(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 November 2018 (15.11.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/206960 A1

(51) International Patent Classification:
B21C 23/00 (2006.01) *B29C 47/00* (2006.01)
B21C 23/12 (2006.01)

(21) International Application Number:
PCT/GB2018/051260

(22) International Filing Date:
10 May 2018 (10.05.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1707519.3 10 May 2017 (10.05.2017) GB

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) **Title:** A METHOD FOR FORMING CURVED LENGTHS OF EXTRUDED PROFILES/SECTIONS IN METAL ALLOYS

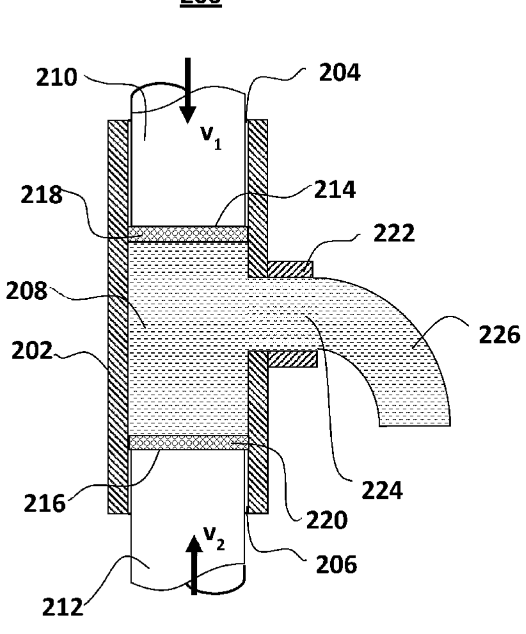

Figure 2

(57) **Abstract:** A method of extruding a material, comprising providing the material into an extrusion chamber of an extrusion apparatus, wherein the extrusion chamber comprises an extrusion orifice and the extrusion apparatus comprises a first compression element and a second compression element in communication with the interior of the extrusion chamber, the first and second compression elements being independently movable relative to the extrusion chamber, moving at least one of the first and second compression elements to compress the material within the extrusion chamber and cause a velocity gradient in the extrusion material across the extrusion orifice and extruding the material through the extrusion orifice such that the velocity gradient forms an extrudate with a curved profile.

WO 2018/206960 A1

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Published:

— *with international search report (Art. 21(3))*

A METHOD FOR FORMING CURVED LENGTHS OF EXTRUDED PROFILES/SECTIONS IN METAL ALLOYS

Field

This disclosure relates to a method and equipment for forming curved metal alloy profiles and more particularly aluminium alloy profiles with predesigned curvature in one extrusion-bending process.

Background

Reducing the weight of metal components used in land, sea and air conveyances leads to a reduction of fuel consumption and therefore a decrease of CO_2 emissions. Aluminium alloy profiles are extensively used as construction elements in industrial manufacturing for the production of ultra-light component structures with a high contour complexity, including seat rails, stringers, and frames in the aircraft industry as well as window frames and roof rails in the automotive industry. This is mainly because they facilitate construction of lightweight, strong, and stiff structures. Taking into account the demand for reduced aerodynamic resistance as well as improved aesthetics, the manufacture and application of highly precise curved aluminium alloy profiles with well adapted properties are quite necessary.

There are several widely acknowledged methods for curving aluminium alloy profiles. Normally they start with manufacturing straight profiles by shape rolling or extrusion, followed by the subsequent secondary bending process such as stretch bending, rotary draw bending, press bending, or roll bending (three-, four-, and six-roll-bending). However, these procedures have disadvantages since: (i) more than one process is needed to achieve the profiles with desired curvature, which greatly decreases manufacturing productivity; (ii) spring-back and cross-sectional deformations usually occur due to the high external bending strain applied in the second bending process; (iii) for hollow sections various fillers and mandrels are used in the secondary bending process to avoid the potential cross-sectional deformation and buckling; (iv) due to the high forces needed for bending profiles, heavy machines are required; and (v) many hollow profiles cannot be bent if the shell is too thin or the curvature is too high.

The challenge to improved production is to manufacture curved profiles with precise curvature, non-distorted cross-sections and well-defined properties at increased productivity.

Summary

In accordance with an aspect of the disclosure there is provided a method of extruding a material, comprising providing the material into an extrusion chamber of an extrusion apparatus, wherein the extrusion chamber comprises an extrusion orifice and the extrusion apparatus comprises a first compression element and a second compression element in communication with the interior of the extrusion chamber, the first and second compression elements being independently movable relative to the extrusion chamber, moving at least one of the first and second compression elements to compress the material within the extrusion chamber and cause a velocity gradient in the extrusion material across the extrusion orifice, and extruding the material through the extrusion orifice such that the velocity gradient forms an extrudate with a curved profile.

