DYNAMICAL MONITORING AND CORRECTION OF ROTARY MACHINES DEFORMATION

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SUMMARY

Geometry adjustment and alignment of machinery, like rotary kilns, in normal operating conditions is presently a standard, whereas monitoring dynamic deformations of such machines has become possible with the help of laser scanning methods.

Such scanning can be carried out by means of a simple and inexpensive geodetic device known commonly as DISTO PRO coupled with a WORKABOUT recorder. Presented in this article is the measurement method scheme and general principles of processing such results by means of computers.

The capability of making use of these results gives the geodesist completely new technical and business opportunities of using such knowledge in forecasting and supervising complicated repairs of machines.
The author is a practicing supporter of the thesis, controversial for some people, the geodesist can intervene more efficiently in cause and effect relationships of ensued deformations through active interpretation and adjustments.

1. INTRODUCTION

The domain of the geodesist is measuring geometric properties of spatial objects, therein complicated machines and equipment, and presenting these properties for the purpose of transforming, adjusting or optimising their geometrical condition.
The considerations presented herein apply to rotary machines like: rotary kilns, mills and rotary drying kilns, calcining furnaces, ventilators, turbines, paper-making machines and many other rotation-based machines.
The nature of rotary movement implicates the need (whenever possible) to make measurements in dynamic condition, i.e. preferably during normal operation.
The rotary kiln - used on a mass scale in the cement, metallurgical and chemical industries - was and still is the subject of particular interest of geodesists, and Polish geodesists were pioneers in the dynamical measurements of these machines. [1] [2] [3].
Measurements allow deviations of kiln axis points from rectilinearity or from assigned geometrical conditions in locations where the kiln is provided with bearings (in support points) and this is where the geodesist's role usually ends. Designing and carrying out adjustments are made with the participation of the geodesist or mostly without him.
From the author's practice it results that active interpretation and adjustment activities, and participation of the geodesist in the decision-taking process is the basis of success –

not only technical but also business success. On one hand, this requires interdisciplinary knowledge, and on the other hand requires taking specific risks. Aligning a rotary kiln during its movement is presently a standard known and applied worldwide under the name "HOT KILN ALIGNMENT".
In 2002 this issue has in been rewarded by the II Award of the Minister of Infrastructure for outstanding creative achievements in the field of geodesy and cartography [4].

Presented below are measurement issues exceeding the subject of classic alignment and covering dynamical monitoring of rotary kiln shell deformations and examples of utilizing such measurements in forecasting, performing, supervising and controlling repairs of these machines.

2. DEFORMATIONS OF ROTARY MACHINE SHELLS

The housing of a rotary kiln is a rotating steel pipe of circular section internally lined with ceramic lining. (Fig. 1) where a temperature of up to 1600°C exists.

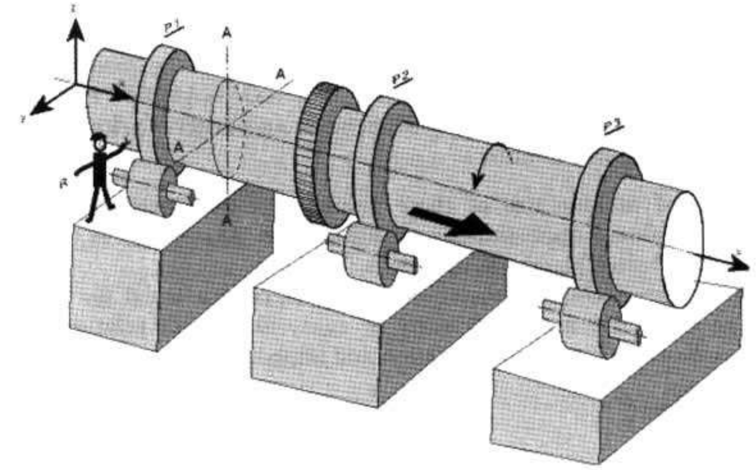

Fig. 1. Diagrammatic drawing of a rotary kiln

Wear and tear or damage of this lining causes local overheating of the kiln shell, which is the cause of radial deformations (indentations) and axial deformations (crank) of the shell.
The degradation process of the kiln shell is a self-driving process because the deformations damage the linings, and these damages severely intensify deformations (this reminds the formation of holes in an). In consequence, the failure to monitor and control this process leads to the need of replacing a part of the kiln shell, i.e. carrying out a very expensive repair.

Deformations of the kiln shell are identified for specific selected cross-sections. Figure 2 illustrates basic dependencies between the rotation axis and the geometric axis in the given cross-section.

