Comparative Analysis of Automatic Methods for Measuring Surface of Threads of Oil and Gas Pipes

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Abstract. In this paper a comparative analysis of methods for measuring complex profile surfaces such as threaded surfaces were carried out. The oil and gas pipe and couplings threads were used as an example of a complex surfaces. A theoretical and experimental evaluation of the reliability, performance and accuracy of the geometric measuring systems in shop floor environment was made in cooperation with executive and ordinary staff. Coordinate measurement machine with stylus, profilometer, conoscopic, confocal, interferometric and laser triangulation methods were involved to solve thread measurement problem. The optimal method of thread geometry measurement for a shop floor was tested and identified as a result of the analysis of pipes and couplings threads. The laser 2D triangulation scanning method was verified as the only suitable for thread measuring problem solution. The results of measurement using this method show a possibility to achieve technical requirements for the premium oil and gas pipes thread.

Keywords: Laser triangulation · Scanner · Contact · Non-contact · Measurement · Thread · Conoscopic · Interferometric · Characteristic of accuracy

1 Introduction

Manual geometry measurement means are one of the biggest current problems of an oil and gas pipe manufacturers. A calipers and other special gauges often require a surface recovery and verification. This increase the amount of non-quality production and maintenance costs. Human factor problems, performance and accuracy requirements leads to the development of new coordinate-measuring machines (CMM).

A wide range of problems in measuring geometry determines the variety of coordinate-measuring technologies and approaches. In the course of creating systems for measuring geometry, the task for developers is to select the optimal method and equipment. Therefore, specialization of technology for various operating conditions, surface features and performance requirements take place. In fact, for each task the existing methods and technologies are modified or new ones are created.

Measurement of premium oil and gas pipe thread is one of the complex problems on automated production lines of metallurgical plants (shown in Fig. 1).

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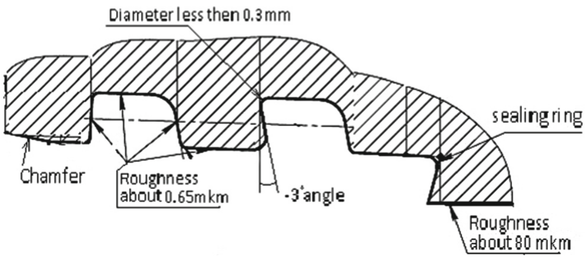


Fig. 1. Drawing of premium thread example.

At the moment all manufacturers of pipes and couplings use two-level geometry inspection. The first level is the total control of the thread by manual gauges and calibers, the second is the selective control of the geometry using casts [1]. The first level takes about 1 min per one part, ensuring that the connection is checked for screwing, but not giving information about the geometry of the teeth and the roughness of the thread.

The second level provides information on the geometry of the teeth and the roughness of the thread, but takes too much time - about 20 min per part. With the advent of premium couplings with sealing rings, grooves and threads of special geometry, contact methods have ceased to provide control of required parameters.

According to the standards the accuracy of measurement should be 5 microns with performance 100 000 points per second. It should also be taken into account that most of the products have a diameter of more than 70 mm.

To solve this problem now operators of production lines use manual thread gauges or casts form the thread surface. All these methods are not integrated in SCADA and depends on human factor. Therefore, pipe plants sometimes supply defective production. It causes accidents.

As you can see at the Fig. 1, the thread has some features, such as the negative angles of the sides of the teeth, the sealing ring, various roughnesses from 0.65 to 80 microns, and small diameters. Reference element for basing of thread is chamfer cone, which axis coincides with axis of thread. Measuring of 4 sections of thread is enough according to API standard [1]. Therefore, precision positioning system is needed to measure reference element and four pipe or coupling sections.

According to required parameters, there are list of existing measuring methods and systems to be considered [2]:

- Contact method with portal CMM or profilometer
- Conoscopic method with portal CMM
- Confocal sensing method with portal CMM
- Interference method with portal CMM
- Laser triangulation method with portal CMM

2 Contact Methods of Measurement

Theoretical and experimental analysis of existing methods should be held to find or create suitable solution.