In accordance with an aspect of the disclosure there is provided an apparatus for extrusion of a material, the apparatus comprising an extrusion chamber for receipt of an extrusion material, the extrusion chamber comprising an extrusion orifice, a first compression element and a second compression element, the first and second compression elements being in communication with the interior of the extrusion chamber and being independently movable relative to the extrusion chamber.

The method may comprise moving both of the first and second compression elements to compress the material within the extrusion chamber. The method may comprise moving the first compression element and second compression element at different speeds.

Moving the first and second compression elements may comprise moving the first and second compression elements along a common axis. Moving the first and second compression elements along a common axis may comprise moving the first and second compression elements towards each other in opposite directions along the common axis. The plane of the cross-section of the extrusion orifice may be parallel to the common axis such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially perpendicular to the common axis.

Moving the first and second compression elements may comprise moving the first compression element along a first axis and moving the second compression element along a second axis different to the first axis. The first axis and the second axis may be parallel to each other. The plane of the cross-section of the extrusion orifice may be perpendicular to the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the first and second axes.

The first axis and the second axis may be at an angle to one another. The plane of the cross-section of the extrusion orifice may be perpendicular to a line that bisects the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the line.

The method may further comprise providing a guide means adjacent to the extrusion orifice to control curvature of the extruded material. The method may further comprise providing a mandrel in the extrusion chamber opposite to the extrusion orifice. Extruding the material through the extrusion orifice may comprise extruding the material with a hollow cross-section defined by the mandrel and orifice. The plane of the cross-section of the mandrel that defines the hollow cross-section of the extruded material may be parallel to the plane of the cross-section of the extrusion orifice.

The method may further comprise preheating the material before providing it into the extrusion chamber.

The first compression element and second compression element may be configured to be moved simultaneously. The first compression element and second compression element may be configured to be moved at different speeds. The first compression element and second compression element may have different cross-sectional areas perpendicular to their direction of movement.

The first compression element and second compression element may be configured to be moved along a common axis. The first compression element and second compression element may be configured to be moved towards each other in opposite directions along the common axis. The plane of the cross-section of the extrusion orifice may be parallel to the common axis.

The first compression element may be configured to be moved along a first axis and the second compression element may be configured to be moved along a second axis different to the first axis. The first axis and the second axis may be parallel to each other. The plane of the cross-section of the extrusion orifice may be perpendicular to the first and second axes.

The first axis and the second axis may be at an angle to one another. The plane of the cross-section of the extrusion orifice may be perpendicular to a line that bisects the first and second axes.

The extrusion material may be a metal alloy. The metal alloy may be aluminium alloy or magnesium alloy. The extrusion orifice may be provided by an extrusion die that defines the geometry of the orifice.

The apparatus may further comprise a guide means adjacent to the extrusion orifice to control curvature of the extruded material. The apparatus may further comprise a mandrel in the extrusion chamber opposite to the extrusion orifice.

The extrusion material may be preheated. The extrusion chamber may be cylindrical. The cross-sectional area of the extrusion chamber may be larger than the cross-sectional area of the extrusion orifice.

According to the present disclosure, there is provided a method of forming curved metal alloy profiles comprising:

(i) providing the sideways extrusion setup, forward extrusion setup or angled extrusion setup;

(ii) pre-heating a metal alloy billet before transferring it to an extrusion container for hot extrusion; or directly transferring the unheated metal alloy billet to the extrusion container for cold extrusion;

(iii) applying pressure to the two dummy blocks through the corresponding two punches simultaneously, the metal alloy billet is pressed against the extrusion die and squeezed through the die opening; and

(iv) adjusting the velocities of the two punches so as to form a velocity gradient across the die orifice and produce a curved profile of the long extruded section.

This has the following advantages:

(i) forming curved profiles without defects such as distortion or thinning of the cross-section, spring-back, wrinkling and folding. Bending is intrinsic to the process, based on internal differential material flow, rather than external bending force;

(ii) forming profiles with ultra-fine grain size for cold extrusion and therefore improved mechanical properties due to severe plastic deformation (SPD) caused by shear stresses in the intersecting deformation zone of the container;

(iii) forming profiles with adjustable arbitrary curvatures in one extrusion-bending procedure, which greatly increases the manufacturing efficiency; and

(iv) no fillers or extra heavy machines are needed for the bending process, which greatly reduces the production cost.

