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Design and Visualization of the Ten-Electrode GlidArc Plasma Reactor Using the Autodesk Inventor Environment

Piotr Krupski[1]

[1] Faculty of Mathematics and Information Technology, Lublin University of Technology, Nadbystrzycka 38D 20-618 Lublin, Poland

Corresponding author's e-mail: p.krupski@pollub.pl

ABSTRACT

The work presents the process of designing a plasma reactor with a gliding arc discharge. The topic discussed is motivated by the large and still modern application potential of non-thermal plasma in the processing of gas mixtures and plasmachemical treatment with the afterglow product. The process of designing a completely new plasma reactor with 10 arc-shaped electrodes is described. In the design process, the author relies on experience with existing sliding discharge reactors at the Lublin University of Technology. The design process is carried out using the modern Autodesk Inventor solid modeler environment. Partial elements of the plasma reactor were designed and assembled into an assembly. The whole work is complemented by the presentation of selected, more important physical parameters of these parts. A special part is devoted to presenting a realistic render of reactor body.

Keywords: GlidArc plasma reactor, multi-electrode plasma discharge, design and visualisation, Autodesk Inventor.

INTRODUCTION

The essence of gliding arc plasma

The development of GAD (Gliding Arc Discharge) plasma reactors began in 1987 and contributed to the implementation of a new method of processing many gas mixtures. A gliding arc discharge was then used as a source of non-thermal plasma generated at atmospheric pressure. Albin Czernichowski and the team from the Plasma Physics Laboratory of the University of Orleans, France in 1990 can be considered a forerunner in the development of GAD Plasma. GlidArc plasma reactors usually have two or more knife-shaped electrodes, between which there is a nozzle supplying the process gas, placed so that the gas stream is fed concentrically along the electrodes. Glid arc discharge plasma, like other arc plasmas, can be generated with direct, alternating and pulsed voltages. The mechanism of plasma discharge can be simple described based on a two-electrode reactor (Fig. 1). The discharge usually takes place in the form of a traveling arc column between knife-shaped electrodes. The process gas is introduced axis symmetrically from below between the electrodes. During the single cycle, there are three main stages: ignition, arc column growth and extinction. Ignition occurs when the voltage on electrodes is able to overcome electrical strength of the gaseous medium, in the so-called ignition zone – in the smallest distance between electrodes. Then, gas dynamic forces lead to the development of the discharge and the upward displacement of the electrodes. During this time, the interelectrode zone is penetrated by the discharge. Until the discharge expires, occurs when the impedance of the ionized column does not allow to taking over the energy necessary for its further development. Figure 1 shows a monochrome photography of a GAD discharge when powered by a switching power supply converter. The photograph was taken using a compact camera. It is possible to observe that many discharges move

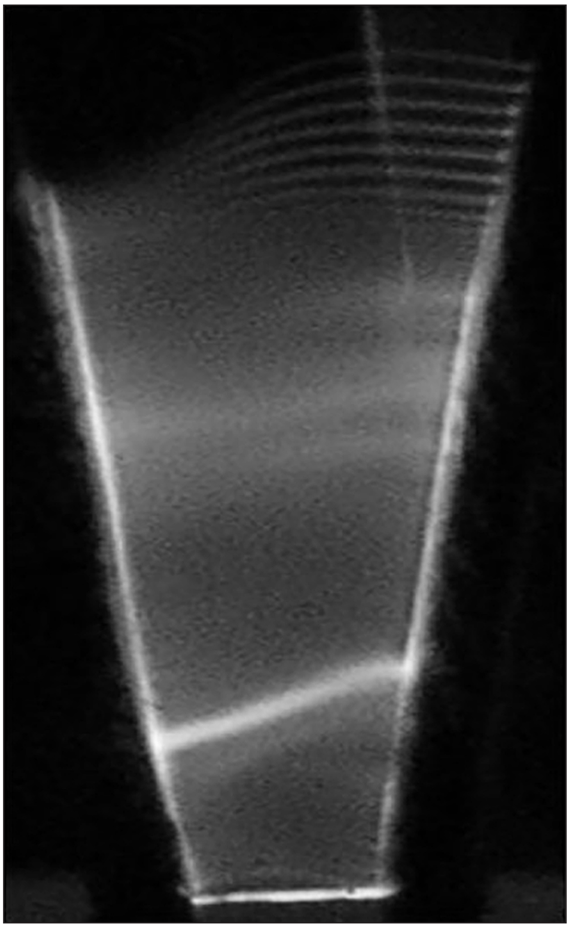

Figure 1. GAD Plasma discharge in a two-electrode reactor (monochromatic photo)

through the electrodes at the same time, creating illusion of a membrane or mesh placed between the electrodes. In fact, there is only one arc column. The resulting plasma is non-equilibrium and non-thermal. This means that the temperature of the electrons is higher than the temperature of the other components. It should be mentioned that in electric discharge the use of the macroscopic concept of temperature is difficult to consider appropriate due to the fact that the conditions of Maxwell's equations are not met.

