# A COMPARISON STUDY OF ON-CMM LASER SCANER AND TOUCH TRIGGER PROBE FOR AUTOMOTIVE MEASUREMENT APLICATIONS

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**Abstract**:

Coordinate Measuring Machines (CMMs) are considered as the most accurate metrology equipment and are used widely in the manufacturing sector. Traditionally, touch trigger probes have been employed but more recently non-contact laser scanning sensors have been developed, offering potential advantages in terms of speed and number of points captured. Laser scanning is attracting significant interest from industry due to its ability to characterise complex, free-form surface geometries which are becoming common in the styling of automotive body panels. However, laser scanning sensors do not currently offer the accuracy and repeatability that can be achieved with touch trigger probes. Furthermore, there are no recognised standards for qualifying non-contact probes, making reliable verification of measurements difficult to achieve. Past research has attempted to qualify the capability of different non-contact probing technologies using small artefacts designed for technology validation; however, little work has been done on the verification of on-CMM laser scanning technologies for large volume, industry-relevant measurement applications. This study used a full-scale machined physical representation of a sheet metal vehicle body to evaluate the measurement agreement and repeatability of a laser scanning sensor, relative to touch trigger probe measurements, mounted on a horizontal arm CMM using individual surface points, edge points and circular holes, located across the entire structure. Through the use of a static repeatability analysis it was found that there was good correlation between touch trigger probe and laser scanner measurements. Repeatability of the laser scanner was found to be better than 28µm for surface, edge and circular holes measurement. Accuracy of the laser scanner relative to the touch trigger probe measurements fell within a range of 50µm which is a factor of 10 lower than typical automotive body-shell manufacturing tolerances. The results collected demonstrate that laser scanning sensor and CMM used in this study would provide a level of accuracy and repeatability better than which is typically required by automotive manufacturers for body-in-white quality inspection applications.

**Keywords**: Laser Scanning, Non-contact Measurement, CMM, Measurement System Capability

## 1. INTRODUCTION

With the need for more competitive manufacturing capabilities, especially in automotive industry, it is vital for manufacturers to monitor their production processes and meet *design intent* [1]. Therefore, accurate measurements are essential in order to ensure their conformity to design specifications [2]. Coordinate Measuring Machines (CMMs) are typically used in dimensional metrology [1] with touch trigger probing systems usually employed. CMMs with touch trigger probes are considered as most accurate metrology equipment because the probe qualification process and measurement uncertainty are well-understood and defined by international standards [3]. More recently, multi-sensor CMMs are becoming popular, generally employing laser scanners due to increasing accuracy in laser scanners, recent development in computing hardware which handles more data, and new generations of software designed to deal with point cloud data. The main advantage of laser scanning sensors, in comparison with touch trigger probes, in the ability to capture many points in a short period of time and to measure contactless. These advantages are important for car manufacturers offering better CMM utilization, capturing more data which helps solving early design problems and dimensional quality control of free-form and complex surface geometries [4-5]. This is of particular interest for car manufacturers, as more measurement throughput will provide them to control and monitor process capability and prevent the need for further CMM investment [6].

There are a number of advantages of laser scanning; full-data capture, ease of operation and speed of data collection. The biggest advantage is its considerably higher measurement speed -up to 75,000 points per second compared to touch trigger probe one point per second. There are more things can be done with laser scan data (point cloud) such as reverse engineering and 3D CAD comparison which allows manufacturers measure to identify and prevent manufacturing defects.

Non-contact measurement technology can typically be categorized into four groups; triangulation, structured light (blue or white), photogrammetry and X-ray Computed Tomography (CT) scanners. Each technology comes with its own limitations, advantages and costs. Laser scanning sensors do not currently offer the accuracy and repeatability that can be achieved with touch trigger probes although they are well established in reverse engineering applications. The main reason is the strong influence of surface quality on measurement results and uncertainty in measurement [3-5]. In other words, measurement uncertainty is affected by the part being scanned.

