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(54) **ELECTROHYDRAULIC FORMING APPARATUS**

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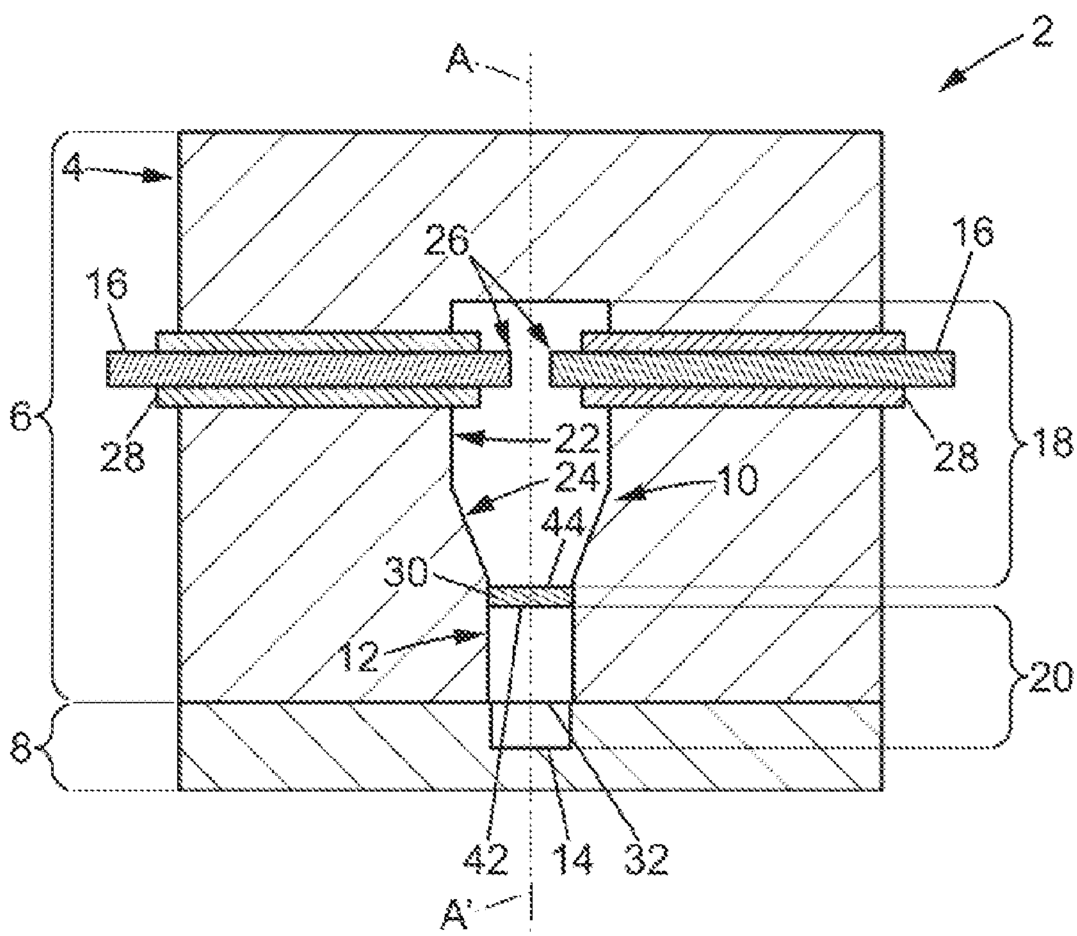
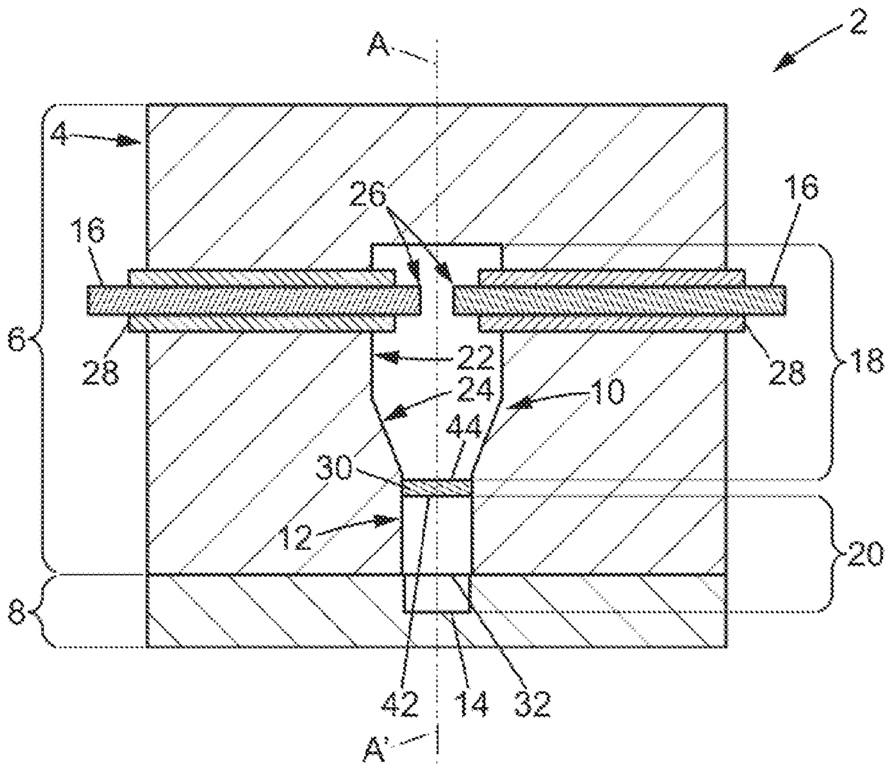
(57) **ABSTRACT**