Brief Description of the Drawings

Exemplary embodiments of the disclosure shall now be described with reference to the drawings in which:

Figure 1a is a schematic illustration of an extrusion apparatus known in the art;

Figure 1b is a schematic illustration of another extrusion apparatus known in the art;

Figure 2 is a schematic illustration of an extrusion apparatus according to an embodiment;

Figure 3a is a schematic illustration of another extrusion apparatus according to an embodiment;

Figure 3b is a cross-section through the line m-m in Figure 3a;

Figure 4 is a schematic illustration of yet another extrusion apparatus according to an embodiment;

Figure 5 is a schematic illustration of the orientation of a first, second and third axis of an extrusion apparatus according to an embodiment.

Throughout the description and the drawings, like reference numerals refer to like parts.

Specific Description

Figure 1a shows an extrusion apparatus known in the art. A cylindrical extrusion chamber 102 has two open ends 104 and 106. An extrusion die 108 with a designed orifice 110 is installed at the first open end 104. The geometry of the orifice 110 is designed to form the extruded material into a chosen shape. A hot or cold billet 112 is placed into the extrusion chamber 102 from the second open end 106.

A punch 114 is positioned at the second open end 106. Its working face 116 would usually be protected by a dummy block 118. The punch 114, together with dummy block 116, acts as a compression element and moves along the extrusion chamber 102 at a velocity v_1, forcing the billet 112 through the die orifice 110, producing a straight extrudate 120.

Another extrusion apparatus known in the art is shown in Figure 1b. In this case, an extrusion chamber 130 has an L-shape in transverse section, rather than being a straight cylinder. In this manner, the billet 132 is forced along a straight section 134 to form the straight extrudate 136. The straight section 134 is of sufficient length to ensure that the extrudate 136 is formed in a straight manner.

Once the straight extrudate 120 or 136 is produced, bending processes such as stretch bending, rotary draw bending, press bending, or roll bending are used to form a curved piece. However, forming curved sections of extrudate in this way has disadvantages such as reduced manufacturing productivity, spring-back, cross-sectional deformation and a requirement for various fillers, mandrels and heavy machinery, as discussed above.

Figure 2 shows an extrusion apparatus 200 according to the present disclosure. A cylindrical extrusion chamber 202 has two open ends 204 and 206. A hot or cold billet 208 is placed into the extrusion chamber 202 from the first open end 204 and/or the second open end 206. For example, an aluminium alloy billet may be pre-heated to 350-550°C for warm or hot extrusion or remain unheated for cold extrusion. A first punch 210 is positioned at the first open end 204. A second punch 212 is positioned at the second open end 206. The respective working faces 214 and 216 of the first and second punches 210 and 212 are protected by respective dummy blocks 218 and 220. An extrusion die 222 with a designed orifice 224 is installed in the side wall of the extrusion chamber 202.

The first punch 210 together with dummy block 218 act as a first compression element and the second punch 212 together with dummy clock 220 act as a second compression element. The skilled person with recognise that these compression elements could be replaced by any other suitable compression means. The first and second compression elements are independently movable relative to the extrusion chamber 202. As described below, this allows the profile of an extrudate to be controlled, particularly with respect to its curvature.

In operation, pressure is applied to the two dummy blocks 218 and 220 via the corresponding two punches 210 and 212 simultaneously. The velocity of the first punch 210 is v_1, and the velocity of the second punch 212 is v_2. As the punches move towards each other, the billet 208 is forced sideways out of the extrusion chamber 202 through the die orifice 224. Its exiting direction is perpendicular to the punch motion direction.

To produce a curved extrudate, the rate of mass flow provided by each of the compression elements can be adjusted. In one embodiment, the velocities of the punches 210 and 212 can be adjusted to provide a curved extrudate. When one punch is moved faster than the other, a flow velocity gradient is produced across the die orifice 224. Therefore, the extruded profile bends towards the side of the extrusion chamber 202 which has the lower extrusion velocity. In Figure 2, the velocity v_1 of the first punch 210 is larger than the velocity v_2 of the second punch 212. Therefore, the extrudate 226 bends towards the second open end 206. In another embodiment, the area of the first dummy block 218 is greater than that of the second dummy block 220. In this instance, the extruded profile will bend downwards as shown in Fig. 2 even when $v_1=v_2$.

