Elaborating Surface Topology Control System for Technological Objects

O N Kuzyakov, M A Andreeva and U V Lapteva
Industrial University of Tyumen, 70 Melnikayte Str., 227, Tyumen 625027, Russia
E-mail: onkuzyakov@mail.ru

Abstract. The basics of elaborating topology control system for technological objects are presented in the paper. The main part of the system is measuring block with laser and ultrasonic distance measuring devices, which enables to have technological object scanned with accuracy demanded. The algorithm of scanning technological object, in particular, vertical storage tank, is presented as well. The system elaborated is an integral part of intellectual decision-support system.

1. Introduction
Currently, elaborating surface topology control system for technological objects represents a task. The features required are high sensibility, high level of automatization and universality (ability to scan a range of technological objects). In particular, such system is to be exploited during scanning vertical storage tanks (VST) in order to identify defects (splits, dents, etc.).

According to [17, 18], the periodicity of full VST survey should be 8-10 years. Such survey includes internal side condition control [19], which is held with the use of manual different technologies. However, such technologies involve high labor intensity and high degree of risk for maintenance engineers.

The execution of a range of automated devices is based on a photometrical method with the use of so-called Moire effect [1-6, 20-22], obtained by projecting a grid of alternating light and dark bands on the object investigated. It is followed by the imposition of image of this grid received to another grid located at some distance from the object and rotated by a known angle. The Moire pattern formed this way provides with information about the object topology. The disadvantage of this method is high complexity of processing data and low resulting accuracy.

Thus, the task is to elaborate a surface topology control system for technological objects, which uses up-to-date high-sensible non-contact methods. The device measuring distance or linear displacement is to be the main element of the system. Signal sent by such device allows identifying local defects of the surface of technological object or surface defects in general.

2. System elaboration
An analysis of measuring devices undertaken showed the laser and ultrasound devices are the mostly commonly used. Distance measurement using these devices involves triangulation or time-of-flight method. Laser measuring devices are more sensible than ultrasound ones. Laser devices measurement accuracy is 0.1 mm and the maximum distance to the object is about hundreds of meters, ultrasound has 1 mm and 20 m for the same features.
A surface topology control system for technological objects (VST in particular) was elaborated according to the analysis mentioned. The measuring devices of the system are ultrasound and laser distance measuring devices. The structure of the system is presented at figure 1.

A measuring block 1 consists of a scanning block 2, which, in turn, has ultrasound and laser distance measuring devices, and microcontroller 3. The measuring block 1 is firmly attached to the mechanism 4 by the metal telescopic bar-bell 5. The mechanism 4 includes two stepper motors, the first of which rotates the bar-bell 5 on its axis and the second displaces it in vertical direction, and stepper motors control block connected to the computer (PC) 6. A measuring block 1 is connected to the PC 6 on the wireless network interface.

![Figure 1. System structure](image)

The system executes as follows: the mechanism 4 displaces the telescopic bar-bell 5 so that the measuring block 1 is level with the highest scanning level. After that the mechanism 4 rotates the bar-bell 5 on its axis in 360 degrees, and the measuring block 1 is switched on from the beginning of the bar-bell 5 rotation. During rotation, the scanning block 2 measures the distance to the VST 7 surface point. The data flows from the scanning block 2 to the microcontroller 3 where data is initially processed according to the program downloaded do the microcontroller 3. The data processed flows from the microcontroller 3 to the PC 6 by means of wireless network interface. The PC 6 executes the major amount of processing and systematizing work according to the program downloaded to it.

After the bar-bell 5 has come full circle, the second stepper motor displaces it a numerous steps down in vertical direction. Then the bar-bell 5 rotates on its axis again and data from the scanning block 2 flows to the microcontroller 3 and finally to the PC 6.

To determine the surface points to which the distance is going to be measured during scanning, the scanning map is formed considering physical parameters of technological object. In case of VST internal side surface the scanning map looks as at figure 2.

