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DESIGN, MODELLING AND SIMULATION OF A GRILL-ROTISSERIE ASSEMBLY

Abstract: *This paper proposes the conceptual design and modelling by iterative improvements of two concepts of grill-rotisserie assembly, based on the idea of multifunctionality. The final variant of the solution was determined by successive modifications and improvements that would optimally satisfy the list of requirements declared at the beginning of the development process. The first concept of smaller dimensions is a simple grill with lid, or roaster with a single attachment. The second model has larger dimensions, for use in campsites, with the possibility of being a grill, but also a rotisserie, thanks to the equipment with several small transverse spikes that can rotate simultaneously, and with a long spike, that allows rotation a whole animal. This complex multi-component system can be considered truly multifunctional. A comparison is made between the first model and the redesigned new model, depending on the dimensions determined by the size of the structure. In addition to this comparison, a simulation of the rotating spike will be performed using the finite element method to establish the feasibility and success rate of such a concept.*

Key words: *conceptual design, modular construction, requirements list, grill-rotisserie configuration, 3D modelling, multifunctionality, simulation.*

1. INTRODUCTION

The "grill-rotisserie" term is associated with a very popular technical system, which serves as a cooking option, the principle used being the application of dry heat on the surface of the food, usually above or below. Iron or stainless steel grill represents the separating surface between the product used and the amount of heat transmitted directly, used for fast cooking, both meat, fish and vegetables.

The design activity of the grill-rotisserie assembly requires solving a set of problems with reciprocal action regarding the calculation, the material used, the constructive form, the manufacturing technology, the economy, whose solutions involve the work of conception from a combinatorial aspect, but especially from a creative aspect. In the phase of conceptual design, certain conditions must be taken into considerations, the input of a variety of criteria must be analyzed, such as:

- the criterion of ensuring the operating conditions (strength, rigidity etc.);
- the criterion of ease in manufacturing and assembly;
- the criterion of manufacturing materials that are easy to purchase and at a minimum cost.

Current trends reveal the development of such a multifunctional assembly, giving the user the opportunity to use it, either as a simple grill or as a rotisserie, with the help of additional components.

2. CLASSIFICATION

A classification scheme for the area of grill-rotisserie assemblies based on the combustible used, the action mode criterion, and the action plane is shown in Figure 1. This classification include examples of use based on constructive shemes.

The constructive solutions presented below have been iteratively developed. To get them, two methods of discursive character have been used, described in the literature [1] under the following names:

1. analysis of constructive solutions having contingency with the given problem;
2. iterative search for solutions [2].

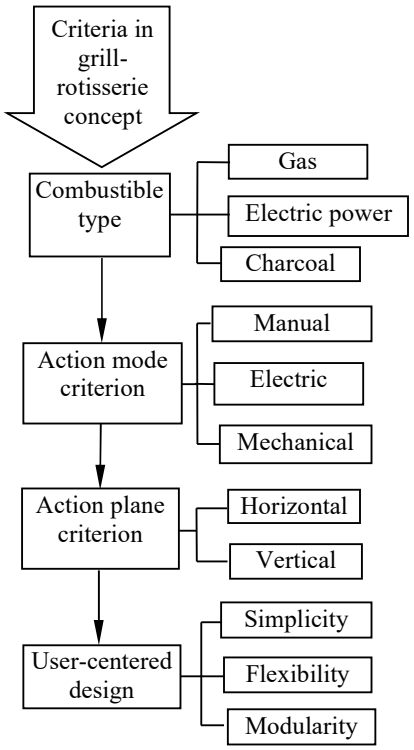


Figure 1 Classification from different points of view for grill-rotisserie assembly.

In the first method, sub-functions performed by the grill-rotisserie assembly were derived from an existing

configuration that led to the identification of the physical effects involved [3].

In the second method, an iterative succession of principle sketches was made, which started from a first idea that was then modified and improved by eliminating the weak parts of conception until final version, which largely satisfies the requirements list.

3. DESIGNING A NEW GRILL-ROTISSERIE

This chapter proposes the first grill-rotisserie assembly, inspired by several existing models on the market, which helped us to create a new configuration.

The constructive structure of this grill-rotisserie makes it a very practical product, which can be easily used in campsites to meet the needs of a fairly large number of participants. Its ability to cook food at the same time on the grill as well as on the rotisserie offers the possibility to prepare several types of dishes.