The essence is to control the volume of material flowing into the die exit 222 per unit time, which can be expressed as $Q=Sv$. Here S is the cross-sectional area and v is the velocity. Therefore, increasing the velocity v_1 and/or the area of the first dummy block 218 can lead to more material flowing into the upper side of the die exit 222 compared with the lower side.

By creating a controlled gradient of flow velocity across the exit of an extrusion die orifice utilizing two extrusion punches, the extrusion and bending operations are performed simultaneously. This removes the need for post-processing of straight extruded pieces to provide curvature, and overcomes the issues mentioned above.

By adjusting the ratio of the velocities of the two punches (or more generally the rate of material flow Q), the curvature of the extrudate 226 can be adjusted. If the velocity ratio is defined as v_2/v_1, a lower velocity ratio tends to increase the material flow velocity gradient at the die exit and lead to greater curvature. When this velocity ratio is less than 1/3, bending curvature increases significantly with reducing velocity ratio. Maximum curvature results at zero velocity of the lower punch 212. The velocity ratio could be changed during extrusion. This will enable the curvature of the extrudate 226 to be changed as extrusion proceeds, which allows more complex extrusions.

Additionally, the relative cross-sectional areas of the extrusion chamber 202 and the orifice 224 can be adjusted to change the curvature. An extrusion ratio is defined as the ratio of the cross-sectional area of the billet to the cross-sectional area of the extruded profile. These areas are controlled by adjusting the cross-sectional area of the extrusion chamber 202 and the extrusion orifice 224 respectively. For solid circular bar extrusion, the extrusion ratio can be defined as the square of the diameter ratio of the extrusion chamber 202 to the orifice 224. For a tubular circular extrusion (a hollow bar), it can be defined as $D_1^2/(D_2^2-D_3^2)$, where D_1, D_2, D_3 are the respective diameters of the extrusion chamber 202, the orifice 224 and a mandrel fixed to the inner wall of the extrusion chamber opposite to the exit die to define the wall thickness of the tube.

A larger extrusion ratio tends to increase the material flow velocity gradient at the die exit and lead to greater curvature. For a constant diameter of the extrusion chamber 202, the curvature of the extrudate 226 is increased as the diameter of the orifice 224 is decreased. Conversely, the curvature of the extrudate 226 is reduced as the diameter orifice 224 is increased. The effect of changing the extrusion ratio is less than that of changing the velocity ratio, especially when velocity ratio is greater than 0.5. Below this value, the effect of extrusion ratio increases as velocity ratio v_2/v_1 decreases.

Figure 3a shows an alternative extrusion apparatus 300 according to the present disclosure. The apparatus 300 is similar to the apparatus 100 of Figure 1a, except that two adjacent punches are used instead of a single punch. A cylindrical extrusion chamber 302 has two open ends 304 and 306. A hot or cold billet 308 is placed into the extrusion chamber 302 from the second open end 306. First and second punches 310 and 312 are positioned adjacent to one another at the second open end 306. The respective working faces 314 and 316 of the first and second punches 310 and 312 are protected by a respective dummy blocks 318 and 320. An extrusion die 322 with a designed orifice 324 is installed at the first open end 304.

The length of the first dummy block 318 is shown as longer than that of the second dummy block 320. In the case that the second dummy block 320 moves faster than the first dummy block 318, then the second dummy block 320 may entirely pass the first dummy block 318. In this case, the billet 308 may flow out of the chamber 302 from the gap between the first dummy block 318 and the second dummy block 320. By implementing a longer profile of the first dummy block, this situation is mitigated.

In operation, pressure is applied to the two dummy blocks 318 and 320 via the corresponding two punches 310 and 312 simultaneously. The velocity of the first punch 310 is v_1, and the velocity of the second punch 312 is v_2. As the punches move alongside each other, the billet 308 is forced out of the extrusion chamber 302 through the die orifice 324.

As in the above embodiment, when one punch is moved faster than the other, a flow velocity gradient is produced across the die orifice 324. Therefore, the extruded profile bends towards the side of the extrusion chamber 302 which has the lower extrusion velocity. In Figure 3a, the velocity v_1 of the first punch 310 is larger than the velocity v_2 of the second punch 312. Therefore, the extrudate 326 bends towards the side of the cylindrical extrusion chamber 302 with the second punch 312. Additionally or alternatively, the areas of the dummy blocks 318 and 320 may be adjusted to provide this effect. Figure 3b shows the dummy blocks 318 and 320 with different cross-sectional areas perpendicular to their direction of movement.

