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3D SCANNING APPLICATION TO IDENTIFY ASSEMBLY EFFORTS INFLUENCE ON A BRAKE BOOSTER

Caleb Carvalho Oliveira

Faculdade SENAI – Campus “Roberto Simonsen”
caleb1037@gmail.com

Fernando César Gentile

Universidade São Francisco
fernando.gentile@usf.edu.br

Leandro Cardoso da Silva

Faculdade SENAI – Campus “Roberto Simonsen”
leandro.cardoso@sp.senai.br

Abstract. One of the industry's main challenges has always been to guarantee the product's quality, requiring increasingly technological innovations for this purpose. In this context, with the industry 4.0 advent, 3D scanning technology emerges, which has been standing out as an efficient tool in the geometry analysis of parts and components, its operation is based on a digitalization process that converts a real object into digital format. One of the devices that has received special attention is the brake booster, which can be deformed during the assembly process, negatively impacting its operation in the vehicle. This paper objective is to evaluate, through 3D scanning, the influence of assembly efforts on the brake booster geometry, for which a series of analyzes was carried out comparing the results with a 3D reference model (CAD). All assembly stages that presented significant efforts were evaluated, and a graphical methodology was developed to interpret the deformation deviations of the parts, generating a new tool for decision-making in the automotive industry. The results obtained were interesting and provided improvements in the brake booster manufacturing process, reaching the proposed objective. With this, it is possible to perceive that 3D scanning plays a fundamental role in guaranteeing the products quality and optimizing industrial processes.

Keywords: Brake Booster, Dimensional and Geometric Analysis, 3D Scanner, COMET 3D, Point Clouds.

1. INTRODUCTION

Among the components responsible for a vehicle braking, there is a device named brake booster, shown in Figure 1. Whose purpose is to amplify the force applied by the driver's feet on the brake pedal and transmit it to the brake fluid, generating wheel's braking.



Figure 1. Brake Booster – Analyzed component.

In the brake booster manufacture, mechanical efforts are applied to several components to guarantee the correct fit between the parts and, consequently, some elastic-plastic deformations are created.

1.1 Purpose and justifications

This paper objective is to identify, through 3D scanning, geometric deviations that could compromise the brake booster quality, generated during its assembly.

This study accomplishment is of fundamental importance, as there are deformations that can cause the device to malfunction, and assembly process knowledge in its details provides a basis for solving possible current or future problems.

1.2 Brake booster

The brake booster is an essential component of automotive vehicle brake systems, amplifying the force applied to the brake pedal to provide efficient braking. According to Kawaguchi (2005), the booster is composed of many elements, such as the diaphragm, diaphragm spring, control valve and the operating rod, among others. The diaphragm acts as a divider between the constant and variable pressure chambers. The constant pressure chamber remains under low pressure (through a vacuum pump), which is the same pressure as the variable pressure chamber when the pedal is not activated (Sclar, 2015). This condition can be seen in Figure 2.1, which represents the brake servo at rest.

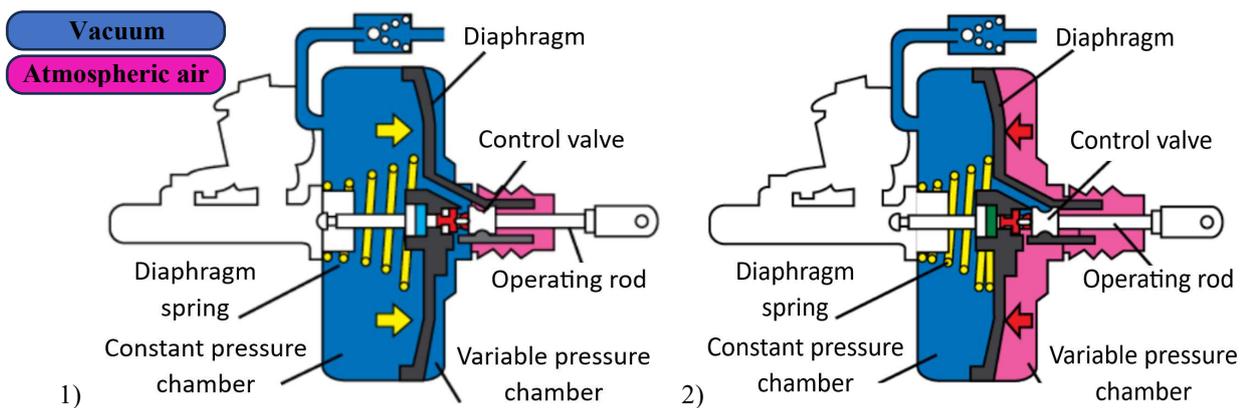


Figure 2. Brake Booster. 1) Brake pedal is not being actuated; 2) Brake pedal being actuated (Pietro, 2014).

When the brake pedal is pressed, the control valve allows air to enter the variable pressure chamber and the forces exerted on the pedal are added to the force generated by the pressure difference between the chambers. This forces combination is transmitted, through the operating rod, to the brake fluid. Figure 2.2 illustrates the activated brake booster, showing the components position in this state.

