

# Study of modern perforation processes specific to the automotive industry

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**Abstract.** The purpose of this paper is to critically present the trend in recent years in terms to use of perforation processes for perforation parts of the cars, operations that have real advantages, including reducing the environmental pollution in general. A study and a critical and comparative analysis are performed, referring to three perforation processes: hydroperforation, laser perforation and thermal erosion perforation. Hydroperforation is a process that is applied in a liquid environment and usually at the end of plastic deformation operations of some tubes by hydroforming in installations specially designed for this purpose. The paper presents some defining characteristics of these processes used in the industry being exemplified for the automotive industry. In general, all three perforation processes are performed at the end of the part formation by plastic deformation by hydroforming.

## 1. Introduction.

The current global trend regarding the accelerated use of efficient, economic and ecological processing processes imposes the need to study in-depth, in the future, the processing processes of current technical and economic global interest, as well as the need to approach theoretical research in the field. Last but not least, the current requirements regarding the reduction of specific energy consumption per production unit must be implemented. Even if it is relatively small, considering a large number of subassembly / products made by this technology, it will be possible, as a whole, to achieve a satisfactory overall result.

At present, depending on the chosen technology, different perforation/drilling processes are used in the case of tubular parts, namely:

- 1) in the air,
  - with associated edges, by plastic deformation
  - by using a single blade, that is without associated cutting edges, typically a punch, by plastic deformation
  - with laser
  - by thermal erosion
- 2) in a liquid medium
  - by hydroperforation
  - by impulse erosion

In recent years, automotive manufacturing and aeronautics have been the main drivers of the ever-increasing application of various processing processes to meet certain production requirements.

The automotive industry has developed, since the 1960s, the deformation of pipes by hydroforming and at the same time various perforation processes to make holes in various tubular parts of the automobile.

These perforation processes propelled and developed by the automotive industry, are:

- 1) hydroperforation
- 2) laser perforation
- 3) perforation by thermal erosion

**2. Specific types of tubular parts, with perforated holes, chassis and car body components**

In the case of parts of the long pipe type, a series of technological problems appear, such as:

- the impossibility, in most of these cases, to use two associated edges, a punch and a cutting plate, because a cutting plate cannot be inserted inside the tubular part;
- occurrence of deformations of the part, in the perforated area, if no cutting plate is used, due to the action of the punch on the tubular wall of the part;
- in most cases, the need to use the special devices, fasteners and tighteners in the holes area, for executing the operation of punching through plastic deformation technology.

The tubular parts are presented in a wide range of constructive forms, having surfaces of revolution / curves or even in the form of pipes, of small, medium or large dimensions. In recent decades, the need for such tubular parts has increased due to the growing demand in the automotive market and in the aerospace industry.

Some characteristic types of such long tubular parts used in car construction are shown in the figures 1- 6 [1].



**Figure 1.** Tubular parts positioned on the car body [1].  
 A- roof headers; B- instrument panel supports; C- radiator supports;  
 D- engine cradles; E- roof rails; F- frame rails.

Figure 1 [1] shows perforated tubular parts, as they are positioned to the car. There is a wide range of parts required in most car installations and in its safety structure: rood headers, instrument panel supports, radiator supports, engine cradles, rood rails, frame rails. These parts have certain holes, having a functional or constructive role.

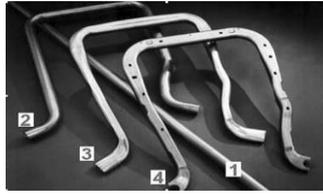
The characteristics of these tubular parts are closely linked to the functional role they must play in the product to which they belong.



**Figure 2.** Rollover bar protection system in Porsche Boxter [1].



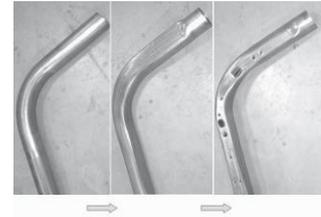
**Figure 3.** Rollover bar protection [1].



**Figure 4.** Hydroformed engine cradle: (1)the initial straight tubular blank, (2)bent, (3)pre-formed, (4) hydroformed and pierced (Courtesy of Schuler Inc) [1].



