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The measurements of the zirconium tubes parameters in the RBMK reactors

L.Mažeika, R.Šliteris, A. Voleišis, K.Kundrotas, V.Kiseliov*

Prof.K.Baršauskas Ultrasound Research Center,

Kaunas University of Technology

**Metal Inspection Department, Ignalina Nuclear Power Plant*

The dimensions of the zirconium tubes - diameters and wall thickness are the most important parameters for safe operation of the RBMK type reactors. Their values usually changes during operation of the unit, so they must be measured periodically. The developed measurement system [1] enables precise measurements along the tube with the rotating transducer head. Carrying out the measurements *in situ* some problems were met. The transportation unit of the transducer head enables the center positioning with accuracy only within 2.0mm. The projection of the head center path along 8m of the tube is presented in Fig.1 (image from top of the tube).

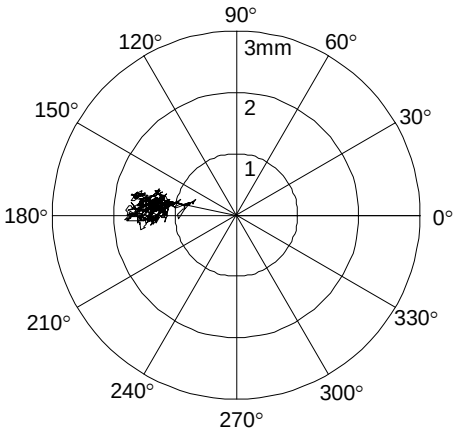

Fig.1. **Projection of the head center path along the tube. The data are taken from *in situ* measurements**

As seen, the transducer head in the large part of the path is located approximately 1.5 0.5mm from the center of the tube. If the transducer head is rotated the dynamic error occurs. Origin of the dynamic error can be explained by Fig.2.

When both channels are working in turn, the measurement in the second channel is performed in the direction not opposite to the direction of the first channel, but with at angle $_{op}$. The angle $_{op}$ depends on the head rotation speed and the duration of the measurement in the first channel. If the measuring head is positioned in the center of the tube a small error can occur only due to ellipsisity of the tube's (Fig.2a). In the case when the measuring head is displaced at some distance d_{ex} from tube center, the significant error $_{ex}$ can occur (Fig.2b). This error depends on the rotation speed also. These errors restrict the rotation speed during the measurements and the total time of the inspection as well.

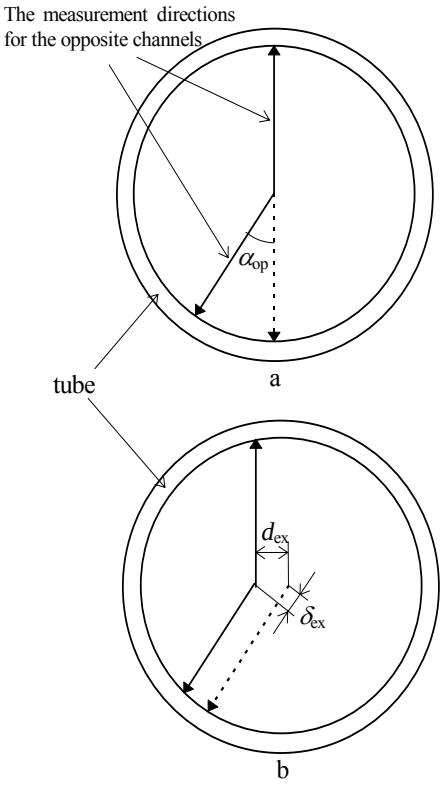

Fig.2. **Explanation of dynamic errors**

The duration of one tube inspection was in the range of 50-80min. Such a time is not acceptable when it is necessary to perform inspection over a few hundreds channels during the maintenance.

From another hand, the actual parameters necessary for analysis are the maximal and the minimal values of the diameters and the wall thickness of a tube. So, it is possible to measure the diameters in some directions and to determine the maximal and the minimal values. The required number of measurement directions can be determined from Fig.3, in which the differences between the maximum radius d_{max} and the measured distance d when the angle between them is $_{max}$- , for the various cases of ellipsisity d_{max}-d_{min} are presented. It is seen that the maximal angle between the measured diameter and the maximal diameter, e.g. the worst case, must be less than 27 for error should be less than 0.1mm (dashed line). This is achievable in the case of 8 measurement channels. In this case 4 diameters are measured at 4 different directions. Then the case maximal angle $_{max}$- $_{m}$ can be

22.5□. Additionally, the measurement error can be reduced using approximation.

