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MODIFICATION OF RACING CAR CYLINDER HEAD USING 3D DIGITIZATION AND REVERSE ENGINEERING

ABSTRACT: Race car drivers experience that engines with identical technical specifications and of the same make did not have same characteristics and do not perform identically. Based on the driving experience, the considered cylinder head enables the engine to have better performance than serially produced parts. Today the technology behind 3D scanning is so advanced that it can be used equally to tactile coordinate measuring machines for geometric measurement. With 3D scanning of parts, the whole surface geometry is measured, and not only selected coordinates. The cylinder head were digitized using an industrial 3D scanner ATOS. After polygonization and transformation of the polygonal model into the desired coordinate system, the geometry of all 4 cavities is obtained, and one of the geometries is adopted as reference. By the process of reverse engineering, a digital twin is obtained and can be replicated an unlimited number of times. CNC machining of cylinder head was performed on 2 different engine cylinder heads. At the time of this paper preparation, the qualifying rounds for the race within the Serbian championship 2020 are being run. Preliminary feedback on the overall effect achieved by the described modifications are that the two engines performing identically.

KEYWORDS: racing car, cylinder head, 3d digitizing, reverse engineering, CNC machining

INTRODUCTION

Internal combustion auto racing events began soon after the construction of the first successful gasoline-fuelled automobiles. Automobile racing is a motorsport involving the racing of automobiles for competition. As one of categories, touring car racing is a style of road racing that is run with production-derived race cars.

Verba Racing Team is the team behind the successful driver Dragan Stojković (Figure 1). The team experienced that engines with identical technical specifications and of the same make did not have same characteristics and do not perform identically. In other words, one engine outperformed the others. In most cases, the reason for the difference makes the way the cylinder head is manufactured. The process consists of automated milling, followed by manual working with a grinding machine. The result of the manual grinding is that the same cylinder heads never become identical.

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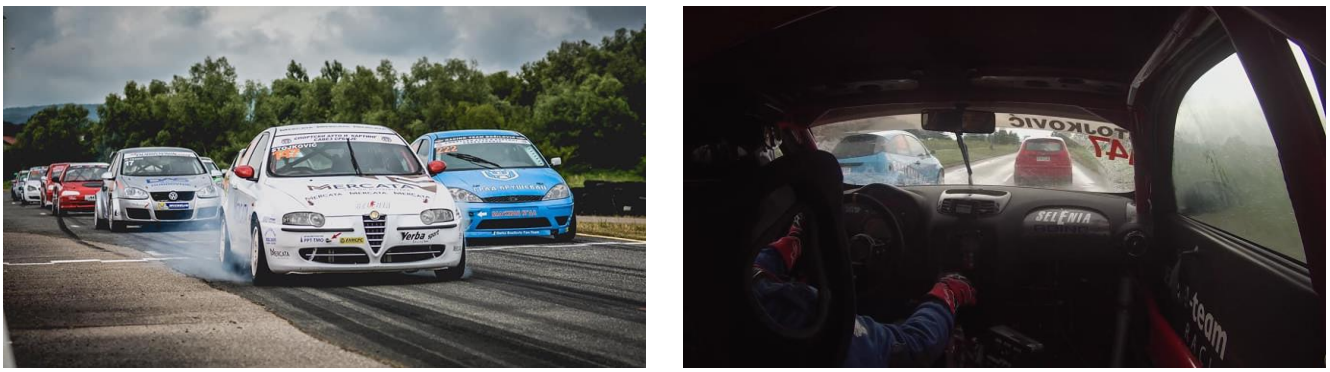
In this paper we make an exact copy of the preferred cylinder head to be able to mill a new cylinder head with the same geometric configurations. This way, the probability that the two engines performing identically is increased.



(a) *(b)*

Figure 1 Verba Team racing car based on Alfa Romeo 147 [9]: (a) exterior, and (b) interior

MATERIALS AND METHODS

We digitize the cylinder head using an industrial 3D scanner ATOS. After polygonization and transformation of the polygonal model into the desired coordinate system, we first compare the geometry of all 4 cavities, and then adopt one of the geometries as reference. According to that geometry we do reverse engineering and later CNC machining of the head.