Applications of GlidArc plasma

Typical, technologically desirable properties of GAD plasma include the fact that it has biocidal, cleaning, decontaminating and odor-removing properties, and allows it to influence the course of chemical reactions, change surface properties, and many others. Among the innovative reports from recent years, it is worth mentioning the studies by Hanon and Gaigneaux [1], who describe the possibilities of using glidarc plasma for the chemical synthesis of heterogeneous catalysts. Othmen et al. [2] mention the prospects for the use of GAD plasma in agriculture and environmental protection in the degradation of plant protection products. Rodriguez et al. [3] describe the possibilities of plasma-assisted deposition of manganese and iron phases on biomorphic fibers. Zheng et al. [4] reviewed research on sliding arc treatment of volatile organic compounds. They showed great application potential in environmental protection. According to Trifi [5], plasma treatment of pharmaceutical pollutants in the pre-utilization process may allow for rationalization of costs and resources. Boyom-Tatchemo et al. [6] estimates that gliding arc plasma appears as an innovative route allowing the stabilization of MnO_2 structure and activity via some cationic species during its synthesis without adding any reactant as is the case with the classical methods. Characterization and photocatalytic properties reveal the fact that with the participation of plasma in the process, product benefits and energy savings are achieved [7]. The above-mentioned plasma can also be used to activate water. Then, as Mogo et al. [8], presents the application of this water brings positive agricultural effects when applied to cereal crop seeds (corn). It is worth noting that the products of plasma removal self-decompose in a short period of time and do not constitute pollution, as in the case of pesticides. A similar application of plasma-activated water is presented by Bostanaru et al. [9]. They present the potential of using water after glidarc treatment to reduce microbial pathogens in the medical space. We are talking about the use of plasma-activated water also in cooperation with other agents to increase the effectiveness of decontamination. Czernichowski [10] described the effects of using GlidArc plasma to produce synthesis gas, which is very valuable as a fuel, energy carrier or intermediate substance. Production of a mixture of carbon monoxide and hydrogen. In the described method, plasma-catalytic conversion of flammable matter was carried out coal-bearing gas, obtaining clean synthesis gas.

The above-mentioned applications of plasma, afterglow gas, plasma-treated surfaces and materials are just a few of a very large group. They represent chemistry, bioengineering, medicine, agriculture, energy and related fields related to the issues of technology development and the progress of modern civilization.

Known concepts for building Glidarc reactors

Over the years of operation, GlidArc non-thermal plasma reactors have acquired a certain form of classic construction. It is a cylindrical form with axially symmetrical working electrodes placed inside. These electrodes usually have a canopy shape, the shape of which increases the distance between the edge parts of adjacent electrodes in the direction of process gas flow. The number of electrodes varies, but depends on the use of the reactor and the power source that supplies voltage to them. Many publications describe the three-electrode design. These are reactors that are powered by three-phase public networks after adjusting the electricity parameters through the power supply system. Many of these power supplies have specially constructed mains transformers. The classic structure of a three-electrode GlidArc reactor is presented by Komarzyniec and Aftyka [11] devoted mainly to GAD power systems. This reactor has a structure that deserves attention because it has additional electrodes whose role is to enable ignition in the so-called ignition zone. This concept is visible in Figure 2.

Hnatuic et al. [12] presents a GlidArc reactor in which the electrodes are made of flat sheet metal. The discharge part is supplemented with perpendicular semi-circular inserts. There are versions with 6 working electrodes. Zhu et al. [13] present the concept of a GlidArc reactor in which the properties of an arc column are used as a conductor with current, subject to the dynamic influence of an external magnetic field. The magnetic field is generated by permanent magnets rotated on the surface of the reactor tube [14]. It is worth noting that this type of GAD design significantly improves the penetration of the interelectrode space by the discharge. Many application concepts of the GlidArc Reactor were presented at the turn of the year by Czernichowski. These are cascade systems and installations with different gas flow directions, multi-electrode, mainly used for chemical engineering and environmental protection purposes [15]. In the reduced scale of the plasmachemical process, two-electrode GAD reactors play an important role. At powers ranging from tens to hundreds of watts, copper wire electrodes bent into an arc profile are used. They are also made of sheets of one or two millimetres thick. An example of such a reactor is shown in Figure 3. Its feature is the fact that the inter-electrode distance can be continuously changed during continuous operation. This is accomplished using a built-in gear that symmetrically controls the electrodes [16–17].

DESIGN AND VISUALIZATION OF THE TEN-ELECTRODE GLIDARC PLASMA REACTOR

The project is based on a glass tube with a diameter of 115 mm. cylindrical glass with a wall thickness of 5 mm. The pipe length was selected

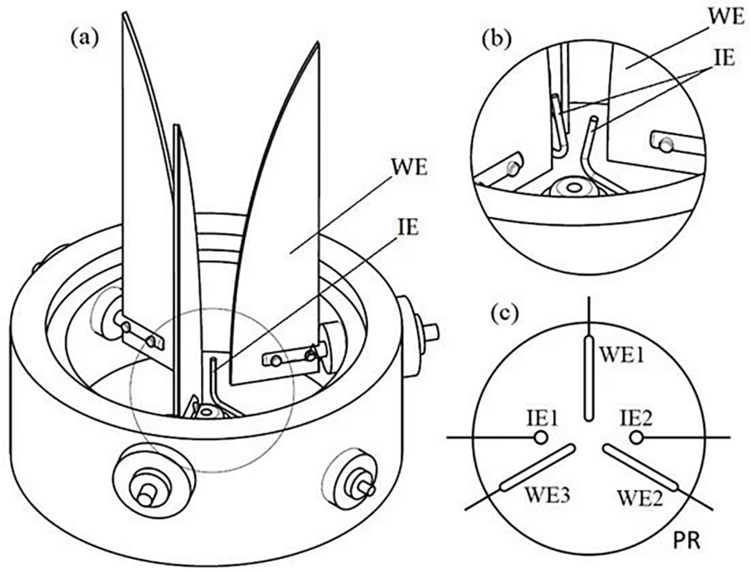

Figure 2. GlidArc-type plasma reactor, (a) overview drawing, (b) system with one ignition electrode, (c) system with two ignition electrodes, WE – working electrodes, IE – ignition electrodes [11]