Figure 4 shows yet another alternative extrusion apparatus 400 according to the present disclosure. The apparatus comprises a Y-shaped extrusion chamber 402, having a first bore 404, a second bore 405 and a central container 406. The first bore 404 and the second bore 405 are positioned at an angle to each other and converge to meet the central container 406, forming the Y-shape. Each of the first bore 404, the second bore 405 and the central container 406 has an open end opposite to the point of convergence.

A first hot or cold billet 407 is placed into the open end of the first bore 404. A second hot or cold billet 408 is placed into the open end of the second bore 405. A first punch 410 is positioned at the open end of the first bore 404. A second punch 412 is positioned at the open end of the second bore 405. The respective working faces 414 and 416 of the first and second punches 410 and 412 are protected by a respective dummy block 418 and 420. An extrusion die 422 with a designed orifice 424 is installed at the open end of the central container 406.

In operation, pressure is applied to the two dummy blocks 418 and 420 via the corresponding two punches 410 and 412 simultaneously. The velocity of the first punch 410 is v_1, and the velocity of the second punch 412 is v_2. As the punches move towards each other, the billet 408 is forced sideways out of the extrusion chamber 402 through the die orifice 424.

As in the above embodiments, when one punch is moved faster than the other, a flow velocity gradient is produced across the die orifice 424. Therefore, the extruded profile bends towards the side of the extrusion chamber 402 which has the lower extrusion velocity. In Figure 4, the velocity v_1 of the first punch 410 is larger than the velocity v_2 of the second punch 412. Therefore, the extrudate 426 bends towards the second bore 405. Additionally or alternatively, the areas of the dummy blocks 418 and 420 may be adjusted to provide this effect.

In the embodiments described above with reference to Figures 2 to 4, the first and second compression elements can be positioned at an angle α, shown in Figure 5. In Figure 5, the first and second axes correspond to the first and second compression elements, with the third axis bisecting the first and second axes and corresponding to the direction of extrusion from the die orifice. Hence, the plane of the cross-section of the extrusion orifice is perpendicular to a line bisecting the first and second axes, with the third axis being parallel to this line.

The first axis is at an angle of $\beta = 180° - \alpha/2$ to the direction of flow of the extrudate from the extrusion apparatus (i.e. the third axis). Likewise, the second axis is at an angle of $\beta = 180° - \alpha/2$ to the third axis.

By having an angle of $\beta < 180°$, a shear stress can be exerted while the billet passes from the entrance to the extrusion chamber to the exit from the extrusion chamber. The shear stress exerted at the intersection between the first axis and the third axis (and likewise at the intersection between the second axis and the third axis) causes severe plastic deformation (SPD) of the billet at the point of intersection of the axes. SPD of the billet results in an extruded profile with an ultra-fine grain size, thereby improving the mechanical properties of the extruded profile. SPD of the billet increases as the angle β decreases (i.e. as angle α increases), thereby giving rise to improved mechanical properties arising from SPD with reduced angle β.

The first and second axes may be orientated at an angle $0° \leq \alpha \leq 360°$. The extrusion apparatus schematically illustrated in Figure 2 corresponds to an angle of $\alpha = 180°$. The extrusion apparatus schematically illustrated in Figure 3 corresponds to an angle of $\alpha = 0°$. The extrusion apparatus schematically illustrated in Figure 4 may have any arbitrary angle between 0° and 360°.

By using any of the above embodiments, curved sections with undistorted cross-sections can be achieved by utilising asymmetric flow in the extrusion die. Since it is a natural bending process based on internal differential material flow rather than external bending force, defects such as distortion and thinning of the cross-section are avoided. The combination of the extrusion and bending processes into a single process, thus eschews the complication of an extra external bending apparatus.

This effect is achieved by variations in velocities v_1 and v_2 of the compression elements (formed of punches and dummy blocks). However, in some embodiments, the compression elements may move at the same velocity, with the velocity gradient across the extrusion orifice being a function of geometric features (such as a greater surface area for one dummy block/compression element in comparison with the other). In other examples, a combination of geometric features and the velocities of the compression elements may result in a desired velocity gradient at the extrusion orifice.

In any of the above embodiments, a guide external to the die orifice 224 may be employed to ensure precise curve accuracy. Any of the above embodiments may be used for extrusion of solid bars or tubes. For hollow extrusion, a mandrel may be fixed to the inner wall of the extrusion chamber opposite to the exit die. The size of the mandrel relative to the size of the die orifice will define the wall thickness of the extruded tube. The curvature of the tube is reduced with increase of wall thickness of the tube. However, the effect of the wall thickness on curvature is small, compared with that of the velocity ratio. Otherwise, a similar tendency in the extrusion of round bars described before also occurs in extrusion of round tubes.