An electrohydraulic forming apparatus includes a mold with an upper portion and a lower portion, an enclosure having a first region, a second region, a mold cavity positioned in the second region, and electrodes having electrode tips positioned in the first region, wherein a piston is mounted so as to be movable in translation within a channel in a fluidtight manner and separates the first region from the second region of the enclosure.




2
A
4
6
8
16
26
28
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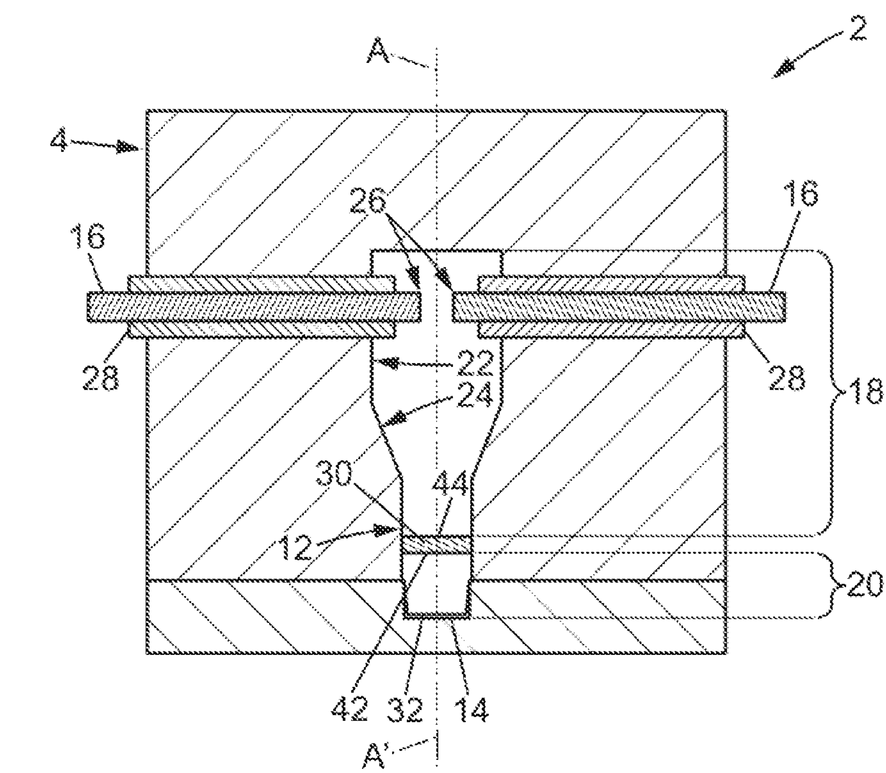
24
10
18
44
30
12
20
42
14
32
A'

