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STUDY ON MILLING STRATEGIES FOR MACHINING RADIATOR GUARDS USED IN ENDURO COMPETITIONS

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Abstract: *Off-road motorcycles are used for both cross enduro and hard enduro. Their use on rough terrain involves certain problems related to the fenders, which are part of these motocross motorcycles. At FM-PARTS, we redesigned and manufactured the fenders from a much more resistant material, compared to the factory one. To carry out this research, it was necessary to redesign the 3D model of the fenders used on KTM 2025 motocross motorcycles. For this 3D model, special devices and tools are required to be able to execute them on the CNC machine.*
Key words: *radiator guards, CNC machine, motocross parts, FEM model*

1. INTRODUCTION

In the category of off-road motorcycles, enduro bikes are included. These are mainly used for off-road travel and can be divided into two categories: Cross Enduro and Hard Enduro. Cross-class vehicles are not equipped with electrical equipment such as headlights and turn signals, so they cannot be ridden on public roads. Although they have the same engine displacement as the Hard Enduro models, there is a significant difference in performance. Motocross bikes accelerate faster, while enduro motorcycles are known for their tall build, high ground clearance, large front wheels, and knobby tires [1-2]. These two sports, motocross and enduro, share motorcycles as a common element, which may look similar at first glance, but there are several important differences between them. Enduro involves riding through natural trails, while motocross takes place on a track specially built for it, with artificial surfaces [3]. Enduro is more of an endurance sport, whereas motocross is more focused on speed and technical skill [4]. Similar to enduro motorcycles, motocross bikes are used in competitions on dirt tracks intentionally designed with many obstacles and jumps. Motocross tracks also feature both long climbs and descents, areas with a lot of sand and gravel, making motorcycle movement as challenging as possible [5-6]. For this reason, we aim to conduct a study on milling strategies [7-9] related to the redesign of radiator guards for the 2025 KTM motocross model. This can be achieved by optimizing the internal design of the radiator [10-11], increasing the heat exchange surface, and improving the airflow through the radiator. As a result, improvements can be observed, such as enhancing the cooling system efficiency of the KTM motocross to ensure better airflow and more effective heat dissipation [12].

Overheating can be a significant issue in motocross, especially under extreme usage conditions. The goal is to redesign the aluminum radiator guards to reduce the risk of overheating and to maintain the engine temperature within acceptable limits [13]. A secondary objective could be to redesign the radiator guards to give them a more attractive appearance and to match the overall design of the KTM motocross. Redesigning the aluminum radiator guards can lead to significant improvements in cooling efficiency, weight reduction, and component durability, thus contributing to the overall performance of the motocross bike [14]. It is important to carry out appropriate analyses, simulations, and testing to validate the new designs and to ensure they meet the specific requirements of motocross applications.

2. EXPERIMENTAL RESEARCH

The 3D model of motocross radiator guards is created using 3D modeling software, such as SolidWorks, which allows the designer to create, or digitally represent, the components of these radiator guards as shown in figure 1. This model can then be used to test the design and tolerances to ensure perfect fit and efficient operation of the components.

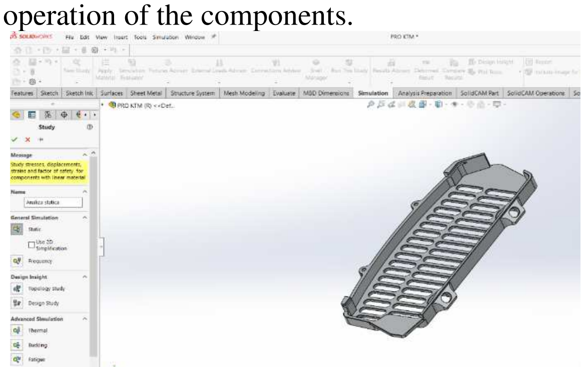

Fig. 1. 3D model of KTM motocross radiator guards – (2025)

2.1 Tooling solutions and process parameters

In the first operation of the manufacture of the fenders, band saw cutting is used and involves the use of such a saw to cut the aluminum material. The semi-finished product cutting operation is performed at the dimensions mentioned below, in figure 2, respectively X342 mm; Y157 mm; Z40 mm. The cutting is done along the length of the rolled bar.

