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To cite this article: O N Kuzyakov et al 2018 J. Phys.: Conf. Ser. 944 012072

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Electronic-projecting Moire method applying CBR-technology

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Abstract. Electronic-projecting method based on Moire effect for examining surface topology is suggested. Conditions of forming Moire fringes and their parameters’ dependence on reference parameters of object and virtual grids are analyzed. Control system structure and decision-making subsystem are elaborated. Subsystem execution includes CBR-technology, based on applying case base. The approach related to analysing and forming decision for each separate local area with consequent formation of common topology map is applied.

Keywords – surface topology, Moire method, system, control, virtual grid, case, algorithm, decision-making.

1. Introduction
Statistical analysis of emergency causes on oil transport and storage facilities showed that the average percentage of accidents caused by a range of defects related to manufacturing and constructing is 32%; percentage of accidents caused by corrosion is 28%; percentage of accidents caused by external factors is 31%. External factors include influence of anthropogenic processes, occasional damage by external organizations and influence of ongoing physical-geological processes of various kinds.

Meanwhile, visual and measurement ways of examining are implemented at almost all stages of life cycle of definite components, part elements and items.

Specificities of particular objects diagnosis are reflected in specialized documents: “The rules of structuring and safe maintenance” and construction codes and regulations.

According to requirements listed in guidance documents, visual and measurement examine is executed at both internal and external sides of the items, which gets significantly complicated because of lack of access to inside cavities of the items.

Technical endoscopic systems (endoscopes, video-endoscope, etc.) or self-moving robotized systems for diagnosing extended objects of large diameter of 1.5 meters and more (for instance, oil intra-field and transport pipelines) are used as examining means during technical diagnosis in oil and gas companies.

Further development and improvement are obtained nowadays by methods of examining technical state of oil and gas industrial facilities. Such methods allow to increase remaining resource of these facilities’ elements and constructions. Ultrasonic, electromagnetic, acoustic, optical and other types of methods are highly spread. One of the perspective and not fully studied method is based on the usage of Moire effect [1-4]. It means formation of Moire pattern of dark and light fringes by overlay of two grids. The pattern may serve as a qualitative and quantitative feature of object surface deformational process.

The important tasks ahead in diagnosing oil and gas industrial facilities are remote visual examining of technical state of items, evaluation of condition of surfaces and welded joints, build quality. Visual monitoring necessity is regulated by guidance documents of Russian Federal Service for Ecological, Technical and Atomic Supervision (Rostehnadzor). One of these documents is...
“Instruction on visual and measurement control” (Guidance Document 03-606-03), which establishes the order of implementing visual and measurement control of main material and welded joints during manufacturing, building, assembling, repair, reconstruction, exploitation, technical diagnosing of technical device and buildings, which are used and exploited at hazardous production facilities controlled by Rostehnadzor.

2. Methods

Differential electronic-projecting method of measuring the form of object surface is available. Its essence is projecting computer-synthesized sample grid containing alternating dark and light fringes, scanning grid by digital camera and comparing picture obtained to sample grid, which results in defining surface parameters in each point [1].

Theoretical prerequisites for elaborating method mentioned are listed below. Forming Moire fringes (phenomenon of mechanical interference) is possible in the following cases:

- overlay of two grids of parallel fringes with equal step values \( \alpha \), angle between the grids is \( \varphi \);
- overlay of two grids with unequal step values \( (\alpha_1 \text{ and } \alpha_2) \), zero angle between the grids;
- overlay of two grids with unequal step values \( (\alpha_1 \text{ and } \alpha_2) \), angle between the grids is \( \varphi \) (presented at figure 1).

![Figure 1. Forming Moire fringes](image)

In case of overlay of two grids with unequal step values \( (\alpha_1 \text{ and } \alpha_2 \text{ respectively}) \) and angles \( \varphi_1 \) and \( \varphi_2 \) between the grids and the \( x \)-axis, Moire fringes are formed with step \( S \) and angle \( \beta \) between the fringes and the \( x \)-axis.

Angle \( \beta \) is defined as follows:

\[
\tan \beta = \frac{\alpha_1 \cdot \sin \varphi_2 - \alpha_2 \cdot \cos \varphi_1}{\alpha_1 \cdot \cos \varphi_2 - \alpha_2 \cdot \sin \varphi_1},
\]

where \( \alpha_1, \alpha_2 \) are step values of the grids overlaid.