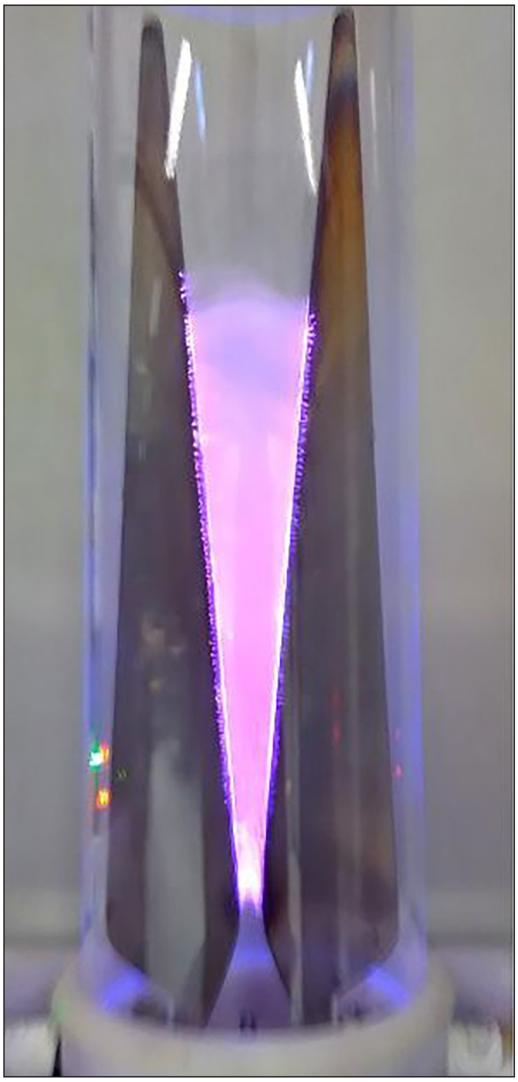

Figure 3. Double electrode GlidArc-type plasma reactor which has an adjustable inter-electrode spacing – regular photo [16]

at 300 mm and according to the assumptions, there will be 10 knife electrodes there. The whole will consist of a base, electrode holder, gas distribution nozzle, discharge pipe, electrodes and a cover with a post-process gas reception port. The model assembly will also include numerous standard elements, such as seals, screws, and nuts. The elements of the ten-electrode plasma reactor, tentatively named "DecaGAD", are designed from basic sketches – flat drawings, and on their basis, solids are obtained through three-dimensional operations (extrusions and revolutions) of these figures. Then these solids are processed into the desired shapes. In the case of elements, the final shape is material for them to realize realistic features. A sketch of the half-section forming the base of the plasma reactor is shown in Figure 4.

The sketch in Figure 4, outlines the shape that forms the outer contour of the reactor base. there are two small circles inside, the role of which is based on the fact that they will create the outline of channels for the sealing O-rings. At this stage, rounding and chamfering are already visible. Based on the sketch prepared in this way, the revolve operation is performed to obtain the shape of the reactor base – Figure 5. Then the operation is repeated to obtain a circle – Figure 6, into which the glass cylindrical discharge tube will be inserted.

In the next step, selected parasitic planes are visible and are used to place holes and make roundings for screw heads. The reactor is mounted to the settling table - not included in the simulation – using threaded 6 holes (Fig. 7). Metric threads M8x1.25 are used. The depth of

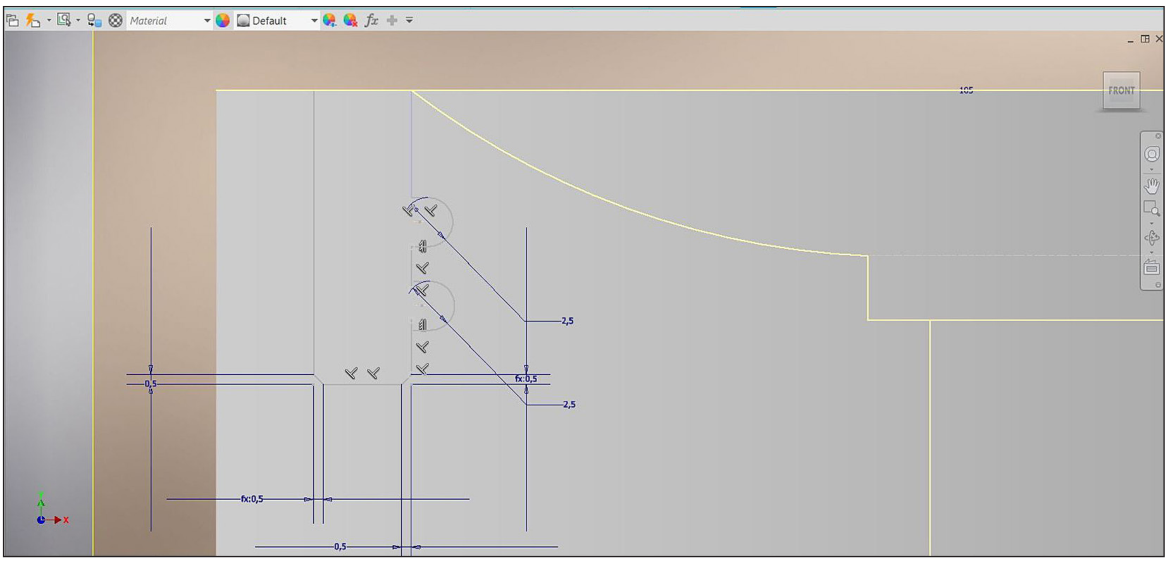

Figure 4. A sketch of the half-section forming the base of the plasma reactor DecaGad

