A methodology of measuring geometrical product specifications using three-dimensional scanning

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Abstrakt

Tento příspěvek se zabývá vlastnostmi laserových liniových skenerů používaných v procesu kontroly geometrických specifikací výrobků. Článek je zaměřen na fázi snímání dat a popisuje průvodní jevy laserového skenování, které komplikují snímání dat. Mezi ně patří sekundární odraz, přímý odraz, překrytí skenů, nebo odlehlé body vznikající při přejezdech skeneru nad hranami. Vhodnou úpravou nastavení parametrů snímání pro daný charakter povrchu lze efekt těchto jevů snížit nebo zcela eliminovat. Článek také popisuje testy teplotní stability dvou typů skenerů Nikon Metrology používaných při kontrole rozměrů strojírenských výrobků. Zjištěné doby potřebné pro stabilizaci jsou 45 min u skeneru LC15Dx a 30 min u skeneru LC60Dx. Systematické chyba způsobená stabilizací je 20 µm u LC15Dx a 37 µm u LC60Dx, což je méně, než u předchozích typů s rozmítaným laserovým paprskem.

Abstract

This paper deals with a performance of laser line scanners that are used in a part inspection process. The aim of this paper is to describe effect of phenomena related to scanning, that complicates data acquisition. Particularly secondary reflection, direct reflection, scan overlapping, outlying points. User can prevent or minimise the effect of described phenomena by optimal setting of scanner parameters stated in this paper. These parameters were determined from an experimental measurements more than 50 various parts. Additionally a thermal stability effect was measured at two types of Nikon scanners used in part dimensional inspection. The stabilisation time and the systematic error was determined for the scanner LC15Dx: 45 min, 20µm and 30 min and 37 µm for the LC60Dx scanner. It is less than characteristics of previous type of laser scanners with rotating mirror.

Key words

3D Scannig, Laser Line Scanner, Dimensional Inspection, Stabilisation interval.

Introduction

A non-contact methods of measuring of industrial products are comming wide-spread next to the CMM with contact sensors. One of them is a measuring using a laser line scanners, that are able to record continuously a surface of measured object. An application of laser scanners in the field of geometrical product specification inspection process entails certain limitations not obvious in the first approach, but with significant effect on the resulting quality of data output. There are described phenomena related to scanning and surface character that negatively influence data output. The description is based on an experimental measurement of various industrial products (sheet metal parts, castings, plastic components, machined parts). As a result of this measurement there are stated optimal scanning parameters for three most frequented types of surfaces. With the knowledge of above mentioned phenomena and with the optimal setting a high quality scan can be acquired with minimum negative effect. A two laser line scanners were used for the measurement: Nikon LC15Dx and LC60Dx. Since different results were observed several times after qualification, a performance of the scanners was tested on a calibration plate. As a result of this measuring there is a graph of thermal stabilisation process as a function of scanner indication on the time from scanner power-up.

1. Data acquisition principle

A laser line scanner is derived from 1D laser triangulation sensor. In comparison to 1D sensor a laser beam goes through cylindrical lens where is stretched to the scanning plane. When the scanning plane intersects a scanned surface, a thin laser line – optical section can be observed. This line si recorded by a CCD camera with a frequency from 20 to 80 Hz (depending on the scanner type). The output from the scanner are 2D coordinates from the camera. To reach 3D representation of scanned surface, there must be an additional device called localizer (usually CMM, MCA). Localizer is positioning the scanner over the scanned surface and assigns 3D coordinates to every image that comes from the scanner (Fig. 1).

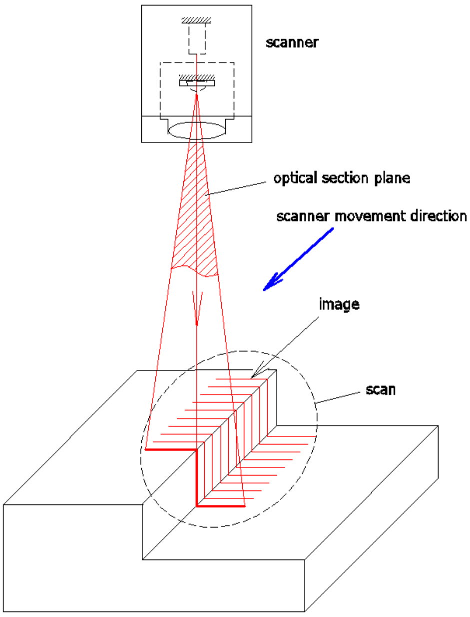

Fig. 1. *Principle of laser line scanning*

A quality of scanned data depends especially on the intensity of received image signal. It is given by the intensity of broadcasted laser beam and by the character of scanned surface such as reflectivity, transparency, roughness, colour [1]. The aim of the scanner developers is to minimise a dependency on these characteristics. Although this effort, there is still a lot of space for the user to modify a settings of scanning parameters and to scan a point clouds with poor quality without knowledge of the following problematics.