**Figure 5.** Safety frame [1].



**Figure 6.** Steps of formation and perforation [1].

Some of these parts have a role in the resistance structure of the product, others have a role of protection against external agents, others have the role of sealing or the role of transport and/or control of fluids in certain installations, or the role of selection/filtering/sorting in the composition of some installations.

### 3. The hydroperforation process.

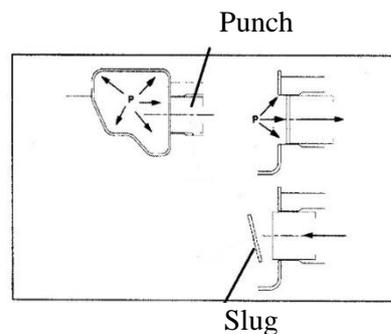
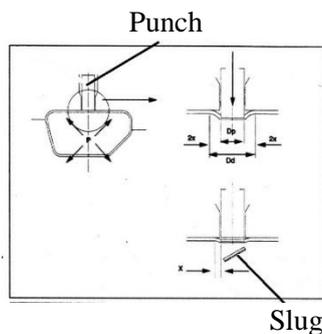
#### 3.1. Defining the process

Hydroperforation is a processing process that uses a special type die, which has a single edge to perform the processing, using a hydraulic pressure.

There are two variants of hydroperforation:

a) The first option of hydroperforation is to exert a punching force from the outside of the pipe, by rounding the punch in the piece, the punch penetrates the piece and loosens the portion of material to the inside of the pipe, as shown in figure 7 [4]. Because the fluid pressure in the inside of the deformable piece wall, in the area around the hole, the deformation is minimal. In figure 7 is denoted by  $D_p$ , the diameter of the punch, with  $D_d$ , the diameter of zone and a slight deformation of the piece, around the hole made, and with  $X$  was noted the distance of deformation of the piece wall, around the hole made.

b) The second option of hydroperforation is with the exercise of a hydraulic perforating force inside the pipe, by superficially pressing the punch on the piece and then withdrawing it, to make the cut the portion of the pipe wall. It is represented schematically in figure 8 [4], it consists in the perforation due to the pressure of the liquid inside the part, which determines the cutting of the wall of the part near the hole in which the plunger punch acts, meaning when the controlled retraction of the punch, the perforation is performed. After perforation, by the reverse controlled movement of the punch in the inside of the tubular part, the cut piece from the wall of the piece is removed from the bore of the punch. In this second option, the piece wall not appear deformed in the hole area, as in the case of the first option.

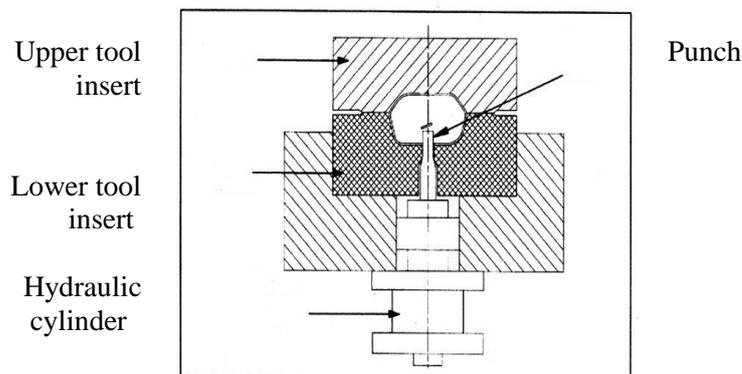


**Figure 7.** The punch penetrates outside the piece and detach the slug of the hole [4].

**Figure 8.** The punch partially penetrates the piece and detachment is done by hydraulics pressure inside the piece [4].

Special installations are used for hydroperforation, they are composed of certain elements that allow drilling operations for various long tubular parts. These elements have been called modules and have a specific structure. Figure 9 [4] shows schematically such an element used in the hydroperforation installation, an element called "module" and comprising:

- the upper part of the die
- the lower part of the die
- the punch that moves in a special and tight bore in the body of the die
- the hydraulic cylinder, which actuates the punch.