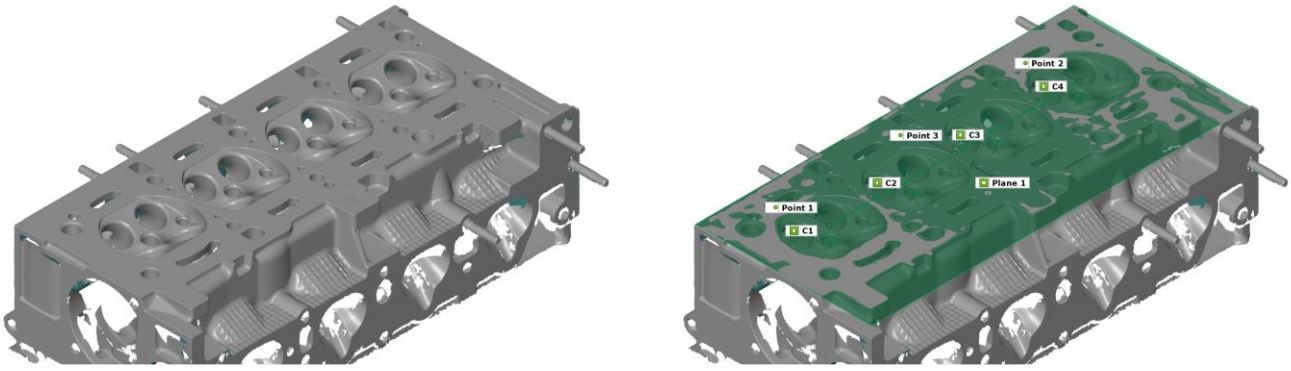
Advanced Topometric Sensor

ATOS (Advanced Topometric Sensor) [1, 6] is an industrial, high resolution, white light, optical 3D scanner (Figure 1). Instead of measuring single points, full part geometry is captured in a dense point cloud which can be translated into polygon mesh describing the object's surface and primitives precisely [2]. 3D scanner consists of sensor, control unit, computer hardware and software [3]. Sensor of optical measuring system consists of two high definition cameras and a projector. The scanning is based on optical triangulation and stereo-viewing [4]. A projector is used to project striped fringe patterns onto the object's surface. Change of shape of lines projected on irregular surface of measured object is recorded simultaneously by the two measurement cameras from different angles [16]. With the help of digital image processing, 3D-coordinates are computed fast and with high accuracy for up to 4 million camera pixels. The captured scan data is then automatically integrated in the predefined reference marker framework [5]. The additional data captured with two cameras of the ATOS system are used to verify the calibration of the system, detect movements and high ambient light changes during the measurement and verify the matching accuracy of the individual scans into the global coordinate system [7, 8, 18].

Common to all ATOS systems is fully accurate 3D measurement, detailed scan in high resolution, fast data acquisition, advanced inspection possibilities, complete geometric analysis and comprehensive reporting module [1].

Object of Digitization - Cylinder Head

In an internal combustion engine, the cylinder head sits above the cylinders on top of the cylinder block [10]. It closes in the top of the cylinder, forming the combustion chamber (Figure 2a).



(a) *(b)*

Figure 2 Poligonam model:
(a) model obtained by 3D digitization, and (b) transformation of poligonal model in desired coordinate system

The head also provides space for the passages that feed air and fuel to the cylinder, and that allow the exhaust to escape. The head is also a place to mount the valves, spark plugs, and fuel injectors. Based on the experience of Verba Team drivers, the cylinder head that we digitize enables the engine to have better performance than serially produced parts.