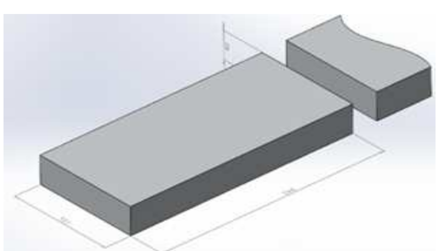

Fig. 2. Material cutting

In the second operation, it is necessary to go through 8 phases of processing the radiator guards for the KTM motocross model – 2025, as follows:

- External roughening of the guards

External roughing in aluminum is a process of removing material from the outer surface of an aluminum part, with the aim of reducing the thickness and obtaining a specific shape. This process is carried out using special tools, such as milling cutters and lathes.

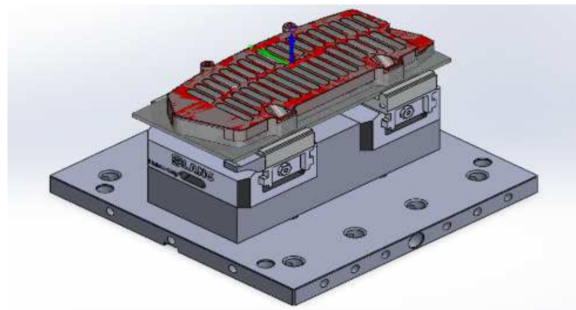

Fig. 3. External roughing of the defenders

The external roughing was performed with a Ø16 end mill with sharp cutting edges. The origin was taken at the center of the workpiece X0; Y0; and above it on the workpiece Z0, as can be seen in figure 3.

- Roughing of clamping channels

The CNC machine mills the material to create the channels for protection to attach to the radiator. These channels must be precise and fit the radiator perfectly with the protection. The produced channels are checked to ensure that they meet the specifications and stability requirements [4-5]. The dimensions, tolerances and finish are checked to ensure that they are of quality.

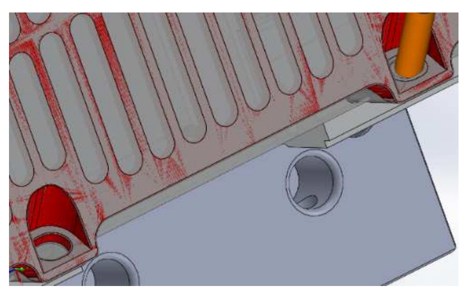

Fig. 4. Roughing out the channels for clamping

The roughing of the clamping channels was machined with a Ø12 front cylindrical milling cutter with sharp cutting edges, see fig. 4. Since the CNC machine is in 5 axes, the table can be tilted to certain degrees as well as flat, according to the 3D model, so several phases can be machined simultaneously in the same operation [6-7]. When several phases are machined in a single operation, the risk of position errors is considerably reduced, displacement and not only.

• Exterior finishing

The exterior finish of aluminum radiator guards is important for aesthetic appearance and to protect the material from corrosion and wear. These guards are used to protect the radiator from objects that can damage the radiator.

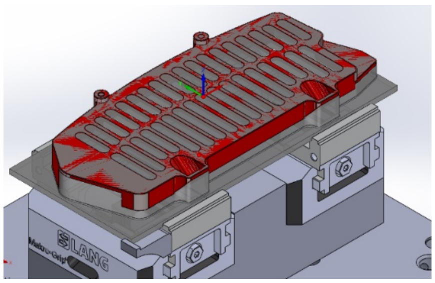

Fig. 5. Exterior finishing

The outer finish was machined with a Ø12 front cylindrical milling cutter with sharp cutting edges. At this stage, the outer contour was finished, the contour of the plug diameters, and then the machine table was tilted on the B axis at 55º to finish the pockets, where the two screws are located, which attach the guards directly to the radiator, see figure 5.