CATIA V5R19 3D modeling software was used to sketch the concept, which, through its complexity and variety of modules, offers a wide range of tools that can turn any dream into a concrete idea. The concept is created using *Part Design, Assembly Design, Sketcher* modules that allow the creation and manipulation of complex surfaces [5]. Finally, the *DMU Kinematics* module is used to simulate the elements designed in the overall configuration, constrained by the imposed dimensions, giving the viewer the opportunity to view the product architecture.

3.1 The design of the first concept

An important support in the construction of this model of grill-rotisserie is the simple geometric shapes that make up the whole set [4]. The eight components of this grill aim to create a constructive structure defined by specific coordinates.

The first grill-rotisserie assembly consists of 8 components, of which 4 main components and 4 additional components (Figure 2). The main components are the legs of the grill, the wheels that allow easy movement from one side to the other, the box of the grill in which the embers will be prepared and the folding lid caught in two hinges. As secondary parts we can list the table for utensils, the wood storage grill, the grill itself and the rotisserie, in this case being a manual one.

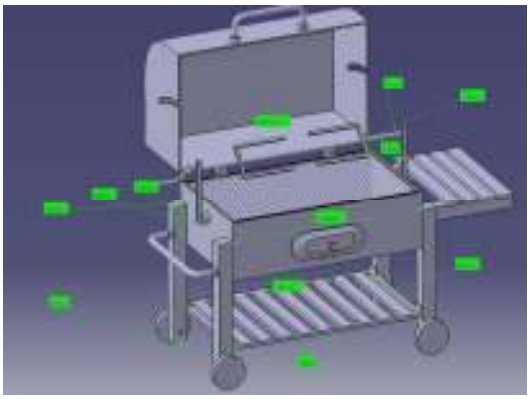


Figure 2 Design of first concept.

The legs of the grill are made of bars with a square section and, due to their weight, are fixed on rollers so that they can be easily moved from one place to another. The four legs are attached to the grill box by screw-nut assemblies and allow the assembly to move in different areas very easily, just by operating the handle on the left.

The box of the grill has a rectangular shape, being made by casting in a mold obtained from a forming mixture consisting of pressed earth combined with sand. On the left side it has a handle, bent in a U-shape, which is attached by welding with special electrodes to the two legs on the left side.

The lid is made of a sheet of steel plate that has been embossed into a mold to obtain the desired shape. The sides of the lid are cut so that the rotisserie rod does not block its closure.

The usefulness of this product is determined by the multitude of facilities it offers, and the quality of the materials and the architecture of the product are arguments that justify the preferred choice of the buyers.

In addition, the folding lid facilitates cooking by keeping the heat when it is used, but also the possibility to cook with it in unfavorable weather conditions (rain, wind, snow etc.).

If it needs to be refilled with charcoal to maintain the temperature, this grill-rotisserie also has an additional door through which the charcoal can be made uniform, refilled or cleaned, so that not to require the grill to be removed during the cooking process.

3.2 Used materials

The materials used to make this grill-rotisserie assembly were chosen so as to maintain the desired performance characteristics over time (Figure 3). Thus, a laminated profile made of OL 37 for the support legs and steel sheet for the grill box were used, which are materials with superior strength and machinability characteristics, easy to purchase. The lid consists of a sheet of iron plate embossed into a mold. The grill consists of parallel and evenly spaced steel rods, while the adaptable support is made of stainless steel. The table for utensils is made of wood.

For the additional components (drive wheels and rotisserie spike) OLC 45 steel was used as material.

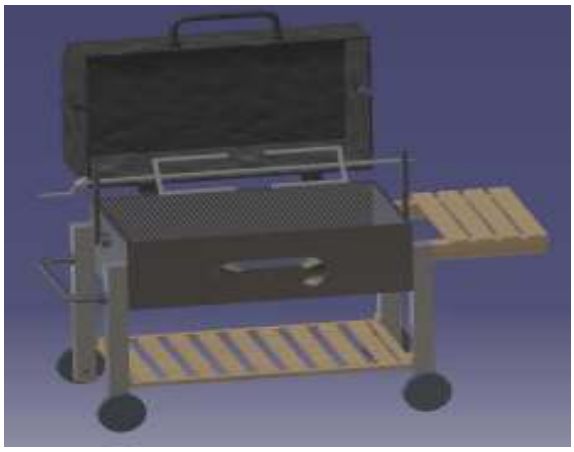


Figure 3 The grill-rotisserie design with applied materials.