According to the Guide to the Expression [13], measurement uncertainty is the uncertainty of results of a measurement on a coordinate measuring system. Ultimately, the objective of assessing uncertainty to make sure that the measurement results are reliable [1]. In many industries, metrologists are using 10:1 gagemakers's rule; Qbery and Jones 1920; Radford 1922; Rolt 1929; ASME 2001b cited in [1]. This means that a metrology process that would have 10 times better accuracy than the feature being measured as shown in Fig. (1)

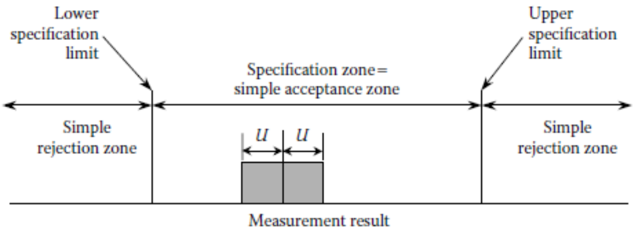


Fig (1): Simple acceptance zone (1)

To improve inspection efficiency and to achieve better results from CMM inspection, a number of challenges need to be addressed: inspection planning [17], data acquisition, and reporting, part and fixture orientation, touch trigger probe orientation and accessibility to component and probe path planning.. Moreover, the complexity of automotive components has dramatically increased in the last decade requiring more skilled operators to perform inspection tasks. For example, free-form surfaced components are difficult and complex to measure. This leads to slow data acquisition such that touch probe measurement technology is not very suitable for rapid data acquisition [4]. The recent developments in manufacturing systems have made the traditional dimensional part inspections bottlenecks in quality. Laser scanning by CMM provides a viable option to overcome such bottlenecks if its accuracy can be quantified in such an application.

Most research has focused on qualifying the capability of different non-contact probing technologies using small artefacts designed for technology validation [2,3,5] however, on the verification of on-CMM laser scanning technologies for large volume, industry-relevant measurement applications within automotive industry. Consequently, the main objective of this study was to use an artefact to evaluate the measurement agreement and repeatability of a laser scanning sensor, relative to touch trigger probe measurements.

## 2. MATERIALS AND METHODS

A LK-HG90 Horizontal Arm CMM (*Nikon metrology, UK*) was used for this study as shown in Fig (2). The accuracy of the CMM measuring arm was certified in accordance with ISO10360-2 with an expanded measurement uncertainty (k=2) of ±1.0 µm + 1.0µm/m. The CMM system configuration used is often seen in the automotive industry and provides access to measure vehicle exterior as well as interior and underbody. A PH10MQ indexing probe head (*Renishaw, UK*) mounted on the CMM measuring arm, which can carry a range of probes and extensions. The following CMM probing systems were used for this study.

Fig (2): A CMM arm with an automotive artefact placed on CMM bed

- **Touch probing system:** A TP20 5-way kinematic standard force touch trigger probe was used with 140mm extension and 20mm long by 2mm diameter stylus (*Renishaw, UK*).
- **Non-contact probing system:** A Metris XC65Dx (*Nikon Metrology, Belgium*) laser scanner was used. The scanner observes part from three directions, using three laser sources. Each laser line can capture 25,000 points per second (in total 75,000 per second)

The automotive artefact used for this study was aluminum CNC machined full-scale physical representation of the manufactured sheet metal body of a premium vehicle (*Jaguar Land Rover Limited, UK*), known as an Environmental Cube (E-Cube). The E-cube has interior and exterior surface features of a production vehicle body, allowing car manufacturer to verify fit, finish and alignment of adjacent parts for the trim maturation purpose and available for part inspection the full of the vehicle model production life [7-8]. The following sections detail the experimental set-up and the experimental procedure.

### *2.1 Experimental Set-up*

The artefact had machined flat faces on its base to allow it to hold rigidly on the CMM bed; hence, there is no need the fixturing of the artefact for CMM measurement. The environment was maintained at a standard 20°C ± 1°C throughout the study [9]. To transform the global coordinate frame of the CMM into the local part coordinate frame of the artefact, three datum plates located to the left side of the E-cube were measured with the touch trigger probe and then a three-axis alignment was performed. For laser scanning measurement, there are a number of parameters that need to be controlled and which have a critical influence over the accuracy of captured points [10]. For this study, a laser stripe distance of 0.1mm was used consistently and the laser profile was set according to the material type of each feature. The parameter values were chosen in order to optimize the laser scanning process, so that features measured with minimum dispersion.

### *2.2 Experimental procedure*

Once the alignment was completed, the measurement program of laser scanning and touch trigger probe was developed separately. For this study sixty-eight surface points, thirteen edge points and fifteen circles were measured. To evaluate laser scanner measurement results in comparison to the touch trigger probe the E-cube features were measured using the same local coordinate frame as the touch trigger probe. The measurement routine was repeated 30 times for each method to evaluate measurement repeatability. The experiment took place with the absence of light, except for three emergency lights located on LH wall of the laboratory.

### *2.3 Statistical Analysis*

In this study there were two comparisons, one for repeatability of each feature measured and a second for the mean difference in position. The repeatability of each feature measured was evaluated using the calculated 2σ and 3σ standard deviation values of the 30 sets of measurement results. This comparison was performed for both touch trigger probe and laser scanner.