1.1 Secondary reflection

During the scanning of a reflective surface a part of laser beam enters to a diffusion reflection and a remaining part is reflected away from the surface with the same angle of reflection as the incidence angle. The intensity of the reflected beam is the greater, the greater is reflectivity of the surface. A beam reflected to a free space do not influence a quality of the point cloud unless it is captured by the CCD sensor. It is just lowering an intensity of the diffusion reflection. If there is another surface in the direction of reflection a secondary reflection is created. Typical situation is a scanning in the inner corner. The intensity of the secondary reflection is often close to the intensity of the main scan line (primary reflection). Due to this effect it is very difficult for the processing software to separate the secondary reflection in field of view of CCD sensor from the primary reflection. That means, the secondary reflections are transferred to the resulting point cloud as an outlying points, that are not representing a real shape of scanned part.

To eliminate secondary reflection is useful to rotate scanner direction approx. 15 degrees from the surface normal. When the scanning plane is perpendicular to the surface, there are no space between primary and secondary reflection on the surface. Processing software cannot decide, which line is correct and both are suppressed. The result is incomplete point cloud. If scanner is tilted, than the space between primary and secondary reflection is bigger and intensity of secondary reflection is lower. Software will filter out just the points that belongs the secondary reflection.

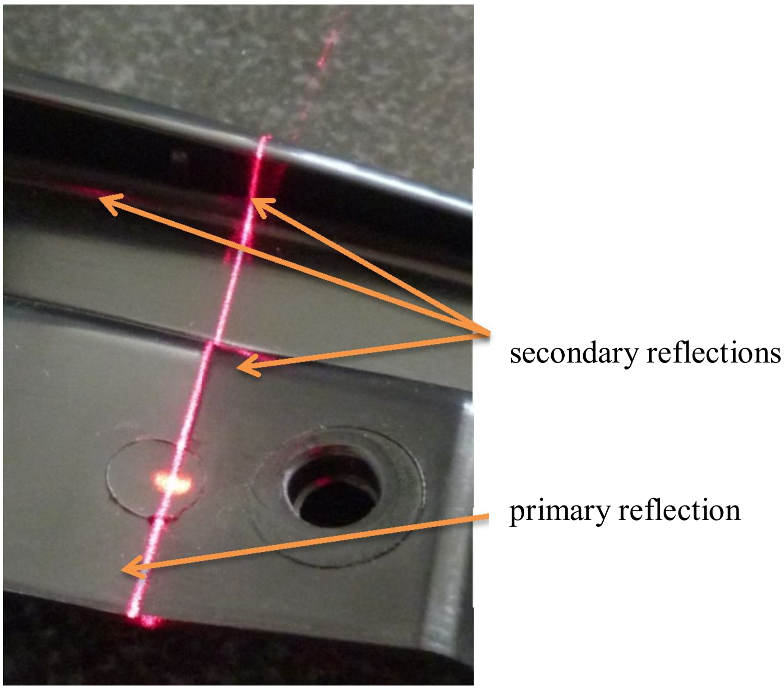

Fig. 2. *Secondary reflections on a plastics component*

1.2 Direct reflection to a sensor direction

A special case can appear while scanning reflective surfaces. It is a direct reflection of laser beam in to camera objective. The sensor of the camera is fully saturated and outputs outlying points that are not corresponding to the scanned surface. Direct reflection appears when surface normal bisects triangulation angle between laser beam and the optical axis of the camera (Fig. 2). This situation can be simulated on a shiny reference sphere. Usually the direct reflection occurs when the scanner is crossing outer rounded edges. The point cloud affected by direct reflection is not complete and contains outlying points that are situated to the direction of the camera optical axis.