Any of the above embodiments may be used to produce curved profiles in any material that can be manufactured by the conventional extrusion procedure. The principal application is extrusion of metal alloys. These include aluminium, magnesium, copper, steel, titanium and nickel. The system has been described with reference to aluminium since this is where the most commercially feasible applications are likely to be, but the implementation is not exclusively related to aluminium.

Any of the above embodiments may be used for hot or cold extrusion. In the case of hot extrusion, the hot metal billet used can be virtually any metal alloy billet which is heated to the temperature generally used in the hot extrusion process. A True Temperature Technology (3T) facility is utilized to record exit temperature of the extruded part. By adjusting the extrusion velocities of the two punches while keeping the extrusion velocity ratio constant, exit temperature is maintained at a reasonable temperature where solution heat treatment (SHT) takes place. The target exit temperature for an extruded part is dependent on the metal alloy. For the 6xxx series aluminium alloys, temperatures within a range of 500-530°C for solution heat treatment should be realised at the die exit to achieve optimal mechanical properties. The extruded part can be quenched after SHT using water, mist spray or air cooling, depending on the alloy and the final mechanical property requirements.

Although the embodiments described in figures 2 to 4 above comprise two compression elements, it will be understood that further compression elements could be incorporated to control curvature in other planes.

Further embodiments of the present disclosure are set out in the following clauses:

1. A method of extruding a material, comprising:
    providing the material into an extrusion chamber of an extrusion apparatus, wherein the extrusion chamber comprises an extrusion orifice and the extrusion apparatus comprises a first compression element and a second compression element in communication with the interior of the extrusion chamber, the first and second compression elements being independently movable relative to the extrusion chamber;

moving at least one of the first and second compression elements to compress the material within the extrusion chamber and cause a velocity gradient in the extrusion material across the extrusion orifice; and

extruding the material through the extrusion orifice such that the velocity gradient forms an extrudate with a curved profile.

2. A method according to clause 1, comprising moving both of the first and second compression elements to compress the material within the extrusion chamber.

3. A method according to clause 2, comprising moving the first compression element and second compression element at different speeds.

4. A method according to clause 2 or 3, wherein the first compression element and second compression element have different cross-sectional areas perpendicular to their direction of movement.

5. A method according to any of clauses 1 to 4, wherein moving the first and second compression elements comprises moving the first and second compression elements along a common axis.

6. A method according to clause 5, wherein moving the first and second compression elements along a common axis comprises moving the first and second compression elements towards each other in opposite directions along the common axis.

7. A method according to clause 5 or 6, wherein the plane of the cross-section of the extrusion orifice is parallel to the common axis such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially perpendicular to the common axis.

8. A method according to any of clauses 1 to 4, wherein moving the first and second compression elements comprises moving the first compression element along a first axis and moving the second compression element along a second axis different to the first axis.

9. A method according to clause 8, wherein the first axis and the second axis are parallel to each other.

10. A method according to clause 9, wherein the plane of the cross-section of the extrusion orifice is perpendicular to the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the first and second axes.

11. A method according to clause 8, wherein the first axis and the second axis are at an angle to one another.

12. A method according to clause 11, wherein the plane of the cross-section of the extrusion orifice is perpendicular to a line that bisects the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the line.

13. A method according to any one of the preceding clauses, wherein the material is a metal alloy.

14. A method according to clause 13, wherein the metal alloy is aluminium alloy or magnesium alloy.

15. A method according to any one of the preceding clauses, wherein the extrusion orifice is provided by an extrusion die that defines the geometry of the orifice.

16. A method according to any one of the preceding clauses, further comprising providing a guide means adjacent to the extrusion orifice to control curvature of the extruded material.

17. A method according to any one of the preceding clauses, further comprising providing a mandrel in the extrusion chamber opposite to the extrusion orifice.

18. A method according to clause 17, wherein extruding the material through the extrusion orifice comprises extruding the material with a hollow cross-section defined by the mandrel and orifice.

19. A method according to any one of the preceding clauses, further comprising preheating the material before providing it into the extrusion chamber.

20. A method according to any one of the preceding clauses, wherein the extrusion chamber is cylindrical.

21. A method according to clause 20, wherein the cross-sectional area of the extrusion chamber is larger than the cross-sectional area of the extrusion orifice.

