kiln

![Graph showing vertical displacement over kiln length.](image)

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)
Longitudinal Bending Stress of the Kiln Shell [MPa]
Shear Stress of the Kiln Shell
Von Mises Stress (Reference Stress) of the Kiln Shell [MPa]

Von Mises stress $\sigma_M$ [MPa] vs. Kiln length $x$ [m]

EXEMPLARY CEMENT PLANT

Rotary Kiln Inspection

February 2012 (Hot condition)