It’s obvious that \( \tan \beta \) does not depend on distances \( c_1 \) and \( c_2 \) between the origin coordinate and the first fringe of respective grid. Thus, after a parallel displacement of one or both systems of lines the angle \( \beta \) does not change. The turn of Moire fringes may be obtained only by a relative turn of overlaid systems of lines.

\( X \)-intercept of Moire fringe is defined as:

\[
b = \frac{\alpha_1 \cdot \alpha_2 + c_2 \cdot \alpha_1 - c_1 \cdot \alpha_2}{\alpha_1 \cdot \cos \varphi_2 - \alpha_2 \cdot \sin \varphi_1},
\]

Distance between the Moire fringe and the origin of coordinates equals
\[ l = b \cos \beta = \frac{b}{\sqrt{1 + \tan^2 \beta}} \]

Fringes step \( S \) is defined upon the formula:

\[ S = \frac{\alpha_1 \alpha_2}{\sqrt{\alpha_1^2 + \alpha_2^2 - 2 \alpha_1 \alpha_2 \cos (\varphi_1 - \varphi_2)}} \]

i.e. distances between all nearby Moire fringes are equal.

And if \( \Delta \varphi = \varphi_1 - \varphi_2 = 0 \), the Moire fringes step equals

\[ S = \frac{\alpha_1 \alpha_2}{\alpha_1 - \alpha_2}, \]

i.e. the less \( \alpha_1 - \alpha_2 \) is, the bigger Moire fringes step is. That is why it is desirable to decrease step value \( S \) for increasing examining accuracy. In case there is an angle between the grids \( (\Delta \varphi \neq 0) \), increasing this angle will result in decreasing step value \( S \). Thus, by programmatically varying parameters \( \alpha_1, \alpha_2, \Delta \varphi \) it is possible to increase the resolution ability of examining method.

3. Results and discussion

Analytical research showed that measurement accuracy is under influence of the following parameters:

- step values \( \alpha_1, \alpha_2 \) of grids projected;
- tilt angles \( \varphi_1, \varphi_2 \) of grids projected.

Variation of Moire fringes step value is presented at diagrams (figure 2) in case of period (step) value of the first grid hold fixed \( \alpha_1 = 0.1 \) cm and step value of the second grid increasing \( \alpha_2 = (0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1.0) \) cm. \( \varphi_2 = (\varphi_1 - \varphi_2) \) is varying from \(-90^\circ\) to \(90^\circ\).

At a more detailed examination of inclined line, it presents a gradual line, which consequently means that increasing grid step value will influence inaccuracy. That is why, for decreasing inaccuracy it is crucial to determine the most optimal angle \( \varphi = (\varphi_1 - \varphi_2) \) and therefore select \( \varphi_1 \) and \( \varphi_2 \) values.

Diagrams at figure 2 show that at angle \( \varphi \) hold fixed, Moire fringes step value \( S \) may be alternated by alternating the second grid step value. Angles \( \varphi = 15^\circ \) and \(20^\circ\) are the more efficient, because they allow step value \( S \) to alternate significantly while alternating step value \( \alpha_2 \).

In case \( \varphi = 15^\circ \) it is applicable to have the second grid step value \( \alpha_2 = 0.2 \) cm and \( \alpha_2 = 0.7 \) cm, so that \( S \) equals respectively \( 0.187 \) cm and \( 0.116 \) cm.

In case \( \varphi = 20^\circ \) and \( \alpha_2 = 0.2 \) cm and \( \alpha_2 = 0.7 \) cm, \( S \) equals respectively \( 0.18 \) cm and \( 0.115 \) cm. Thus, at a small angle \( \varphi = 15^\circ..20^\circ \) Moire fringes step value for similar grids alternates insignificantly.

Computational experiment on revealing dependency of Moire fringes step value at an angle hold fixed allows to make a conclusion on Moire fringes step value \( S \) decreasing with the increasing of the second grid step value \( \alpha_2 \).