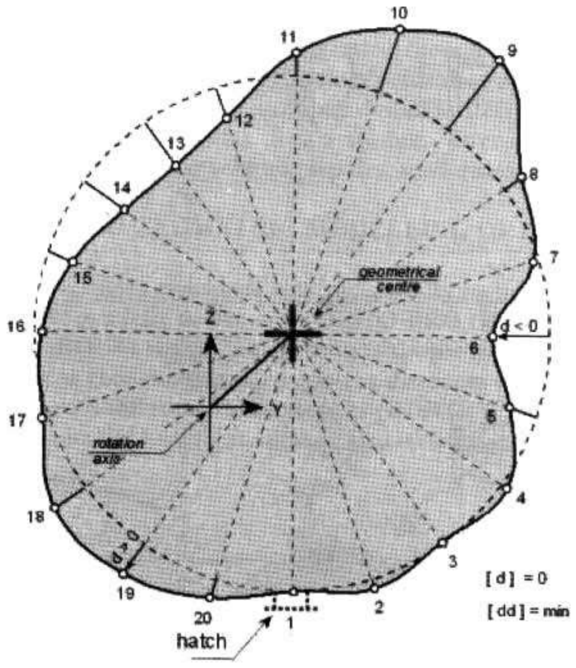

Fig. 2. Dependencies between the rotation axis and the geometric axis in the given cross-section

The rotation axis is the reference point of the co-ordinate system (Y,Z), in relation to which the position of the geometric axis is defined. A section's geometrical centre is understood as the centre of the most likely circle fitted in the existing section with maintaining Gauss's condition that the sum of radial deviations "d" is equal to zero, and the sum of their squares is the least.

$$[d] = 0$$
$$[dd] = min$$

The section's geometrical centre during the kiln's movement rotates around the rotation axis, and the rotation radius is the eccentric "e" (commonly called the crank), and this eccentric is orientated (angle α) in relation to the shell generating line that has a characteristic element, the kiln's manhole for example.

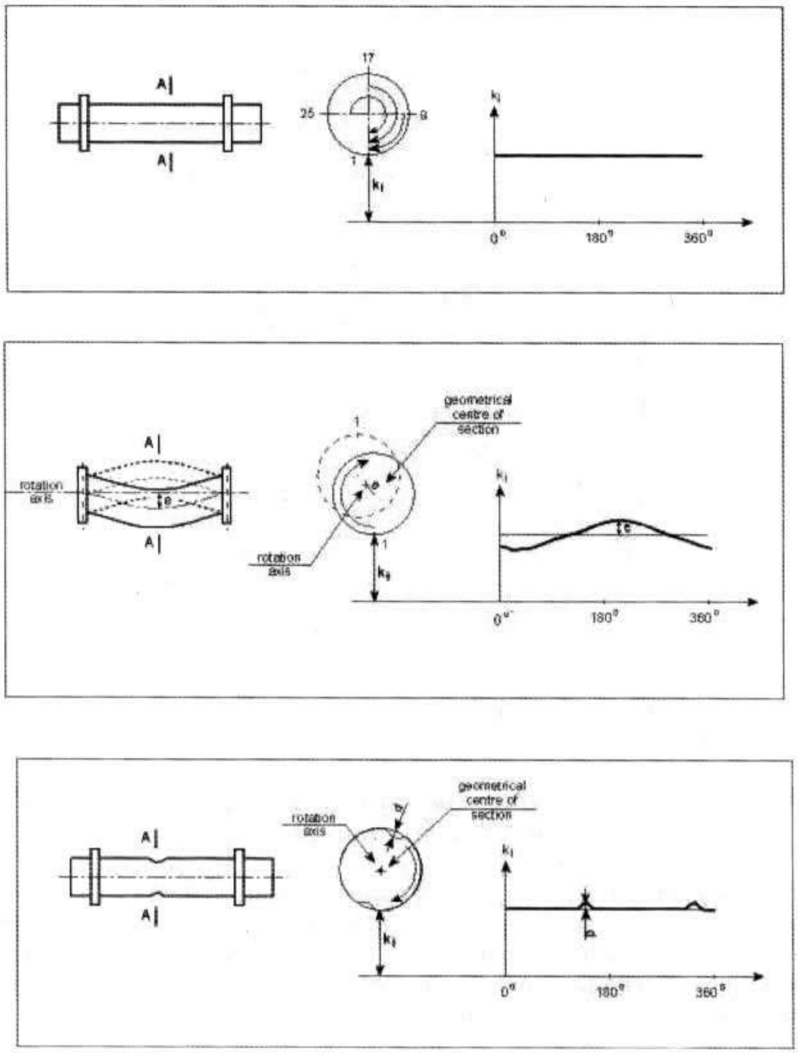

Fig. 3. Geometrical characteristics of axial and radial deformations of the kiln shell