3.3 Simulation using DMU Kinematics

Figure 4 shows the working method for organizing geometric elements using the *DMU Kinematics* module, which highlights the joints of the previously modelled assembly. Thus, after all the parts have been assembled, dynamic simulation can be performed to visualize the trajectories and positions of the moving elements.

The assembly allows 3 rotations. The first rotation is that of the lid so that it can be closed and opened at a maximum of 90 degrees. The second rotation allows the coal feeder lid to be opened and closed, and the third rotation is 180 degrees between the two mounting brackets on the surface of the grill box (Figure 5).

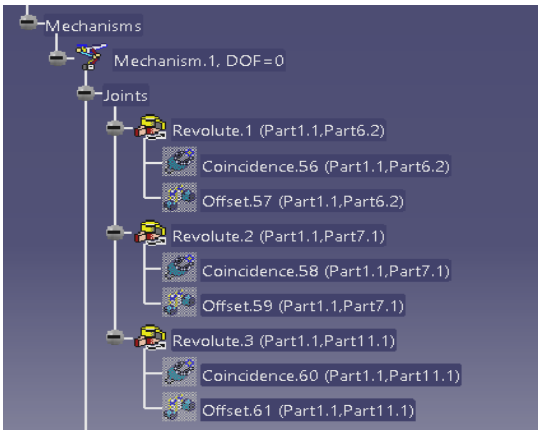


Figure 4 Simulation mechanism-tree of joints.

Figure 5 Rotation of the lid.

3.4 The design of the second concept

The first model can be completely redesigned for extra productivity.

Thus, if the first model could be used especially in the courtyard of your home or in certain campsites, this new model (Figure 6) is intended in principle for boarding houses or places where events are organized with a large number of people, requiring a grill with a increased capacity so that large quantities of meat can be prepared at the same time.

Compared to the first model that had a single longitudinal rotisserie and small construction dimensions, which allowed limited or consecutive preparation of products, the new model has the ability to prepare several foods simultaneously, due to the larger size, but also the small transverse spikes, as well as the main rotisserie that can support an entire animal.

The new grill-rotisserie concept is based on several workstations that are driven during operation by a V-belt transmission driven by an electric motor. The assembly is compact, using a judicious location of the following components:

- metal frame;
- outer tray;
- inner tray;
- belt wheel arms;
- belt wheels;
- belt tensioning mechanism;
- protection latticework;
- trapezoidal belts;
- adaptable support for longitudinal spike;
- transverse spikes;
- longitudinal spike;
- motor for transverse stations;
- motor for longitudinal rotisserie;

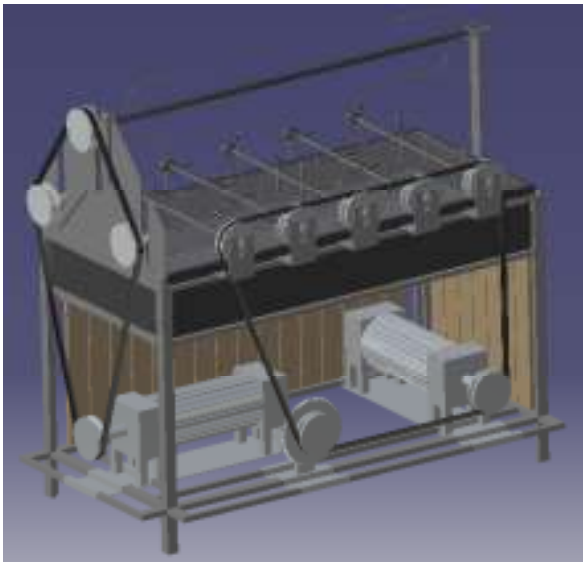


Figure 6 Final design of the second concept.

4. MODELLING MAIN COMPONENTS

The previous chapters have introduced all the necessary data for sketching the gril-rotisserie concept. For this, the CAD software used is Catia V5, a multi-platform engineering software developed by Dassault Systèmes.

The product tree was structured within the program, including all the components of the assembly.

Thus, the *Sketcher, Assembly Design* and *Part Design* modules were used to model each component, which can be found in the *START -> Mechanical Design* menu [6].

4.1 Grill

The grill (Figure 7) consists of 5 detachable grills, made of food grade stainless steel, being a material recommended by the WHO (World Health Organization) as a non-toxic material when heated to high temperature.

These grills consist of a 10 mm thick frame, inside which are welded rods of the same thickness, along its entire width. The total length of the grill is 1490 mm, with a width of 690 mm.

