ROTARY DRUMS

ALIGNMENT ANALYSIS, INSPECTIONS OF THE CARRYING SYSTEMS AND SHELL'S GEOMETRY

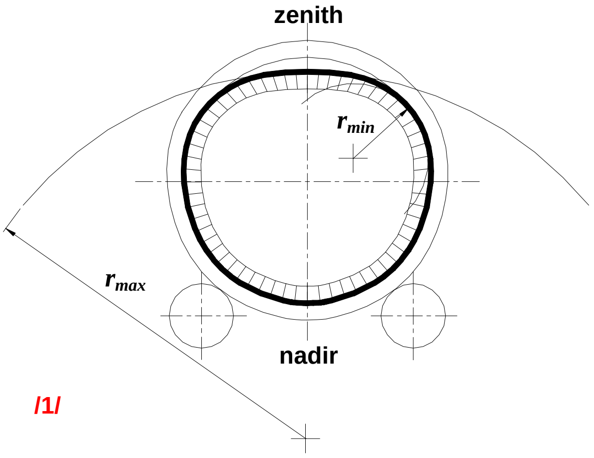
EVALUATION OF THE ROTARY KILN STATE BY MEASUREMENT OF ELASTIC OVALITY OF THE SHELL

INTRODUCTION

The shell is one of the basic components of a typical rotary drum. The shell is a thin-walled steel pipe, and the shell (plate) of the shell is exposed to elastic strain generated independently of the plastic strain. The elastic strain can have the following forms:

- bends of the drum (pipe) axis,
- torsional deflection of the shell (pipe),
- radial deformation of individual sections of the shell (pipe).

The last form of deformation is particularly dangerous, because it has a clearly cyclical nature and the cycle period corresponds to the duration of single rotation of the facility. This cyclic character is detrimental from the point of view of both fatigue durability of the shell material (steel) and the durability of the drum's inside lining (refractory, concrete), and the problems with lining are found mostly in the rotary kiln type facilities.
Radial deformation of cross-section most frequently occurs in the support areas of the shell. As a result of the deadweight of the shell plate and external loads (for example weight of the lining inside the kiln), elastic strain develops on the cross-section of the drum which is trying to adapt shell shape to the stiffening ring which is installed on the shell with some clearance /1/.



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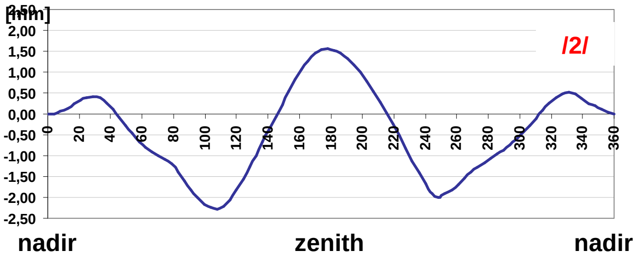
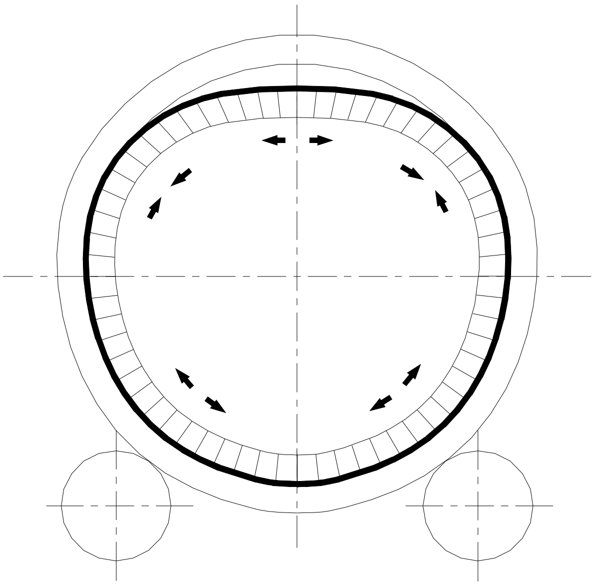
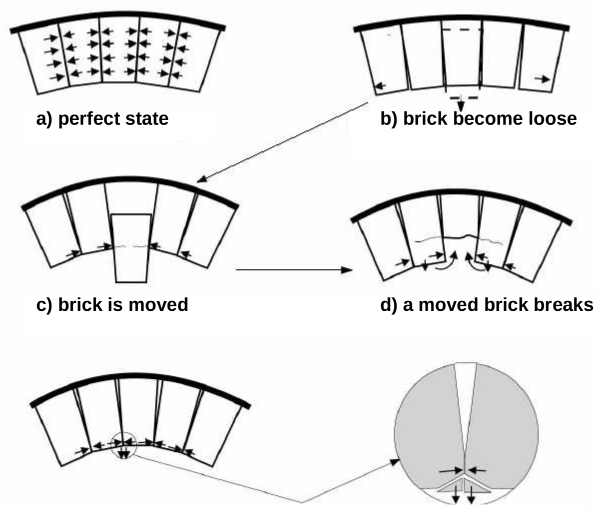
This means that during the rotation of the facility, a point related to the shell surface does not travel along a perfect circle, but along a deformed outline with a different radius of curvature for each circumferential position of this point. Relative changes of the radius can be illustrated as the function of the facility rotation angle /2/. The fact that the radius is changing means that the shell plate undergoes cyclical bending, and the risk of fatigue cracks of the steel drum shell is rising as the amplitude of the changes increases.