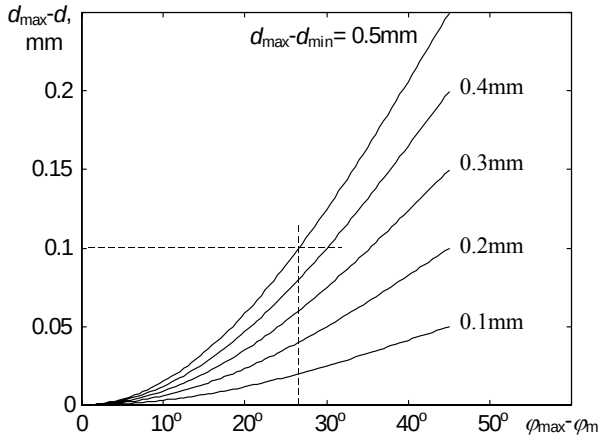

Fig.3. **The differences between the maximal diameter d_{max} and measured diameter d when the angle between them is $_{max}$- , for the various cases of the ellipsisity of the tube d_{max}-d_{min}.**

To evaluate the error in such an approach the simulation was performed using the Monte-Carlo method. There were simulated measurements in 4 direction (diameters) for the some case of ellipsisity □d_k=d_{max}-d_{min} :

$$d_{ijk} = \sqrt{r_x^2 + r_y^2}\,\Delta_m,$$

where

$$r_x = d\cos((i-1)\cdot 45^\circ + \varphi_0);$$

$$r_y = d\sin((i-1)\cdot 45^\circ + \varphi_0);$$

i=1..4 is the number of directions, □$_0$ is the orientation angle of the maximal diameter of the ellipse in respect to x axis, generated randomly with uniform distribution in the range 0□-22.5□, □$_m$ is the measurement error with the normal distribution and □=0.02 , □d_k=0, 0.025, ..., 0.5mm; j=1..N; N - is the number of the samples (set consisting of 4 diameters, k=1,2,3,4); k - 1..21 is the number of the analyzed ellipsisity.

The minimal min(d_{ijk}) and the maximal max(d_{ijk}) diameters were selected from each sample and mean value of the errors were calculated:

$$\overline{\Delta_{\min_k}} = \sum_{j=1}^{N}\left(\min(d_{ijk}) - d_{\min_k}\right),$$

$$\overline{\Delta_{\max_k}} = \sum_{j=1}^{N}\left(\max(d_{ijk}) - d_{\max_k}\right).$$

Additionally, each data set k was approximated by the ellipse and the mean value of the errors were calculated:

$$\overline{\Delta'_{\min_k}} = \sum_{j=1}^{N}\left(d'_{\min_k} - d_{\min_k}\right),$$

$$\overline{\Delta'_{\max_k}} = \sum_{j=1}^{N}\left(d'_{\max_k} - d_{\max_k}\right),$$

where $d'_{\min_k}$ and $d'_{\max_k}$ are minimal and maximal diameters of the approximated ellipsis.

The results of the simulation are presented in Fig.4. The measurements can be performed in both cases with error less then required (0.1mm), especially a small error is observed if the approximation is used. The larger error (□0.03mm)in the region of small ellipsisity can be explained, that in the simulation the relatively big measurement errors, up to 0.1mm, were assumed. In this case, the randomly generated and selected maximal and minimal values in the samples have some difference between them. So the probability that measurement result will show a circle is very low.

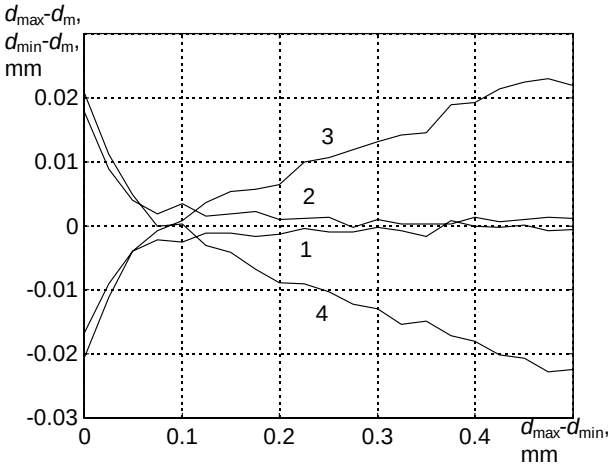

Fig.4. **The mean values of the errors if the approximation is used(1,2) and if not used (3,4). 1,3 - for minimal diameter, 2,4 - maximal diameters.**

The developed equipment was approved in the Ignalina NPP [2]. About 150 channels where measured during maintenance periods in the 1996. The total time necessary to perform measurements on one channel is about 2min and with preparing works takes about 10min.

Reference

1. **R.Kažys, L.Mažeika, R.Šliteris, A.Vladišauskas, A.Voleišis, K.Kundrotas.** Ultrasonic measurement of zirconium tubes used in channel type nuclear reactors, NDT&E International, vol.29, No.1, pp.37-49, 1996
2. Technical report of 'Express Zirconium Tube Meter', KTU, Kaunas, 1996, 60p.

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Cirkonio vamzdžių parametrų matavimas RBMK reaktoriuose

Reziumė

Išanalizuotos cirkonio vamzdžių vidinio ir išorinio diametrų ir sienelių storio matavimo paklaidos, atsirandančios dėl matavimo galvutės pozicionavimo netikslumo. Pateiktos priežastys ribojančios matavimo greičio padidinimą. Pasiūlyti paklaidų eliminavimo bei matavimo greičio padidinimo būdai.