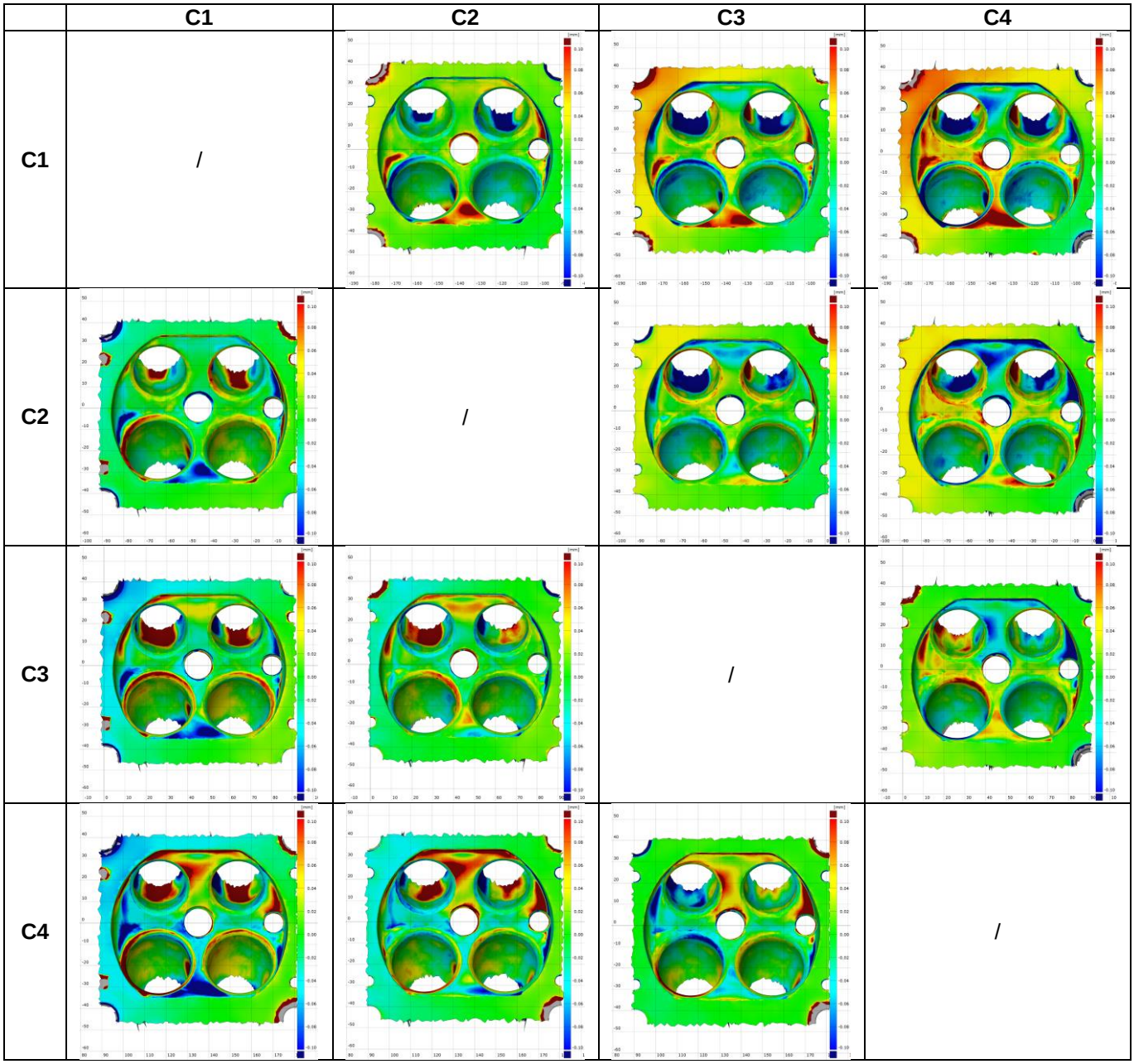


Figure 3 Mutual comparison of the cavities

Before scanning, the object was drained and thoroughly cleaned, as the resolution of the scanner is such that dirt particles, scratches, and other undesirable residue will be visible in the scan data. Most of the internal components are removed. For the scanning, the engine was placed on a high accuracy rotary. For the complete 3D scan of digitization object, 25 individual measurement were created, resulting in a dense scan data set. This scan data set was than polygonised and reduced in size by removing overlapping points. This triangulated file, called an STL file, is a facetted representation of the scan geometry. While we focused just on cavities of cylinder head, other areas are not captured during the scanning process (Figure 2a). Transformation of polygonal model in appropriate coordinate system is shown in Figure 2b.