FIG. 1


2
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16
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42
32
14
A'

FIG. 2

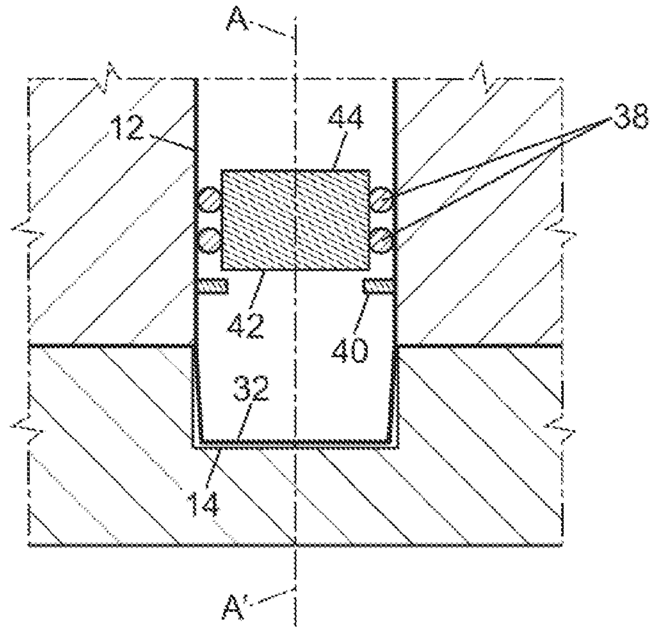

FIG. 3

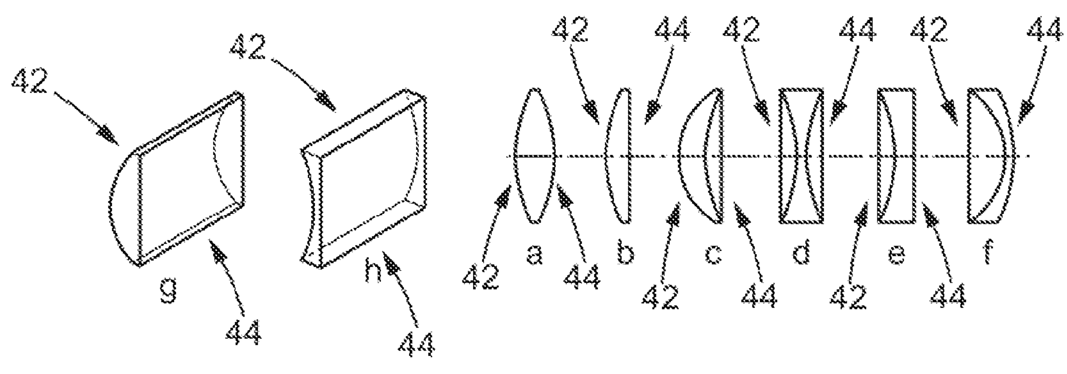

FIG. 4

ELECTROHYDRAULIC FORMING APPARATUS

[0001] The present invention relates to an electrohydraulic forming apparatus.

[0002] Electrohydraulic forming apparatuses are increasingly being used for the production of mechanical parts. These forming apparatuses make it possible to obtain parts of relatively complex appearance while controlling production costs. For example, the automotive and aerospace industries use such apparatuses.

[0003] A hydraulic forming process is a process of manufacturing by deformation. It enables plastic deformation of a metal part of relatively small thickness. To achieve this deformation, a fluid is used which, when pressurized, enables the deformation of said part on a mold. Several techniques are used to pressurize the fluid.