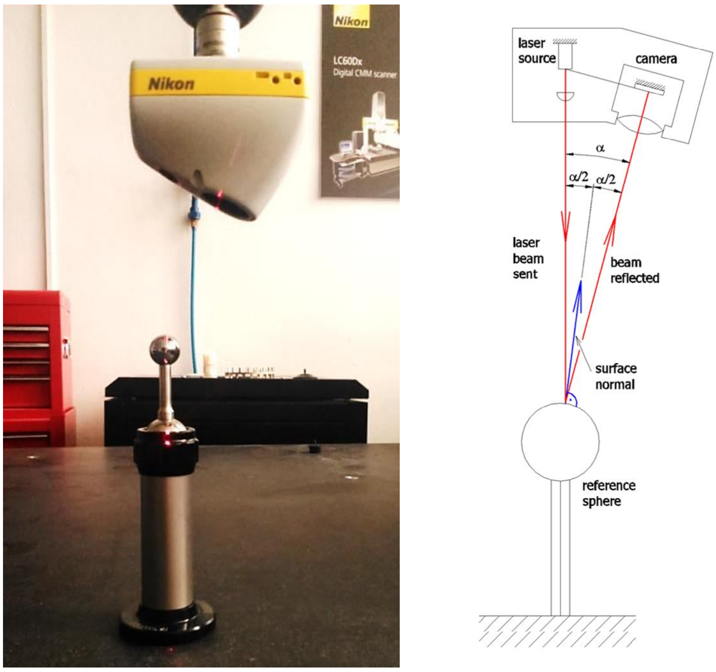

Fig. 3. Example of direct reflection on reference sphere

1.3 Scanning a surface step

The significant source of outliers is an orientation of scanning plane parallel to scanned object. During the scanner move above the edge the laser line is splitted by the edge in the way that one part of the line is projected on the surface to be scanned and the remaining part is spreaded on the adjacent surface of the step (Fig. 4). This part of the laser line generates outlying points.

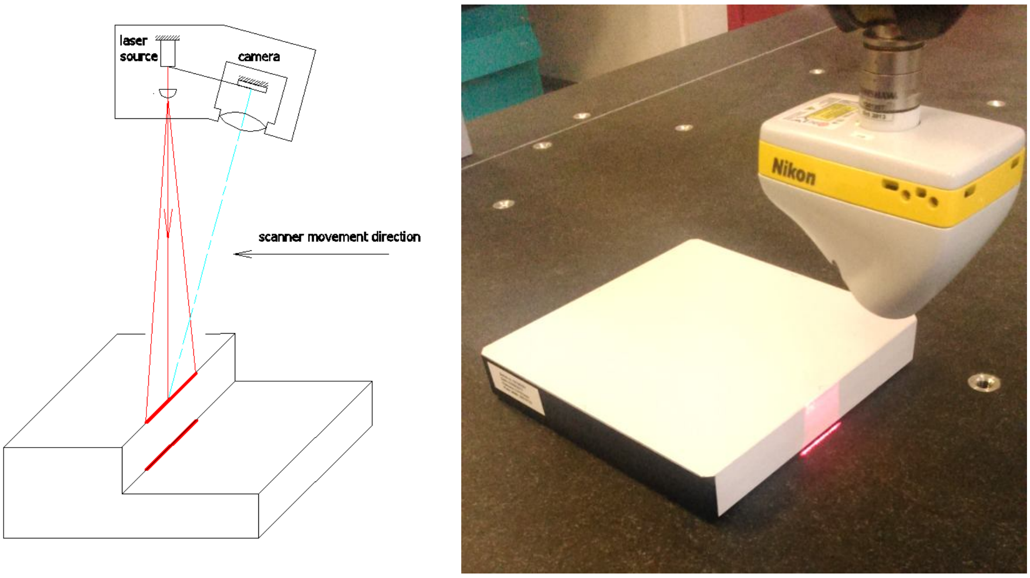

Fig. 4. Left: scheme of the laser line disruption by the edge. Right: The same situation with LC15Dx scanner moving over the edge of a reference artefact.

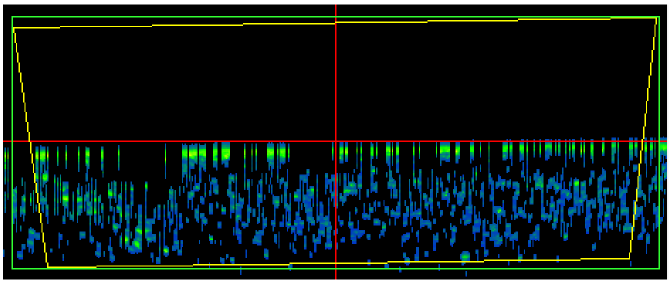

Fig. 5. *A result of longitudinal disruption of laser line. Raw image from camera: green points are transferred to the point cloud, the blue points are filtered out due to a low intensity.*