Consequently, the brake fluid is pressed inside the master cylinder, which in turn presses the brake fluid responsible for activating the braking devices on the vehicle's wheels. This process results in the generation of braking forces, allowing the vehicle to decelerate and stop safely, as highlighted by Pietro (2014).

1.3 3D Scanning

3D scanning technology emerges with the 4th industrial revolution and is closely linked with digital manufacturing (Haleem et al., 2022). It is a resource that provides the transformation of physical geometric data into digital data by creating a file in point cloud format that represents the shape and size of the scanned object (Haleem et al., 2020).

Its use is recent, when compared to industry current technologies, and its great advantage in relation to coordinate measuring machines (CMM) is the possibility of acquiring a much larger amount of data at the same time, as shown in Figure 3 below:

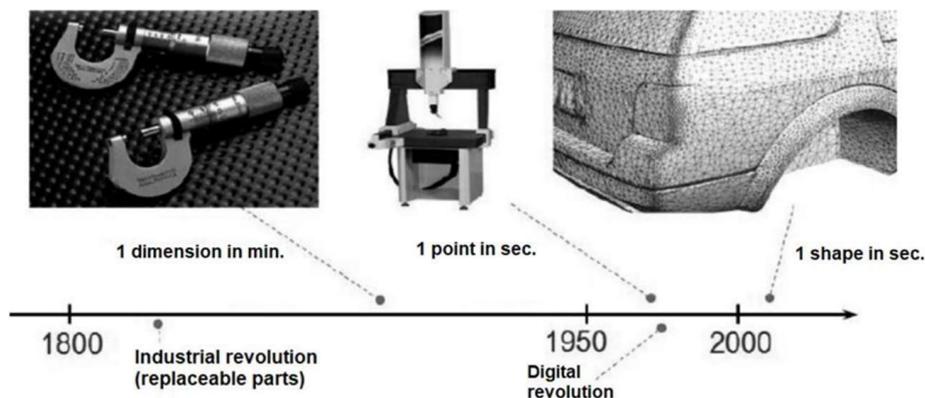


Figure 3. Object measurement historical development (Stojkic et al., 2020).

The equipment operating concept is based on the radiation in form of striped light (blue or white) that is emitted on the surfaces under analysis, as shown in Figure 4 below, it does not require physical contact, the light reflection is captured by a high-resolution camera (Jeught et al., 2016). The obtained data are then analyzed in a high-performance computer that locates all points coordinates in the camera visible area based on the inclination and thickness of the projected stripes on the piece through trigonometric calculations (Javaid et al., 2019).

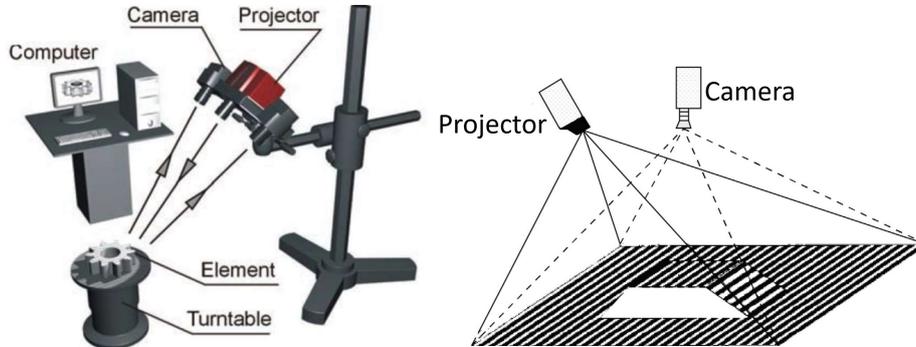


Figure 4. 3D Scanner operation concept (Stojkic et al., 2020 and Jeught et al., 2016).

This resource applications are diverse, the following examples may be cited: Reverse Engineering – Objects reconstruction/cloning; Quality Control – Products control during manufacturing; Architecture – Creation of historic buildings in virtual models; Art – Cataloging/reconstruction of cultural items such as statues and fossils; Medicine – Studies with living things, such as creating prostheses and anatomical studies (Tóth et al., 2014).

2. METHODOLOGY

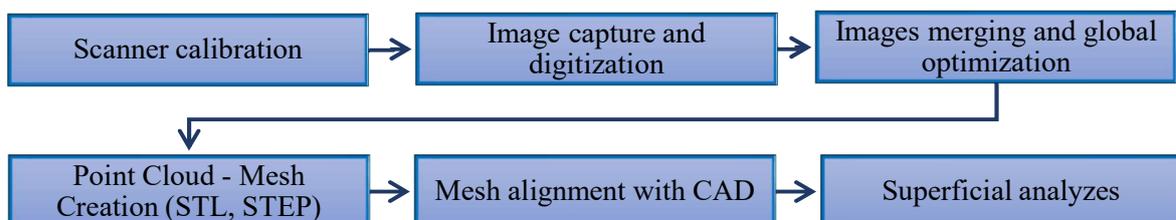
The used scanner is based on structured blue LED light, consisting of a camera and a projector, as shown in Figure 5. The manufacturer is the company Zeiss and the model used in this work was the COMET-LED-2; the software that groups the captures (point cloud) and creates and processes the meshes is Colin 3d.

