Integrated CAD/CAM Approach for Experimental Stands in Hydrogen Explosion Analysis

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Abstract. Hydrogen is considered a promising clean energy carrier gas for the future and is used in fuel cell systems to generate electricity without producing greenhouse gas emissions. However, the safe storage and handling of hydrogen are essential for the widespread adoption of hydrogen as an alternative energy source. Research into hydrogen explosions is aimed at developing safe storage methods, safety guidelines, and accident prevention measures - crucial objectives for the sustainable growth of the hydrogen economy. Fundamental research into fast hydrogen combustion requires specially designed and built experimental stands to ensure both safe operation and recording of explosion parameters. More than a simple combustion chamber, often the geometry of the stands must contain elements to increase the complexity of the explosion process. In this respect, this paper deals with the possibilities of designing and 3D printing obstacles that can be placed in the path of hydrogen explosions on research stands to modify the cross-section, direct the pressure waves, turbulence the fluid movements, or even suppress the flame front. By combining the computer-aided modeling and design facilities offered by the Autodesk Fusion 360 software, digitized models are converted into 3D objects by the process of dividing them into thin horizontal layers (slices) and transmitting the information thus generated to the 3D printer, using Ultimaker Cura. Here, through the process of material deposition and fusion (FDM), the thermoplastic material is extruded, deposited layer by layer, rapidly cooling, and solidifying to form the final object.

1 Introduction

Hydrogen, as a relatively clean and abundant energy carrier, is viewed with great interest as a possible replacement for fossil fuels. However, due to its extraordinary explosive potential, the storage and handling of hydrogen continues to be a significant obstacle. Extensive studies and experiments are needed to create reliable safeguards against hydrogen explosions.

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The behavior, kinetics and processes of hydrogen explosions can be better understood if researchers investigate different experimental procedures and methodologies [1]. In order to create effective safety regulations and technical solutions, awareness of these issues is crucial.

Scientists are able to replicate and study many elements of hydrogen explosions thanks to experimental setups. Key parameters, including hydrogen content, ignition sources, confinement, and shape, typically must be precisely combined in these configurations to produce the desired explosion characteristics [2]. Hydrogen explosion experiments allow scientists to methodically assess the impact of many variables and probe the underlying mechanisms.

Pressure profiles, temperature changes and flame growth rates can be measured in real time using experimental setups [3], [4]. Eruption predictions and risk assessments rely heavily on these data points to validate and refine computational models.

In the field of scientific research, the study of chemical reactions and their associated phenomena is an essential aspect in the understanding and development of modern technologies. One of such extremely interesting and complex phenomena is the explosion of flammable gas mixtures. Among them, hydrogen-air mixture is known for its high explosive potential and its varied uses in industry, energy and other fields.

In this paper, we propose to present an innovative approach for the realization of an experimental stand dedicated to testing the explosion of the hydrogen-air mixture. For the physical realization of the experimental stand, the design and creation of several experimental models are proposed, regarding the delimitation of some interconnected enclosed spaces. A series of "obstacles" with holes are made to delimit closed spaces. When breaking through "obstacles" with different resistance, several experimental models are taken into account.

For the design and creation of the "obstacles", two advanced technologies are combined: the Fusion 360 software, which offers powerful modeling and simulation capabilities, and the Creality CR 10 Max 3D printer, which allows the production of complex parts and/or components with high precision and low costs.

The Creality CR 10 Max 3D printer is the main tool used in the study to produce the parts and components needed to build the experimental stand. With the help of this printer, durable and accurate parts are obtained that fit perfectly together, thus ensuring the correct operation of the stand and the safety of experiments.

The present work is structured in the following sections: presentation of the objectives and importance of the study, review of the specialized literature on the explosion of the hydrogen-air mixture, detailed description of the design and functionality of the experimental stand, the manufacturing process using the Creality CR 10 Max 3D printer, results and conclusions.

Through this work, the usefulness and efficiency of the combination of Fusion 360 software and Creality CR 10 Max 3D printer in making an experimental stand for testing the explosion of hydrogen-air mixture is investigated.

2 Presentation of the objectives and importance of the study

The main underlying objective is to design and build an experimental stand dedicated to the analysis of the hydrogen-air mixture explosion, using the Fusion 360 software and the Creality CR 10 Max 3D printer. In this experimental stand, the aim is to design "obstacles" for interconnected closed spaces. Using the Fusion 360 software, a detailed design of the "obstacles" is developed, allowing the manipulation, monitoring and control of the test conditions of the hydrogen-air mixture and the possibility of increasing the complexity of
the stand geometry. Aspects such as safety, efficiency and design modularity are considered to facilitate experimental operations and ensure accurate and reproducible results.