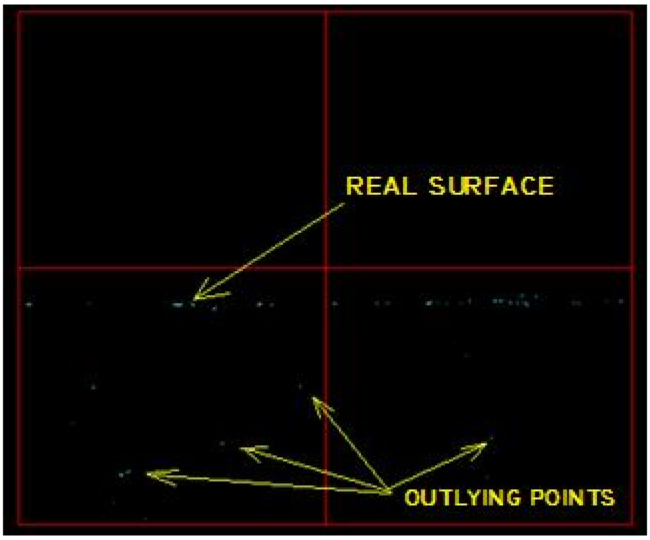

Fig. 6. *A result of longitudinal disruption of laser line after camera image processing. Partially transferred real surface and noise at the bottom of field of view.*

1.4 Scan overlapping

Single scans on the same surface are not connected one to each other exactly on its borders, but with certain overlap.

Resulting point cloud can contain two types of overlapped areas:

- overlapped points in one scan
- overlapped scans

The first of them is given by the way of scanner positioning on the CMM, where the scanner is moving in one orientation above scanned surface in parallel paths. The distance between parallel paths is set to cover the surface by scanned points without gaps with small overlap. User can set the width of the overlapping area of two neighbour scans. This type of overlap does not affect scanned data significantly.

The second type of overlap is caused if the same surface is scanned using different orientations of the scanner. An overlap error can be defined as a distance between two points of overlapping scans measured perpendicular to the surface. A size of the error depends on uncertainty of scanner qualification, on orientation of the scanner relative to the surface and on uncertainty of CMM (localizer). Example of overlap effect is shown in following figures. On the figure 7 is cross section of polygonal mesh consisting of four single scans. The size of overlapping error 0,055 mm is typical for the LC60Dx scanner connected to CMM with a PH10M head with a specification $MPE_E=1,8+L/350\ \ [\mu m]$. The second figure (fig.8) shows overlap typical for more accurate type of the scanner LC15Dx. Outlying points in the raw data (in red) were filtered out during postprocessing by a curvature filter. The data after filtration are marked green.

Fig. 7. *A detail of a section of four overlapping scans. Overlapping error in [mm].*

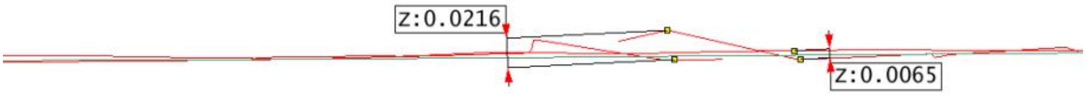

Fig. 8. *Overlapped data scanned by LC15Dx. Value 0,0216 mm is an outlying value, during filtration is filtered out – see green line.*

Overlapping can be minimised by a requalification of all scanner orientations in one moment if possible, but it cannot be excluded absolutely during scanning. It can be eliminated in a data processing phase using subtraction of single scans and filtering the point cloud.

Although we cannot completely exclude above mentioned phenomena, it can be minimised. On the one hand by using an optimal positioning of the scanner, on the other hand by using an optimal scanning parameters according to surface character. Examples of the optimum parameters as a result of experimental measurement of more than 50 parts, are shown in following paragraphs.

1.5 Recommended scanner settings according to surface character

From a point of view of capturing a data by a laser line scanner a surfaces can be classified in to three categories:

Basic surface

Smooth surfaces with light matte colours.

Fig. 9. *Artefact with a basic surface character*

It is possible, at basic type of surface, to capture any outer form without necessity of changing the scanning parameters. Surfaces that belong to this category are surfaces of calibration artefacts, ceramic parts and products from plastics with light colours and matte surface. Surfaces covered with a layer of white mattifying spray are considered as a basic surface.
Although the layer of matting spray will change a dimension from few hundredths to tenths of milimeter, final uncertainty of scanning a sprayed surface can be better than on the shiny surface, since unwanted reflections are eliminated. If a large number of reflective parts should be measured, a spraying of the surface is not useful, since it increases costs for a measuring process and complexity of preparation (a separated room, a time for spraying, a time for cleaning).