The reference 3D model (CAD) creation was carried out in the Catia V5 software and the comparison between the 3D model and the mesh was carried out using the GOM Inspect software (surface analyses).



Figure 5. Zeiss 3D scanner COMET LED 2 – Scanner used in the analyses.

The methodology used in this study focuses on quality control, through the part dimensional analysis. The method used in this case follows steps that are indicated in the diagram shown below (Kumar et al., 2018 and Bernal et al., 2013):



2.1 Scanner calibration

Like any measuring instrument, the scanner also needs a proper calibration, which was done before each group of measurements. In the calibration process, a special checkered plate, as shown in Figure 6, is scanned in different positions. These captures are then associated with each other, giving the software a reference to ensure accurate measurement results (Bernal et al., 2013).

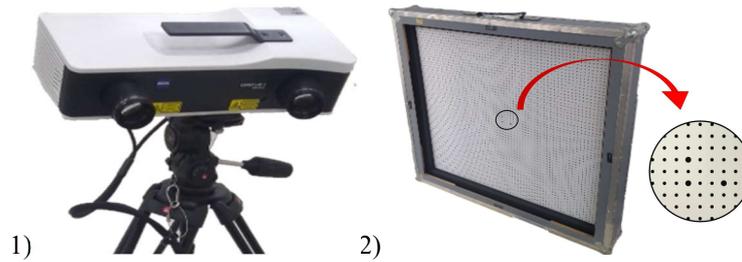


Figure 6. 1) Scanner; 2) Calibration plate.

2.2 Image capture and digitization

This step objective is to capture the maximum details of the part being scanned, mainly the regions that will be analyzed later. With that in mind, the piece was positioned on a turntable, which allowed a complete scan around a rotation axis, according to Figure 7. The piece was covered with white powder, which considerably improves the scanner's optical capture conditions. The white color reflects light better, and the powder can be easily removed with a cloth.

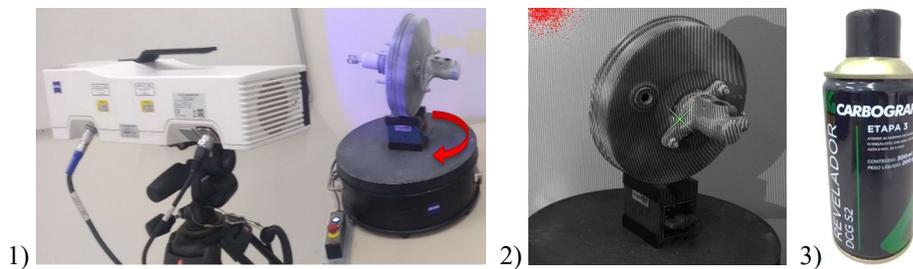


Figure 7. 1) Image capture process; 2) Image captured by the scanner; 3) White powder used to cover the piece.

2.3 Images merging and global optimization

Usually, with just one scan, it is not possible to perform all the necessary data collection. In these cases, after acquiring two (or more) captures, it is noticed that it is necessary to merge them. For data merging, it is necessary to observe common geometries (surfaces, edges, etc.) so that they are brought to the same coordinate system (XYZ axes).

After the alignment, a resource was used that allow to evaluate the convergence degree between the captures. This resource is known as global optimization, it displays a color gradient on the capture's surface, in which it is possible to verify possible regions with misalignment, which are highlighted in red, as can be seen in Figure 8 below:

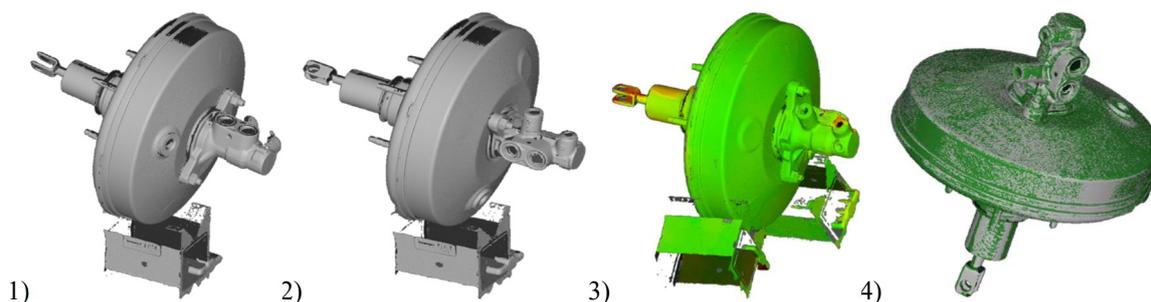


Figure 8. 1) First scan; 2) Second scan; 3) Global optimization; 4) Final merge.

At this stage, it was necessary to be careful when eliminating details that were not part of the object. In Figure 8, for example, between stages #3 and #4, the magnetic base that served as support during scanning was removed.