. • Drilling

The drilling was processed with a drill with a diameter of Ø5, the preliminary phase for threading the hole with the M6 h6 tap. The CNC drilling process begins with fixing the material on the machine's worktable, in a vice with movable jaws, then the drill performs the translational movement, on its own axis up and down, depending on the program, until the desired hole is created, see figure 6.

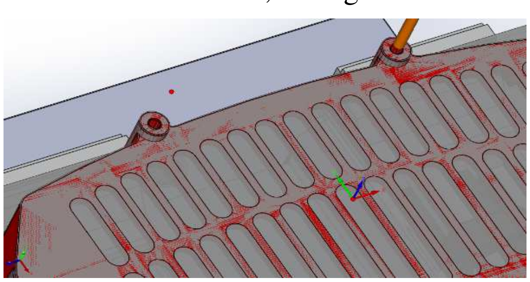

Fig. 6. Drilling Ø5 drill

Carbide drill bits are mainly used in the metalworking industry. They are made from a hard and durable material called tungsten carbide, which is known for its hardness and wear resistance properties.

• Tapping

CNC tapping is a process of producing threads in a part using a CNC machine. This process involves using a cutting tool (taper) to cut threads into a part, such as the one shown here, tapping the radiator guards for mounting. The tapping was done with an M6 x1 Tap, fig. 7.

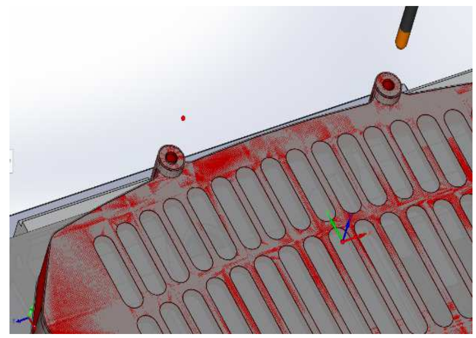

Fig. 7. M6 tap

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• Air Channels

The air inlet channels were machined using a flat-end cylindrical milling cutter with a diameter of Ø10, featuring sharp cutting edges (see Fig. 8). The milling of the channels with the flat-end cylindrical cutter on a CNC machine is an automated machining process, which employs specialized software to control the movement of both the cutter and the workpiece.

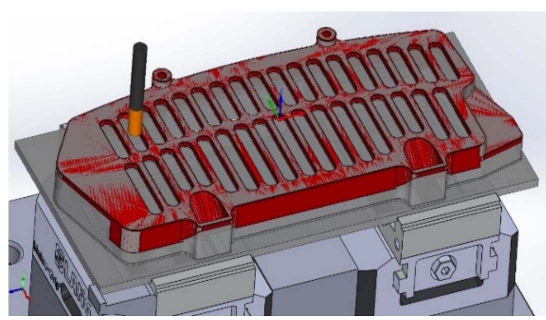

Fig. 8. Cooling Channels

The air channels were designed to allow airflow to reach the radiator during engine operation, thereby enabling coolant cooling and, consequently, ensuring the efficient performance of the cooling circuit.

In the second operation, the external contour of the radiator guards was machined from a semi-finished workpiece with dimensions of 342 ×

157 × 40 mm. The material was clamped in four imprinted jaws on two vises, with jaw openings up to 185 mm. These vises were precisely aligned on the machine table using a dial indicator, with micrometer accuracy. Finally, the sharp edges were removed with a chamfering tool, both to prevent workplace accidents and to ensure better positioning of the parts for the third operation. For a clearer view of the completed second operation, see Fig. 9 below.