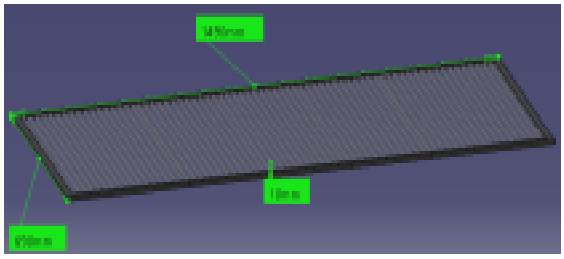


Figure 7 Grill.

4.2 Belt wheel arms

The belt wheel arms (Figure 8) were made of 5 mm thick stainless steel. It was bent at 90 degrees by pressing. These arms are detachable elements, being fastened with screws to the metal frame. Once these arms are removed, the assembly can be used as a simple grill.

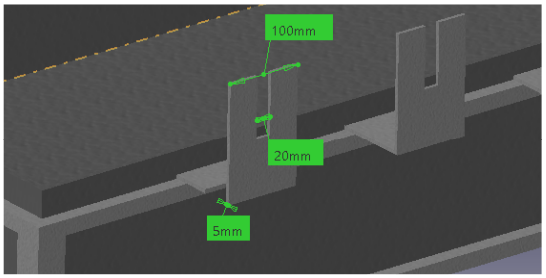


Figure 8 Belt wheel arms.

4.3 Belt tensioning mechanism

The belt tensioning mechanism (Figure 9) made of aluminum has a horizontal movement on the metal frame by means of a sheet metal guide and fixing with screws.

This mechanism also has an additional component, with a toothed profile, in case of a change in the gearing process, from the trapezoidal belt, to the toothed belt or with chain.

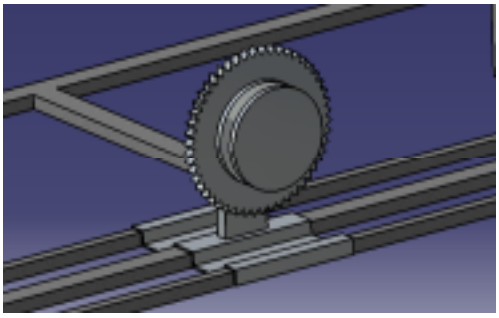


Figure 9 Belt tensioning mechanism.

4.4 Adaptable support for longitudinal spike

The adaptable support for the longitudinal spike is made of 5 mm thick stainless steel sheet, obtained by stamping on a special press.

On this support, two fixed rollers were mounted, horizontally, and one height adjustable, also having the role of tensioner (Figure 10).

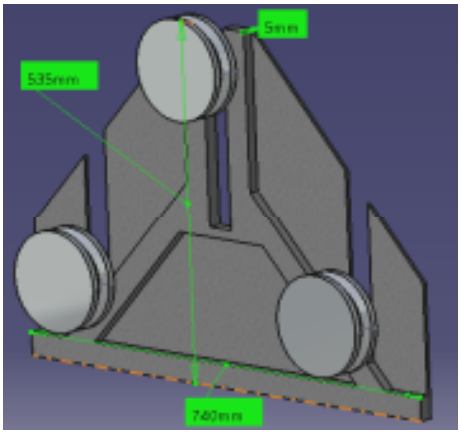


Figure 10 Adaptable support for the longitudinal spike.

The tensioning roller is positioned in the upper part of the adaptable support, having the role of engaging the longitudinal spike. Mounting the support on the metal frame of the grill is done by screws.

4.5 Engines

This grill-rotisserie assembly is driven by two electric engines, of different sizes and powers. The first motor (Figure 11), responsible for the movement of the 5 transverse spikes, has the following characteristics [7]:

- power supply: 220 V;
- rotation capacity: 10 rpm;
- frequency: 50 Hz;
- power: 80 kg·cm/7.85N·m;
- ventilated for cooling.

The dimensions of this engine are 600x180x180 mm and it weighs about 8 kg, with the possibility of easily rotating fully prepared pieces of meat of 10 kg, distributed proportionally on each spike.

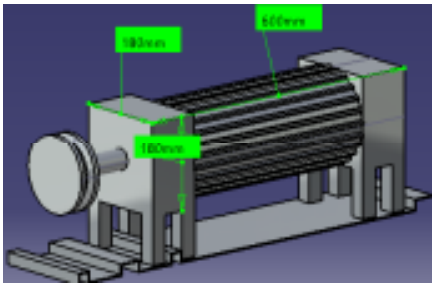


Figure 11 Engine for transverse stations.