2.4 Point Cloud – Mesh Creation (STL, STEP)

The result obtained through 3D scanning is a cloud of points, however, its representation in space needs to be in a structured form. This representation was performed using a triangular mesh that was adjusted to the cloud of points. As the capture resolution increases, the triangles amount present in the mesh also increases. An example is the Figure 9, which has 3.4 million triangles with an average edge of 0.35 mm.

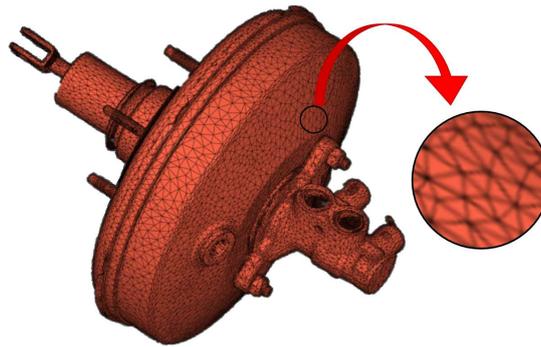


Figure 9. Triangles mesh – STL file extension.

2.5 Mesh alignment with CAD

The triangular mesh obtained has a coordinate system oriented randomly (as shown in Figure 10.1 for example), for this reason it was necessary to take references so that the orientation is adequate according to the analysis needs. The correction was made by superimposing the mesh on a 3D model (CAD), which has a defined orientation, taking as reference geometric shapes present in the brake booster, to fix the six degrees of freedom of a free body (plane, line, cylinder, etc.), as shown in Figure 10:

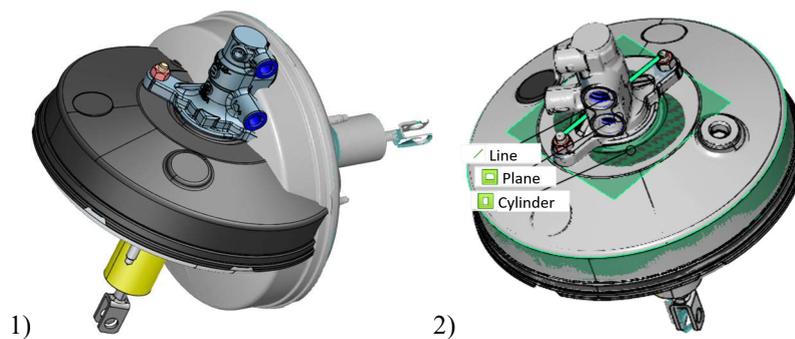


Figure 10. 1) Before alignment – Random orientation (example); 2) After alignment – Same CAD orientation.

2.6 Superficial analyzes

Through the alignment shown in Figure 10, it was possible to evaluate some divergences between the surfaces, taking the CAD model as a reference, this is done through a color gradient, in which were visualized regions that are coincident (in green), positive deviation (in red) and negative deviation (in blue). To identify the value in millimeters of the displacements generated by the deformations, a bar was used as a reference, in which it is possible to identify maximum and minimum values of variation, as shown in Figure 11.

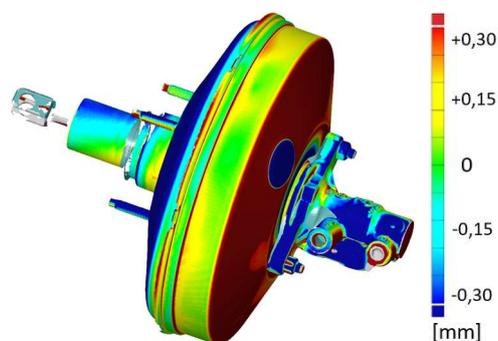


Figure 11. Data obtained through surface analysis – Range ± 0.30 mm.

Based on these data, it was possible, after each assembly stage, to understand how the components were deforming, and when deviations outside the specified range were identified, the responsible department was contacted so that a correction could be made. The brake booster assembly involves many stages; however, the study was directed only to

those on which there were significant mechanical efforts. Each step of the methodology mentioned above, except calibration, was applied in each of the following important assembly stages: 1) As-supplied component condition (upper housing); 2) Lower housing screws crimping; 3) Lower and upper housings crimping; 4) Screwing of process nuts; 5) Finished product – After master cylinder assembly. In Figure 12 these steps can be seen:

