Providing of Axis’ Alignment Accuracy of Rotary Kilns During the Repair Process

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INTRODUCTION

Uneven wear of basic surfaces, deformation and sometimes destruction of the shell occur during the unit operation under dynamic loads. All these phenomena cause additional shape errors of basic surfaces as well as shape errors of kiln shell dimensional position [1].

For thirty years the machine-building department of BSTU after V.G. Shukhov has been gaining significant experience in designing [2] and implementation of special equipment for machining support units of rotary kilns [3]. Such machining of basic support rollers and tyres [4], rigidly connected to the shell, brings additional errors to geometric properties of the unit and requires subsequent kiln alignment [5] and its position adjustment to provide straightness of axis and theoretical angle of inclination of a kiln.

MATERIALS AND METHODS

There are many various methods of straightness alignment of kiln axis that use geodetic and special equipment. The majority of them are implemented by leveling the specific points of kiln tyres or retaining rings. All these methods require the presence of highly qualified team of geodesists making measurements and at the same time don’t provide the accuracy of alignment of rotation axis because of significant deviations of shape of the kilns and retaining rings from round shape [1].

Shape of kilns operated for a long time as well as welded kilns (without following machining) is approximating to the shape of an ellipse and if they are used as basic parts, errors, in some instances reaching 10-15 mm [1] according to kiln angle of rotation, occur. In such cases support rollers keeping their round shape [6] in spite of the more intense wear then kilns have are used as basic parts.
Use of rollers’ axes as measuring bases is implemented by displacement of rollers’ centers beyond their shells with monitoring their position and comparing their actual position with position of displaced rollers’ centers as long as the straightness of rotation axis is provided. The centre of roller is defined as point of intersection of its axis and perpendicular defined by the centre of contact line of tyre and support roller.

Selection of basic supports that defines the measurement errors is matters. Any of the supports can be used as basic supports, however during the selection of front and rear heads the accuracy of control increases several times, so it’s recommended to implement the alignment in this way. At first the coordinates of support rollers’ centers for general case of positioning the support nodes are defined and then the desired relations for particular cases will be given.

Position of support node parts of the first basic support is denoted with solid line and I-index and of the second (or another) basic support – with dashed line and i-index (Fig. 1).

**Fig. 1**: Diagram for defining coordinates of rollers’ centers.

According to law of cosines, on condition the rotation axis passes the geometric centers of the first tyre and the i-tyre we have:

$$\cos \angle B_1 = \frac{\rho_1^2 + L_1^2 - \rho_n^2}{2L_n \rho_1} \quad \cos \angle B_i = \frac{\rho_n^2 + L_n^2 - \rho_i^2}{2L_i \rho_n}$$

(1)

where

$$\rho_1 = R_1 + r_i; \quad \rho_n = R_n + r_i; \quad \rho_i = R_i + r_i$$

(2)

Triangles $C_i OB_i$ and $C_i OB_i$ give us the coordinates of the center of support i-roller ($x_i$ and $y_i$):

$$x_i = C_i B_i - C_i$$

(3)

where

$$C_i B_i = \rho_1 \cos(\angle B_1 \pm \alpha_{d1}); \quad C_i B_i = \rho_n \cos(\angle B_i \pm \alpha_{di})$$

or

$$C_i B_i = (R_i + r_i)(\cos \angle B_i \cos \alpha_{d1} \pm \sin \angle B_i \sin \alpha_{d1}); \quad C_i B_i = (R_i + r_i)(\cos \angle B_i \cos \alpha_{di} \pm \sin \angle B_i \sin \alpha_{di})$$

Therefore:

$$x_i = \frac{(\rho_1^2 + L_1^2 - \rho_n^2) \cos \alpha_{di}}{2L_1} \sqrt{\rho_1^2 - \frac{(\rho_1^2 + L_1^2 - \rho_n^2)^2}{4L_1^2} \sin \alpha_{di}} - \frac{(\rho_n^2 + L_n^2 - \rho_1^2) \cos \alpha_{di}}{2L_n} \sqrt{\rho_n^2 - \frac{(\rho_n^2 + L_n^2 - \rho_i^2)^2}{4L_n^2} \sin \alpha_{di}}$$

(5)

Abscissa of the center of the left support roller of the i-support is written as:

$$x_{ni} = B_i A_i - B_i A_i - x_i$$

(6)

where

$$B_i A_i = L_i \cos \alpha_{d1}; \quad B_i A_i = L_i \cos \alpha_{di}$$

therefore

$$x_{ni} = L_i \cos \alpha_{d1} - L_i \cos \alpha_{di} - x_i$$

(7)

Ordinate of the right support roller of the i-support is written as:

$$y_n = OC_1 - OC_i$$

(8)