Historically, the first devices used to control the geometry of the object were the contact probes. The probe method of measuring the geometry of the surface is a wide spreaded on the production plants (shown in Fig. 2).

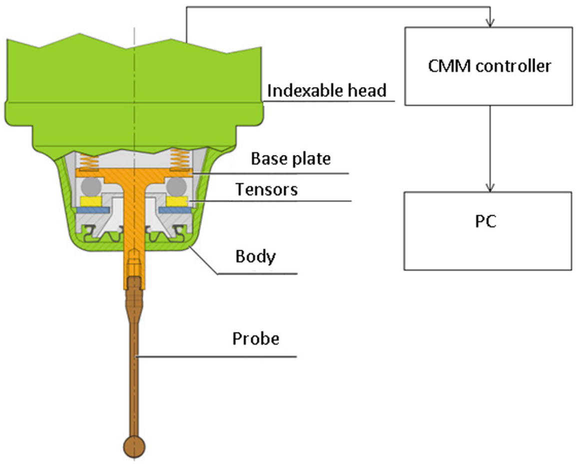


Fig. 2. Contact probe with indexable head based on portal CMM.

As probes are used thin rods with tips made of metal, ceramics, ruby or sharpened needles of high hardness. The tips on the rods are often balls of different diameters (minimum 0.3 mm). The probes are driven along a certain trajectory relative to the surface. In case of probe mount on CMM with indexable head the angle of probe could be changed from −105 to +105 at A axis and from −180 to +180 at B axis [3] (shown in Fig. 3).

The mechanical vibrations of the probe are converted into electrical vibrations and enter the processing unit (CMM controller), where the measured profile of the object is formed.

The use of digital processing of the signal from the contact probe allowed to reduce the electronic noise to a level equivalent to the rms surface roughness of 1–2 nm with a needle load of 0.5–2 mg. Modern CMMs have a high sensitivity (about 4 nm in space) [4]. But due to the finite size of the touching surface of the probe, this type of measuring probes reproduces the microrelief only in the case of far-away microroughnesses or slightly-wavy surfaces, as can be seen in Fig. 4.

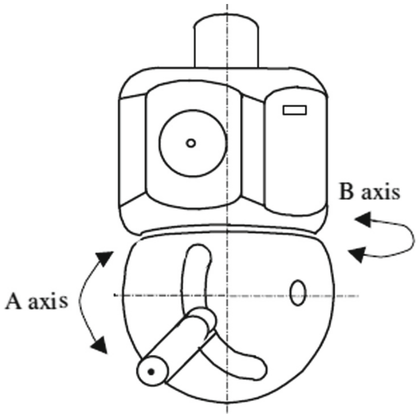


Fig. 3. Indexable head PH10 on CMM.

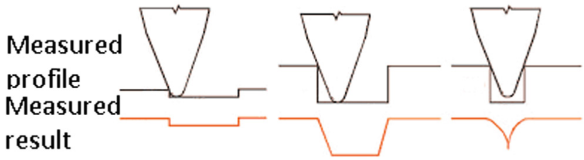


Fig. 4. Distortion of information about geometry in the measurement of a complex part.

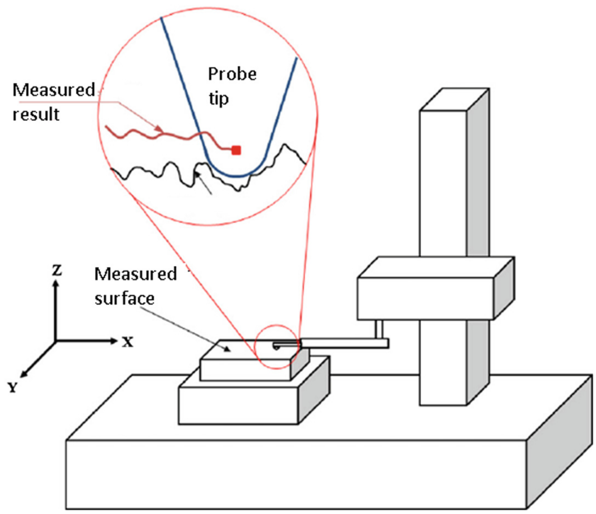


Fig. 5. Profilometer measures rough surface.