/2/

Cyclical changes of the shell plate radius also influence the life of internal lining in the facility. Such influence is best illustrated on the example of wedge-shaped brick. When the drum surface becomes deformed, the lining is subjected to alternating tensioning and compression forces /3/. Such alternating forces can lead to the brick falling out or chipping out. Typical mechanisms of lining degradation are shown in fig. /3/. Figure /3a/ represents a perfect situation, that is when the shell is not deformed and bricks correctly adjoin each other. The distribution of forces in the contact areas between the bricks is then correct. Figure /3b/ shows a situation when the radius of curvature increases excessively, the load on the surface of the bricks decreases, and even the gaps between them become wider. When the shell radius becomes large enough, the bricks may move /3c/ or even fall out totally. When a brick falls out, the adjacent bricks become loose, so in consequence it might lead to an extensive reduction of the lining, thus exposing the steel drum shell to high temperatures. If a loosened brick does not fall out but stays in place /3c/, when the circumferential position of the facility changes then as a result of the reducing radius of curvature it will undergo compression. Such a situation might cause the braking of the moved brick in the cross-section compressed by the edges of adjacent bricks and the chipping out of a large portion of this one. The remaining part will resume its original position, but the lining in this area is already significantly thinner /3d/. In case of smaller radius changes or better fit of the bricks (smaller initial play at installation), the movement of the bricks is limited, but chipping can also be observed. In this latter case, the chipping is caused by micro-losses in the areas of local accumulation of loads – on the edges /3e/.





/3/ e) bricks become tighter and the edges start chipping

To summarize, the phenomenon of cyclic change of the radius of curvature in the shell cross-section has a detrimental impact on both, the life of internal drum lining and on the life of the shell plate. The said strain is unfortunately inevitable, especially because of the frequent and necessary from the design point of view loose fit between the outside shell diameter and the internal support ring diameter.

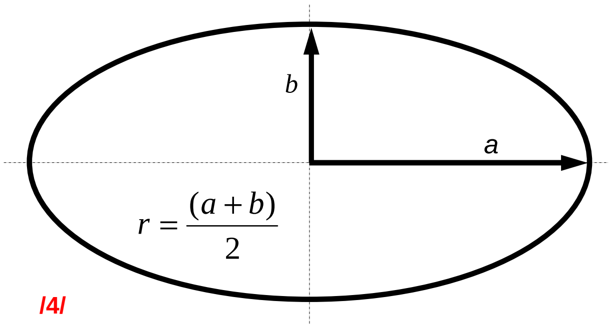
Periodical monitoring and keeping the strain as small as possible is consequently the only method to extend the trouble-free drum operation in this area.