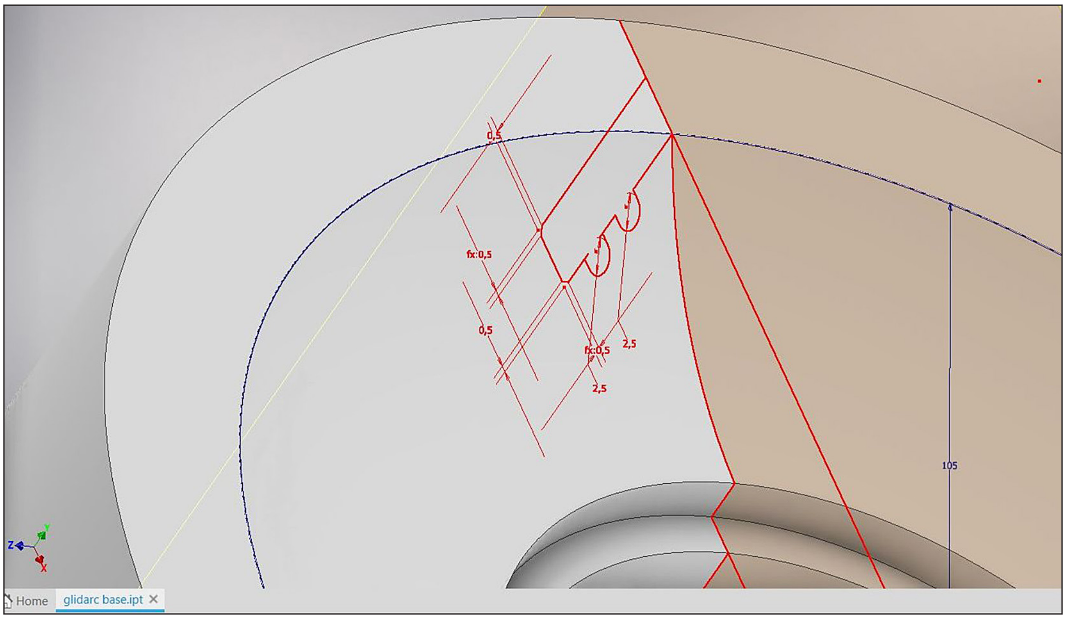

Figure 5. Forming the shape of the reactor base using a sketch (external contour) the base of the plasma reactor DecaGad

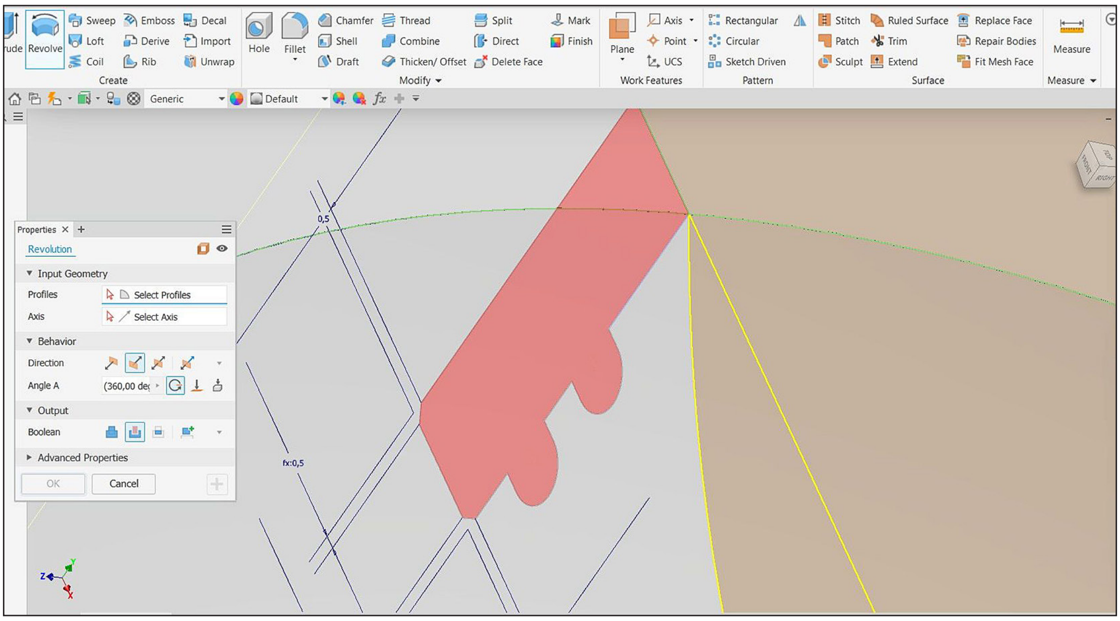

Figure 6. A completing the solid shape of the reactor base using a contour sketch to connect to the glass cylinder. The revolve command is used

the mounting holes in the base is 24 mm. The smaller holes visible in Figure 7, offset towards the center line, are M5x0.8 holes and are intended for mounting the electrode holder. Their net thread length is 15 mm. To make it easier to use Allen screws for assembly, subtle chamfers were also introduced to the design of their heads.