In the case of closely located microroughness, the probe, sliding along their vertices, transmits only the general contour of the relief. The resolving power of the CMM depends on the radius of the rounding of the probe and the nature of the topography of the surface. In addition, the probes wear out and due to their fragility they often break. When the probe is in the groove, it is possible to break it.

Measurement of diameters less than 0.3 mm using probe with spherical tip is impossible, because minimum diameter of sphere is 0.3 mm. Therefore, only needles should be used.

Needles are usually used in profilometers, devices for measuring the profile of an object in a given section (shown in Fig. 5). Experiment was held using Mitutoyo profilometer for measurement of premium casing coupling 168 mm diameter (shown in Fig. 6).

Result of experiment shows impossibility to measure small diameters of internal thread using profilometer, because probe angle about 45°–55° is required to reach these places. It is impossible to lead probe inside with 125 mm diameter coupling. Required angle could be reached in case of external thread. However, during experiment two tips of probes were broken, because of grooves and roughnesses (shown in Fig. 7).

It can be stated, that contact method doesn't suitable for measurement of complex part with small diameters, because needles are required to measure them. In turn, needles are very fragile and not suitable to grooved surface.

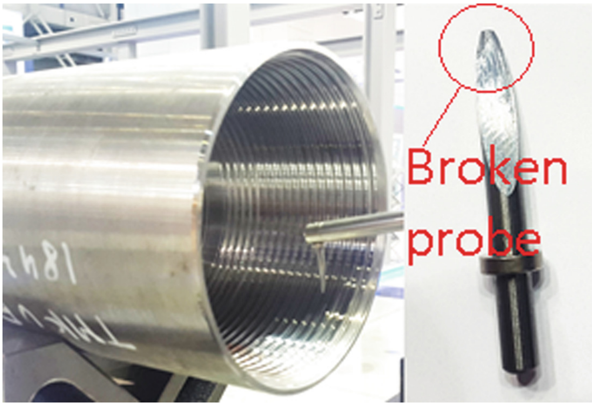


Fig. 6. Experimental measurement of casing coupling using profilometer Mitutoyo and broken probe.

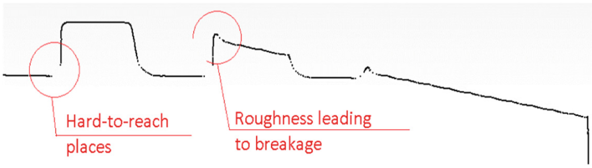


Fig. 7. Point cloud of the coupling thread section collected using profilometer.

Also, measuring time for contact methods is about 20 min per pipe/coupling, or 500 points per second. This is not suitable for automatic production lines, because one CNC produces one pipe or coupling per minute.

3 Conoscopic Method of Measurement

A relatively new method of measuring the geometry of a surface is conoscopic holography.

In classical holography, a hologram is created by recording an interference pattern formed between an object beam and a reference beam using a coherent light source [5].

One of the problems of optical methods of geometry inspection is the measurement of the surface with sharp differences in altitude. The larger the field of view of the optical system, the lower its numerical aperture (shown in Fig. 8). The light that hits the surface through the interferometer lens must be collected again to focus on the digital matrix in order to process the information and create the desired 3D surface map.

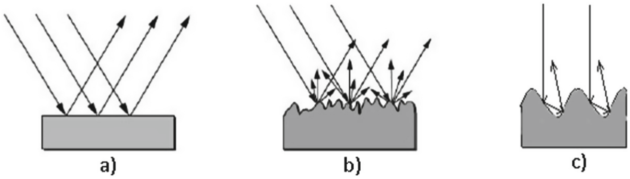


Fig. 8. Examples of reliefs of measured surfaces and reflection of rays: (a) a smooth surface reflects incident light with an angle equal to the angle of incidence; (b) the rough surface reflects a part of the light at an angle equal to the angle of incidence, and part dissipates in different directions; (c) the threaded surface also reflects and diffuses the light as in case b, but in addition creates interference noise from the adjacent tooth.