Let us theoretically assume that a newly build kiln is an ideal pipe, its cross-sections are circles, and the centres of these circles lie on one straight line (Fig. 3.1.). If in a given cross-section A-A we would measure the distance to the rotating kiln shell, we would receive identical readings of the distances „k_i"= const, and the graph of these distances in the function of the rotation angle would be a straight line. This would indicate the lack of radial deformations and lack of axial deformations (crank). If the shell would in all sections have the shape of circles, but the centres of these circles would not lie on one straight line, then measuring the distances k_i we would receive a graph, which would be a sinusoid (Fig. 3.2.). This would reflect the existence of eccentricity of the geometrical axis in relation to the rotation axis. If the cross-sections are not circles, but their geometrical centres lie on one straight line, then we will receive the graph shown in Figure 3.3. In reality, shell cross-sections are not circles, and their geometrical centres

do not lie on one straight line, regardless if the kiln is new or operated for a longer period of time. Distinguishing radial deformations from axial deformations (crank) was not easy and for that reason rarely applied in practice, though theoretically solved [2]. The application of computer processing technology with the support of laser scanning allowed to revolutionize methods of identifying dynamic deformations of machines, opening completely new opportunities for assessing, interpreting and modelling geometric transformations of these machines (repairs, modernizations).

3. LINEAR SCANNING AND GEOMETRIC MODELLING OF DEFORMATIONS

Dynamic deformations of rotary machines may successfully be measured with the use of a known and inexpensive geodetic device – the DISTO PRO rangefinder coupled with a computer, i.e. WORKABOUT, which can serve as a simple laser scanner. It should be noted that while a typical geodetic scanner registers distances and angles to motionless objects, the situation here is different as the scanner (DISTO) is motionless but registers distances to a moving object of known angular characteristics (time of one rotation and theoretical geometry).

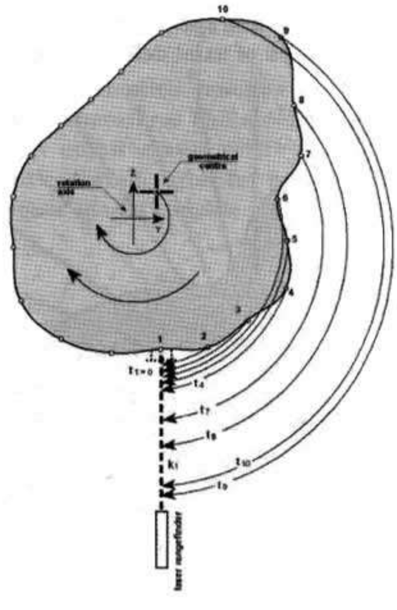

Fig. 4. Scheme of laser scanning of deformations in the kiln's section

Linear scanning [5] allows to quickly obtain mass data, related in this case to one variable – distance „k_i" (Fig.4) in the function of time or rotation angle in relation to the starting point. For one section we will receive a series of data k_i , t_i measured during many rotations of the machine (many supernumerary observations characterizing that section). Such data is presented in the graph (Fig. 5) and reminds raster graphics, which should be vectorized with the help of known programs.

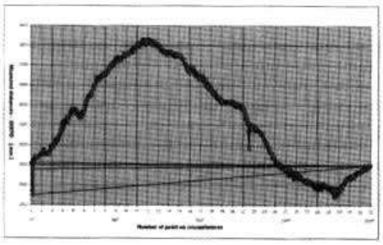

Fig. 5. Scanning results (raster graphics)

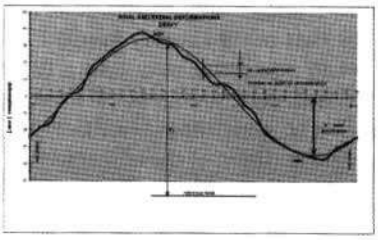

Fig. 6. Geometry modelling - approximation of axial and radial deformations

The next step is the approximation of vectorized data, whereas known is the theoretical shape of the section, which should be a circle, which simplifies the numeric issue. Geometric modelling allows defining the section's axial and radial deformations, which is shown in Figure 6.

For the use of the user (mechanic) a graph of radial deformation is drawn up for each section (Fig. 7) and summary graph of axial deformations for all sections (Fig. 8).