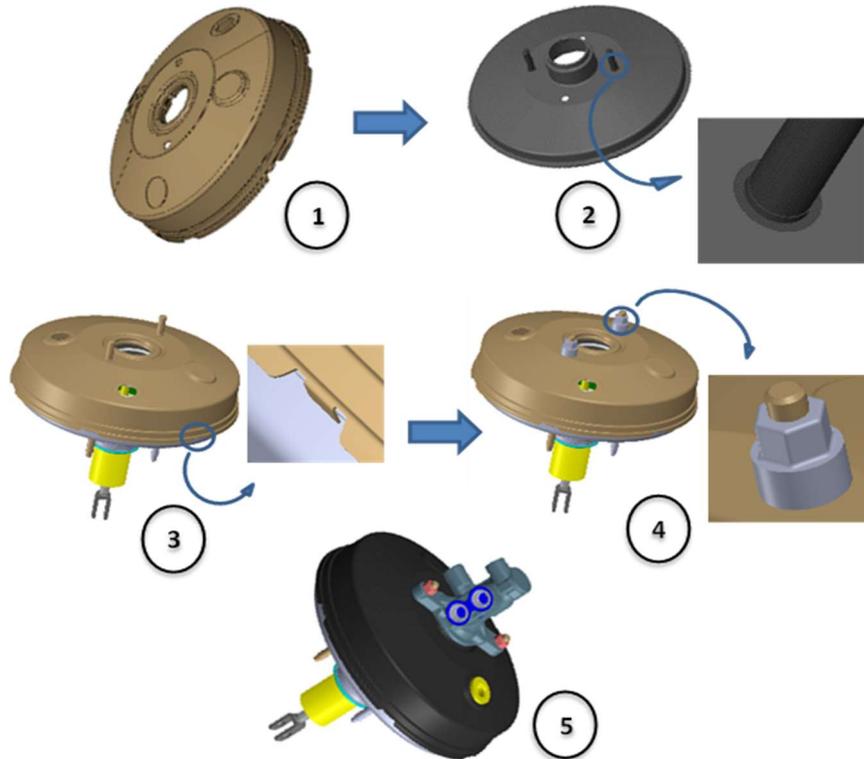


Figure 12. Assembly steps that are subject to stress and deformation.

In steps 1, 3, 4 and 5, the main dimensions to be evaluated are: dimension of 49.5 mm (+0.3 mm) and master cylinder support face flatness (< 0.3 mm), as shown in Figure 13. In step 2, only the upper face flatness (< 0.3 mm) is evaluated. Finally, in the last step (step 5), the 1 mm height variation will also be verified.

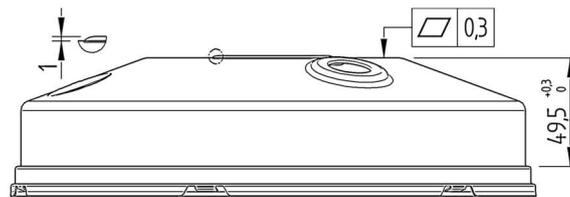


Figure 13. Analyzed dimensions.

The values were obtained through dimensional features of the analysis software (GOM Inspect), according to Figure 14. Through the dimensions highlighted in red, it is possible to evaluate the variation in the internal components' accommodation, making possible, indirectly, to know if was carried out the correct component's assembly.

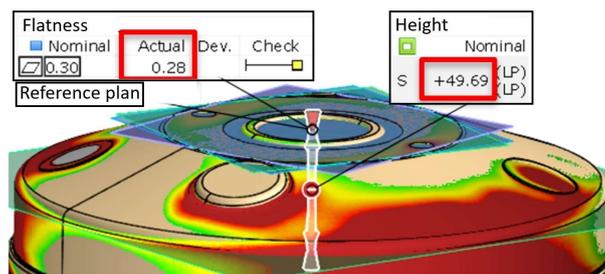


Figure 14. Obtaining dimensions in the dimensional analysis software.

3. RESULTS AND DISCUSSIONS

Before analyzing each step, the scanner was calibrated, a report was issued in which the equipment accuracy was exposed. In Figure 15, shown below, it is possible to see that the maximum error of the scanner is 0.024 mm, with the maximum permissible error being 0.038 mm, it means the calibration was done correctly.

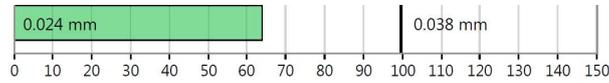


Figure 15. Scanner calibration results – Quality figure / threshold [%].

3.1 As-supplied component condition (upper housing)

In Figure 16 (step 1 of Figure 12), it is possible to visualize a highlighted red region and some blue regions in part of the housing outer contour, being remnants of previous processes (stamping). These deformations do not compromise the brake booster assembly conditions and operation, considering the parameters stipulated in Figure 13, the flatness is evaluated and as can be seen, there are no values that deviate from the stipulated.

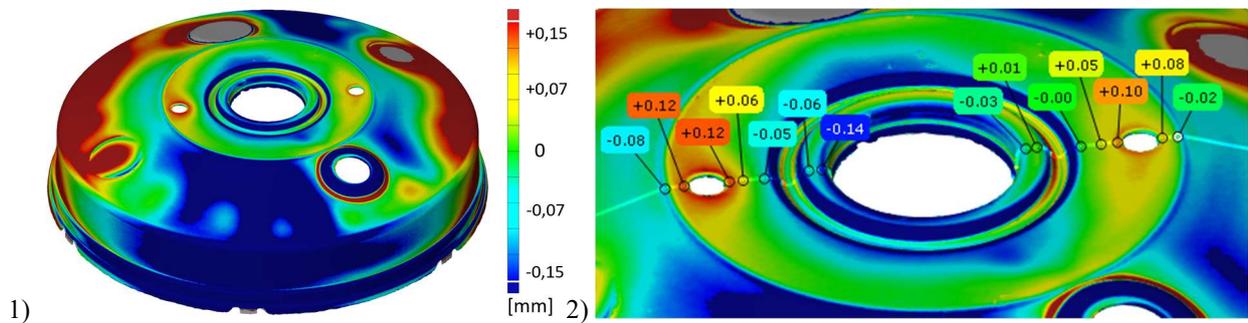


Figure 16. Results obtained in step 1. 1) Color gradient; 2) Tie rods holes region detail.