Analyze undertaken showed that considering \( \alpha_1 = 0.1 \) cm, the most desirable parameters are \( \alpha_2 = (0.2 \) cm; \( 0.7 \) cm), \( \varphi = (15^\circ; 20^\circ) \), accordingly \( \varphi_1 \) and \( \varphi_2 \) values are to be found. In this case, \( \varphi_2 \) is defined as \( \varphi_2 = \varphi_1 - \varphi_2 \), meanwhile it is recommended that \( \varphi = (15^\circ; 20^\circ) \). Besides, Moire fringes step value \( S \) dependency on natural brightness level \( \Phi \) is proved experimentally. If brightness alternates within the range \( 16\times10^4\div175\times10^4 \) Lux, the number of pixels in the image decreases from 9926 to 5256.

Therefore, image quality decreases from 100% \((16\times10^4 \) Lux\)) to 52% \((175\times10^4 \) Lux\)). For minimizing this inaccuracy, it is recommended to operate at minimal brightness or to use projecting facilities with greater level of luminous flux. For implementing method described it is offered it improve system previously elaborated in order to minimize complexity of processing collected data at low resulting accuracy.
For achieving this goal, it is necessary to elaborate system for defining surface topology, which uses up-to-date, high-accurate contactless methods and ways of intellectual data processing. Structure of such system is presented at figure 3.

The system consists of processor module with downloaded program implementing electronic-projecting Moire approach for defining surface topology; read-only memory storing programs and data, including case-base; digital projector and digital video-camera for implementing projecting sample grid and taking picture of grid projected.

System execution algorithm is presented at figure 4.
Figure 4. System execution algorithm

Setting parameters and forming grid to be projected on object surface are implemented at the first stage. A picture of grid projected taken is entered to video RAM of processor module thereafter by using digital video camera. Preliminary processing and analyzing image taken allows either to continue processing or redo projecting grid. If image taken is sufficient, processing of this image is performed according to a precise program, which disposes of shades and increases contrast. Virtual grid generation in processor module, formation and visualization of Moire pattern on the display of processor module are implemented at the next stage. Further mathematical processing of image taken is to define coordinates of Moire fringes centers, develop matrix of heights for each local area of object examined. The next stage is precedent (case) search on the basis of Cased-based reasoning (CBR) technology [5-13], i.e. search of case from case base according to similarity criteria set. CBR allows solving task by using solutions already known, i.e. adapting solution of already known task considering collected experience to match current state.
If case base adjustment or extra examining hypothesis is required, algorithmic loop is performed all over again. Decision-making block execution is presented at figure 5 in more detail.

**Figure 5.** Functioning algorithm of intellectual decision-support subsystem

At the first stage scanning accuracy is set, and case \( P \) is formed by using case building model stored in knowledge base as a set of rules. Case \( P \) defines a problematic situation in a formalized language. Case formed in this way enters block, which performs comparison and definition of its similarity degree to case \( C \) retrieved from base storing ready cases. Search of case is performed on the basis of nearest neighbor method. Metric \( d_{CP} \) serves as alignment criteria; \( d_{CP} \) is defined by formula of Euclidean distance (distance between two points):

\[
d_{CP} = \sqrt{\sum_{i=1}^{n} (x_i^C - x_i^P)^2},
\]

where \( n \) is a number of features compared, \( x_i^C \) is value of \( i \)-th feature of case \( C \), \( x_i^P \) is value of \( i \)-th feature of case \( P \). If \( d_{CP} \) value meets set alignment criteria, then solution is formed. Otherwise, adjustment of case retrieved is implemented in accordance with set scanning parameters. Case adjusted is wrote thereafter into case base and solution is formed.

It is noteworthy that processing of video taken requires consideration of zoom coefficient \( K_z \), which may be defined by a program on the basis of sample (reference) and projected (object) grids comparison. Automatic adjustment of fringes step value and width, which considers accuracy value, angle between optical axes of projecting and taking image subsystem components, allows to increase level of confident identification of data collected.
In the long run, it is possible to increase complexity of cases structure and to change algorithm of their retrieval.

Final stage is program integrity of separated local areas and forming common topology map, which makes up a base of defect nature over the entire surface area.

4. Conclusion

To sum up, using electronic-projecting Moire method including CBR technology allows to obtain high-quality surface topology map considering experience (data) previously collected, and widen base of cases, which describe separate local areas of examined surface as well.

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