Table 1 *– Recommended parameters for basic surface*

Parameter	units	value
Laser intensity	[1]	automatic
Minimum intensity of reflected signal	[1]	25-50
Exposure	[1]	1-4
Reflection filter	-	no
Point distance	[mm]	0
Stripe distance	[mm]	0,1 - 3

Easy to scan surface

Surfaces of lighter colours, slightly reflective, or dark (black) matte surfaces, slightly rugged.

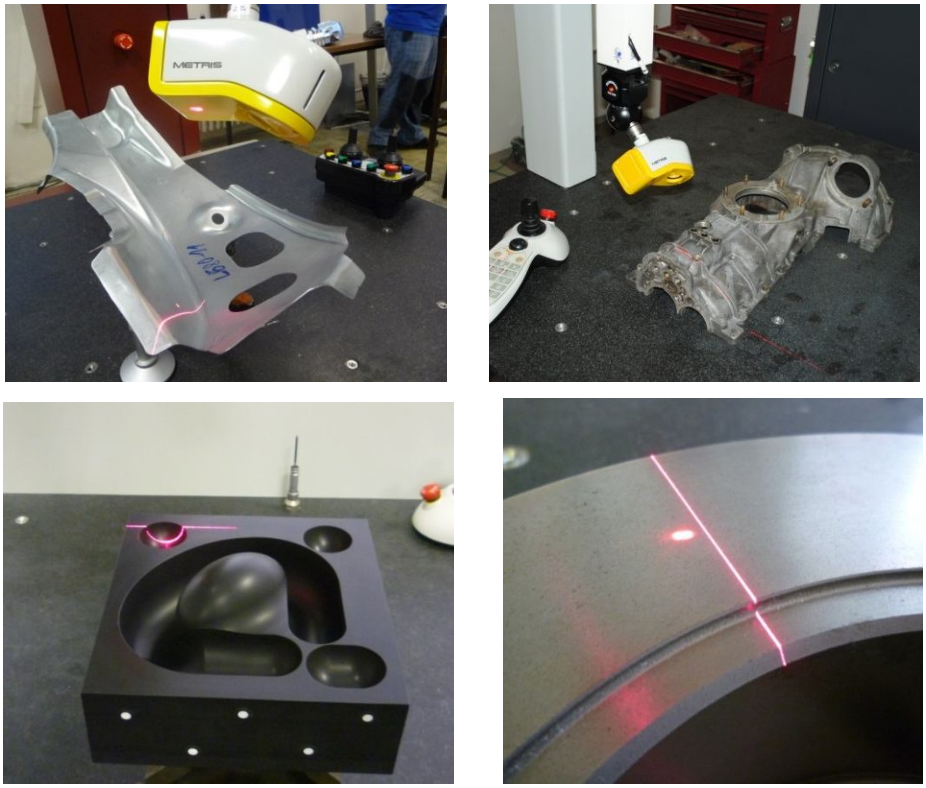

Fig. 10. *Examples of parts with easy to scan surface*

These surfaces can occasionally induce some of negative phenomena (especially secondary and direct reflections). It depends on concrete form of the part. E.g. secondary reflection on trim edge of sheet metal component. The scanner can be adapted for concrete type of the surface by simple changing scanning parameters, that are valid for complete part. Resulting point cloud contains negligible number of outlying points, that was generated by a local reflections or scanning line split on edges. Those points are reliably filtered during data postprocessing and will not affect point cloud anymore.

This category includes surfaces of rubber parts, sheet metal components, castings with machined functional areas.

Table 2 *– Recommended parameters for easy to scan surfaces*

Parameter	units	value
Laser intensity	[1]	automatic
Minimum intensity of reflected signal	[1]	25-50
Exposure	[1]	4 - 20
Reflection filter	-	yes
Point distance	[mm]	0
Stripe distance	[mm]	0,1 - 3

Difficult to scan surfaces

Highly reflective surfaces (mirrors) or less reflective black surfaces (e.g. black shiny surface of plastic components, semi-transparent surfaces), rugged surfaces.

Fig. 11. *Example of objects with difficult to scan surface*

On a difficult to scan surface we cannot avoid the negative phenomena. Certain parts of the surface are filtered out due to a big amount of secondary reflections. Other parts cannot be captured due to direct reflection. A point cloud contains bigger number of outlying points (noise) especially in neighbour of edges. Small details are distorted from this reason. Scanning parameters must be changed almost for each scan. Although that fact it is not possible to completely scan the part, only in a case that a mattifying spray is used. There are frequently used transparent or semi-transparent materials, where the diffusion reflection is created under a real surface. That causes an error dimensional measurement on such surfaces. This effect can be partially eliminated by decreasing the intensity of the laser beam, then the penetration depth will be smaller.