The second, more powerful engine, which can easily rotate a preparation of approximately 100 kg, is responsible for rotating the main longitudinal spike and also has the following characteristics [7]:

- power supply: 220 V;
- rotation capacity: 3.2 rpm;
- frequency: 50 Hz;
- power: 110 kg·cm/9.56 N·m;

• ventilated for cooling.

The dimensions of this engine are 700x205x205 mm and it weighs approximately 10 kg.

5. MODES OF OPERATION

Being a multifunctional grill-rotisserie concept, this product can be used in 3 ways:

• simple large grill; If you want to use this product only for the barbecue function, the additional components will be abandoned and only the outer tray, inner tray, latticework and metal frame will be kept (Figure 12);

• rotisserie with several small transverse spikes; In addition to the components attached to the first mode of use (simple grill), the arms of the belt wheels, the belt wheels, the transverse spikes, the tensioning mechanism, the motor and the trapezoidal belt will be attached (Figure 13);

• rotisserie with longitudinal spike, for events in which it is desired to rotate an entire animal (Figure 14).

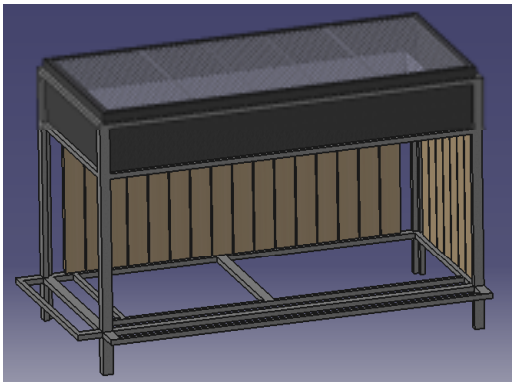


Figure 12 Simple large grill.

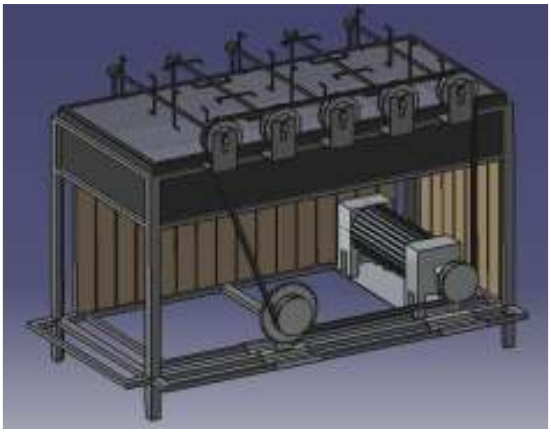


Figure 13 Rotisserie with several small transverse spikes.

The third way of use involves disassembling the 5 transverse spikes together with the corresponding attachments. These components can be stored in the system because the working height for the longitudinal spike does not lead to interference between them. Then mount the adjustable support, the second 10 kg motor, the longitudinal spike, the belt tensioning wheel and the two fixed guide rollers (Figure 14).

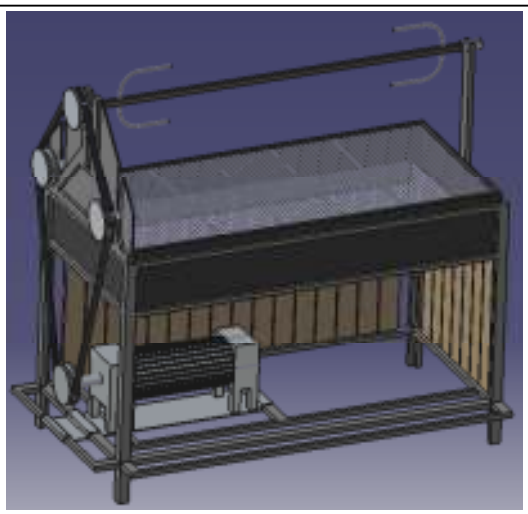


Figure 14 Rotisserie with longitudinal spike.

6. FINITE ELEMENTS ANALYSIS

Due to the multiple functions that the product performs, it contains a larger number of components. Increasing the number of components decreases the safety of their operation within the assembly. Solving the problem of raising the operational safety of the components and the product as a whole requires increasing the quality and safety of the separate elements that make up the grill-rotisserie system.