[0004] One of the processes used is an electrohydraulic forming process. This process is based on the principle of an electrical discharge in fluid stored in a tank. The released amount of electric energy generates a wave which propagates very quickly in the fluid and enables plastic deformation of the mechanical part against the mold. To do this, electrodes positioned in the fluid release an electric charge stored in energy storage capacitors.

[0005] To achieve this deformation, a non-negligible amount of water is required. The deformation of the part is proportional to the volume of water displaced during the explosion generated by the electric arc. In addition, a step of emptying the tank is necessary after each explosion in order to retrieve the formed part. Such apparatuses are therefore generally preferred for the production of parts in small series.

[0006] However, the generation of electric arcs causes wear to the electrodes and the appearance of small particles which, due to gravity, fall onto the part positioned at the bottom of the mold. These particles then result in defects in the formed part.

[0007] U.S. Pat. No. 7,493,787 discloses an electrohydraulic forming apparatus in which a membrane is used to retain two volumes of liquid. A apparatus adapted to generate a high voltage pulse is coupled to electrodes in order to create a shockwave in one of the volumes of liquid. The shockwave thus generated is transferred through the membrane to the other volume of liquid, thus deforming a part against a mold. Due to the use of a membrane separating the two volumes of liquid, only the volume of liquid in which the part to be deformed is placed must be drained when changing the part, which improves productivity. Furthermore, the part to be formed is protected from particles resulting from electrode wear. Such a apparatus is of relatively complex design however, because it is composed of at least three parts. In addition, the strength of the membrane directly impacts the reliability of the apparatus. Plus the use of a membrane allows only the simple transmission of the shock wave.

[0008] The object of the present invention is to provide an electrohydraulic forming apparatus of relatively simple design, meaning that it preferably comprises only two parts with improved reliability compared to apparatuses of the prior art. In addition, the present invention advantageously provides an electrohydraulic forming apparatus in which the manufacturing costs are reduced while meeting current standards. Advantageously, the part to be formed is protected from particles resulting from electrode wear, which makes it possible to obtain parts with the desired surface condition.

[0009] To this end, the invention proposes an electrohydraulic forming apparatus comprising a mold with an upper portion and a lower portion, an enclosure having a first region, a second region, a mold cavity positioned in the second region, and electrodes having electrode tips positioned in the first region,

characterized in that a piston is mounted so as to be movable in translation within a channel in a fluidtight manner and separates the first region from the second region of the enclosure.

[0010] Due to the use of a piston, the reliability of the electrohydraulic forming apparatus is improved. Productivity is also improved because it is not necessary to drain all the liquid contained in the mold of the electrohydraulic forming apparatus.

[0011] To avoid the potential risk of the piston jamming in the channel, the piston may have first guide means complementary to second guide means of the channel.

[0012] In one exemplary embodiment, the guide means comprise three ribs to limit the degrees of freedom of the piston to one.

[0013] In a variant, the second guide means comprise three grooves, thus optimizing translational movements of the piston within the channel.

[0014] To optimize the deformation of a part positioned on the mold cavity, the piston has a first face of planar shape and directed towards the mold cavity.

[0015] In a variant, the piston may have a first face of a shape selected from the set of concave and convex shapes and directed towards the mold cavity.

[0016] In order to optimize the movement of the piston within the enclosure, the piston has a second face adapted to the shape of the enclosure and directed towards the first region.

[0017] In a variant, the piston has for example a second face of a shape selected from the set of concave and convex shapes and directed towards the first region.

[0018] To prevent the piston from falling into the lower portion of the mold, the channel may have a stop adapted to retain the piston. In this exemplary embodiment, a spring may be positioned between the piston and the stop in order to improve the reproducibility of the details on the parts to be formed. Due to the presence of the spring, the piston is returned to a determined and identical height after each emptying of the mold.