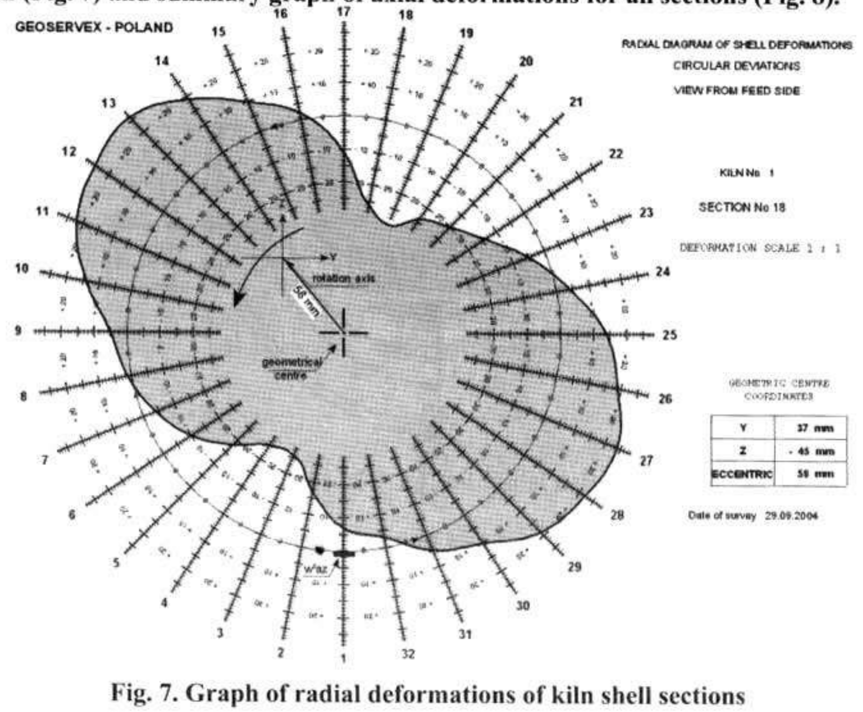

Fig. 7. Graph of radial deformations of kiln shell sections

The kiln shell axial deformations presented in Figure 8 are suppressed (distorted) by the reactions of support rollers. In other words, if the kiln shell would not be supported (if it was suspended in vacuum) its deformations would be much higher.

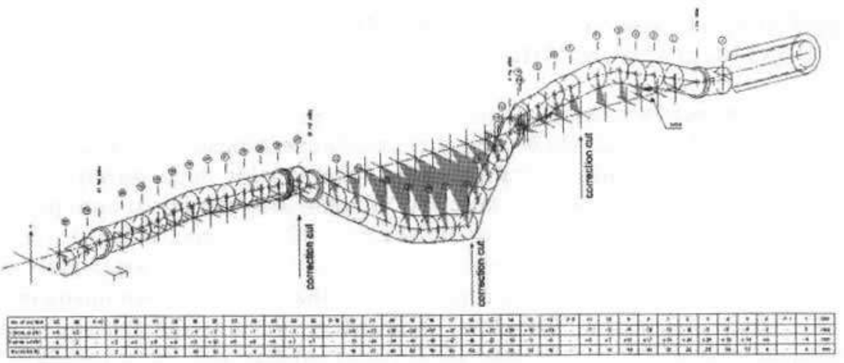

Fig. 8. Summary graph of kiln shell axial deformations

These dynamical deformations must be taken into account and identified in two ways.. The first is the measurement of cyclic inclinations of foundation supports (which does not require comments) and the second is the measurement of changes in the deflections of roller shafts.

The measuring scheme of deflection changes is shown on Figure 9, and the measurement itself is carried out with the help of a digital clock sensor coupled with a computer.

Deflections of roller shafts are the implicit function of the kiln shell's eccentric and other dynamic effects, such as temperature. These deflections are small, in an order of hundredths of a millimetre, but unmistakable verify the deformation. This method is particularly acknowledged and comprehensible for mechanics, additionally verify such data by measurement of engine load (variable amperage in the function of kiln's rotation angle).

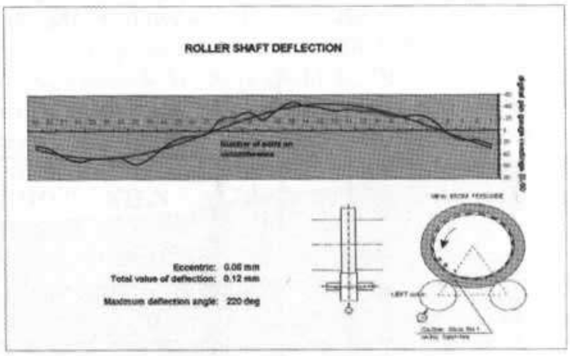

Fig. 9. Scheme of measuring and calculating roller shaft deflections

The presented reasoning may seen somewhat complicated, nevertheless the essence of the issue is exclusively the geometry of the rotating object and its changes caused by dynamic effects like: wear and tear, temperature, rotation movement, etc.