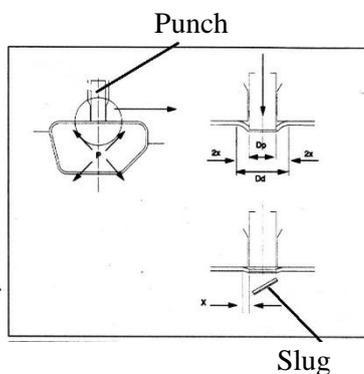
**Figure 9.** The scheme of a module used in installations of hydroforming and hydroperforation [4].

The module presented is a unit with a simple structure, because it provides only one hydraulic cylinder, but it can act more punches. This structure allows easy use for various cases of perforation, by relatively simple mounting on the positioning of the punches in relation to the given part.

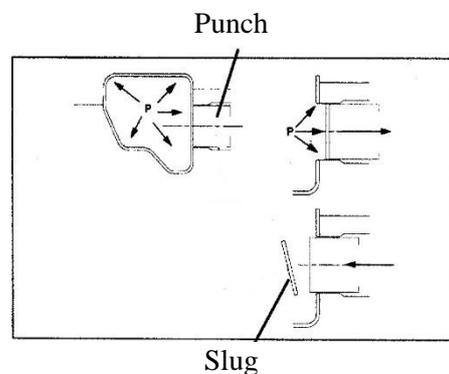
A problem with hydroperforation is the removal of the slug, resulting from perforation.

Figure 10 [4] shows the case where the slug it remains partially on the wall of the piece. This case is characteristic of the first perforation option presented. If this slug if this residual material interferes with the operation of the part then it must be removed by secondary operations, subsequent to the perforation and the part must remain clean.

Figure 11 [4] shows the case where, after perforation, the slug is attached to inside edge of the hole.



**Figure 10.** The core of the hole remains partially attached attached to inside edge of the hole [4].

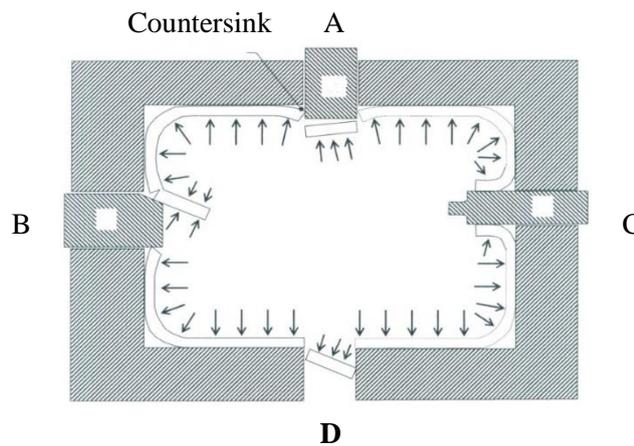


**Figure 11.** The slug are turn to inside of the part [4].

Figure 12 [4] shows the schemes of the different cases of detachment of the slug at hydroperforation. These presents for cases:

- total detachment and movement inside the part (top A, in figure 12 );
- partial detachment and remains trapped inside by the edge of the hold (left B, in figure 12 );
- total detachment and movement to the outside of the part (bottom D, in figure 12 );
- detachment and movement towards the inside of the part and the remaining hole edges, turned inwards (right C, in figure 12 ).

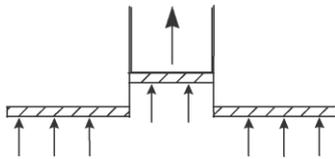
The holes made by hydroperforation have small positioning tolerances and a good dimensional accuracy .



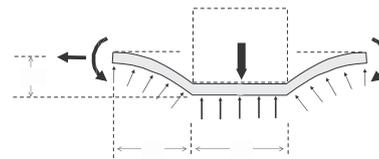
**Figure 12.** Cases of detachment of the core of the holes when hydroperforating parts [4].

### 3.2. Technological constraints on hydroperforation

The diameters of the holes are limited to a minimum of  $2g$ , where „g” is the wall thickness of the tubular part.