[0019] Features and advantages of the invention will be more apparent from the following description, made with reference to the accompanying schematic drawings in which:

[0020] FIG. **1** is a schematic simplified cross-sectional view of an electrohydraulic forming apparatus according to the invention,

[0021] FIG. **2** is a simplified schematic view corresponding to FIG. **1**, in another position,

[0022] FIG. **3** is an enlarged and simplified schematic view of a detail of another embodiment of the invention, and

[0023] FIG. **4** shows different piston shapes.

[0024] FIG. **1** is a schematic representation of an electrohydraulic forming apparatus **2** comprising a mold **4** having an upper portion **6**, a lower portion **8**, an enclosure **10**, a channel **12**, a mold cavity **14** positioned in the lower portion **8**, and electrodes **16**.

[0025] Such an electrohydraulic forming apparatus **2** may be arranged on a frame (not shown in the figures) made of a metal or metal alloy for example such as hardened steel.

[0026] The upper portion **6** of the mold **4** in the embodiment illustrated in the drawing is positioned above the lower portion **8** of the mold **4**. The lower portion **8** is fixed to the upper portion **6** by clamping means for example (not shown in the figures). Preferably, the mold **4** (comprising the upper portion **6** and the lower portion **8**) is composed of a high-density material, for example such as a metal or metal alloy.

[0027] The enclosure **10** has a first region **18**, a second region **20**, and the channel **12**. As illustrated in FIG. **1**, the enclosure **10** has a first wall **22** that is rotationally symmetrical with respect to an axis A-A' and is for example of cylindrical shape with a determined diameter.

[0028] The enclosure **10** also has a second wall **24** of frustoconical shape, connected to the first wall **22** and to the channel **12**.

[0029] The enclosure **10** is also adapted to receive, in the first region **18**, the tips **26** of electrodes **16**. The electrodes **16** are high-voltage electrodes (several tens of kV). Here, they are held perpendicularly to the axis of revolution A-A' (FIG. **1**). In order to insulate the electrodes **16** from the mold **4**, an insulating sleeve **28** is used.

[0030] The electrodes **16** also have an adjustable and modifiable inter-electrode space which makes it possible to control the triggering of an electric arc between them.

[0031] An electrical storage apparatus (not shown in the figures) is used that is suitable for storing an amount of electrical energy sufficient to generate at least one electric arc between the electrodes **16**. In order to control the amount of electrical energy delivered by the electrical storage apparatus to the electrodes **16**, a pulse generator (not shown in the figures) is coupled to the energy storage apparatus. As the pulse generator and the electrical storage apparatus are known to those skilled in the art, they are not presented in the present description.

[0032] In a preferred embodiment, the channel **12** has a circular cylindrical shape and has a determined length sufficient to allow movements of a piston **30** corresponding to the deformation to be made to a part placed facing the mold cavity **14**. The channel **12** is also adapted to the mold cavity **14**.

[0033] The lower portion **8** receives the mold cavity **14** which defines the final shape to be given to the part **32** to be produced by electrohydraulic forming (EHF). Depending on the complexity of the shape of the part **32** to be formed, the mold cavity **14** may have a large form factor with high precision details.

[0034] Also, the lower portion **8** may comprise tubing (not shown in the figures) coupled to vacuum means (not shown in the figures) for eliminating any air present between the part **32** and the mold cavity **14** Thus, during the process of forming the part **32**, there is no counter-reaction (caused by the presence of air between the part **26** and the mold cavity **14**) to oppose the deformation of the part **32**.

[0035] The piston **30** is mounted so as to be movable in translation within the channel **12** in a fluidtight manner and forms the separation between the first region **18** and the second region **20** of the enclosure **10**. The first region **18** is filled with a first fluid and the second region **20** is filled with a second fluid.