The light reflected from the surfaces of a larger angle, than lens can collect, either does not hit on the digital matrix, or hit in a distorted form, which makes it impossible to accurately measure (shown in Fig. 9).

In the paper [6], an experiment is described to assess the error of a measuring system based on CMM and ConoProbe Mark3.0 cone sensor, manufactured by Optimet, a leader in the market of conoscopic sensors. Turbine blade was measured with error about 0.030 mm.

Taking into account the submicron accuracy of the sensor according to the documents [5], this indicates a significant increase in the measurement error when scanning polished, well-reflecting surfaces at large (more than 45°) angles of incidence.

In this paper, thread of tubing coupling with diameter 73 mm. was measured using a ConoProbe Mark3.0 sensor and a special sensor displacement system, which is a carriage driven by a ball screw and a stepper motor (shown in Fig. 10). The sensor

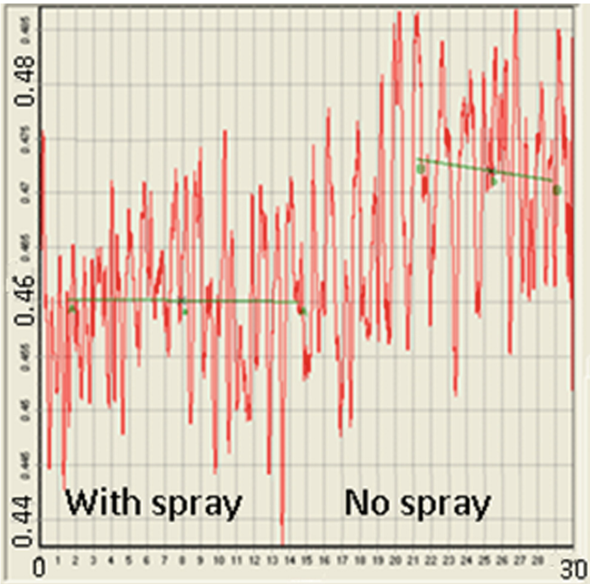


Fig. 9. Accuracy of measurement by a conoscopic sensor of a mirror surface with application of a spray and without.

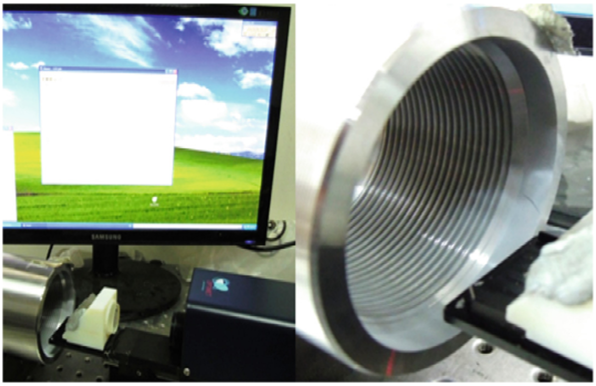


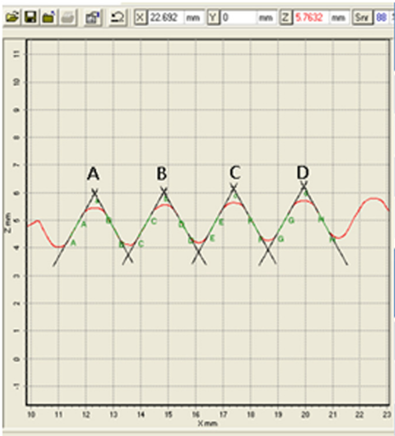
Fig. 10. Experimental set up for coupling measurement using conoscopic probe.

error is about 0.0002 mm. The error of the displacement system is about 0.001 mm. The scanning speed of the sensor is no more than 9000 points per second.

During experiment it was found, that without applying a special spray to the thread surface the measurement error is 0.040 mm, which does not satisfy the requirements normative documents [1]. Spray removes the mirror effect from the surface and reduce interference from the adjacent tooth. The structure of the spray is a granules of about 0.010 mm. in diameter. Therefore, the measurement error after application became about 0.020 mm (shown in Fig. 9).

The analysis of the data obtained during experiment showed that the measurement error with this system is about 0.020 mm (shown in Fig. 11). This error is sufficient for non-premium production.