The scanning map is formed as follows: horizontal strings, which represent horizontal scanning levels, are put on the side surface model of VST whereby the highest scanning level matches the top border of the model as shown at figure 2. The model height $H$ equals VST height and its length is $2\pi R$ where $R$ is VST radius. The distance between the horizontal scanning levels $v$ equals the value of vertical scanning step.

After scanning levels are formed, scanning points which represent the surface points to which the distance is to be measured are put along the length of each scanning level. The distance between the
points \( h \) equals the value of horizontal scanning step. The first scanning point of each level matches the left border of VST side surface as shown at figure 2.

\[
K = \frac{1000 \cdot H}{v} \cdot \frac{1000 \cdot 2\pi R}{h},
\]

where \( H \) is VST height value (m), \( R \) is VST radius value (m), \( v \) is the value of vertical scanning step (mm), \( h \) is the value of horizontal scanning step (mm).

Therefore, scanning map of technological object (VST in particular) is a set of scanning points with the distance \( h \) (the value of horizontal scanning step) between them, which are put along the length of each scanning level with the distance \( v \) (the value of vertical scanning step) between two next levels. The overall number of measurements equals the overall scanning points number \( K \):

The topology control system for VST internal side surface executes in accordance to algorithm shown at figure 3.

**Figure 2.** Scanning map formed

**Figure 3.** System execution algorithm
According to the algorithm, system initialization is to be held at the beginning of system execution. After that the following VST parameters and scanning parameters are entered: the height value \( H \), the radius value \( R \), the horizontal scanning step value \( h \), the vertical scanning step value \( v \).

The system sets scanning accuracy considering the parameters entered. The decision is made the following way: if at least one of \( h \) and \( v \) values is smaller than 0.1 mm, high accuracy is demanded. Otherwise, high accuracy is not demanded.

In accordance with decision-making result on VST scanning accuracy the system sets the measuring device. If high accuracy is demanded, the laser device is to be the means of measuring, otherwise, the ultrasound device is chosen.

After that level-by-level VST scanning starts in conformity with algorithm at figure 4.

![Figure 4. VST scanning algorithm](image)

VST scanning begins with mechanism positioning the measuring block 1, which consists of laser or ultrasound measuring device, into the reference position. This considers the measuring device orientated towards the first scanning point of the highest scanning level.

Each horizontal scanning level is scanned as follows: after the distance to the scanning point is measured, the measuring block rotates clockwise by the horizontal scanning step value \( h \). While rotating data flows from the measuring device to the microcontroller, which keeps data until the end of current level scanning. When the mechanism has rotated the measuring block on its axis in 360 degrees (counted from the first scanning point of current level), i.e. scanning of current level finished, the scanning level data flows from the microcontroller to the computer, which keeps it until the end of VST scanning.

Then system checks if current scanning level is the last one. In case there are more levels to be scanned, the measuring block is displaced down by the vertical scanning step value \( v \), i.e. the measuring module moves down to the next scanning level. Otherwise, VST scanning finishes.

After the end of scanning, processing of VST scanning data executes in accordance to the program kept in PC. Data systematizing and displaying result are executed thereafter.

In case VST scanning with different parameters is demanded, system execution goes back to parameters entering step. Otherwise, intellectual decision-support system [23-24] execution starts. The intellectual decision-support system role is to search a similar precedent in precedent base and to save a new precedent or to adjust it in order to make a final decision [7-16]. A precedent is defined as follows:
CASE = \sum L_{nvi}, \quad M, \quad (2)

where \sum L_{nvi} is a set of parameters measured (distances to the scanning points in particular), \( M \) is a complex parameter including similarity degree of current set of parameters to precedent from precedent base, precedent extraction algorithm and decision.

After that VST surface topology control system execution suspends.

3. Calculations

In order to evaluate the effectiveness of system elaborated, necessary memory amount and time for technological object scanning were counted (in case of VST).