Most holes are made by straight extrusions of their outline placed on a plane. For this purpose, planes from the rectangular coordinate system contained in origins are used. If necessary, tangentially offset planes are generated or planes spread over the model contours are used. Threads are added with a dedicated tool from Inventor toolbox. The method of making the GAD base model is clearly visible in the view with a cross-section drawn along the central XY plane, obtained by the so-called slice graphics – Figure 8.

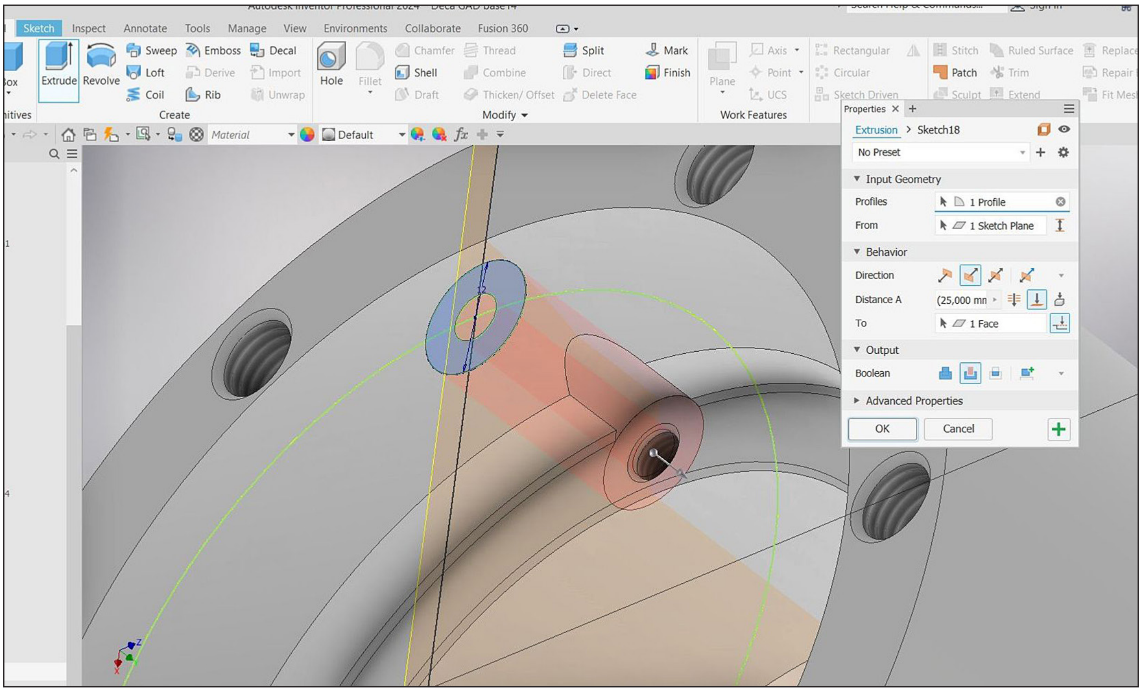

Figure 7. Crude model of the plasma reactor base while making a recess to fit the head of the Allen screw

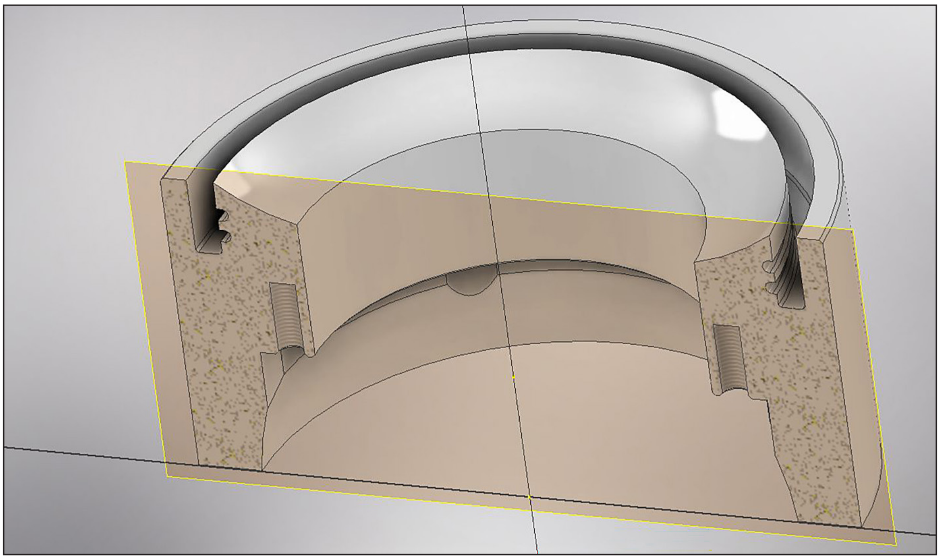

Figure 8. Crude model of the The method of making the GAD base model in the view with a cross-section drawn along the central XZ plane, obtained by the slice graphics

The design of the element in which the electrodes will be embedded was initially carried out in a manner analogous to the described base. A sketch was prepared – a flat drawing, which was a half-section of the raw body of the electrode holder and revolving into the solid – Figure 9. Then, a drilling was made from the upper part to insert the electrode. Drilling for electrode was made by extrusion from the plane into the material using the Boolean operation in the remove material mode.