As a result, this method is technologically difficult to integrate into production line, due to the fact that it is necessary to apply and remove the spray from the surface, and also measurement of the premium pipes and couplings is impossible.



Points Delta	Full Angle
A	58.878
B	58.704
C	60.109
D	59.509

Points Delta	Pitch (μm)
A - B	2.5206
B – C	2.548
C - D	2.559

Fig. 11. Accuracy of measurement by a conoscopic sensor of a mirror surface with application of a spray and without.

4 Confocal Method of Measurement

Confocal sensing is one of fast and precise methods of geometry measurement. Light is focused using a lens on a measured object, reflects from it and returns into the sensor. In a monochromatic confocal sensor a single-color light is used and the sensor and object have to be mechanically moved with respect to each other to keep the object at the focal point of the lens. This makes the technique very slow and unsuitable for shop floor measurement of pipes and couplings.

In contrast, white-light confocal sensors use light composed of a many colors. The lens focuses each color at a slightly different location, and by measuring the returned light's exact color we can evaluate the distance with up to nanometric precision.

An example of confocal chromatic principle of measurement is CHRocodile CLS sensor made by Precitec company [7] (shown in Fig. 12).

A white light source is used to illuminate the surface of a part. The light travels via fiber from the CHRocodile control unit to an optical probe which then spreads the focal length over a discrete number of points creating a full spectrum of light as shown in the graph. Sensor contains 192 channels of measurement, which provide 2D line (5 mm length) scanning of an object. Based on the wavelength of the reflected light, a very precise (lateral resolution: less than 1 μm) distance measurement can be taken up to 2 000 times per second (or 384 000 points per second). Also sensor has high acceptance angle, up to 45°, which provides possibility to measure slope surfaces, such as thread teeth. The optical probe determines the measuring range (up to 35 mm), or focal depth of the spectrum (shown in Fig. 13). Because of the high numerical aperture of the probes and dynamic range of the sensor, it is possible to measure on nearly all materials.

However, these sensors are very cumbersome. They cannot be mount on indexable head. It causes to problem not only with scanning of sealing elements of premium production, but also with scanning of internal surfaces of holes diameter less than 100 mm. Therefore, they are suitable only for non-premium production and only for outside thread.

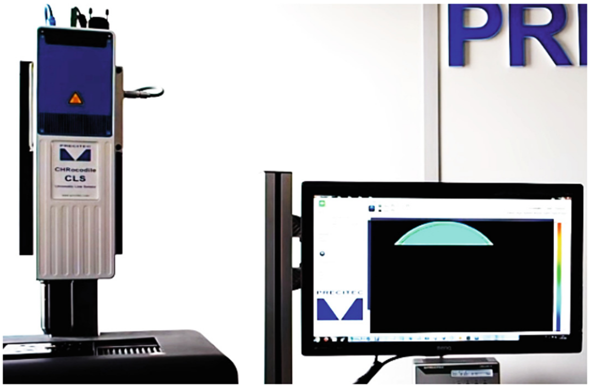


Fig. 12. Precitec CHRocodile CLS confocal chromatic sensor.

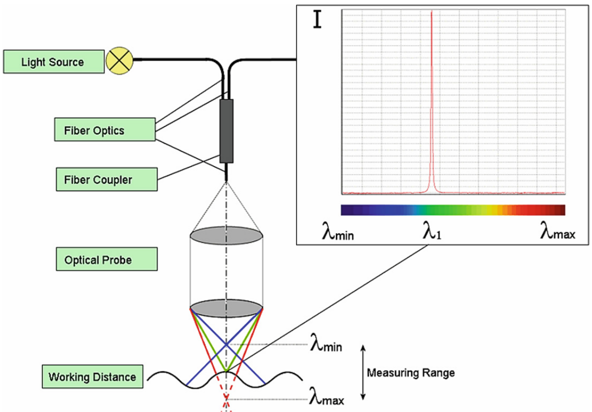


Fig. 13. Scheme of the confocal chromatic sensor.

5 Interferometric Method of Measurement

An example of modern interferometric sensor is Hexagon hp-o (shown in Fig. 14), which is based on frequency-modulated interferometric optical distance measurement method.