***Table 3** – Recommended parameters for difficult to scan surfaces*

Parameter	units	value
Laser intensity	[1]	automatic or manual if transparent
Minimum intensity of reflected signal	[1]	10-30
Exposure	[1]	20
Reflection filter	-	yes
Point distance	[mm]	0
Stripe distance	[mm]	0,1 - 3

2. Scanner qualification, warmup period

There are almost the same sensor qualification rules both for the laser line scanners and tactile sensors. Qualification is performed on a reference artefact, usually sphere or plate. Validity of qualification is dependent on fixing scanner to the construction of CMM and changing of environmental conditions in time.

The corrections obtained from the sensor qualification become not valid after a certain time. It is due to environmental temperature changes, collisions, dirts, rigidity of fixing the probe head to CMM quill, or repeatability of CMM reference position. Error qualification or a measurement can be caused also by skipping a sensor warmup time. The scanner is containing a source of laser radiation, that heats a construction of the scanner. This fact causes a change of triangulation angle and extension of scanner mounting pin. It is necessary to keep certain time for the scanner stabilisation to avoid temperature stabilisation error during qualification or measurement. Manufacturers of the scanner are trying to minimise this temperature drift by adding a cooler fan to scanner body, but it is not enough to eliminate effect of warming up completely. User should know warm up time to keep it before measurement. This parameter is missing in scanner specification declared by manufacturer, moreover there is said that warm up time is zero for LC15Dx [5]. This statement is not probable, since previous type of the scanner LC50 needed more than one hour warm up time [2]. From this reason there were made a measurement with two types of scanners: LC60Dx and LC15Dx from Nikon Metrology actual product range.

1.6 Warm up test procedure

A calibrated reference plate with defined planarity 0,01 mm was placed on a CMM table. A basic scanner orientation was chosen (indexing head axes position: A=0°; B=0°) to focus the scanner on the middle part of the reference plate (marked green in the figure 12), where are no edges.

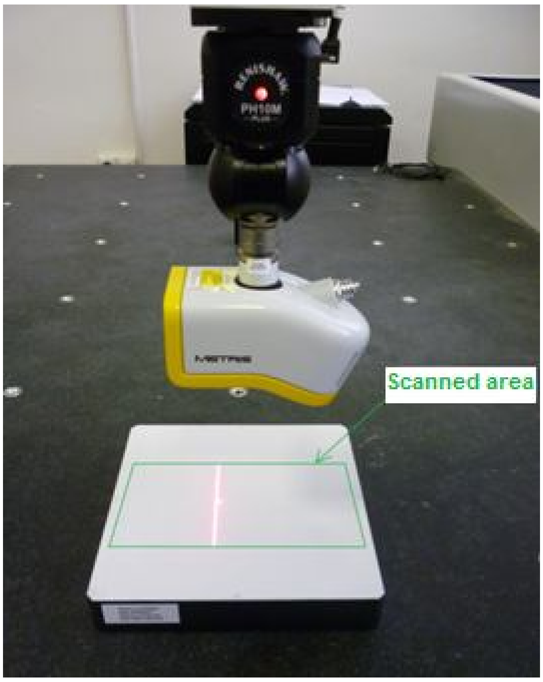

Fig. 12. *A warm up test configuration: CMM LK Altera 15.10.7, scanner LC60Dx, reference plate with green marked scanned area 175x60 mm at LC60Dx, 175x18 mm at LC15Dx.*

The reference plate was scanned with a parameters stated in table 4. The scan was repeated every 5 minutes from the start up to at least 1 hour from the start up, when the scanner should be fully stabilised, based on experience with previous type of scanners. The scanner was positioned in three different distances from the plate, to get data from complete range of field of view.

Table 4 *- Parameters of warm up test*

Parameter	units	value
Laser intensity	[1]	automatic
Minimum intensity of reflected signal	[1]	50
Exposure	[1]	1
Reflection filter	-	no
Point distance	[mm]	0
Stripe distance	[mm]	0.5
Filter saturated points	-	no
Continuous scan	-	yes
Scanned area dimensions	[mm]	175x60
Point cloud filtration	-	no
Ambient temperature	°C	25

The plate was scanned by the bottom, by the middle and the top margin of field of scanner view. A least square plane was fitted to every scan. A coordinate of the middle of the plane z_r parallel to Z axis of the CMM was recorded to the table. Additional information such as number of points in the point cloud n, standard deviation s and range R calculated from perpendicular distances of single points d_i from fitted plane.

$$s = \sqrt{\frac{\sum_1^n d_i^2}{n}} \qquad (1)$$

$$R = d_{max} - d_{min} \qquad (2)$$

The first scan was set as a reference and positions of the other scans are evaluated as a perpendicular distances d_j from the reference scan.

$$d_j = z_{r\,j} - z_{r\,0} \qquad (3)$$

Distances d_j were plotted in a graph d_j-t, where t is a time elapsed from the scanner power up.