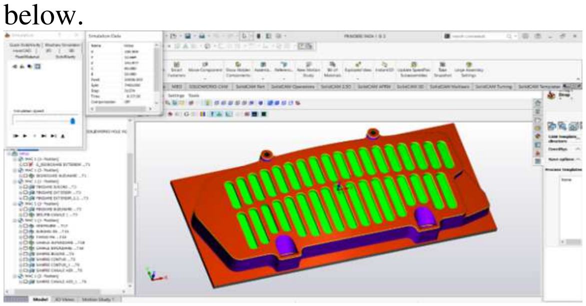

Fig. 9. Operation Two – Completed

For the third operation, the need for designing profiled jaws is highlighted, which replicate the external contour of the radiator guards previously machined in the preceding operation. These jaws were designed using SolidWorks software and are classified as fixtures (see Fig. 10). Fixtures in industrial engineering are essential components that facilitate manufacturing processes and enhance efficiency in industry. A wide variety of fixtures are employed in industrial engineering; in the case of radiator guards, vises are used as the main fixtures.

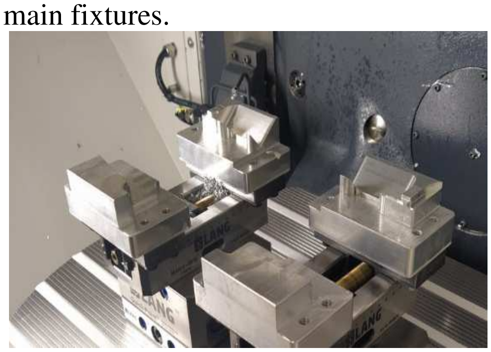

Fig. 10. Shaped Clamping Jaws

Operation Three involves several machining stages, after the part has been rotated and clamped in the vise with a maximum force of 40 N. The clamping force is measured using a torque wrench, thereby ensuring that the part remains undeformed at the end of the machining process.

The stages through which the part progresses in the third operation are as follows:

- Facing

In this stage, a face milling cutter with a diameter of Ø50, equipped with five indexable inserts, was selected for the removal of 3 mm of material, considered as allowance for clamping in the jaws during the second operation (see Fig. 11). Subsequently, roughing was performed with the face milling cutter in the areas where roughing was possible, in order to facilitate the next roughing tool.

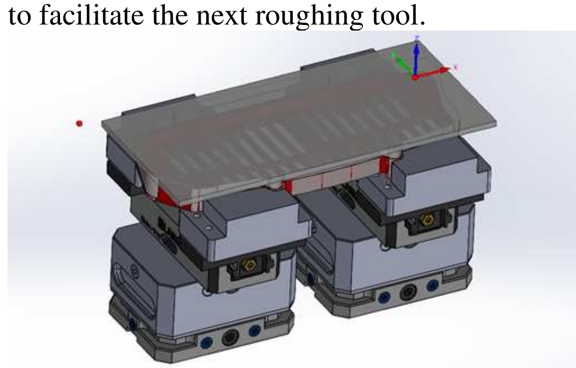

Fig. 11. Workpiece Before Operation 3

Face milling cutters are commonly used in metal machining, but they can also be employed for machining other materials, such as plastics or wood. They are available in various sizes and shapes to suit different applications and machining equipment (see Fig. 12).

Fig. 12. Face Milling Cutter with Ø50 mm Diameter

In the facing stage, a cutting regime was selected with a feed rate of 1600 mm/min and a spindle speed of 5423 rpm [13]. The feed rate is denoted by the letter *F*, and the spindle speed by the letter *S*. In this stage, the face milling cutter enters the part from the exterior along an arc, in order to avoid vibrations when the active part of the cutter—in this case, the inserts—engages the material[14].

3. RESULTS AND DISCUSSION

The primary objective of this research is to study, through the finite element method (FEM), the static behavior of a material subjected to multiple loading factors. Static analysis is a technique used to investigate structural or thermal problems in which the system is assumed to be in equilibrium, meaning that the externally applied forces and moments are balanced by the internal forces developed within the material.