EVALUATION METHOD

The most popular estimator used to evaluate the elastic strain of the shell cross-section is the parameter called the elastic shell ovality ratio ω_0. It has been discovered that a deformed cross-section of the shell can be sufficiently approximated by an ellipse, i.e. a particular case of an oval. Then the degree of flattening (ovality) of an ellipse can be described by the following formula:

$$\omega_0 = \frac{(a-b)}{r}\cdot 100\% = 2\frac{(a-b)}{(a+b)}100\%$$, where:

a – length of ellipse major semi-axis
b – length of ellipse minor semi-axis
r – average ellipse radius /4/ .



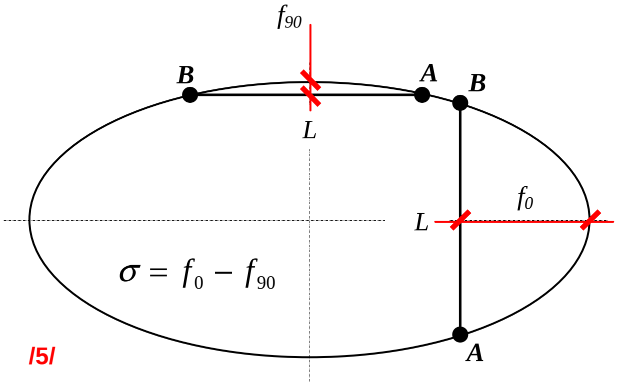
/4/

In practice, in the formula above, *a* and *b* are respectively the largest and the smallest radius of curvature in a given cross-section, that is r_{max} and r_{min} /1/. Then the above formula assumes the following form:

$$\omega_0 = 2\frac{(r_{\max} - r_{\min})}{d}\cdot 100\%$$, where:

d – nominal shell diameter in the analysed cross-section.

The searched value is then the maximum difference of the radiuses, i.e. the maximum range of the shell radius variation.
Apparently, when the facility is rotating, it is much easier to determine the relative variation of the radiuses than their absolute values. It can be done indirectly by measuring the difference of distance between the cross section outline and the chord of constant length *L* – which connects two selected points *A* and *B* located on the surface of the examined cross section /5/.



Then, in a typical ellipse the minimum and maximum values of the measured distances are for the vertical and horizontal position of the chord, respectively. The scheme of this measurement method is shown on figure /5/.

For this measurement method, the elastic shell ovality ratio is calculated according to the following simplified formula:

$$\omega_0 = \frac{4}{3} d\sigma \cdot 100\% \,.$$

This formula is an approximated identity in relation to the previous formula based on the maximum and minimum radius.

SHELLTESTER
– principle of operation

The embodiment of the described method is the instrument called the Shelltester. It consists of an one-metre long beam with magnetic feet on its ends to install the beam on the drum shell, and an electronic sensor located in the middle of the beam length which measures the relative change of the shell curvature during the rotation of the facility **/6/**.


/6/

This instrument, designed, manufactured and implemented by the Eurokiln engineers, allows automated data collection and storage in the instrument's memory with simultaneous wireless transmission of results to the computer, where further analysis are processing **/7/**, **/8/**.


/7/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ROUTINE TESTS SCOPE

The routine tests scope includes the measurements on all drum stages – in each case on two cross-sections of the shell, the inlet and outlet, just before and just behind the ring. In each cross-section, the data is obtained from three places on the circumference (A, B and C) – equally spaced every 120^0.
This standard test scope may vary, depending on the limitations of the instrument installation in a given area of the shell and/or conscious decisions of the service recipient - consulted with the engineer who performs the measurements.
As a standard, the following parameters are also determined:

- shell and ring temperature,
- circumferential migration of the ring relative to the stage section of the shell,
- under-ring clearance.

This data is always strongly correlated with the shell elastic ovality and is a necessary supplement of the analysis of the drum shell deformation.

DIAGNOSTIC POSSIBILITIES

The basic parameter obtained during the measurements with the Shelltester is the elastic shell ovality ratio. Comparing the measured value with the allowable limits and comparing the results from individual stages of the rotary drum gives a basic view of the occurrence risk of drum shell fatigue cracks and/or forecast life of the internal lining (if any).
Determining the allowable limits is not easy to do, particularly in the context of the fatigue durability of the shell steel plate. Without detailed strength calculations, it is difficult to determine to which extent the stress in the shell is generated by the bending of the geometrical axis of the shell (tube bending) and to which extent by torsional deflection. Consequently, it is difficult to determine which level of additional residual stresses can be allowed due to the deformation of the once cross section profile – the ovality. Nonetheless, by making some assumptions,

one can attempt to formulate general standards which enable estimating of such allowable limits.