Like the flatness value, the reference height (49.67 mm) is also within the tolerance range, according to values shown in Figure 17.

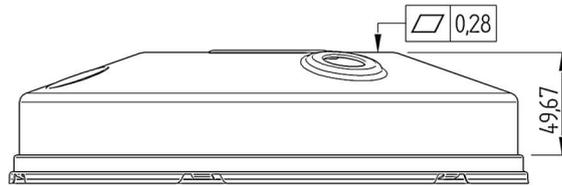


Figure 17. Results obtained in step 1 – Important dimensions.

3.2 Lower housing screws crimping

In the screws crimping into the lower housing (step 2 of Figure 12), the screw heads were deformed. It is crucial that the area around this crimp remains flat. However, when analyzing the results in Figure 18, it was verified that the crimping did not occur as expected, evidenced by the red region around the screws, indicating a flatness defect.

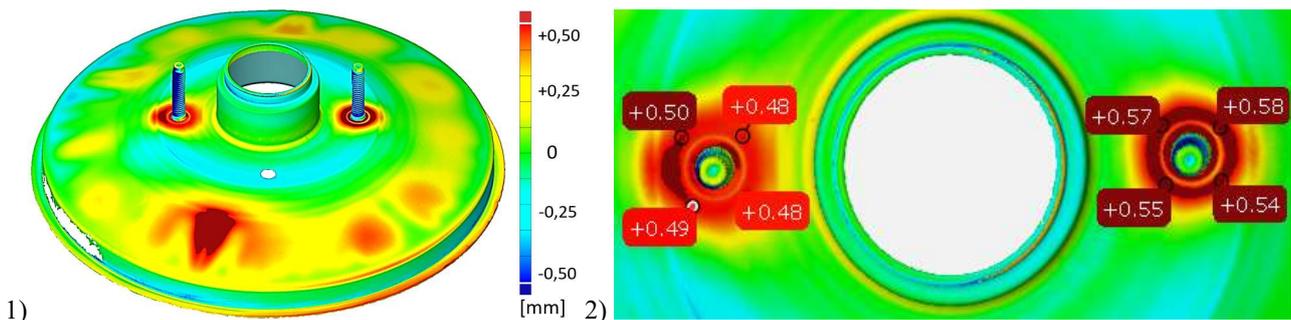


Figure 18. Results obtained in step 2 – Initial phase. 1) Color gradient; 2) Crimping region detail.

If the correction is not made, this deviation may cause improper operation due to brake booster poor seating in the vehicle, which may cause problems such as vibration, poor fixation, and screws warping, for example. Therefore, when the defect was detected, the group responsible for the tooling was called in to correct the issue and then carry out a new analysis. The changes made to the tooling proved to be effective and, as can be seen in Figure 19, the flatness defect was corrected to guarantee the quality and component proper functioning.

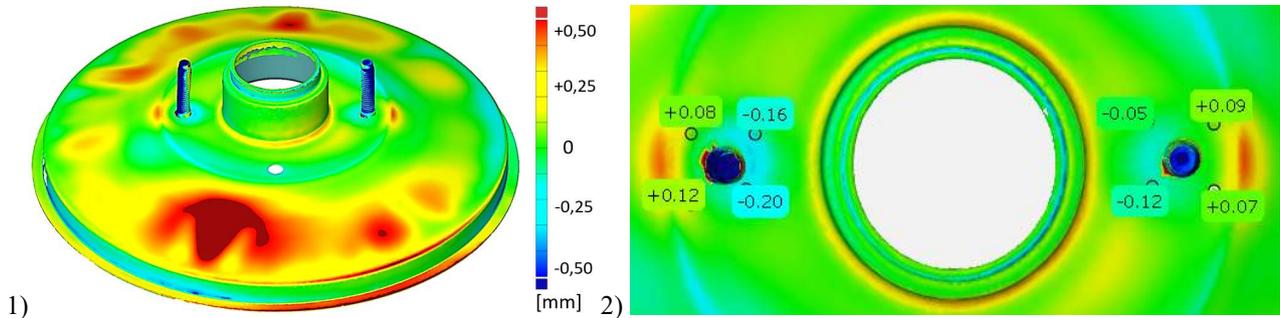


Figure 19. Results obtained in step 2 – Final phase. 1) Color gradient; 2) Crimping region detail.

3.3 Lower and upper housings crimping

To fix the set, a crimping process was performed, in which 12 flaps around the upper housing are bent, ensuring the attachment between the housings (step 3 of Figure 12). Inside the assembly, the diaphragm spring was positioned (Figure 2) and, as shown in Figure 20, a red region appears in the central part because of the deformation generated by the spring, forcing the housing outwards, a result that occurs as previously stipulated in the project.