Through this investigation, we aim to determine whether the material employed is suitable for the specific operating conditions, as well as to assess the fulfillment of the secondary objective: the efficiency of the radiator's cooling system under conditions of thermal overloading.

3.1 Static Analysis

The finite element method (FEM) analysis starts from the 3D model. There is a variety of software available for performing static simulations; however, in this context, SolidWorks Simulation is used due to its static analysis capabilities.

In the initial phase of the simulation, it is necessary to specify in the software the type of material from which the motocross radiator guards are made.

As shown in Figure 13, the material used is AL6063. This hard aluminum alloy is resistant to high temperatures while also offering good mechanical strength.

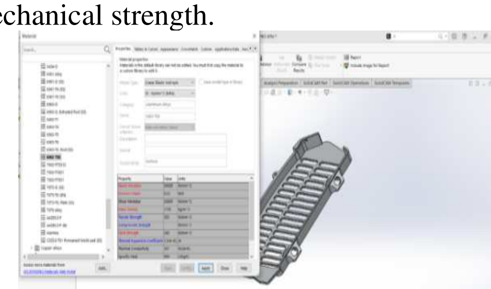

Fig. 13. Material for the 3D Model

After selecting the material, the surfaces in direct contact with the radiator are identified, as shown in Figure 14.

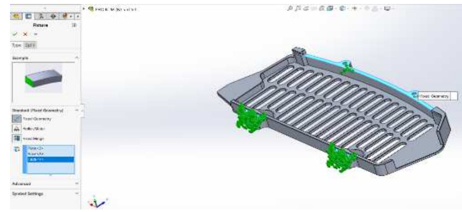

Fig. 14. Attachment Points of the Radiator Guards

Through these three surfaces, the guards are mounted onto the radiator.

The next step involves selecting the two channels below using the 'roller/slider' function. Once the guards are virtually mounted on the radiator, SolidWorks allows the simulation of the attachment exactly as it is fixed in reality on the engine. Subsequently, a tightening force of 150 N/mm² is applied to the areas where the part is screwed onto the radiator, as shown in Fig. 15.

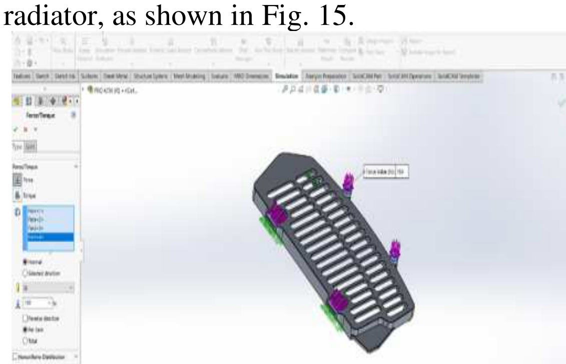

Fig. 15. Simulation of the Clamping Force of the Guards on the Radiator

In the next step, the static analysis process is simulated, taking into account the clamping force of the screws. The yield strength of AL6063 is 240 N/mm², while the Von Mises stress obtained from the analysis is 2.107 N/mm². This indicates that the part can withstand the loads when mounted on the motocross radiator, and therefore no redesign is necessary, as shown in Figure 16.