Initially the electrode embedding hole, it has an asymmetrical oval shape, then it turns into a hole with a diameter of 6. This shape results from the structure of the electrode embedding element. The electrode requires a mounting element, which is also a connector for connecting voltage passing through the electrode holder has and ending with an M6 external thread (Fig. 10). The mentioned previously hole for embedding the electrode – embedding element assembly was duplicated in

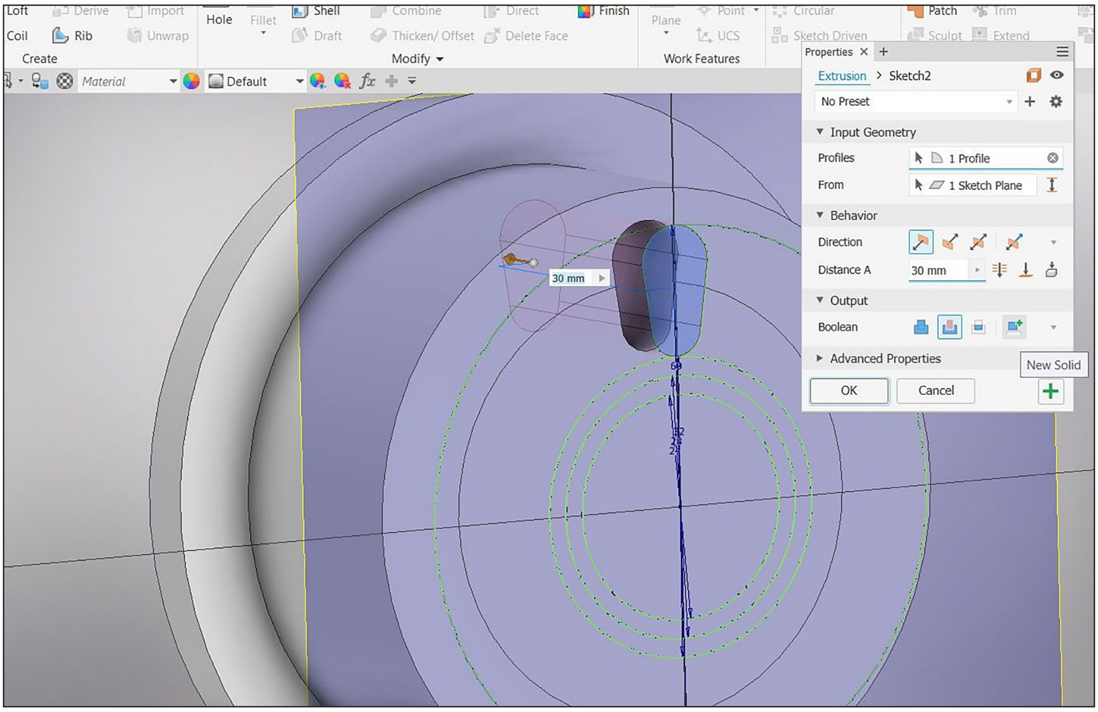

Figure 9. Crude model of the The method of making the DecaGAD electrode holder with an added parasitic plane and an extrusion that removes material into the electrode hole

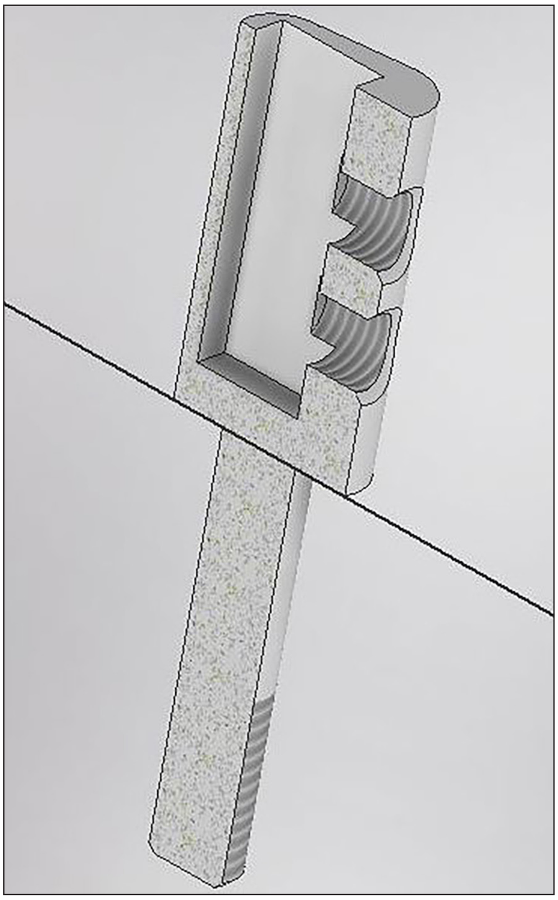

Figure 10. DecaGad reactor electrode mounting – the cross-section, visible relative to the axis of the clamping screw holes

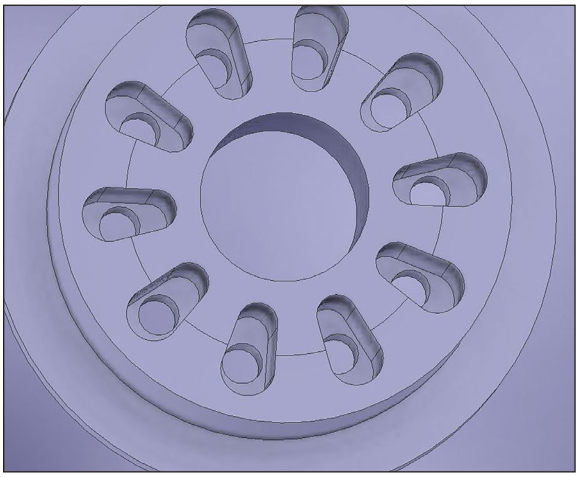

Figure 11. Electrode holder with holes made for inserting ten electrodes, obtained using a circular pattern tool (circular pattern)

a circular pattern adequate to the number of 10 electrodes This is shown in Figure 11.