**Figure 13.** The forces that appear when the punch detaches the material [5].



**Figure 14.** The forces that appear when the punch is withdrawn and the detachment is made by hydraulic pressure [1].

Figure 13 [5] shows the forces that appear during the perforation process, if the punch is the one that penetrates the material, when the force acts from the outside of the tube to the inside of it.

Figure 14 [1] shows the forces that appear in the perforation process, when the hydraulic force acts on the perforation and the punch retracts, the pressing force is from the inside to the outside of the tube.

### 3.3. Advantages of hydroperforation

The use of hydroforming has been able to expand due to research in the field of materials, with the current accentuated tendency to obtain light materials but with very high mechanical resistance, materials increasingly required for the manufacture of cars and airplanes. Such materials can positively influence the Weight/Power characteristic, as it must be as small as possible, in the case of cars and airplanes, in order to be able to develop higher speeds and accelerations, with maximum economic efficiency.

Figure 15 [2] shows a part where a minimum and a maximum hole they are made by hydroperforation, for the wall thickness of the tubular part, between 2 and 6 mm.



**Figure 15.** Maximum and minimum hole obtained by hydroperforation [2].

Figure 16 [2] shows a picture of a hydroforming installation used to make automotive components.

Figure 17 [2] shows an automated hydroforming and hydroperforation manufacturing line from Opel, a car manufacturer.



**Figure 16.** Hydroforming installation [2].



**Figure 17.** Automated hydroforming and hydroperforation manufacturing line [2].

Advantages of the hydroforming and hydroperforation, compared to classical processes:

- the holes obtained by hydroperforation have small positioning tolerances and a good dimensional accuracy;
- reducing the weight of semi-finished products;
- reduction the number of part components obtained by assembly;
- lower costs of the components and the assembly;
- lower equipment costs;
- increased strength and rigidity of the finished parts obtained;
- a high dimensional stability (geometric tolerance and positioning of the hydroperforated holes) of the finished parts obtained.

#### **4. The laser perforation process**

Laser perforation has seen a spectacular development through the recent use of robotics in drilling tubular parts such as long pipes. Laser beams are monochrome and coherent electromagnetic radiation in the optical field, characterized by exceptional directionality and brightness.

Elements for carrying out the process, are:

- collimated laser beam
- optical focusing system
- environment work

- the object to be processed

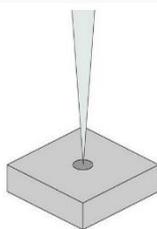
When laser perforation, a laser beam makes non-contact holes with a range of very small diameters to very large diameters in various materials. When laser drilling, a short laser pulse, introduces energy into the part in a very short time, so that the material is melted in that area and vaporizes, and due to the resulting vapor pressure the molten material is evacuated from the hole. When processing with the help of lasers with ultrashort pulses in a regime of picoseconds, the solid state material evaporates directly, without liquefaction, avoiding the heating of the part.

There are several laser perforation procedures, as follows:

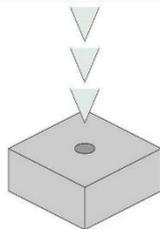
➤ Perforation with individual impulses

In this case, an individual laser pulse with a comparatively high energy performs the perforation. Numerous holes can be made very quickly.

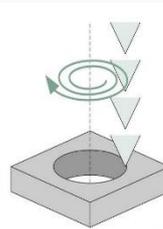
Figure 18 [8] shows the simplified scheme of the perforation with individual impulses process.



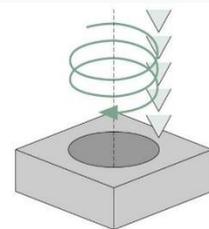
**Figure 18.** Scheme of the perforation with individual impulses [8]



**Figure 19.** Scheme of the percussion perforation [8]



**Figure 20.** Scheme of the perforation by drilling [8]



**Figure 21.** Scheme of the helical perforation [8]

➤ Percussion perforation

When percussion drilling, the punching is done through several pulses with reduced durations and energies. This perforation process allows to obtain deeper and more precise holes, compared to the perforation with individual pulses. Also, by percussion perforation smaller diameters of the holes are possible.