The importance of this study lies in its contribution to the scientific and technical field, as well as its potential impact on industrial safety. Understanding the phenomenon of hydrogen-air explosion is essential for the development and implementation of risk prevention and control measures in various sectors such as the energy industry, chemical industry and transport. By using the Fusion 360 software and the Creality CR 10 Max 3D printer to make the experimental stand, an innovative and efficient approach to the study is demonstrated, bringing practical and theoretical contributions to this field.

3 Review of specialized literature regarding the explosion of the hydrogen-air mixture

The explosion of the hydrogen-air mixture is an intensively studied research topic in chemical sciences and industrial safety engineering. The unique properties of hydrogen as a flammable gas, together with its reactive nature, make the hydrogen-air mixture one of the most dangerous and interesting explosion systems.

Review of the relevant literature reveals numerous studies and research on the behavior and characteristics of the explosion of hydrogen air mixture. In these studies, critical factors influencing explosion such as hydrogen concentration, stoichiometric ratio, ignition temperatures and pressure parameters were investigated. [5-11]

One of the important aspects analyzed in the specialized literature is the phenomenon of flame propagation in the hydrogen-air mixture. Research has shown that the hydrogen flame has a higher propagation speed than the flame of conventional fuel gases, making it extremely fast and violent. The mechanisms and physical processes responsible for flame propagation in the hydrogen-air mixture were investigated in detail, including mass transfer effects, heat transfer, and chemical reaction kinetics.

Studies also focused on determining critical explosion parameters, such as the maximum pressure reached during the explosion and the maximum temperature generated. These critical values are essential for risk assessment and the development of appropriate protective measures in the industry.

In addition, the literature also covers issues related to the prevention and control of hydrogen explosions. Various methods and technologies have been proposed and studied, such as detection and early warning systems, fire extinguishing devices and ventilation systems, which can help minimize the risks and limit the effects of hydrogen explosions.

Reviewing the literature in this field is essential to understand the theoretical foundations and existing experimental results and to identify research gaps and current challenges. This information will guide and support the design and construction of the experimental stand for testing the hydrogen-air mixture explosion.

4 Description of the design and functionality of the experimental stand

The design of the experimental stand for testing the explosion of the hydrogen-air mixture is made in a virtual environment, according to fig.1. Boundary obstacles of enclosed spaces are designed in Fusion 360 and drawings are exported in .STL format, which is a format commonly used when printing 3D objects.
The experimental prototype of the stand is designed in the form of a rectangular spiral, with metal walls, to ensure the resistance of the material to overpressures acting in the horizontal plane. The spiral shape offers the possibility of analyzing the explosion process with the change of the direction of propagation, on this route there are membrane obstacles, which divide the inner volume of the spiral into separate chambers.

To satisfy the criterion of transparency on the vertical axis (imposed by the Schlieren recording techniques), the metal spiral is closed at the bottom and the top with two polycarbonate plates, a material that ensures transparency and resistance to overpressures at the same time.

Thus, the high-speed video recordings will benefit from the transparency, in the vertical plane, of the experimental model, ensuring the retrieval of data on the fluid velocities in the explosion process and the observation of the behavior of the flame front, as well as the marking of important moments during this process (initiation of the explosive atmosphere, rupture of membranes).

The collecting of data regarding the explosion overpressures will be ensured by placing pressure sensors in the holes of the upper polycarbonate plate, the collected data being transmitted, by means of an amplifier, to the computing unit for analysis.

An electric spark generator system will have the electrodes arranged in the explosion cell in the center of the coil.

The current stand is modeled in the FLUENT application, to obtain a data set from the simulations of hydrogen explosions in interconnected closed spaces.

It should be mentioned that the computer simulation aims to approximate the overpressure values generated by the air-hydrogen explosion. However, the set of values obtained provides the designer with a reference point in sizing the polycarbonate sheets and how to assemble the experimental model.

The modular design and customization options allow the stand to be adapted to various configurations and experimental requirements.

Based on the results obtained from the computer simulations performed on the virtual model in the FLUENT application, the physical experimental stand will be created, with the aim of validating and verifying the behavior of the hydrogen-air mixture explosion in interconnected closed spaces.
5 The 3D modeling process with Fusion 360, structured in stages

Step 1: Create the basic sketch
Before starting the basic sketch of the object, it is recommended to set the measurement unit to millimeters in the Document Settings. This will ensure consistency and accuracy in object sizing and modeling. After the unit of measurement is established, the creation of the basic sketch begins using the "Sketch" tool in the top menu of the Fusion 360 interface [12], [13]. This tool allows drawing and constructing 2D geometries in the selected plane.

Basic sketching can be done using various geometric drawing and construction tools such as lines, circles, arcs and polygons. This basic sketch serves as the foundation for the subsequent three-dimensional model, fig.2.