22. An apparatus for extrusion of a material, the apparatus comprising:
    an extrusion chamber for receipt of an extrusion material, the extrusion chamber comprising an extrusion orifice;
    a first compression element and a second compression element, the first and second compression elements being in communication with the interior of the extrusion chamber and being independently movable relative to the extrusion chamber.

23. An apparatus according to clause 22, wherein the first compression element and second compression element are configured to be moved simultaneously.

24. An apparatus according to clause 23, wherein the first compression element and second compression element are configured to be moved at different speeds.

25. An apparatus according to clause 23 or 24, wherein the first compression element and second compression element have different cross-sectional areas perpendicular to their direction of movement.

26. An apparatus according to any of clauses 22 to 25, wherein the first compression element and second compression element are configured to be moved along a common axis.

27. An apparatus according to clause 26, wherein the first compression element and second compression element are configured to be moved towards each other in opposite directions along the common axis.

28. An apparatus according to clause 26 or 27, wherein the plane of the cross-section of the extrusion orifice is parallel to the common axis.

29. An apparatus according to any of clauses 22 to 25, wherein the first compression element is configured to be moved along a first axis and the second compression element is configured to be moved along a second axis different to the first axis.

30. An apparatus according to clause 29, wherein the first axis and the second axis are parallel to each other.

31. An apparatus according to clause 30, wherein the plane of the cross-section of the extrusion orifice is perpendicular to the first and second axes.

32. An apparatus according to clause 29, wherein the first axis and the second axis are at an angle to one another.

33. An apparatus according to clause 32, wherein the plane of the cross-section of the extrusion orifice is perpendicular to a line that bisects the first and second axes.

34. An apparatus according to any one of clauses 22 to 32, wherein the extrusion material is a metal alloy.

35. An apparatus according to clause 24, wherein the metal alloy is aluminium alloy or magnesium alloy.

36. An apparatus according to any one of clauses 22 to 35, wherein the extrusion orifice is provided by an extrusion die that defines the geometry of the orifice.

37. An apparatus according to any one of clauses 22 to 36, further comprising a guide means adjacent to the extrusion orifice to control curvature of the extruded material.

38. An apparatus according to any one of clauses 22 to 37, further comprising a mandrel in the extrusion chamber opposite to the extrusion orifice.

39. An apparatus according to any one of clauses 22 to 38, wherein the extrusion material is preheated.

40. An apparatus according to any one of clauses 22 to 39, wherein the extrusion chamber is cylindrical.

41. An apparatus according to clause 40, wherein the cross-sectional area of the extrusion chamber is larger than the cross-sectional area of the extrusion orifice.

42. A method according to any one of clauses 1 to 21, further comprising varying the speed of movement of the first compression element and/or the second compression element to vary the velocity ratio as the material is extruded.

43. An apparatus according to any one of clauses 22 to 41, wherein the first compression element and/or the second compression element are configured to be moved at a varying speed.

Claims:

1. A method of extruding a material, comprising:

   providing the material into an extrusion chamber of an extrusion apparatus, wherein the extrusion chamber comprises an extrusion orifice and the extrusion apparatus comprises a first compression element and a second compression element in communication with the interior of the extrusion chamber, the first and second compression elements being independently movable relative to the extrusion chamber;

   moving at least one of the first and second compression elements to compress the material within the extrusion chamber and cause a velocity gradient in the extrusion material across the extrusion orifice; and

   extruding the material through the extrusion orifice such that the velocity gradient forms an extrudate with a curved profile.

2. A method according to claim 1, comprising moving both of the first and second compression elements to compress the material within the extrusion chamber.

3. A method according to claim 2, comprising moving the first compression element and second compression element at different speeds.

4. A method according to claim 2 or 3, wherein the first compression element and second compression element have different cross-sectional areas perpendicular to their direction of movement.

5. A method according to any of claims 1 to 4, wherein moving the first and second compression elements comprises moving the first and second compression elements along a common axis.

6. A method according to claim 5, wherein moving the first and second compression elements along a common axis comprises moving the first and second compression elements towards each other in opposite directions along the common axis.

7. A method according to claim 5 or 6, wherein the plane of the cross-section of the extrusion orifice is parallel to the common axis such that extruding the

material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially perpendicular to the common axis.

8. A method according to any of claims 1 to 4, wherein moving the first and second compression elements comprises moving the first compression element along a first axis and moving the second compression element along a second axis different to the first axis.