## 3. RESULTS

Eight surface points out of sixty-eight could not be measured by XC65Dx laser-scanner. In touch trigger probe systems, the probe is fixed to the motorized probe head for controlling different orientations; known as A- and B angles. Total angular movement for A axis is from 0° to 105° in 7.5 steps and for B axis is 0° ±180° in 7.5 steps as shown in Fig (3). These features were measured with touch trigger probe using “A = 105°”probe angle. The maximum angle with the XC65 is “A= 97.5°”. Therefore these features lie outside of the acceptable incident angle for the laser lines. These surface points were located on the roof ditch area, cant rail and tailgate aperture as shown in Fig (4).

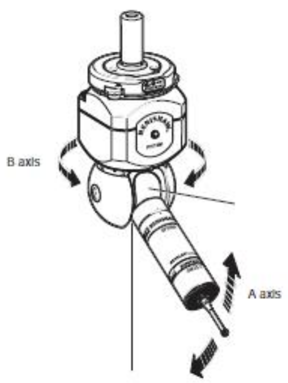


Fig (3): Illustaration of the PH10 motorised probe head

For laser scanning measurement, there were only two points with repeatability greater than 25µm and a further point greater than 50µm at 3σ standard deviation. Repeatability of the point greater than 50µm was due to one of the three laser sources of XC65Dx cross scanner being obscured by part of the body structure. Fig (5) demonstrates point measurement results in 2σ and 3σ repeatability distribution for laser scanning and touch trigger probe.


Fig (4): Examples of some features which cannot be evaluated by XC65Dx laser line scanner.

Two of the thirteen edge points measured by laser scanning were excluded from analysis due to numerous “failed to evaluate” errors in thirty runs. The reason for this inability to calculate a value from the collected data for these two points is not known and requires further investigation. The average 3σ repeatability for laser scanner was 14.3µm compared to 6.4µm with touch probe trigger. Overall, the main difference in position from evaluated edge point’s measurement results was 23.7µm with stronger agreement being shown with touch trigger probe as shown in Fig (6).

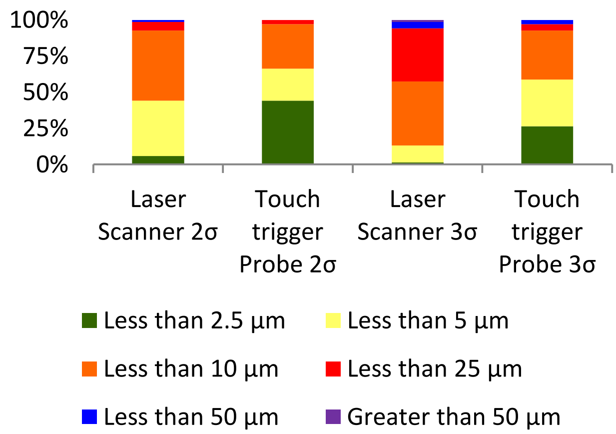


Fig (5): Points measurement results in 2σ and 3σ repeatability distribution.

Ten of the fifteen circle features were threaded holes and five of them were non- threaded holes. The average 3σ repeatability for touch trigger probe was 4.3µm compared to 27.5µm with the laser scanning scanner. The mean difference in position was 13µm.

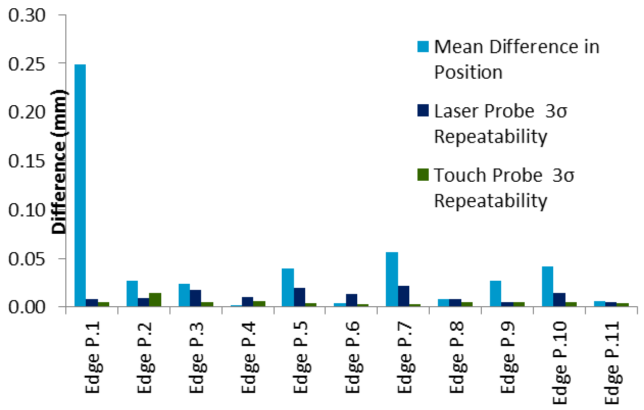


Fig (6): Edge points measurement results in 3σ repeatability distribution.