Where

$$OC_1 = \rho_1 \sin(\angle B_1 \pm \alpha_{d1}); \quad OC_i = \rho_i \sin(\angle B_i \pm \alpha_{di})$$

or

$$OC_1 = \rho_1 (\sin \angle B_1 \cos \alpha_{d1} \pm \cos \angle B_1 \sin \alpha_{d1}); \quad OC_i = \rho_i (\sin \angle B_i \cos \alpha_{di} \pm \cos \angle B_i \sin \alpha_{di})$$

Therefore:
Ordinate of the center of the left support roller is written as
\[ y_n = \frac{(\rho_n^2 + L_1^2 - \rho_n^2)}{4L_n} - \frac{(\rho_n^2 + L_1^2 - \rho_n^2)\sin \alpha_i}{2L_n} \]
\[ y_n = \sqrt{\rho_n^2 - \left(\frac{L_1^2}{2}\right)} - \sqrt{\rho_n^2 - \left(\frac{L_1^2}{2}\right)} \sin \alpha_i \]

where \( A_iA' = L_i \sin \alpha_i \); \( A_iA'_1 = L_1 \sin \alpha_b \)

Therefore:
\[ y_n = L_i \sin \alpha_i - L_i \sin \alpha_{di} - y_n \]

Position of the support nodes shown in the Fig. 2 is the most general case that is usually relatively simple.

Let’s see some of the particular cases of position of the mentioned support nodes in which relations (1), (2), (3) and (4) are significantly simplified.

If \( \alpha_{di} = \alpha_{di} = 0 \):
\[ x_n = \frac{\rho_n^2 + L_1^2 - \rho_n^2}{2L_n}; \quad y_n = L_i - L_i - x_n \]

If \( \alpha_{di} = \alpha_{di} = 0 \); \( \rho_n = \rho_n = \rho_n \) and \( \rho_n = \rho_n = \rho_n \)
\[ x_n = \frac{L_1}{2}; \quad y_n = L_i - L_i - x_n \]

Therefore we have the opportunity to define the theoretical values of coordinates of support rollers’ centers for all of the possible cases.

3. Discussion:

The following geometric methods of defining the coordinates of rollers’ centers are known [7]. Devices of ISCB-type mounted on the surface of support rollers by means of movement mechanisms which produce the magnetic field or SC-8 devices which have the magnet mount installed inside the case are applied for defining actual values of coordinates of rollers’ centers [8].

During the controlling of straightness of rotation axis by displaced centers of rollers there is also a need to control the parallelism between support rollers’ axes. Devices of ISCB-1- or ISCB-2-type may be applied for such controlling and the controlling itself may be implemented similarly to one described above or the device with target may be mounted on all the tyres three times: in the middle – for defining coordinates of the roller’s center and at the ends – for comparison of coordinates allowing to estimate the parallelism between rollers’ axes and kiln’s rotation axis if the rollers’ diameters in these sections are defined [9].

Method of aligning the rotation axis of kiln was developed by the machine-building department of BSTU named after V.G. Shukhov and it was implemented by number of enterprises of Russia and CIS countries.

The substance of suggested method providing the installation accuracy of rotary kiln is the installation of support rollers providing the parallelism between their rotation axes. Then the machining of outer surfaces of support rollers and tyres by means of special machine tool is implemented, their diameters are measured and the actual position of kiln axis is defined. This requires the estimation of actual position of tyres’ centers considering geometric properties of the first tyre and corresponding roller support. After that the actual position of kiln axis is defined by projections of tyres’ centers onto two mutually perpendicular planes, one of which is vertical and the other one passes horizontal plane at a set angle of kiln’s inclination. By connecting the projections of tyres’ centers broken lines are formed which are the projections of axis onto two planes mentioned above. By adjusting positions of rollers of roller supports the positioning of tyres’ centers on the same line, parallel to line drawn at a set angle of kiln’s inclination, is provided [10].

Suggested method aims to increase life and productivity of roasting rotary kiln by providing straightness of rotary kiln’s axis and installing kiln at a set angle of inclination.

It can be achieved by defining the actual position of tyres’ centers considering geometric properties of each tyre and corresponding roller support; by defining the actual position of axis in two mutually perpendicular planes, one of which is vertical and the other one passes horizontal plane at a set angle of kiln’s inclination; by projecting tyres’ centers onto each of the them and connecting the projections with broken lines the positions’
adjustment of rollers of roller supports is implemented, that provides the positioning of tyres’ centers on the same line, parallel to line drawn at a set angle of kiln’s inclination [11].