Figure 19 [8] shows the simplified scheme of the percussion drilling process.

➤ Perforation by drilling

Drilling involves perforating by means of several laser pulses. First, an initial hole is made by percussion perforation. Then the original hole is enlarged, moving over the piece on several circular paths, getting bigger and bigger. Thus, most of the molten material is discharged down from the orifice.

Figure 20 [8] shows the simplified scheme of the perforation by drilling process.

➤ Helical perforation

No initial hole is made in the helical perforation. The laser moves from the first pulses on a circular path above the material. In this way, much of the material is discharged upwards. The laser processes in depth, in the form of a helical ladder. Thus, it is possible to monitor the focal point, so that it is permanently at the bottom of the perforation. After the laser penetrates the material, several more trajectories can be added. They serve to extend the lower part of the perforation and to smooth the edges. The helical perforation allows the realization of very large and deep holes, of high quality.

Figure 21 [8] shows the simplified scheme of the helical perforation process.

Making different diameters can be obtained by the size of the holes of the laser nozzle.

Figure 22 [8] shows the laser nozzle.



**Figure 22.** The laser nozzle [8]

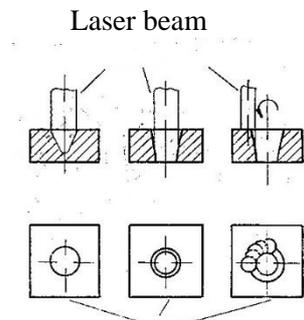
Materials processed currently by laser are:

- ceramic materials, such aluminium, ruby, and synthetic sapphire, natural or synthetic diamond;
- macromolecular materials such polyethylene, polycarbonates, polystyrene, polyacetates;
- high alloyed steels with Ni, Cr, Co (inclusively stainless and refractory steels, W, Mo, Ti, Cu);
- brass;
- metal-ceramics materials (metal carbides).

Types of parts subjected to laser perforation are bore parts, tubular parts, pipes.

Figure 23 [3] shows the laser perforation operations:

- perforation by copying
- perforation
- enlargement



**Figure 23.** Various operations of perforation carried out using a laser [3].

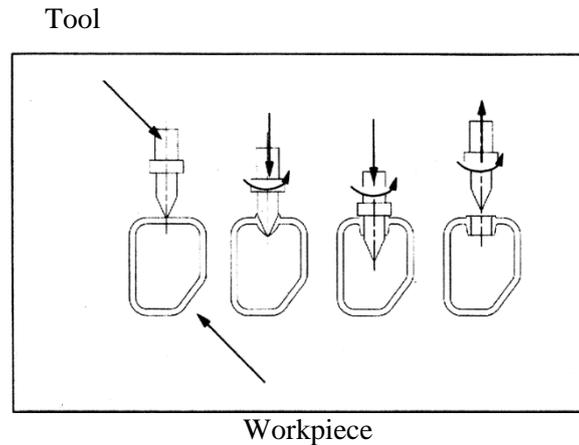
Laser applications in the automotive industry are to reduce the weight of vehicles, massive components are increasingly being replaced by pipe structures. Thus, pipes are used in the manufacture of head restraints, transverse beams and seat structures [8].

The advantages of using laser perforation are:

- a very good machining accuracy;
- a high productivity and efficiency, the process can be automated or even robotic today.

### 5. The thermal erosion perforation process

Thermal erosion perforation of long tubular parts is an innovative process, which uses a rotary tool with sharp edges, which penetrates the part and causes a strong heating of the part in the work area and the material is removed, resulting the holes in the parts. Schematically, this processing process is presented in figure 24 [4]. This process has a high productivity, the processing time of an orifice being 5-6 seconds.



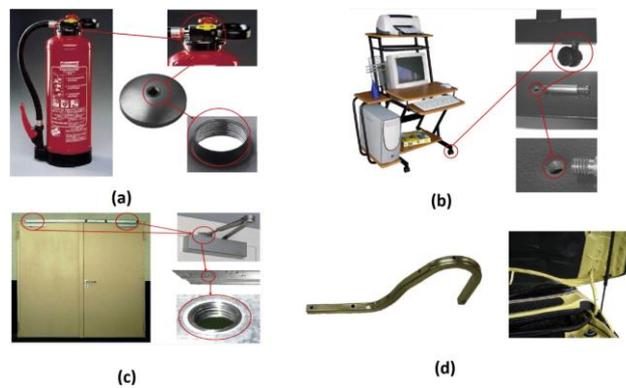
**Figure 24.** The scheme of the thermal erosion perforation process [4].