If in simplicity we assume that the allowable cyclically changing stresses (alternate pulsating) for typical steel grades is 40MPa, and that 50% of this total stress is from the pipe axis bending and 50% from the deformation of the shell cross section, and the torsional stresses and negligibly low, that we can infer that the elastic ovality should not exceed the values for which the corresponding stresses reach 20MPa.

For this limit, a range of allowable ovality values can be determined as a function of the internal shell diameter **/9/**, but please note that the upper limit for such range of allowable values corresponds to the minimum typical thicknesses of the stage sections of the shell, and the lower - to the maximum ones. The typical shell thicknesses for individual diameters are given in brackets **/9/**.

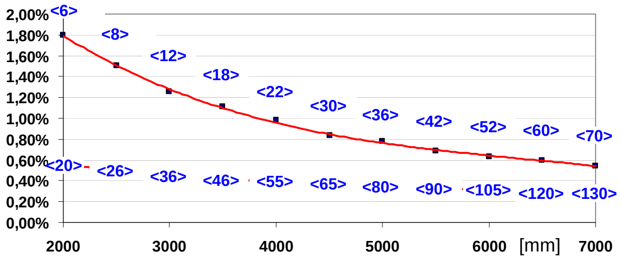

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Diagram **/9/** shows that for example for the diameter 5000mm, the ovality should not exceed 0.35% - for the shell thickness 80mm and 0.80% - for the shell thickness 36mm.

In relation to the internal shell lining, the allowable deformation limits shall be specified by the lining manufacturer and/or supplier. Very roughly, it can be assumed that the ovality (expressed in percent) shall not exceed one tenth of the shell diameter part (expressed in metres). For example, for the 3600mm diameter, the approximate allowable elastic shell ovality ratio can be 0.36% (the result of the calculation: 0.1 x 3.6m).

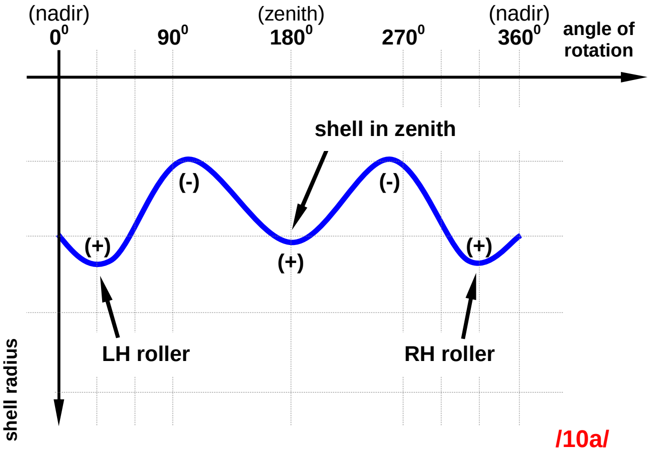
ANALYSIS OF THE DIAGRAMS

Additional useful information can be obtained from the analysis of the shape of curves in the diagrams which illustrate the changes of the cross section radius of curvature as a function of the angle of drum rotation. The diagrams provide information about possible causes of increased ovality.

In case of routine tests scope, the measurements on a single stage are performed in 6 locations of the Shelltester (2 sections x 3 positions A, B and C). From each of six measurements we receive a separate curve. Each curve individually and their mutual comparison are a very valuable sources of additional diagnostic information.

If there was not any shell deformation, the curve (in the Cartesian system of coordinates) will be a straight line (meaning absence of indications from the sensor).

Such a situation however never happens, because the deformation is always there and even if the shell is tightly fitted in the ring, the equipment recreates the deformation corresponding to the change of its radius. These are of course very small, but in the majority of rotary drums clearly visible and representing the characteristic points on the circumference of the facility. Such points, which correspond to the extremes of the shell radius of curvature (also of the ring in this case) are shown in figure **/10a/**.