4. INTERPRETATION OF MEASUREMENT RESULTS, FORECASTING AND CONTROLLING REPAIRS OF ROTARY MACHINES

Results of kiln geometry measurements of a kiln during normal operation shown on the drawings (Fig. 7, Fig. 8 & Fig.9) are the basis of technical interpretation and for forecasting repairs. The role of the geodesist may end at this stage, however these days customers expect utmost complex services, therein interpretation and proposal of corrective actions.

The measurement results are always confronted by the user with phenomena occurring in the kiln, like: falling out of firebricks, shell damage, increased amperage of engines, vibrations, etc.

In the situation shown on Figure 8, it can be seen that there is a shell axis inflection point in section 17, and that this section has the highest unallowable radial deformations (Fig. 7) for this kiln. These deformations are the effect of fireproof lining falling off (which has been proven) and have caused a permanent axial deformation. The repair of this type of damage is based on making corrective cuts (cutting the shell) in a few locations and realignment of the shell.
The locations of proposed corrective points are shown on the drawing (Fig. 8) and is nothing else than modelling geometry. What obviously has to be calculated are the parameters of corrective wedges, i.e. the thickness of the wedge and angular orientation.

Figure 10 illustrates actions based on cutting out two wedges and the effects of such action in straightening the kiln's end. The first corrective cut has liquidated lateral run-out of thc ring and shell crank at the support point, the second cut has liquidated axial run-out of the outlet end.

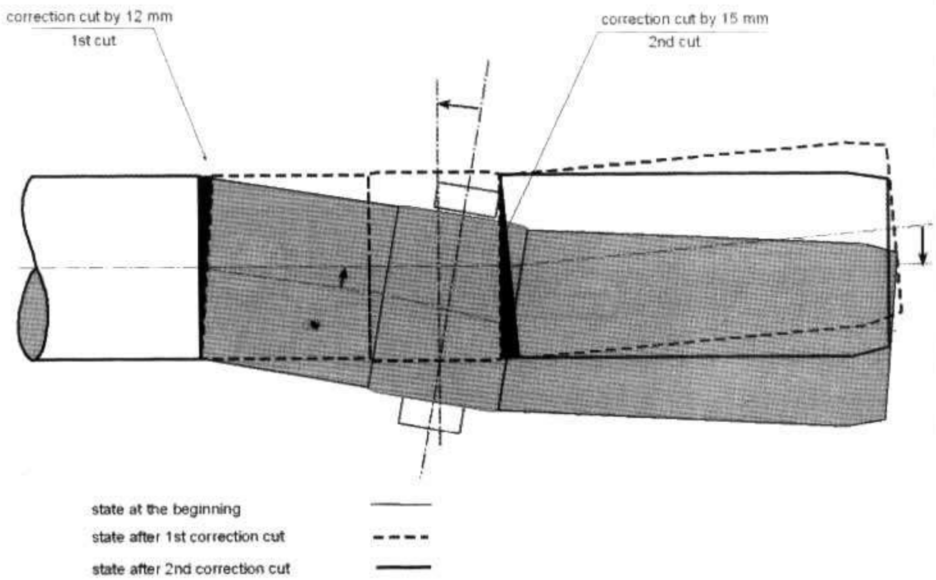

Fig. 10. Scheme of straightening the rotary kiln shell

The effects of straightening the kiln shell are controlled on every stage of the repair process by means of methods referred to in chapter 3 of this publication.

The presented examples are very simple, but provide an outline of the ways and methods of correcting shell deformations of rotary machines.
Calculating parameters of corrective cuts is strictly connected with maintaining supervision over the repair process, controlling the repair and assuming responsibility for the effects of the repair in the part related to geometry. Such activity is connected with certain risk and requires multidisciplinary technological knowledge and experience.
The active participation of the geodesist in interpreting measurement results and in taking decisions connected with the repair is the basis of technical and business success.
Works connected with performing geodetic measurements and calculating deformations of rotary machines are considerably developed, whereas modelling geometry for repair needs requires further theoretic and experimental works. Such research is carried out by geodesists, mechanics and information technology specialists.

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