![Fig. 2. Basic sketch for two types of obstacles](image)

Stage 2: Adding features and functionality
After the basic sketch is created, the next step is to add features and functionality to the 3D model. This can be done using the 3D modeling tools available in Fusion 360, such as "Extrude", "Revolve", "Fillet" and "Chamfer" [12-15]. For example, by using the "Extrude" tool, we can extrude the basic sketch to create a three-dimensional shape of the object, fig.3.

![Fig. 3. Extruding the two models in Fusion 360](image)

Stage 3: Detailing and refining the model
After the basic shape of the object is created, the next step is to detail and refine the model. Here, additional details can be added, such as holes, ribs, grooves, or other specific features of the object. The advanced modeling tools in Fusion 360 allow precise manipulation and adjustment of model shape and detail.

Step 4: Analysis of object shape and size
After completing the model, it is important to check the shape and dimensions of the object. Fusion 360 offers analysis tools, such as the "Inspect" tool fig.4, which allows the measurement of distances, angles and other geometric features of the model. This step ensures that the model conforms to the desired specifications and requirements.

In fig.4, another type of "obstacle" type object is presented, made for the study of the frontal behavior of the flame and the pressure field in the explosion process of air-hydrogen mixtures.

Step 5: Export the file for 3D printing
After analyzing and finalizing the model, the last step is to export the file for 3D printing. Fusion 360 allows model export in .STL format, which is a common format used by most 3D printers [16]. Exporting is done by using the "Export" tool, ensuring that the model is prepared and optimized for the 3D printing process.

Within the project, several prototype shapes are made, each with a specific geometric shape and designed in separate sketches. This allows you to explore different design options and evaluate various configurations for the test stand.

Each object created is done in similar design steps, starting with the creation of a basic sketch, which represents the reference shape in Fusion 360. Then, by adding specific features and functionality, the sketches can be modeled into 3D form.

Each prototype is the subject of iterations and optimizations, as feedback is obtained the results obtained can be evaluated. These iterations involved adjustments to the shape, dimensions, and geometric details to achieve the goals and requirements of the project.

By creating several prototype forms, different variants will be compared and evaluated and critical decisions will be made for the final design of the experimental stand. This process allows for an optimal result that meets the initial requirements and ensures functionality and safety in hydrogen-air explosion testing.

6 The manufacturing process using the Creality CR-10 Max 3D printer
In this project, the Creality CR-10 Max 3D printer is taken into account to manufacture the parts separating the rooms, which are called "obstacles" and which are an integral part of the experimental stand.

The manufacturing process will start with 3D modeling of the spacers. After creating the 3D models and exporting to the STL format, which is a three-dimensional geometric representation of the objects, the generated files will be uploaded to the 3D printer software.

Ultimaker Cura software stands out as the most efficient and complete tool for preparing 3D printing on the Creality CR-10 MAX printer. With an intuitive interface, advanced functionality and perfect compatibility, Ultimaker Cura gives users the opportunity to fully exploit the printer's potential, achieving superior results in the additive manufacturing process.

To ensure quality and consistent printing, the standard profile corresponding to the Creality CR-10 Max printer [17] can be selected. This profile includes optimal settings for the type of filament used and ensures good adhesion between the base layer and the print platform.

The manufacturing process using the Creality CR-10 Max 3D printer and Ultimaker Cura software provides flexibility and control over the production of the parts and components needed to build the test stand. In this way, we obtain precise results, durable parts [18] that fit perfectly together, thus contributing to the correct and safe operation of the stand.

7 Results and conclusions

The experimental stand created, starting from the results obtained within this project, will bring a series of valuable information regarding the explosion of the hydrogen-air mixture in a controlled environment.

First, the spiral shape of the experimental stand allows a directional change in the propagation of the explosion. This aspect makes it easier to observe and record how the explosion develops along the spiral path, depending on the configuration and positioning of the membrane obstacles. Previous research results [19], [20] have shown that the strategic placement of obstacles influences the pressure distribution and explosion behavior in each separate chamber.

Also, the pressure sensors installed in the upper part of each chamber provide accurate data on the pressure generated during the explosion. By analyzing this information, pressure variations can be assessed depending on the geometry and size of the room, as well as the presence of obstacles. These results allow the understanding of the explosion behavior and the identification of possible critical areas or vulnerabilities in the structure of the stand.

The design proposed in this paper for the objects used as "obstacles", will be tested in the first phase in the virtual environment. After the 3D printing of these objects, the hydrogen explosion experiments will be carried out on the actual experimental models.

The a priori testing of the experimental model in the virtual environment allows the construction of stands with increased safety for studying the hydrogen explosion process, bringing to the fore the understanding and improvement of safety measures in this field.

Finally, this work makes significant contributions to the research of hydrogen-air mixture explosion. The design and functionality of the test stand as well as the models proposed in this paper can be used as a starting point for further investigations and improvement of safety systems in various applications involving the handling and use of hydrogen.
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