Diameter of this sensor is about 3 mm, weight is less then 190 g, measuring range is up to 10 mm., performance is about 1000 points per second, resolution is 0.9 nm. This sensor is easy mount on indexable head. The big disadvantage of this sensor is a very small acceptance angle (for 10 mm. range, angle is about 0.3°). Therefore, it cannot be used to measure sharply sloped thread surface.

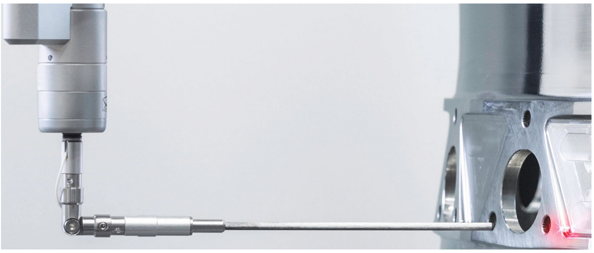


Fig. 14. Hexagon hp-o interferometric sensor.

Of course, pitch of thread could be measured using interferometer sensor [9], but it just one from set of parameters.

6 Laser Triangulation Method of Measurement

Non-contact geometry measuring methods are show the biggest efficiency when used in high performance production lines [10].

An example of such dimension inspection means are the computer vision and optical measuring systems. Optical measuring systems provides high performance and precision for complex surface inspection. Sensors like 2D laser scanners can measure areas of an inspected parts in a split of secconds.

The principle of optical triangulation is realised due using opticzl scheme, which includes the laser emitter 1 and CMOS-matrix 5 as receiver of a reflected light. Laser beam goes through the lens 2, which forms the line 3. Line is projected on the object surface 7. The scattered radiation is received by CMOS-matrix. CMOS matrix generates digital image with intensity values. This image is used to calculate contour of the measured surface by CPU 6, which calculates the distance to the object (Z coordinate) for each of the set of points along the laser line on the surface (X coordinate) [11].

An example of 2D laser scanner is Nikon LC15Dx [12]. This is one of the precise and fastest scanner in the world for now. Weight is less then 370 g., measuring range is 18 mm. width and 15 mm. height, performance is about points/sec, probing error is 1.9

micron, which is very close to contact method precision (shown in Fig. 16). This sensor is easy mount on indexable head (Fig. 15).

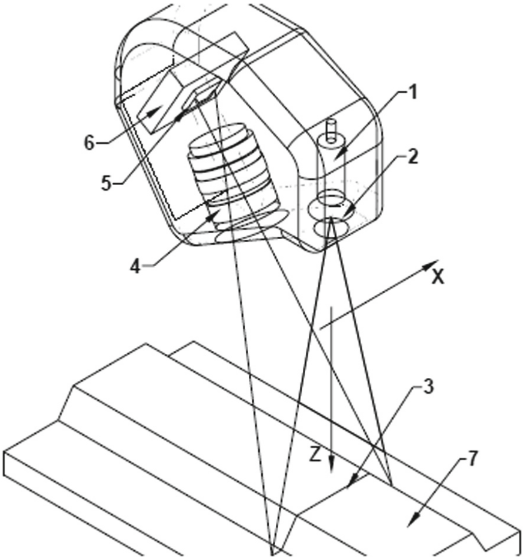


Fig. 15. Scheme of the 2D laser scanner.

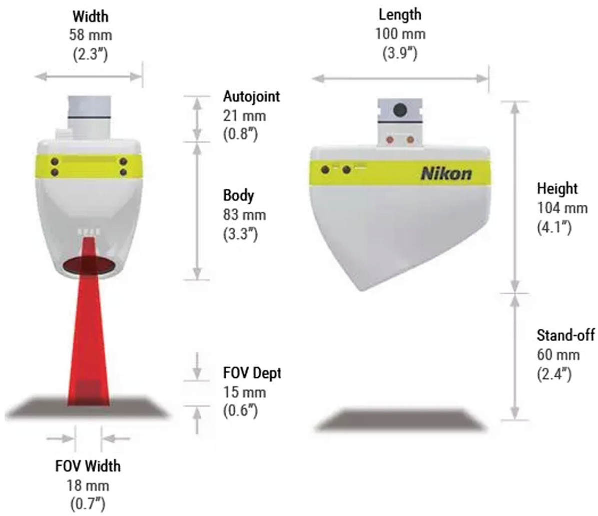


Fig. 16. Nikon LC15Dx 2D laser scanner.