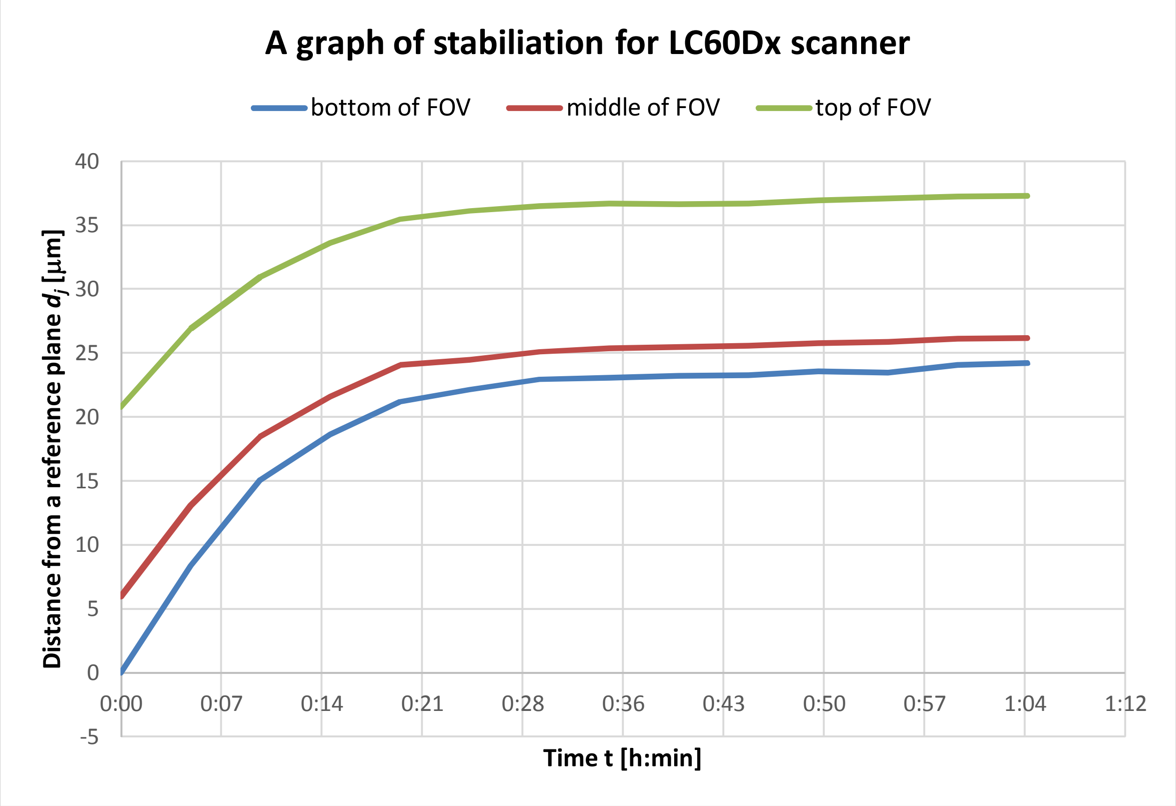

Fig. 13. *A result of warm up test for the LC60Dx scanner*

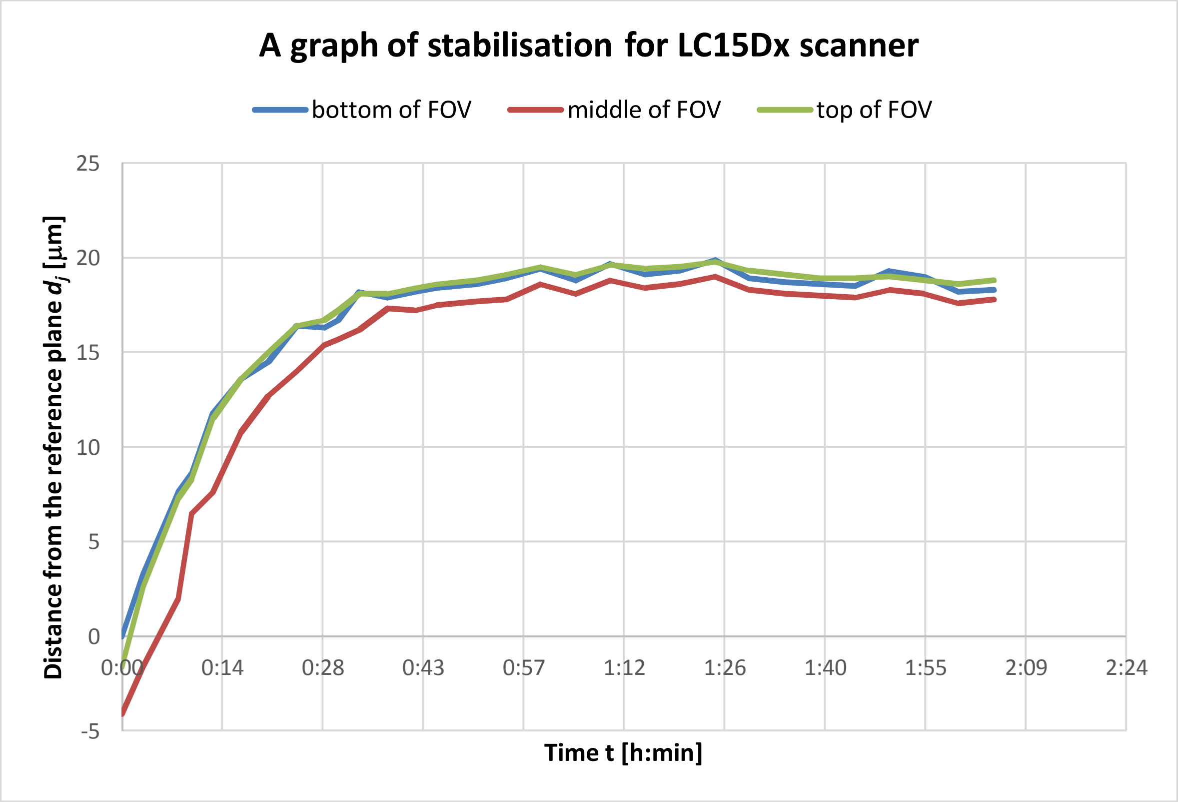

Fig. 14. *A result of the warm up test for the LC15Dx scanner*

The graphs show that a time needed for the stabilisation of LC60Dx scanner is 30 min, and for LC15Dx scanner 45 min. User should keep this time before starting of measurement, otherwise the error maximum of 37 µm at LC60Dx and 20 µm at LC15Dx can be brought to the measurement.

Table 5 *– Results of the temperature stabilisation (warm up) test*

Scanner type	LC15Dx	LC60Dx
Stabilisation interval	45 min	30 min
Stabilisation error	20 µm	37 µm
Max. difference between top and bottom of FOV	6 µm	20,8 µm

Conclusion

A problems of the negative phenomena accompanying the scanning with laser line scanners were observed. Effects of the secondary reflections, direct reflections, scanning over edge, and scan overlapping were described. All these phenomena influence final quality of a point cloud, e.g. form deviation of measured object. A measurement of more than 50 components (sheet metal, castings, machined parts) was performed. As a result from the measurement there are stated recommended parameters of scanner setup for three most frequented types of surface. These parameters can be used as methodological support for users of laser line scanners.

This paper also shows influence of the heat generated by the laser source inside the scanner. Scanners need certain time to get in to stable state after start up. A measurement was performed to determine this time and a magnitude of an error caused by a stabilisation process for two types of scanners from Nikon Metrology actual product range. The stabilisation time for LC60Dx is 30 min, for LC15Dx is 45 min. It is shorter than time at previous type of scanner, where the stabilisation time was longer than 1 hour [2], but it is still not zero. It must be taken into account before measuring with the laser line scanners otherwise it will bring a systematic error to a scanner output of more than 20 μm.

Used symbols and abbreviations

CCD – Charge-Coupled Device
CMM – Coordinate Measuring Machine
d_j – perpendicular distance between reference plane and j^{th} scanned plane
FOV – Field Of View
MCA – Manual Coordinate Arm
MPEe – Maximum Permissible Error (according to ISO 10360)
PH10M – type of Renishaw motorised indexing probe head
R – range of all point distances from least square plane
s – standard deviation calculated from all point distances from least square plane
z_r – coordinate of the middle of least square plane fitted to reference point cloud

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