Since fixed positions of tyres’ axes, which are bound with tyre’s instant centers by minimum number of components of dimensional chain – radiuses of rollers and tyre, in the fixed coordinate system, are used as input data during estimation, then the displacement of tyre’s center from theoretical axis may be defined with maximum accuracy. This displacement defines the bending of axis on specified roller support. Every deviation of axis from straightness causes deformation of shell, increased wear of rollers, tyres and cones of bearings, destruction of refractory lining and increased electric energy consumption [7].

Fig. 3: Rotary kiln’s cross section.

Fig. 3 represents kiln’s cross section intersecting one of roller supports in rectangular coordinate system with machine tool installed under tyre.

Drawing projections of actual position of kiln’s axis onto two coordinate planes allows detecting of value of axis’ displacement on all the roller supports, to analyze the technological load distribution along the kiln’s length and to implement the adjustment with minimum displacements. In addition, formed broken lines of axis’ projections are in fact calculation schemes, since accurate stress–strength analysis of kiln’s shell may be implemented if kiln’s shell is considered as continuous beam with hollow structural section [12].

All of the above allows providing of reliable and durable work of rotary kiln.

The substance of suggested method is represented on illustrated materials (Fig. 4). Suggested method of providing axis’ straightness of roasting rotary kiln is implemented as follows.

Geodetic alignment of axes’ coordinates of all the support rollers in relation to rectangular coordinate system parallel to axial planes, one of which is vertical, is implemented.

Alignment of coordinates of rollers’ axes may be implemented, for instance, by means of theodolite with millimeter rail or by means of kit of ISCB-3-type devices.

If the results of alignment of rollers’ rotation axes reveal deviations from their parallelism to each other and from set angle of kiln’s inclination, then corresponding axes are adjusted by means of one of the known methods until their positions will be parallel to the other axes [1].

After that analysis of shapes of all the tyres and rollers is implemented to identify the need of correcting shapes of operating surfaces.

Special lathe 3 is installed for machining operating nodes, each of which includes tyre 1 and two support rollers 2, for correcting shape under tyre 1 between rollers 2. Lathe 3 installation is implemented so trajectory of movement of carriage 4 with tool 5 would be parallel to axes of rollers 2, and tool 5 itself would be mounted in radial direction relatively to outer surfaces of rollers 2, which were initially machined, and outer surface of tyre 1 after remounting carriage 4 with tool 5.

After machining operating surfaces of rollers 2 must have cylindrical shape and outer surfaces of tyres 1 must be in continuous contact with surfaces of rollers 2 over the entire length of node’s power stroke during rotation.

Diameters’ measuring of each pair of support rollers and diameters’ defining of corresponding tyres, for instance, by means of three-point method, are implemented in the next step.
After that according to data of geodetic alignment of axes’ coordinates, represented in Fig. 4, of all the support rollers, and measuring their diameters, as well as keeping in mind the diameters of corresponding tyres, the definition of actual position of each roller’s center point, signed with O, is implemented by means of defining the coordinates \( x_0 \) and \( y_0 \) of center by solving systems of linear equations:

\[
\begin{align*}
\frac{d_A + D_A}{2} &= \sqrt{(x_A + x_i)^2 + (y_A - y_i)^2} \\
\frac{d_B + D_B}{2} &= \sqrt{(x_B + x_i)^2 + (y_B - y_i)^2} \\
x_n - x_A &= \sqrt{\left(\frac{D_A - d_A}{2}\right)^2 - (y_A - y_i)^2} + \sqrt{\left(\frac{D_B - d_B}{2}\right)^2 - (y_A - y_i)^2}
\end{align*}
\]

where \( d_A \) – diameter of left roller of i-support; \( D_A \) – diameter of i-tyre; \( x_{A_i} \) и \( y_{A_i} \) – axis’ coordinates of left roller; \( d_B \) – diameter of right roller of i-support; \( x_{B_i} \) и \( y_{B_i} \) – axis’ coordinates of right roller; \( x_0 \) и \( y_0 \) – coordinates of tyre’s center.

Then defined points are projected onto mutually perpendicular planes, one of which is vertical and the other one is drawn at a set angle of kiln’s inclination.

Broken lines, which represent the projections of roasting rotary kiln’s curved axis onto vertical plane (Fig. 4) and horizontal inclined plane, are formed by connecting together the projections of tyres’ centers. In addition, \( \Delta x_0 \) and \( \Delta y_0 \) – deviations’ values of actual position of each tyre’s center in specified planes.