In this paper, external premium pipe thread diameter 245 mm. was measured using LC15Dx 2D laser scanner with CMM Altera (shown in Fig. 17).

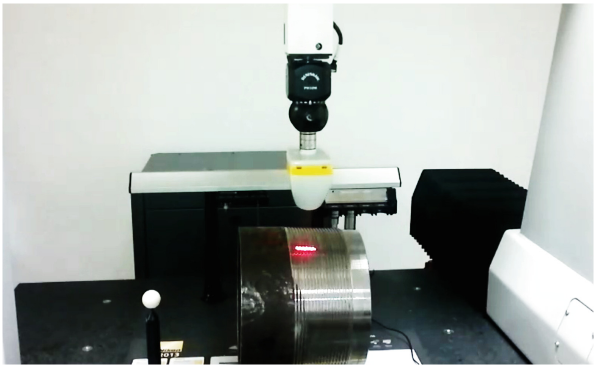


Fig. 17. Nikon LC15Dx 2D laser scanner with CMM Altera in measurement of external premium pipe thread.

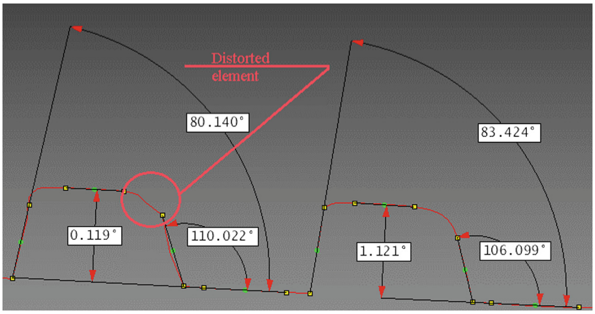


Fig. 18. Point cloud measured by Nikon LC15Dx 2D laser scanner and analysed in CAMIO software.

During experiment it was found, that collected thread point cloud is distorted in places with small radiuses, because of mirror reflection between adjacent teeth. This was the reason of big dispersion of angle values (more than 0.5°) (shown in Fig. 18).

Analysis of distortion causes could be held using images directly from scanner video matrix. This image shows distorted parts of the signal and their features.

These features have pulse nature and appear in special places. The same problem of signal distortions was discussed and solved in another paper [13].

LC15Dx model has a stand-off distance 60 mm. and body dimensions 104 mm. height, 100 mm. length, 58 mm. width. The smallest pipe hole for measurement by this scanner is about 170 mm, which is not satisfy to the requirements of pipe producers. But it is possible to create special 2D scanner for diameters less then 70 mm (for example LS2D made by LLC Geomera).

If problem of filtration of these distortions is solvable, then laser triangulation method satisfies technical requirements (shown in Fig. 19).

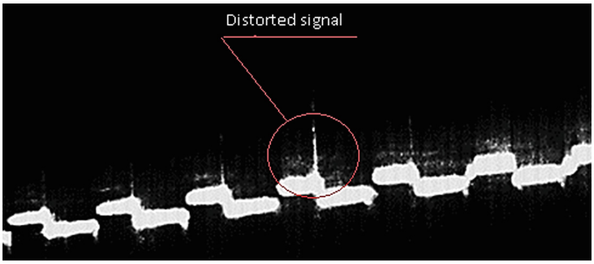


Fig. 19. Point cloud measured by Nikon LC15Dx 2D laser scanner and analysed in CAMIO software.

Acknowledgments. As a result of the work comparative analysis of automatic methods for measuring the surface of threads of oil and gas pipes was held. Analysis of technical characteristics and experimental thread measurements revealed options to achieve the required parameters of accuracy and productivity. According to experiments the most possible and universal solution for internal and external thread measurement is laser 2D triangulation in combination with special filtration algorithms.

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