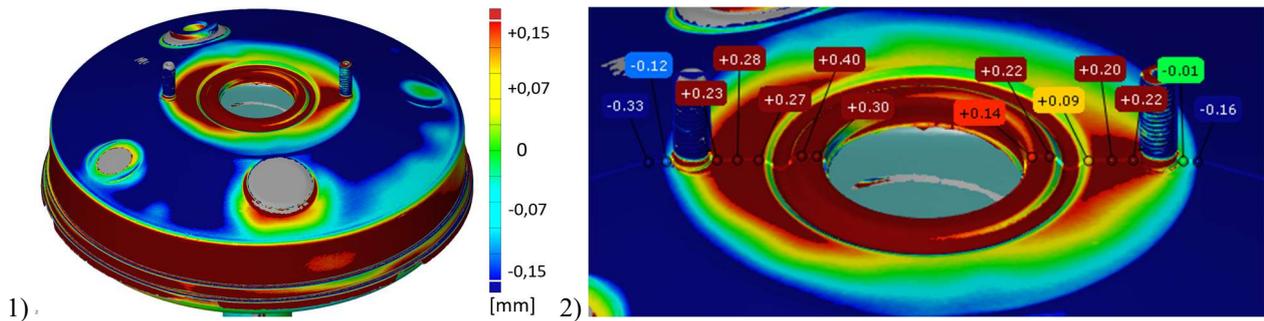


Figure 20. Results obtained in step 3. 1) Color gradient; 2) Tie rods region detail.

3.4 Screwing of process nuts

After the crimping step (Step 3), assembly of other components is carried out, followed by the measurement of a critical dimension that interfaces with the master cylinder, ensuring the assembly proper fit for subsequent operations.

For that, it is necessary to accommodate the upper housing and correct the deformation shown in Figure 20. To occur this, process nuts were screwed (step 4 of Figure 12), and as shown in Figure 21, the deformation generated by the spring was avoided and the top flatness corrected, this is concluded due to the green region around the process nuts.

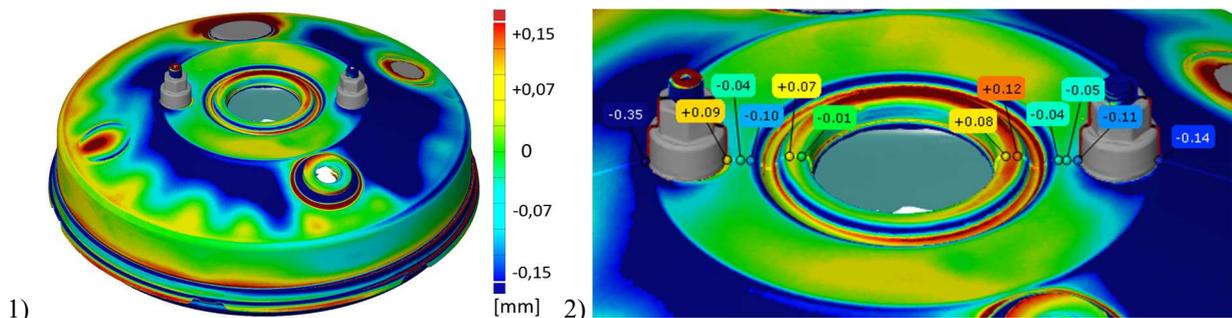


Figure 21. Results obtained in step 4. 1) Color gradient; 2) Tie rods region detail.

In Figure 22 below, the important geometries in Figure 13 are shown, both within the tolerance field:

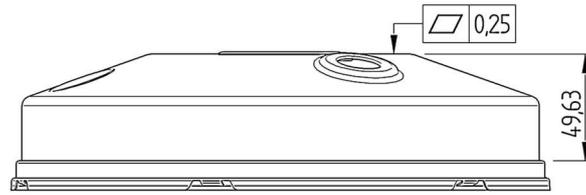


Figure 22. Results obtained in step 4 – Important geometries.

3.5 Finished product – After master cylinder assembly

During the final step, when assembling the master cylinder, significant deformations were observed on its support face, indicated by the intense color transition between red and blue in the region around the master cylinder. This reveals the presence of a depression in this region, as illustrated in Figure 23.

These deformations were a 1 mm displacement consequence of the protrusion, shown in Figure 13, so that it was leveled with the master cylinder flange face, as can be seen in Figure 24. This protrusion, when deformed, has the function of ensure brake booster tightness (sealing that does not allow leaks).