According to [7] and in the last decade, thermal perforation has been widely used in the aerospace and automotive industries, due to its unique advantages over the conventional perforation process: finishing the surface of the thermally perforation hole.

The surface roughness of the thermally perforated hole on galvanized steel is very good and significant variable parameters are made, such as:

- axial speed;
- tool angle;
- the thickness of the workpiece.

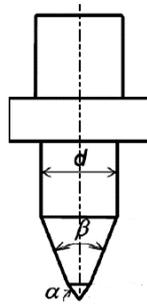
Figure 25 [6] shows examples of tubular parts in which holes were made by thermal perforation, some with thread.



**Figure 25.** Various tubular parts with holes made by thermal erosion [6].

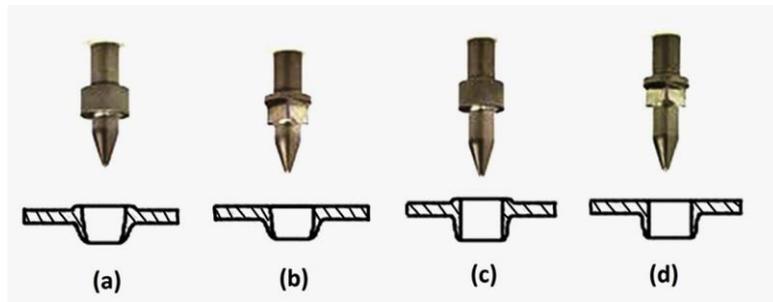
According to [7] the conventional perforation process produce a massive environmental pollution, because they produce a waste of metal chips, span.

A thermal perforation tool is shown in figure 26 [6].



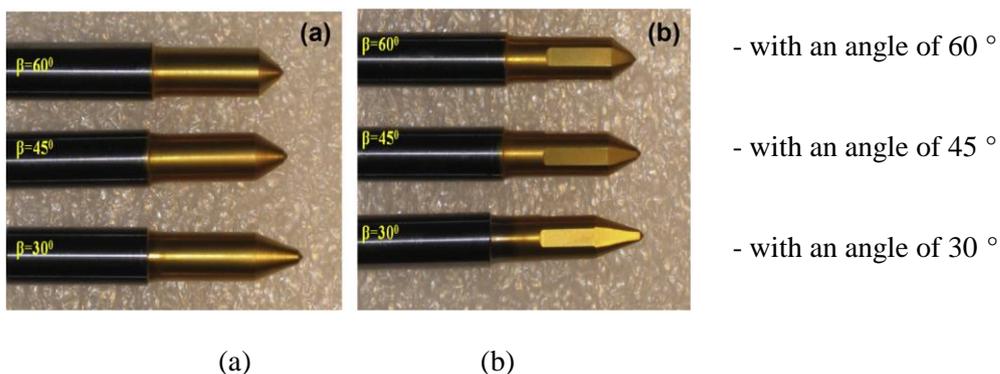
**Figure 26.** Representation of a tool used for thermal erosion perforation [6].

The various tools used for thermal perforation are shown in figure 27 [6].



**Figure 27.** Various tools used for thermal erosion perforation [6].

Figure 28 [6] shows different thermal perforation tools, with two types of contact friction surfaces 100% (a) and 50% (b). It is observed that the conical portions can have angles of  $30^\circ$ ,  $45^\circ$  or  $60^\circ$ .



**Figure 28.** Thermal perforation tools:  
 (a) with 100% contact friction surface (b) with a contact friction surface of 50% [6].