[0036] In a preferred embodiment considered here, the first fluid and the second fluid are water. Advantageously, by virtue of the presence of the piston **30** in the channel **12**, the water contained in the first region **18** is isolated from the water contained in the second region **20** of the enclosure **10**. Thus, particles worn off the tips **26** of the electrodes **16** are stopped by the piston **30** and do not reach the part **32**. It should be noted, as illustrated in FIGS. **1** and **2**, that the first region **18** and the second region **20** vary with the positioning of the piston **30** within the channel **12**.

[0037] The piston **30** is, for example, made of a material identical to the material of the mold **4**. Advantageously, in order to ensure the fluidtight seal between the first region **18** and the second region **20**, the piston **30** has a diameter identical to the diameter of the channel **12**. The piston **30** is mounted so as to be movable in translation within the channel **12**, thus enabling translational movements along the axis of symmetry A-A' from a first position (FIG. **1**) to a second position (FIG. **2**).

[0038] To optimize the seal between the first region **18** and the second region **20**, sealing means may be used, for example such as elastic rings **38** positioned between the piston **30** and the channel **12**.

[0039] FIG. **3** shows a partial cross-sectional view of the electrohydraulic forming apparatus **2** with the two elastic rings **38**. In an alternative embodiment, to improve the retention of the elastic rings **38** on the piston **30**, the latter may have grooves (not shown in the figures) of a shape and depth adapted for receiving and retaining the elastic rings **38** which form a seal between the piston **30** and the channel **12**.

[0040] Also, to avoid rotation about axis A-A' during the translational movements of the piston **30** within the channel **12**, and thus eliminate any risk of the piston **30** jamming, it is provided in one embodiment that the channel **12** comprises at least one groove (not shown in the figures) and that the piston **30** comprises at least one rib. The groove of the channel **12** is adapted to engage with the rib of the piston **30**.

[0041] In order to improve the reliability of the electrohydraulic forming apparatus **2**, the piston **30** may comprise three ribs equally distributed around the piston **30**, and the channel **12** may comprise three equally distributed grooves, the ribs being positioned to face the grooves. The piston **30** thus has a single degree of freedom and forces are better distributed during the transition from the first position (FIG. **1**) to the second position (FIG. **2**), which improves the service life of the electrohydraulic forming apparatus **2**.

[0042] In an alternative embodiment, to prevent the piston **30** from leaving the channel **12**, the latter has a stop **40** as illustrated in FIG. **3**. Preferably, the stop **40** is positioned on a lower portion of the channel **12**. Furthermore, this stop **40** also prevents the piston **30** from exiting and/or falling out of the channel **12** when the second region **20** of the enclosure **10** is drained.

[0043] In a variant, to facilitate repositioning the piston **30**, a spring (not shown in the figures) may be used. The spring is for example positioned on an outer edge of a first face **42** of the piston **30** and bears against the stop **40**. The spring then makes it possible to return the piston **30** to its first position after a step in the process of electrohydraulic forming of the part **32** placed in the mold cavity **14**.

[0044] The transition from the first position to the second position of the piston **30** as presented above in the description is achieved by the propagation of a first wave generated by an electric arc at the electrodes **16**. The first wave so generated propagates in the first region **18** perpendicularly to the axis A-A' toward the piston **30** and more precisely toward a second face **44** of the piston **30**.

[0045] The first wave has an energy which depends, among other things, on the power of the electric arc. The movement of the piston **30** within the channel **12** enables transferring almost all the energy of the first wave to the water contained in the second region **20**, giving rise to a second wave. The second wave thus created propagates towards the mold cavity **14** in order to deform the part **32** arranged thereon.

[0046] Advantageously, the use of an electrohydraulic forming apparatus **2** with a piston **30** positioned in the channel **12** to isolate the first region **18** from the second region **20** allows improving the quality of the part **32**. When the electric arc is triggered at the electrodes **16**, a relatively small quantity of material is torn from the electrodes and forms particles which fall into the fluid, in this case water. These torn-off particles fall onto the piston **30** due to gravity and do not reach the part **32**, in contrast to apparatuses of the prior art which comprise a single volume of fluid.