/10a/

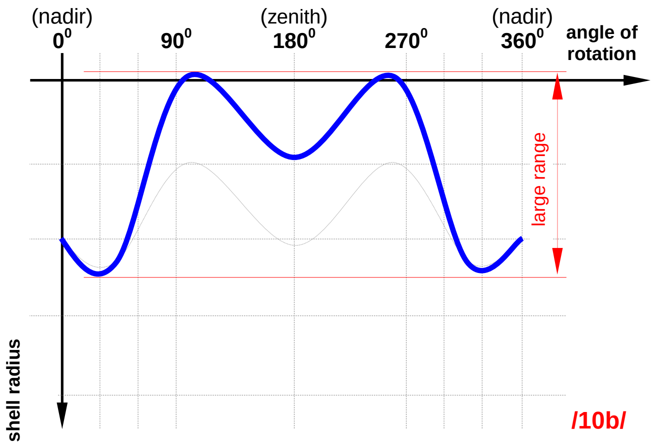
The curve shown this figure clearly indicates that the shell (ring) is straightening (the radius of curvature is increasing) in the location of contact with the rollers and in the zenith position.

Lets us assume that the shell behaviour according to figure **/10a/** is correct. However, this curve is not always perfect. The classic deviations from the standard are presented on the figures **/10b/** - **/10h/**. The figures represent the changes of the curve shape depending on the type of defect present in the facility – stage. These are for example:

- excessive load of the ring and/or under-dimensioning of the ring **/10b/**,
- excessive under-ring clearance **/10c/**,
- insufficient load of the ring and/or over-dimensioning of the ring **/10d/**,
- crank of the shell geometrical axis **/10e/**,
- misalignment of the support system axis – in the horizontal plate **/10f/**,
- shell crack **/10g/**,
- incorrect inclination of the rollers (and the ring) relative to the local inclination of the rotation axis **/10h/**.

Of course, in actual conditions such defects are present in a larger or smaller amount and extent, and the resulting curves do not always have such unambiguous character.

Despite possible difficulties, the curves however provide an additional opportunity for a general evaluation of the technical condition of a rotary drum, and in case when the analysis includes the strength calculations, the detected defects can be even evaluated in quantitative terms.



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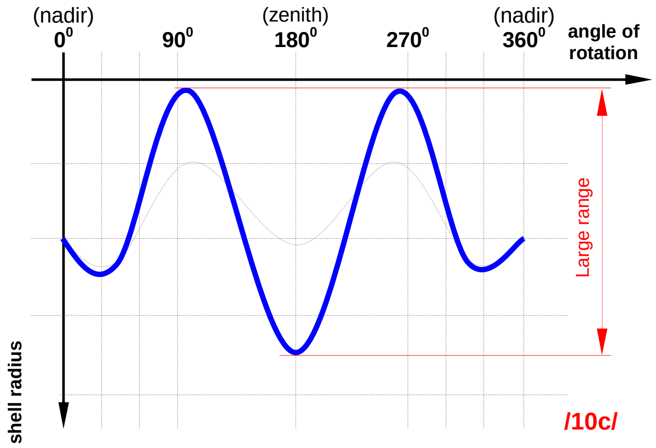

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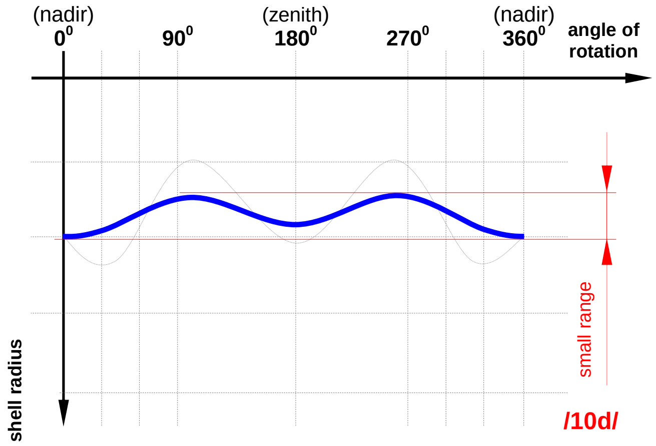