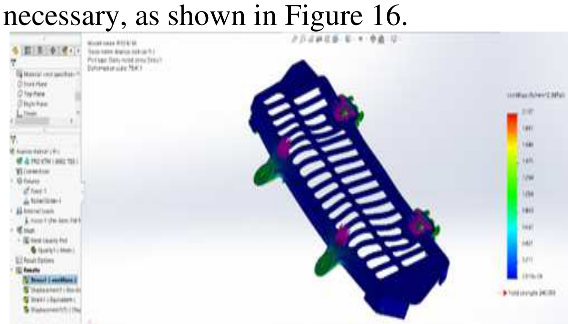

Fig. 16. Simulation of the 3D Parts

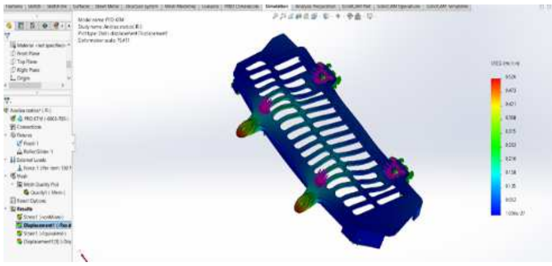

Fig. 17. Displacements of the Part

When the radiator guards are mounted on the engine and the clamping force is applied, the resulting displacements of the part are only 0.526 microns, as shown in Figure 17.

In the next simulation, the scenario is illustrated in which the motorcycle, weighing 115 kg, impacts an obstacle at a speed of 60 km/h, as depicted in Figure 18.

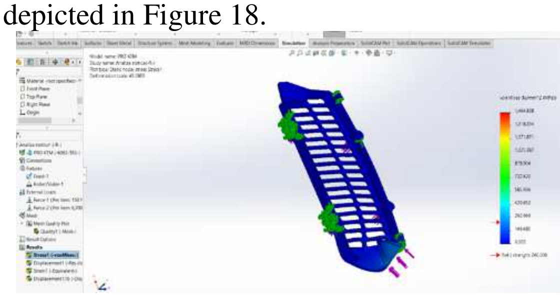

Fig. 18. Deformation of the Part under Applied Force

Following the application of a force of 6700 N/mm², the part deforms in the area where the force is applied. Despite the deformation, the parts remain strong and do not fail.

As illustrated in Figure 19, the wall subjected to the 6700 N/mm² force experienced a displacement of 0.940 microns relative to the initial position of the profile.

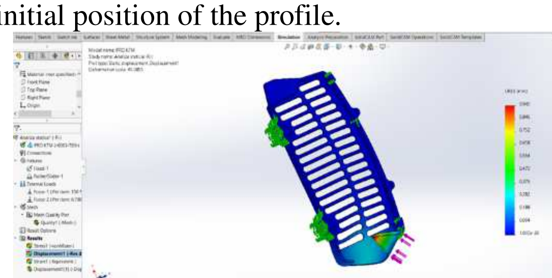

Fig. 19. Wall Displacement of the 3D Parts

Referring to the figure below, a 'split' is performed on a specific area of the total surface, where a force of 500 N/mm² is applied, simulating an impact on the front part of the radiator.

Following the application of the 500 N/mm² force, the effect of the impact on the part can be observed, as shown in Figure 20. Additionally, it can be noted that the maximum stress reached is 100.105 N/mm² (MPa). In other words, the part withstood the impact and did not fail.

As can be observed, on the surface where a force of 500 N/mm² is applied, the part deforms by 0.345 mm relative to its initial position. This indicates that, even at the point of maximum deformation, the part does not fail.

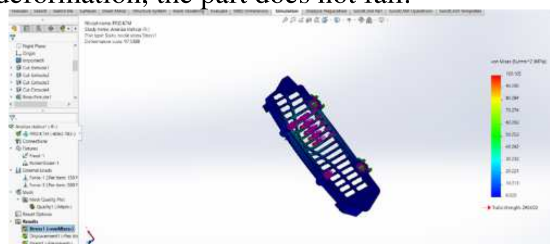

Fig. 20. Application of Force on a Restricted Area

3.2 Thermal Analysis

Thermal analysis is based on evaluating heat transfer through thermal conductivity. This property reflects a material's ability to conduct heat and is specified for each material used in the component. Heat capacity, which is the amount of heat a material can store, is an important property in thermal analysis, as it influences the component's thermal response to temperature variations.

The heat transfer coefficient measures a material's ability—or the interface's capacity—to transfer heat through convection or radiation. This coefficient can vary depending on boundary conditions and the surface characteristics of the component.