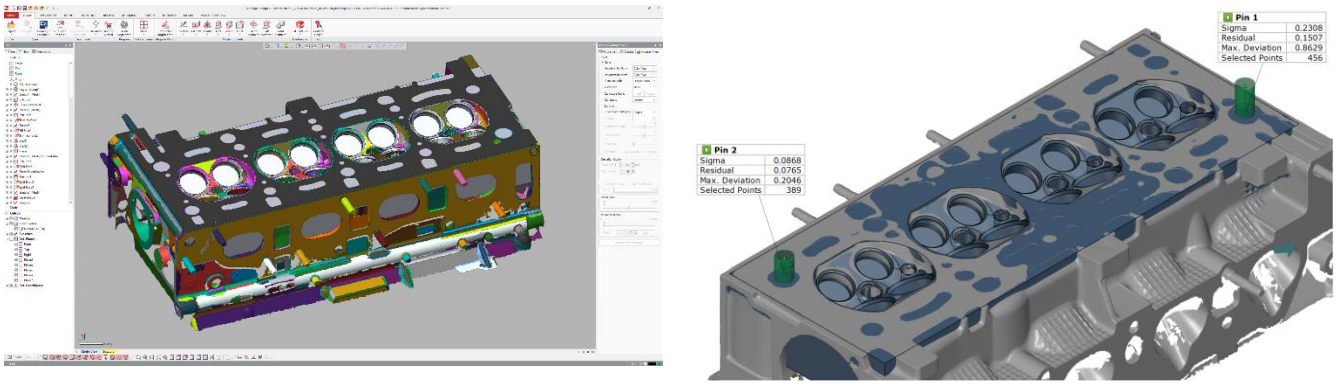
We obtained by 3D scanning 4 different cavities and it was necessary to determine which of them to reconstruct. The figure 3 shows a mutual comparison of the cavities (Figure 3) [14, 20, 21]. It should be noted that the members of the “matrix” are symmetrical with respect to the main diagonal, only the sign of the deviation is opposite. Comparisons around the main diagonal show smaller deviations, but it can also be noticed that cavities C1-C2 and C3-C4 should be grouped according to deviations. In addition, the deviations of the cavities that are more distant from each other are greater. Therefore, we decided to reconstruct cavity C1 from pairs C1-C2 and C4 from pairs C3-C4, as representable. In the continuation of the paper, the procedure on the reconstruction of the C1 cavity is presented.

Reverse Engineering of Cylinder Head

The STL file was then brought into Geomagic Design X (3D Systems Inc., Rock Hill, SC). Geomagic Design X is a complete Scan-to-CAD solution for various manufacturing and engineering applications. The software has reverse engineering and parametric CAD capabilities. (Figure 4a) [13, 17, 19]. The gap filling process is essential, as we want to end up with completely closed geometry to create a solid for use in SolidWorks.