The memory amount \( P_h \) (bits), necessary for storage horizontal scanning level data is given by:

\[
P_h = \frac{2\pi R \cdot 1000}{h} \cdot n, \quad (3)
\]

where \( R \) is VST radius value (m), \( h \) is a horizontal scanning step value (mm), \( n \) is a microcontroller parity value (\( n \) is assumed to be equal 8).

The memory amount \( P \) (bits), necessary for storage full VST scanning data is calculated upon the formula:

\[
P = K \cdot n, \quad (4)
\]

where \( K \) is a number of scanning points. Considering equations (1), (3), (4), for VST-100 where \( H = 6 \) m, \( R = 2,365 \) m, the calculations were held. Results of the calculations are presented in table 1.

Table 1 shows that at some values of set parameters (vertical and horizontal scanning step values) it is more effective to use streaming data while sending scanning data from microcontroller to PC. As an example, for VST-100 considering \( v = h = 10 \) mm it is effective to send data after the end of each horizontal level scanning as shown in algorithm at figure 4. The system is to make the decision about a proper data flowing strategy considering VST parameters and scanning parameters entered.

| Vertical scanning step, mm | Horizontal scanning step, mm | Memory amount for storage horizontal scanning level data, Kbytes | Memory amount for storage full VST-100 scanning data, Mbytes |
|---------------------------|-----------------------------|---------------------------------------------------------------|-------------------------------------------------------------|
| 5                         | 5                           | 2.90                                                          | 3.40                                                        |
| 10                        | 10                          | 1.45                                                          | 0.85                                                        |
| 15                        | 15                          | 0.39                                                          | 0.97                                                        |
| 20                        | 20                          | 0.29                                                          | 0.73                                                        |

The amount of time \( t \), necessary for VST internal side surface scanning is calculated as given by:

\[
t = K \cdot t_m + \left( \frac{H \cdot 1000}{v} - 1 \right) \cdot t_v, \quad (5)
\]

where \( t_m \) is data reading periodicity value of the measuring device (msec), \( t_v \) is a time of measuring block displacement (\( t_v \) is assumed to be equal 1 sec).
Considering equation (5), VST scanning time is to be calculated for values of vertical and horizontal scanning steps \( h = \nu \) which equal 5, 10, 15 and 20 mm. Results of the calculations are presented in table 2.

| Data reading frequency, Hz | Data reading periodicity, msec | Scanning step value \((h = \nu)\), mm | Scanning points number (in each level) | Each level scanning time, sec | Full scanning time, h |
|---------------------------|--------------------------------|----------------------------------|-------------------------------------|----------------------------|----------------------|
| 200                       | 5.0000                         | 5                                | 2972                                | 14.86                      | 17.83                |
|                           |                                | 10                               | 1486                                | 7.43                       | 4.46                 |
|                           |                                | 15                               | 991                                 | 4.95                       | 1.98                 |
|                           |                                | 20                               | 743                                 | 3.71                       | 1.11                 |
|                           |                                | 5                                | 2972                                | 11.89                      | 14.27                |
| 250                       | 4.0000                         | 10                               | 1486                                | 5.94                       | 3.57                 |
|                           |                                | 15                               | 991                                 | 3.96                       | 1.58                 |
|                           |                                | 20                               | 743                                 | 2.97                       | 0.89                 |
|                           |                                | 5                                | 2972                                | 9.91                       | 11.89                |
| 300                       | 3.3333                         | 10                               | 1486                                | 4.95                       | 2.97                 |
|                           |                                | 15                               | 991                                 | 3.30                       | 1.32                 |
|                           |                                | 20                               | 743                                 | 2.48                       | 0.74                 |
|                           |                                | 5                                | 2972                                | 7.43                       | 8.92                 |
| 400                       | 2.5000                         | 10                               | 1486                                | 3.71                       | 2.23                 |
|                           |                                | 15                               | 991                                 | 2.48                       | 0.99                 |
|                           |                                | 20                               | 743                                 | 1.86                       | 0.56                 |

The calculations show that increasing data reading frequency and horizontal and vertical scanning step values results in decreasing amount of time necessary for scanning technological object.