[0047] In addition, the use of a piston **30** in the channel **12** to isolate the water contained in the first region **18** from the water contained in the second region **20** advantageously reduces the time required to fill and empty the water contained in the second region **20**.

[0048] Thus, the movement of the piston **30** from its first position to its second position occurs without resistance and can be carried out in a relatively short time, for example less than one millisecond, which makes it possible to obtain a rapid deformation of the part **32** and thus a better deformation of the part **32**.

[0049] In order to improve the transfer of energy between the first wave and the second wave, the second face **44** of the piston **30** may have a concave shape for example and the first face **42** of the piston **30** may have a convex shape (FIG. **4***d*). Propagation of the second wave in the lower portion **8** is thus optimized, improving the deformation quality of the part **32** after deformation.

[0050] In other exemplary embodiments, as illustrated in FIGS. **4***d* to **4***f*, the first face **42** may have a greater or lesser radius of curvature. Thus, depending on the radius of curvature selected, it is possible to improve the focusing of the second wave on the part **32** in order to optimize its deformation.

[0051] The first face **42** and the second face **44** may also have other shapes as illustrated in FIGS. **4***a* to **4***c*, with lesser or greater curvatures, optimizing the deformation of the part **32**. Also, the piston **30** may have a rectangular shape, preventing any rotation within the channel **12**.

[0052] More generally, the first face **42** is shaped to match the deformation to be made to the part **32** and the second face **44** is shaped to match the shape of the first region **18**.

[0053] The present invention therefore proposes an electrohydraulic forming apparatus comprising a mold having an enclosure with a channel and a piston positioned in said channel as well as a mold cavity. The mold proposed here is composed of only two parts, facilitating its assembly and limiting its manufacturing cost. The use of a piston in the channel in order to separate a first region from a second region reduces the volume of fluid to be emptied between two manufacturing phases and improves the gain in productivity. Indeed, the time to manufacture a part corresponds to the time required to position a part on the mold cavity, fill the enclosure with fluid, close the enclosure, and trigger an electric arc before the fluid is emptied. Moreover, due to the presence of two separate volumes of fluid, the particles torn from the electrodes when the electric arc is triggered do not fall on the part to be formed, such that the quality is not impacted.

[0054] The present invention is not limited to the embodiments described above by way of non-limiting examples, to the shapes represented in the drawing, and to the other variants mentioned, but relates to any embodiment that is within the reach of a person skilled in the art and within the scope of the following claims.

1. An electrohydraulic forming apparatus comprising:
- a mold with an upper portion and a lower portion,
- an enclosure having a first region, a second region, and a mold cavity positioned in the second region,
- electrodes having electrode tips positioned in the first region,
- a piston amounted so as to be movable in translation within a channel of the enclosure in a fluidtight manner and separates the first region from the second region of the enclosure.

2. The electrohydraulic forming apparatus according to claim **1**, wherein the piston comprises first guide means complementary to second guide means of the channel.

3. The electrohydraulic forming apparatus according to claim **2**, wherein the first guide means comprise three ribs.

4. The electrohydraulic forming apparatus according to claim **2**, wherein the second guide means comprise three grooves.

5. The electrohydraulic forming apparatus according to claim **1**, wherein the piston has a first face of planar shape and directed towards the mold cavity.

6. The electrohydraulic forming apparatus according to claim **1**, wherein the piston has a first face of a shape selected from the set of concave and convex shapes and directed towards the mold cavity.

7. The electrohydraulic forming apparatus according to claim **6**, wherein the piston has a second face of planar shape and directed towards the first region.

8. The electrohydraulic forming apparatus according to claim **6**, wherein the piston has a second face of a shape selected from the set of concave and convex shapes and directed towards the first region.

9. The electrohydraulic forming apparatus according to claim **1**, wherein the channel has a stop adapted to retain the piston.

10. The electrohydraulic forming apparatus according to claim **9**, wherein a spring is positioned between the piston and the stop.

* * * * *