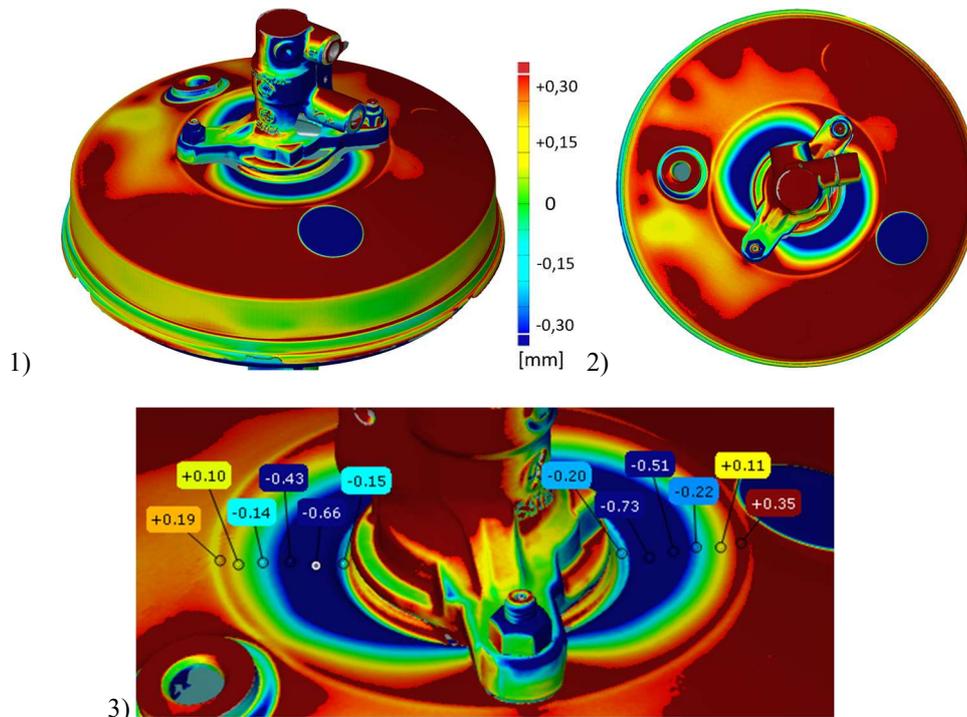


Figure 23. Results obtained in step 5. 1-2) Color gradient; 3) Deformation gradient region detail.

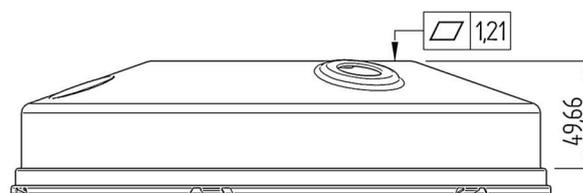


Figure 24. Results obtained in step 5 – Important geometries.

Although the flatness shown in Figure 24 (1.21 mm) has extrapolated the tolerance indicated in Figure 13 (0.3 mm), it can be safely said that the component will not fail for this reason, even because this deformation was already foreseen in the design. This statement comes from the fact that the reference height (49.5 +0.3 mm) remains very close in steps 1, 4 and 5, as shown in Figure 25, which demonstrates that the housing is not yielding during the load's application, ensuring that the internal components' accommodation was not affected.

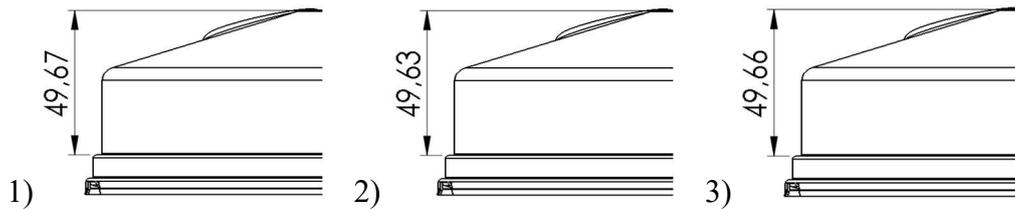


Figure 25. 1) First step; 2) Fourth step; 3) Fifth step.

It is extremely important to point out that the correct assembly ensures proper seating between the operating rod and the master cylinder, which are responsible for the correct braking perception by the driver, thus avoiding common problems, such as “pre-engaged brake” or “deep pedal”, often found on faulty brake boosters. The correct assembly guarantee is essential for an efficient and safe brake system performance.

4. CONCLUSION

Analysis using 3D scanning technology has demonstrated its effectiveness in identifying and correcting geometric deviations, highlighting this methodology in several applications. A relevant example is the application in product development, especially in the prototype phase. Through reverse engineering, it is possible to create geometric models (CAD) that accurately reproduce real parts, including small variations and imperfections inherent to manufacturing processes. Subsequently, these models can be imported into simulation environments (CAE), where finite element analysis (FEA) allows much more accurate predictions about the component’s performance and durability.

Furthermore, this technique can be applied to validate the new products industrialization with different geometries and tooling in the same machine, which expands its application scope, optimizing industrial processes and validating improvements and developments. It is also useful in analyzing the failures or defects root causes that may be related to manufacturing process deformations. Through dimensional reports, it is possible to identify or rule out the possibility that the problem is linked to the process.

In the current scenario, where excellence in manufacturing is fundamental, 3D scanning analysis presents itself as a valuable ally in the automotive industry and other sectors. The possibility of identifying deviations, correcting them, and supporting decisions in the critical components manufacturing is a notable advance. Therefore, we can conclude that the 3D scanning methodology applied in this study not only met expectations, but also paves the way for its implementation in product and process development projects, providing significant gains in terms of quality and efficiency.

5. REFERENCES

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