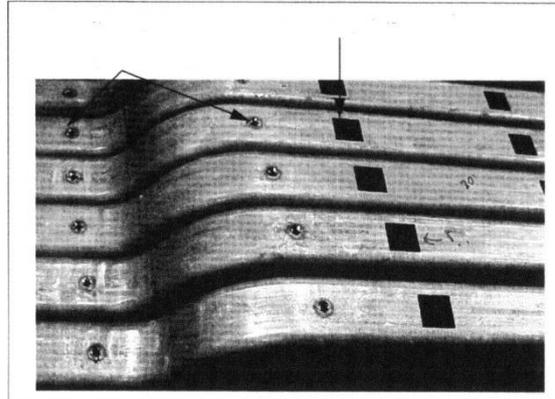
The thermal perforation tools practically create a reflection of the material inside the tubular part, and at the end of the perforation, the tools also make a compaction of the upper part of the work area, and make a flat surface on the part, only that no chips are produced.

Pipe-type tubular parts are subjected to this process, having the holes made for self-tapping screws.

Figure 29 [4] shows on the same parts, the holes made by thermal erosion perforation (a) and holes made by laser perforation (b).

a) Flow perforation holes,  
suitable for 6 mm self-  
tapping screws

b) Laser cut slots



**Figure 29.** a) Flow perforation holes, suitable for 6 mm self-tapping screws; b) Laser cut slots [4].

Advantages of the thermal erosion perforation process are indicated in the following:

- in order to reduce emissions pollution, it should replace the conventional drilling process;
- is an energy efficient and clean perforation process, which has attracted several car manufacturers and the aerospace industry in recent years;
- the processing time and production cost of perforation and the risk of rejection are reduced;
- due to the high speed of the tool, a large amount of thermal energy is produced in the perforation area and thus a movement of the material is achieved, so that no metal chips result.

## Conclusions

In the present paper, three modern perforation processes have been studied and critically analyzed: hydroperforation, laser perforation and thermal erosion perforation. They are important processes as they have been successfully applied in recent years, especially in the automotive industry.

These perforation processes are a consequence of the requirements in certain sectors of activity their results being demanded by novel engineering studies and technology. The results were spectacular leading to the development of technologies to produce parts and subassemblies that are as light as possible, as durable as possible, as cheap as possible, and as environmentally friendly as possible.

Compared to the classic perforation/drilling processes, these three innovative processes have been intensively applied also due to the fact that light materials with very good mechanical and technological characteristics have been obtained, such as alloy steels, magnesium alloys, aluminum alloys.

In parallel with the hydroperforation, the laser perforation process and more recently the thermal erosion perforation process were applied for certain components.

One proved that these three processes are very adequate, because they have a good productivity, a good dimensional accuracy and positioning of the holes, they achieve a better protection of the environment by reducing polluted emissions. Finally the advantages of these processes were presented, compared to the classic perforation/drilling procedures, namely:

### ➤ Hydroperforation

- holes with low positioning tolerances and good dimensional accuracy are obtained by hydroperforation;
- allows to reduce the weight of semi-finished products;
- implicitly leads to the reduction of the number of components of a part obtained by assembly;
- achieves lower costs of components and assembly;
- leads to lower costs of car equipment;

- finished parts with increased strength and rigidity are obtained;
- is characterized by a high dimensional stability of the finished parts obtained (geometric tolerance and positioning of the hydroperforated holes).
  - Laser perforation
    - parts with holes with a very good processing precision are obtained;
    - the process has a high productivity and efficiency, the process can be automated and robotized;
    - allows the realization of holes in parts made of different materials (high steels alloyed with Ni, Cr, Co, brass, metal-ceramic materials, macromolecular materials).
  - Thermal erosion perforation
    - when making the holes, there are no metal chips, due to the high speed of the tool, a large amount of thermal energy is produced in the perforation area and thus a flow of the material is made, without steel chips;
    - processing time and production cost of perforation are reduced;
    - the risk of rejecting the parts is reduced;
    - it is an energy efficient and clean perforation process, and that is why in recent years it has started to be used more and more in the production of cars and in the aerospace industry;
    - is part of technological processes that reduce polluted emissions.

One considers that the purpose of this paper has been fully achieved, meaning to make a study and a critical analysis of these three innovative perforation processes, used successfully in the automotive industry.

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