## 4. DISCUSSION

In manufacturing industries, it is vital to comply with the geometric specifications on the drawing [1]. Therefore, there is a need to make a useful measurement plan before developing the measurement program. American Society of Mechanical Engineers (ASME) standard *B79.7.2-1999*: *Dimensional Measurement Planning* is a good discussion point of measurement planning [11]. CMM technology generates discrete point measurements to create ideal geometric elements such as circles and slots, commonly used by automotive manufacturers, comparing with nominal part geometry in order to detect errors in the production system. However, there is close link between the cost of measurement (i.e. time, resources, operator and so on) and the number of discrete points identified. Therefore, there is a trade-off between the number of surface point can be measured and measurement time. Automotive manufacturers aim to minimize the number of inspection points to reduce costs [12], causing disputes between managers and quality departments; management believe they measure too much whereas quality department say that do not measure enough. Overall, for manufacturers, it is vital to maintain up to date with their measurement capabilities.

In evaluating measurement system capability and correlation between systems, the authors categorize measurement error metrics by part feature type. The feature types investigated in this study include surface points, edge points, and circles. Surface and edge point features have shown that it should be possible to obtain a 3σ repeatability of 25µm or better using laser-scanner. For example, 64 surface points out of 68 was 25µm or less. There is a strong agreement between the reported deviation values 98.5% of the measured deviations were within 50µm when measured with the laser scanner and touch trigger probe, as shown in Fig (7). The results suggests surface point measurements using touch trigger probe could be replaced with laser scanning; so it would help to reduce cycle time.

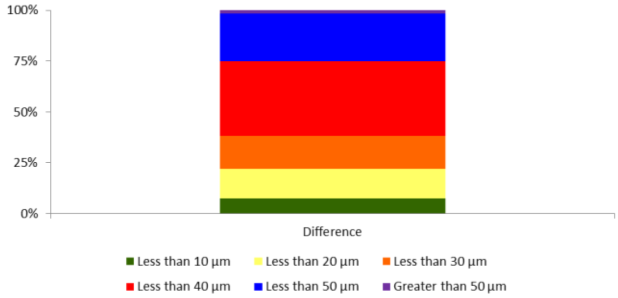


Fig (7): Difference between laser scanner and touch trigger probe measurement values.

The result of this study indicates that the repeatability of showing the XC65Dx laser scanner is 50µm or better, that the XC65Dx is capable of meeting typical industry standards, evaluating against: measurement system capability relative either to historical part variation values or to typical tolerance widths as mentioned 10:1 ratio in Introduction Section. Therefore, a tolerance ±0.5mm can be measured with confidence using the laser scanner in this study. Table (1) shows summary of the results on average at 2σ and 3σ level based on feature type.

Table 1: Summary of the repeatability results in average at 2σ and 3σ level.

| *Feature Type* | *Laser Scanner* | | *Touch Probe Trigger* | |
|---|---|---|---|---|
| Sigma Distribution | 2σ | 3σ | 2σ | 3σ |
| Surface Point Measurement | 7µm | 10.6µm | 4.3µm | 6.4µm |
| Edge Point Measurement | 9.5µm | 14.3µm | 4.3µm | 6.4µm |
| Circle Measurement | 18.3µm | 27.5µm | 2.9 µm | 4.3µm |

With increasing cost in accomplishing the 10:1 ratio, it has becomes more important to companies to better understand the uncertainty in measurement and make appropriate decisions about their parts. According to risk analysis in ASME TR. B89.7.3.2 –*Measurement uncertainty and conformance testing* [16], there are always risks and associated costs involved that companies needs to consider when deciding on how to cope with measurement results which are close to the specification limits. Consequently, there are some challenges that need to be addressed to improve CMMs utilization, different probing solutions (with their uncertainty) and the ease of their use, especially in automotive industry, where profit margins are limited due to competitive market. The utilization of CMM systems could be improved using non-contact probing equipment by developing international standards for the uncertainty estimation methods for these systems. Also, many of them were tested at laboratory environment; it is still unclear how they would operate on the factory environment.

## 4. CONCLUSIONS

The findings from this study show that that the XC65Dx non-contact measurement system is an appropriate method to replicate touch trigger probe at least for certain features, such as surface point and edge points. As a result, the overall of conclusion of this research is that the XC65Dx non-contact measurement system represents a feasible measurement system alternative for automotive manufacturers in the context of measurement capability. Moreover, the non-contact measurement system offers substantial advantages over contact measurement system which provide discrete points measurements. It provides to fully measure a part; hence, the potential to make better decisions on how to solve upper-stream /downstream dimensional concerns.

The automotive artefact selected for this measurement study was E-cube, which is a machined product so that not all features measured are representative body-in-white (BIW) features due to manufacturing method, design and different color slides cover. There is need for further study on BIW to investigate how laser scanner can respond real production BIW.

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