At the center of the electrode holder there is a hole with an M25x1 thread, used for nozzle installation of process gas distribution systems. There is a nozzle system with three gas supply sections 1, 2 and 3. Thanks to this, the nozzle system designed in this way can allow for obtaining process mixtures already inside the reactor, without premixing. The center nozzle hole is single in its section. this is important due to the fact that gas with low ionization energy can be fed there – which will improve ignition parameters. The second section of the holes forms a separate set of nozzle inlets. It can be used to supply e.g. main gas - subjected to plasma treatment. The third section of holes is spaced along the largest diameter. It can be used to cooling the electrodes. Sections 2 and 3 have nozzle holes directed slightly in a spiral. This can be seen in the slice graphic view – Figure 12. This allows you to give a spin direction to the process mixtures.

The nozzle also has an adapter element, visible in the cross-section in Figure 13. On the nozzle side it is sealed with O-rings, and on the opposite side it has threads for screw-in connectors. The nozzle assembly is sealed by conical surfaces inside the electrode holder. This prevents gases from leaks between components.

The nozzle assembly and the intermediate connector (Fig. 12–13) were made using methods and tools analogous to those of the base and electrode holder. Due to this, the description of this process has been omitted. The top cover was also modelled. It is mounted on the discharge tube, just like on the reactor base. Its upper part has the shape of a dome, which without thresholds leads to a spigot adapted to be

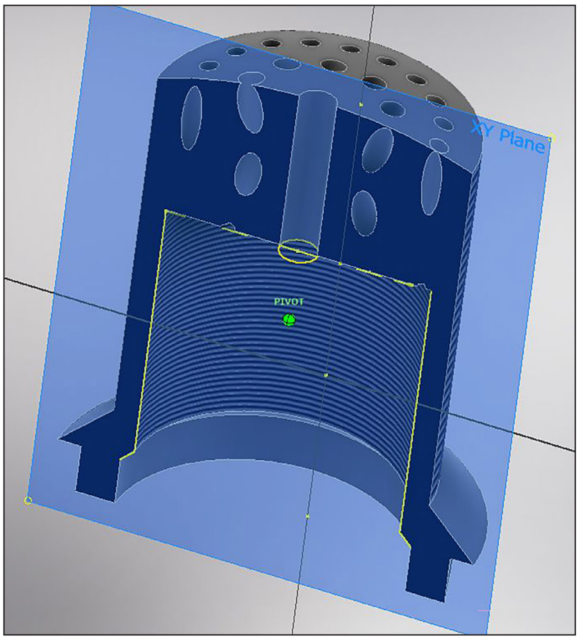

Figure 12. Nozzle for supplying process gases – cross-section view with the cutting plane and the geometry projection visible in yellow, which is appropriate for making the mating element

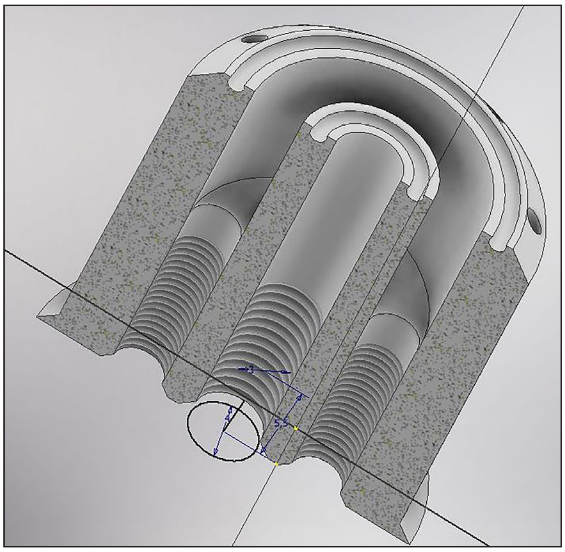

Figure 13. Nozzle adapter element for supplying process gases – cross-section view

connected to a flexible hose. This system allows for simple collection of substances after the plasma process. There is also a seal with the discharge pipe using an O-ring 115×4. The process of modelling this element was also analogous to that of the DecaGad reactor base and electrode holder. In contrast, this element has low shape complexity and a wireframe view style is used to show it in Figure 14.

The part design process ends with the creation of a knife electrode model. In this case, the sketch is drawn spatially by 3 mm – Figure 15. We can also mention a simple rubber seal that covers the electrode shaft. It is not a standardized element, but its implementation is simple and does not require any comments. It will be visible on each of the electrodes in the final renderings.