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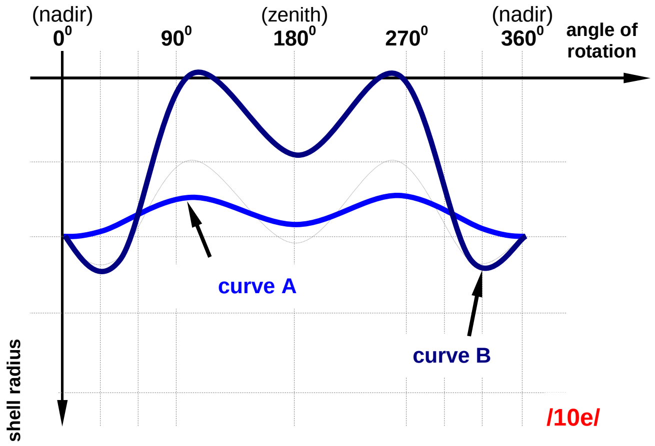
MEASUREMENT CONDITIONS

- rotational speed of the facility: 0.5 ÷ 3.5 rpm (recommended 2.5 rpm),
- maximum shell temperature: < 350°C,
- ambient temperature: 0 ÷ 40°C,
- safe access to the measured cross sections (it may require temporary object's stoppaging).



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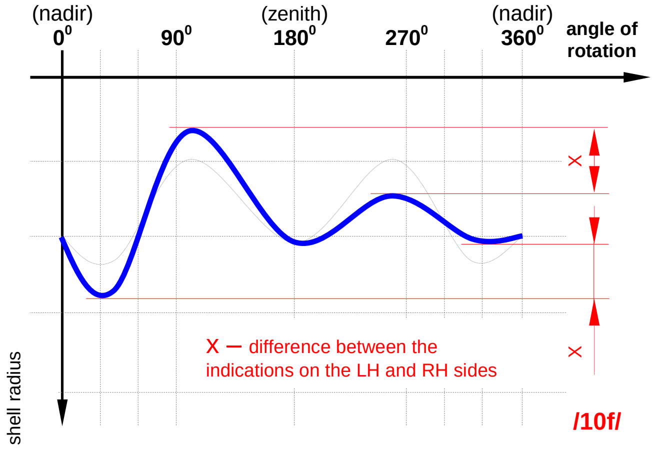

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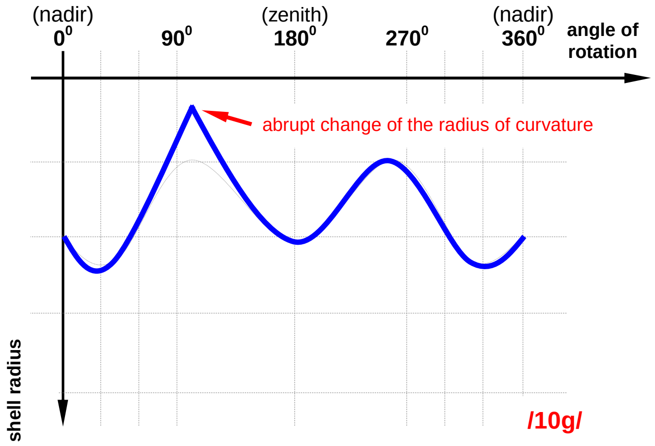

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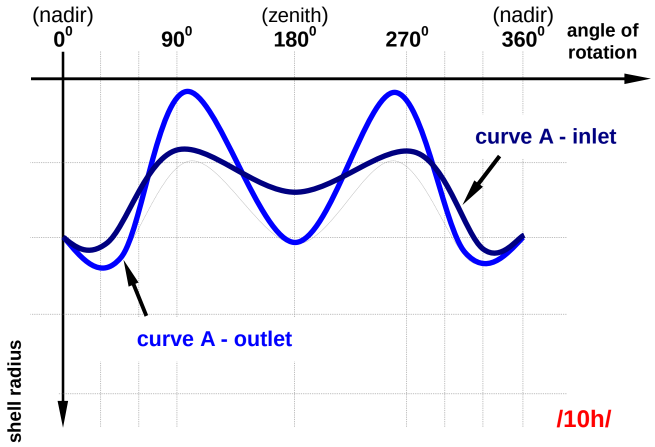

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