4. Conclusion

Thus, a universal automatic system for surface topology control of technological object (VST internal side in particular) elaborated is characterized by lack of human factor influence. Laser and ultrasound measuring devices, which are the main parts of the system, provide with an opportunity to undertake the surveys with accuracy demanded. Decision support of choosing necessary scanning accuracy and identifying the nature of the defects is realized in the system as well.

References

[1] Chiany F P 1979 Moire Methods of Strain Analysis Exp. Mech. 19 pp 230-308
[2] Post D 1967 Analysis of Moire Fringe Multiplication Phenomena Appl. Opt. 11 pp 1938-1942
[3] Guild J 1956 The Interference systems of Crossed Diffraction Gratings (Oxford: Clarendon Press) p 152
[4] Durelli A J, Sciammarella C A, Parks V J 1973 Interpretation of Moire Patterns J. Eng. Mech. Div., Proc. ASCE 71
[5] Durelli A J, Rajaiah K 1980 Determination of Strains in Photo-Elastic Coatings Exp. Mech. 20 pp 57-64
[6] Redner A S 1980 Photoclastic Coatings Exp. Mech. 20 pp 403-405
[7] Schank R C, Abelson R P 1977 Scripts, plans, goals and understanding (Erlbaum, Hillsdale, New Jersey, US) p 248
[8] Simpson R L 1985 A computer model of case-based reasoning in problem solving: an
investigation in the domain of dispute mediation Technical Report GIT-ICS-85/18
[9] K.J. Hammond 1986 CHEF: A model of case-based planning In Proc. American Association for Artificial Intelligence, AAAI-86 pp 267-271
[10] Sycara E P 1987 Resolving adversial conflicts: An approach to integrating case-based and analytic methods Ph.D Thesis Technical Report No. GIT-ICS-87/26
[11] Koton P 1989 Using experience in learning and problem solving Ph.D. Thesis MIT/LCS/TR-441
[12] Althof K-D, Auriol E, Barlette R, Manago M 1995 A review of industrial case-based reasoning tools AI Intelligence
[13] Information on http://www.iccbr.org/
[14] Aamodt A, Plaza E 1994 Case-based reasoning: foundational issues, methodological variations, and system approaches AI Communications, IOS Press 7 pp 39-59
[15] Alterman R 1989 Panel discussion on case representation In Proceedings of the Second Workshop on Case-Based Reasoning
[16] David B S 1991 Principles for case representation in a casebased aiding system for lesson planning In Proceedings of the Workshop on Case-Based Reasoning
[17] Guidance document 19.100.00-KTH-545-06 Ultrasound control of side surface and welded joins while exploitation and renovation of vertical storage tanks (in Russian)
[18] Guidance document 153-39.4-078-01 Regulars of operation of oil-trunk pipelines and oil bases tanks (in Russian)
[19] State standard 8.570-2000 ICG Vertical cylindrical storage tanks. Audit methodology (in Russian)
[20] Kuzyakov O N, Kucheryuk V I 2002 Methods and means of measuring surface topology, displacements and deformations (Tyumen: TSOGU) p 172 (in Russian)
[21] Kucheryuk V I, Kuzyakov O N, Dubatovka U V 2005 Surface topology identifying device by using Moire method Patent RF 2267087
[22] Kucheryuk V I, Mishenev A A 2012 Tanks defects control device with Moire method Patent RF 2454627
[23] Bashlykov A A 2016 The basics of projecting informational systems for intellectual decision-support Automatization, telemechanization and communication in oil industry, Moscow: OJSC “VNIIST-Neftegazproekt” 11 pp 12-24 (in Russian)
[24] Bashlykov A A 2014 Analysis of organization intellectual information decision-support in emergency situations Automatization, telemechanization and communication in oil industry, Moscow: “VNIIOENG” 8 pp 3-9 (in Russian)