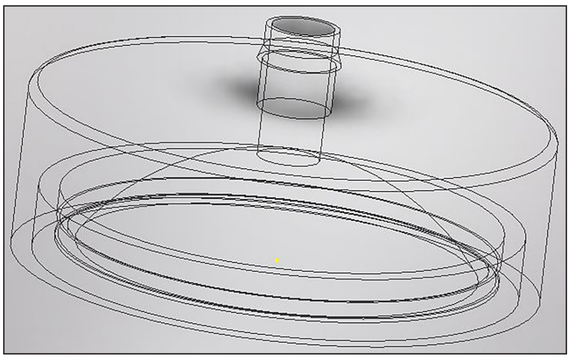

Figure 14. DecaGad plasma reactor top cover, model seen in wireframe style in Autodesk Inventor environment

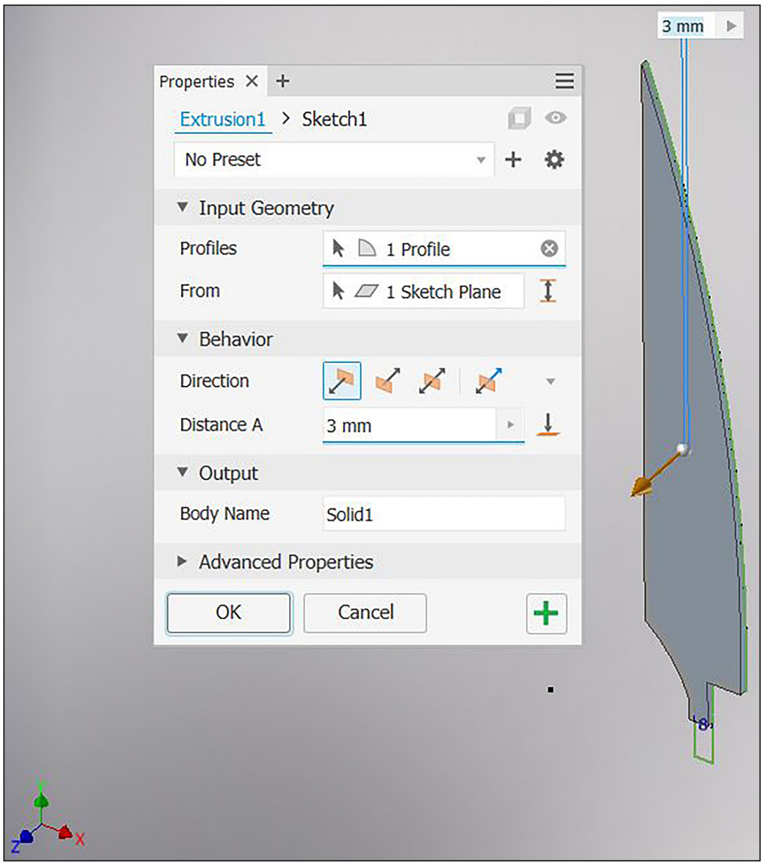

Figure 15. DecaGad plasma reactor electrode during the extruding from sketch to solid

Figure 16. The render of DecaGAD electrode assembly from Autodesk Inventor Studio environment

RENDERING DETERMINING PHYSICAL PARAMETERS

This study describes the fabrication of the components of the DecaGAD plasma reactor. These were: a base, an electrode holder, an electrode clamp which is also an electrical connector, a nozzle unit for the distribution of process gases, a cover and a knife electrode. Using these parts, saved in the *.ipt metric standard. At the next step assembly in *.iam standard prepared. Many standard elements from the AD Inventor Environment content center library were used for assembly. These were mainly: screws, nuts, seals and fastening screws. The work also does not describe the creation of a discharge pipe. This element was considered widely available, included in the borosilicate glass pipe range. The electrode assembly has been rendered – Figure 16. It consists of the mounting clamp, the cross-section of which was shown earlier – in Figure 10, and the electrode shown in Figure 15. An electrode shaft sealant was added. Rendering was performed in the Inventor Studio environment. Added direction and type of

Figure 17. The render of DecaGAD Plasma reactor obtained in Autodesk Inventor Studio environment

lighting. The render was made in 600 iterations. The entire reactor was rendered in front view. The base was supplemented with a missing inscription. This rendering was generated in over a thousand iterations to achieve the basic characteristics of a realistic appearance. Light was also used here. Reflections, contours and reflections of light are visible – Figure 17. Using the iProperties tool, after adding materials to the elements, the masses and geometric volumes were determined. The results from this simulation are summarized in Table 1.

CONCLUSIONS

The article presents the steps of designing an example reactor with a sliding discharge. It is a reactor with 10 knife-shaped electrodes. A modern solid modeler with a set of additional environments from Autodesk Inventor, Profesional 2024 version, was selected for design. This software is a standard in advanced industry and design work. It also has the ability to perform strength analyses. The design of the plasma reactor, called DecaGAD, was made from sketches drawn on planes in a 2D system. three-dimensional shapes were obtained mainly through rotations and extrusions. Components were assembled and renders of selected assemblies were made. It is worth emphasizing the realistic nature of these renders, which can be obtained even without using significant computing power. In the simulation process, the basic physical characteristics of the obtained elements were also determined. It is worth mentioning that such possibilities are extremely important for designers who have to determine the cost of large-scale production. All elements created in the virtual environment can be made as real components.

Table 1. Selected physical parameters of the plasma reactor elements obtained in the simulation

Part name	Added material	Mass	Geometric volume	Geometric area
		Unit, g	Unit, mm^3	Unit, mm^2
Base	Aluminum 6061-AHC	928	343796.345	70921.110
Electrode holder	Electrotechnical ceramic	449	118335.040	36411.152
Electrode clamp	Copper	180	1962.857	1967.658
Gas nozzle	UHMW	9,329	9924.715	8313.094
Gas nozzle adapter	UHMW	5	5846.219	4293.388
Electrode	Stainless steel	150	18746.364	14295.730
Electrode shaft seal	Rubber, silicone	0,98	564.920	650.157
Glass discharge tube	Borosilicate glass	1130	518362.788	210800.867
Reactor head cover	Aluminum 6061-AHC	911	337337.307	54782.639

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