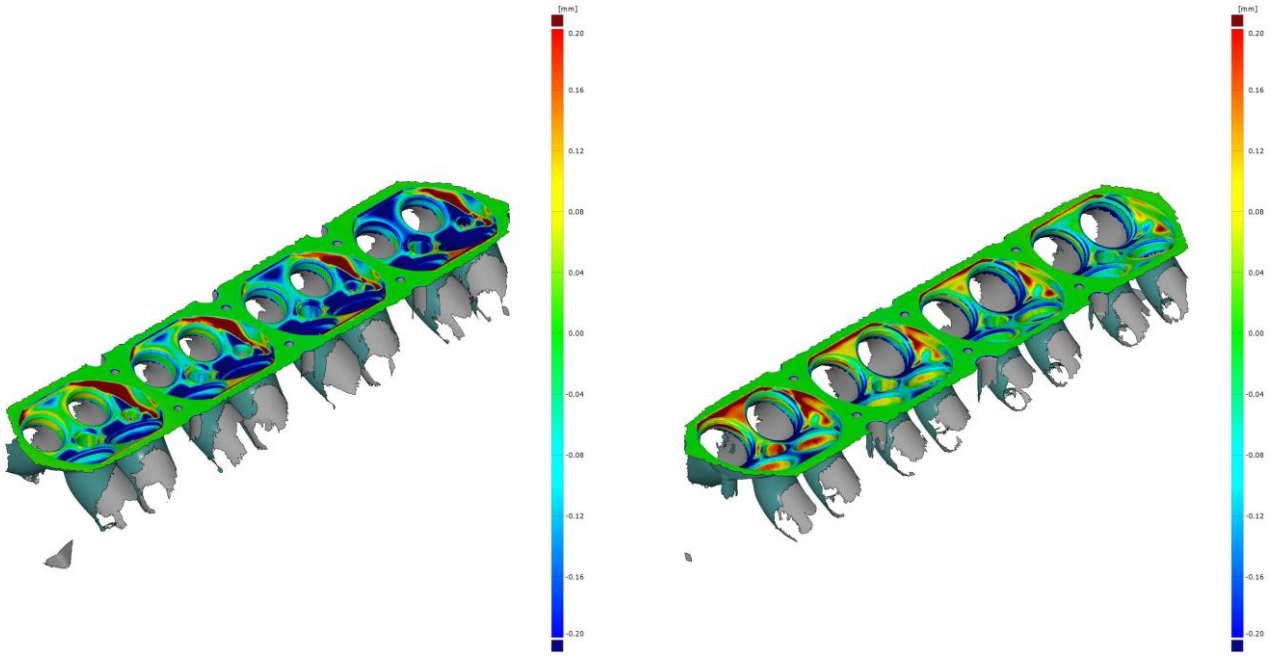
By comparing the reconstructed CAD model with the scanned geometry, we found that the deviations in the zone of the cylinder we reconstructed are minimal and that the reconstructed geometry faithfully describes the real configuration of the cavity (Figure 5).

Transformation of the CAD model in relation to the coordinate system of the machine was performed via Pins 1 and 2, for which we determined by measuring the circle that they deviate very little from the ideal circle constructed at the place where we will place the circle by touching the machine. In addition to these pins, we use the plane on which the cylinder head lies on the cylinder block and the direction of all 4 cylinders (Figure 4b).



(a) *(b)*

Figure 4 Reverse Engineering of Cylinder Head:
(a) Geomagic Design X, and (b) Positions of pins for transformation in CNC machine coordinate system



(a) *(b)*

Figure 5 Deviation of reconstructed surface in reference to scanned surface

CNC Machining of Cylinder Head

CNC machining of cylinder head was performed on DOOSAN DNM 5700 [11], the best-in-class vertical machining centre fully equipped with the most standard features built-in (BIGPLUS spindle, dual chip augers, FANUC 0i-M controls with Doosan's Easy Operation Package (EOP), through-spindle coolant, spindle chiller) (Figure 6a and 6b).

Since reconstrucion of geometry and generation of CAD model, 2 different engine cylinder heads have been made by CNC machning (Figure 6c).

(a) *(b)* *(c)*

Figure 6 CNC machining of cylinder head:
(a) DOOSAN DNM 5700, (b) machining process, and (c) finished part

CONCLUSIONS

Contemporary technology behind 3D scanning is so advanced that it can be used equally to tactile coordinate measuring machines for geometric measurement. With 3D scanning, the whole surface geometry of the part is measured, and not only selected coordinates. 3D scanning is primarily used for reverse engineering or quality control/part verification. The reverse engineering process consists of two steps: 3D digitization (the data acquisition) and the processing of the files into solid models.

The cylinder head were digitized using an industrial 3D scanner ATOS. After polygonization and transformation of the polygonal model into the desired coordinate system, the geometry of all 4 cavities is obtained, and one of the geometries is adopted as reference. By the process of reverse engineering, a digital twin of physical model is obtained and can be replicated an unlimited number of times. CNC machining of cylinder head was performed on 2 different engine cylinder heads.

Most of race car drivers experience that engines with identical technical specifications do not perform identically. Our main aim was to show a methodology by which any part of an engine can be replicated countless times. The complete procedure is shown on the example of the cylinder head. At the time of this paper preparation, the qualifying rounds for the race within the Serbian championship 2020 are being run. Preliminary feedback on the overall effect achieved by the described modifications are that the two engines performing identically.

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