Consequently, in order to meet the requirements for operation without defects of the product, it is necessary to check the components for extreme operating conditions, in compliance with the essential requirements established at the beginning of the development process and the spatial constraints established in the embodiment design phase.

The stress analysis was made for the two type of spikes (transverse and longitudinal). The finite element mesh is of the beam type in a uniform distribution. The finite element model was generated with free meshing command such that the solid model is not restricted by any special meshing requirements and the Catia V5 meshing algorithms automatically generate a best-fit pattern of nodes and elements.

For this, the module *Analysis & Simulation -> Generative Structural Analysis* is used [6].

The load scheme and boundary conditions are presented in the Figure 15 for the longitudinal spike. The symbols at the ends of the spike emphasize boundary conditions in these parts to avoid translation movements at selected nodes.

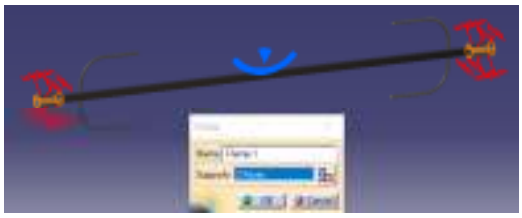


Figure 15 The load and boundary conditions scheme.

A stress analysis was made for a force of 1000 N (equivalent to 100 kg) applied to the upper face (Figure 16).

Figure 16 Application of force.

The equivalent (von Mises) stress distribution is presented in Figure 17. The area of maximum equivalent stress is placed in the middle of the spike. The maximum equivalent stress value increases with the load below the limit of the recommended admissible safety factor values, which in literature is indicated at the value c_a = 1.5 ... 3 (for pieces subjected at fatigue) [8].

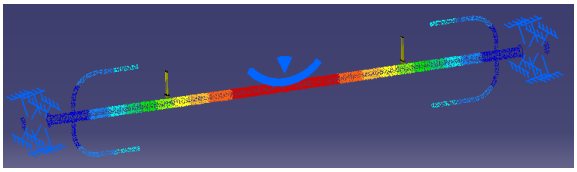
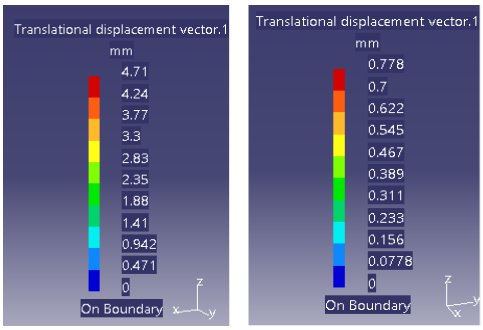


Figure 17 Equivalent (von Mises) stress.

The longitudinal spike successfully withstood a weight of 100 kg, the displacement resulting from this load being in the central area of 4.71 mm (Figure 18-a).



a b

Figure 18 Displacement depending on the load.
a-for longitudinal spike; b- for transverse spike

For the second spike, the transverse one, a weight of about 10 kg was applied. Figure 19 shows the stress distribution which is similar to that obtained for the longitudinal spike.

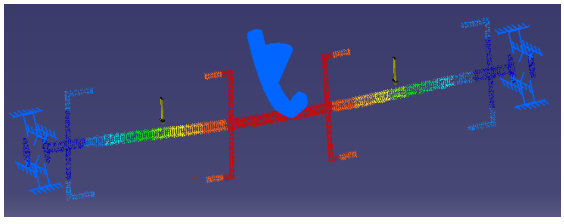


Figure 19 Stress distribution for the second spike.

In this case, a maximum displacement of less than 1 mm occurs, which demonstrates that the transverse spike has a proper behaviour (Figure 18-b).

The finite element analysis applied to a spike demonstrates that its shape and dimensions are appropriate in terms of the strain and stress state and the avoidance of stress concentrators.

7. CONCLUSIONS

The aim of this work was to remodel the rotary grill assembly in order to increase its functionality and to adapt it to different conditions of use. A very important factor that highlights the flexibility in use of this product is the fact that it can be configured as a simple grill, a transverse rotisserie or a complex rotisserie.

Due to the finite element analysis of the spikes, it was found that this product is resistant to overload, which leads to an increase in its life span.

The embodiment design of the grill-rotisserie assembly took into account the economic success of the product by ensuring a high quality of the components and the product as a whole, by the multiple functions ensured and the manufacturing cost as low as possible.

In conclusion, this product will be a desired one by those who want to organize events with a large number of people, and can be used in large spaces in the middle of nature.

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