With projections of axis’ actual position onto two planes and keeping in mind values \( x_0 \) and \( y_0 \) for each roller support, calculation of values \( I_{A_i} \) and \( I_{B_i} \) and definition of direction of support rollers’ displacement providing straightening of kiln’s axis, are implemented. Since the position of kiln’s axis is defined by two planes, displacement calculation correcting the position of kiln’s axis is written as formulas below which consider the deviations of tyres’ centers in both planes:

\[
\begin{align*}
I_{A_i} &= \left(\frac{L_s}{2} + \Delta x_0\right) - \sqrt{\left(\frac{D_A - d_A}{2}\right)^2 - \left(\frac{L_s}{2}\right)^2 - \Delta y_0} \\
I_{B_i} &= \left(\frac{L_s}{2} + \Delta x_0\right) - \sqrt{\left(\frac{D_B - d_B}{2}\right)^2 - \left(\frac{L_s}{2}\right)^2 - \Delta y_0}
\end{align*}
\]

where \( I_{A_i} \) – required displacement of left roller; \( L_s \) – distance between rollers’ axes; \( \Delta x_0 \) – horizontal curvature of kiln’s rotation axis; \( D_i \) – tyre’s diameter; \( d_A \) – diameter of left roller; \( d_B \) – diameter of right roller;
Because of great complexity of displacement values’ calculations and calculations of displacements themselves, they may be implemented by means of software.

Adjustment of rollers’ positions that provides positioning of tyres’ centers on the same line, parallel to line passing center of the first tyre at a set angle of kiln’s inclination, is implemented after defining calculated displacements of rollers. Position adjustment is implemented by displacing each roller according to the value of required displacement \( \Delta x \) and \( \Delta y \). Fig. 3 represents kiln’s cross section intersecting one of roller supports with machine tool installed under tyre; Fig. 4 represents front projection of kiln, vertical projection of actual position of kiln’s axis, projection of kiln’s axis onto plane perpendicular to vertical plane and drawn at a set angle.

Suggested method of providing axis’ straightness of roasting rotary kiln is implemented as follows.

Geodetic alignment of axes’ positions of all the support rollers in relation to rectangular coordinate system that is parallel to axial planes, one of which is vertical, is implemented.

Alignment of coordinates of axes’ positions may be implemented, for instance, by means of tachymeter, theodolite with millimeter rail or by means of devices of ISCB-type.

If the results of alignment of rollers’ rotation axes reveal deviations from their parallelism to each other and from set angle of kiln’s inclination, then corresponding axes are adjusted until their positions will be parallel to the other axes.

After that analysis of shapes of all the tyres and rollers is implemented to identify the need of correcting shapes of operating surfaces [13].

If calculations of displacements of support rollers are accurate then following equations must be applied:

\[
\begin{align*}
    l_i &= \left( \frac{L}{2} - \Delta x_i \right) - \left( \frac{D_i + d_i}{2} - \frac{L}{2} - \Delta y_i \right), \\
    l_r &= \left( \frac{L}{2} + \Delta x_r \right) - \left( \frac{D_r + d_r}{2} - \frac{L}{2} - \Delta y_r \right),
\end{align*}
\]

where \( l_i \) and \( l_r \) – required displacements of rollers;
\([\Delta x_i]_0\) and \([\Delta y_i]_0\) – horizontal and vertical curvature of kiln’s rotation axis;
\( L \) – distance between rollers’ axes;
\( D \) – tyre’s diameter;
\( d_i \) – diameter of left roller;
\( d_r \) – diameter of right roller.

4. Results:

Optimal position of kiln’s axis should be defined according to results of alignment and machining with tool. Following recommendations must be followed during the alignment of kiln’s axis by displacing the roller supports. Angle of kiln’s inclination must be equal to one that is set. Rollers of supports that are located close to kiln’s drive must be displaced considering the retention of optimal radial clearances in gear contact [14]. During the calculation of vertical displacement angles of installation of tyres’ on rollers may be significantly different from calculated value of 30°, that must be considered and specified for each of the roller supports. Because of great complexity of displacement values’ calculations and calculations of displacements themselves, they may be implemented by means of software. In this instance it’s desirable to select optimal position of kiln’s axis in terms of minimum displacements of roller supports. If there is a risk of breaking the geometry of gear contact between ring gear and under ring gear, then it’s necessary to impose restrictions on displacement of roller supports that are located close to drive[15].

5. Conclusion:

Indirect methods of measurements, that don’t consider shape of particular parts and nodes of large-sized industrial equipment, are generally applied during its alignment with the intention of most accurate positioning its particular parts and nodes. It’s particularly important to aware shape of basic parts, for instance, tyres and support rollers in case of rotary kilns. Cylindrical parts’ deviations from regular geometric shape may be corrected during the repair process by means of machining using special machine tool. Suggested method of alignment allows considering of variation of basic parts’ dimensions.

6. Main Points:

1. Errors that occur during the process of indirect measurements are generally commensurate with accuracy tolerances of the mutual arrangement of unit’s parts and nodes.
2. Use of simulated bases adds additional errors.
3. Suggested method provides maximum compliance of principle of unity and permanence of bases and therefore provides maximum accuracy.

REFERENCES