For thermal analysis, the 3D model of the part is imported. It is verified that the model is accurate and complete, containing all the necessary details and features for the analysis. Additionally, the initial temperatures of the component and the boundary conditions must be specified to simulate heat transfer under realistic conditions. These conditions may include boundary temperatures, heat fluxes, and similar parameters.

The results of the thermal analysis include the temperature distribution within the component. These can be represented through vectors or graphs, indicating the direction and intensity of heat fluxes. Thermal analysis allows the evaluation of the component's thermal performance, such as cooling relative to a radiator or preventing overheating in an

electronic system. This may involve calculating thermal safety factors or comparing maximum temperatures with acceptable limits.
It should be noted that the heat transfer coefficient is 15 W/K, and the ambient temperature is 25°C, which corresponds to 298.15 K.
The initial ambient temperature is 25°C, and the thermal analysis shows only a negligible change, reaching 25.025°C, as illustrated in Figure 21. It is observed that the radiator temperature does not increase significantly, demonstrating that the radiator guards are effective and that the cooling openings are sufficiently large to ensure optimal heat dissipation.

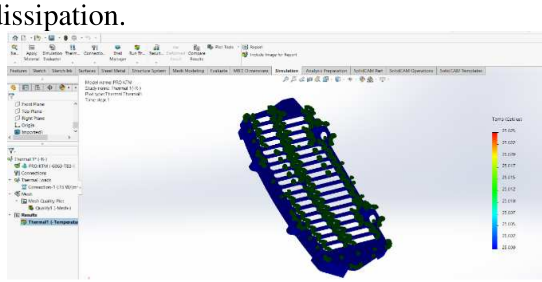

Fig. 21. Thermal Analysis Simulation

4. CONCLUSION

In conclusion, the redesign of the radiator guards must be carried out in compliance with technical standards and safety regulations, and collaboration with specialists is recommended to ensure compatibility and optimal functionality of the cooling system.

The redesign of the radiator guards for the 2025 KTM motorcycle aims to enhance radiator protection against impacts and to optimize the airflow necessary for engine cooling. The new design uses aluminum Al 6063, a lightweight, corrosion-resistant, and high-temperature-resistant material, thereby contributing to reduced vehicle weight and improved performance. The redesign must be executed carefully, following technical standards and in collaboration with specialists, to ensure the safety and efficiency of the motorcycle's cooling system.

An important conclusion from this research is that the use of the finite element method (FEM) allowed for the structural analysis and optimization of the radiator guard design. This approach identified critical areas subjected to concentrated stress, leading to improved strength and durability of the components. At the same time, the grille geometry was designed to ensure efficient and unobstructed airflow to the radiator, helping maintain the engine's optimal operating temperature even under extreme conditions.

Although the redesign brings multiple benefits—such as increased durability, improved thermal performance, and customization possibilities, it also presents certain drawbacks, including higher costs, longer production time, and potential installation challenges. Additionally, the modifications may affect the manufacturer's warranty.

5. ACKNOWLEDGMENT: The authors gratefully acknowledge the administrativeand technical support provided by TUCN for this work.

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Studiu privind strategiile de frezare pentru prelucrarea apărătorilor de radiator utilizate în competițiile de enduro

Rezumat: Motocicletele off-road sunt utilizate atât pentru cross enduro, cât și pentru hard enduro. Utilizarea lor pe teren accidentat implică anumite probleme legate de apărători, care fac parte din componentele acestor motociclete motocross. La FM-PARTS, am reproiectat și fabricat apărătorile dintr-un material mult mai rezistent, comparativ cu cel din fabrică. Pentru a realiza această cercetare, a fost necesară reproiectarea modelului 3D al apărătoarelor utilizate pe motocicletele motocross KTM 2024. Pentru acest model 3D sunt necesare dispozitive și unelte speciale pentru a le putea executa pe mașina CNC.
Cuvinte cheie: apărători de radiator, mașină CNC, piese motocross, model FEM

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