9. A method according to claim 8, wherein the first axis and the second axis are parallel to each other.

10. A method according to claim 9, wherein the plane of the cross-section of the extrusion orifice is perpendicular to the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the first and second axes.

11. A method according to claim 8, wherein the first axis and the second axis are at an angle to one another.

12. A method according to claim 11, wherein the plane of the cross-section of the extrusion orifice is perpendicular to a line that bisects the first and second axes such that extruding the material through the extrusion orifice comprises extruding the material through the extrusion orifice substantially parallel to the line.

13. A method according to any one of the preceding claims, wherein the material is a metal alloy.

14. A method according to claim 13, wherein the metal alloy is aluminium alloy or magnesium alloy.

15. A method according to any one of the preceding claims, wherein the extrusion orifice is provided by an extrusion die that defines the geometry of the orifice.

16. A method according to any one of the preceding claims, further comprising providing a guide means adjacent to the extrusion orifice to control curvature of the extruded material.

17. A method according to any one of the preceding claims, further comprising providing a mandrel in the extrusion chamber opposite to the extrusion orifice.

18. A method according to claim 17, wherein extruding the material through the extrusion orifice comprises extruding the material with a hollow cross-section defined by the mandrel and orifice.

19. A method according to any one of the preceding claims, further comprising preheating the material before providing it into the extrusion chamber.

20. A method according to any one of the preceding claims, wherein the extrusion chamber is cylindrical.

21. A method according to claim 20, wherein the cross-sectional area of the extrusion chamber is larger than the cross-sectional area of the extrusion orifice.

22. An apparatus for extrusion of a material, the apparatus comprising:

an extrusion chamber for receipt of an extrusion material, the extrusion chamber comprising an extrusion orifice;

a first compression element and a second compression element, the first and second compression elements being in communication with the interior of the extrusion chamber and being independently movable relative to the extrusion chamber.

23. An apparatus according to claim 22, wherein the first compression element and second compression element are configured to be moved simultaneously.

24. An apparatus according to claim 23, wherein the first compression element and second compression element are configured to be moved at different speeds.

25. An apparatus according to claim 23 or 24, wherein the first compression element and second compression element have different cross-sectional areas perpendicular to their direction of movement.

26. An apparatus according to any of claims 22 to 25, wherein the first compression element and second compression element are configured to be moved along a common axis.

27. An apparatus according to claim 26, wherein the first compression element and second compression element are configured to be moved towards each other in opposite directions along the common axis.

28. An apparatus according to claim 26 or 27, wherein the plane of the cross-section of the extrusion orifice is parallel to the common axis.

29. An apparatus according to any of claims 22 to 25, wherein the first compression element is configured to be moved along a first axis and the second compression element is configured to be moved along a second axis different to the first axis.

30. An apparatus according to claim 29, wherein the first axis and the second axis are parallel to each other.

31. An apparatus according to claim 30, wherein the plane of the cross-section of the extrusion orifice is perpendicular to the first and second axes.

32. An apparatus according to claim 29, wherein the first axis and the second axis are at an angle to one another.

33. An apparatus according to claim 32, wherein the plane of the cross-section of the extrusion orifice is perpendicular to a line that bisects the first and second axes.

34. An apparatus according to any one of claims 22 to 32, wherein the extrusion material is a metal alloy.

35. An apparatus according to claim 24, wherein the metal alloy is aluminium alloy or magnesium alloy.

36. An apparatus according to any one of claims 22 to 35, wherein the extrusion orifice is provided by an extrusion die that defines the geometry of the orifice.

37. An apparatus according to any one of claims 22 to 36, further comprising a guide means adjacent to the extrusion orifice to control curvature of the extruded material.

38. An apparatus according to any one of claims 22 to 37, further comprising a mandrel in the extrusion chamber opposite to the extrusion orifice.

39. An apparatus according to any one of claims 22 to 38, wherein the extrusion material is preheated.

40. An apparatus according to any one of claims 22 to 39, wherein the extrusion chamber is cylindrical.

41. An apparatus according to claim 40, wherein the cross-sectional area of the extrusion chamber is larger than the cross-sectional area of the extrusion orifice.

42. A method according to any one of claims 1 to 21, further comprising varying the speed of movement of the first compression element and/or the second compression element to vary the velocity ratio as the material is extruded.

43. An apparatus according to any one of claims 22 to 41, wherein the first compression element and/or the second compression element are configured to be moved at a varying speed.

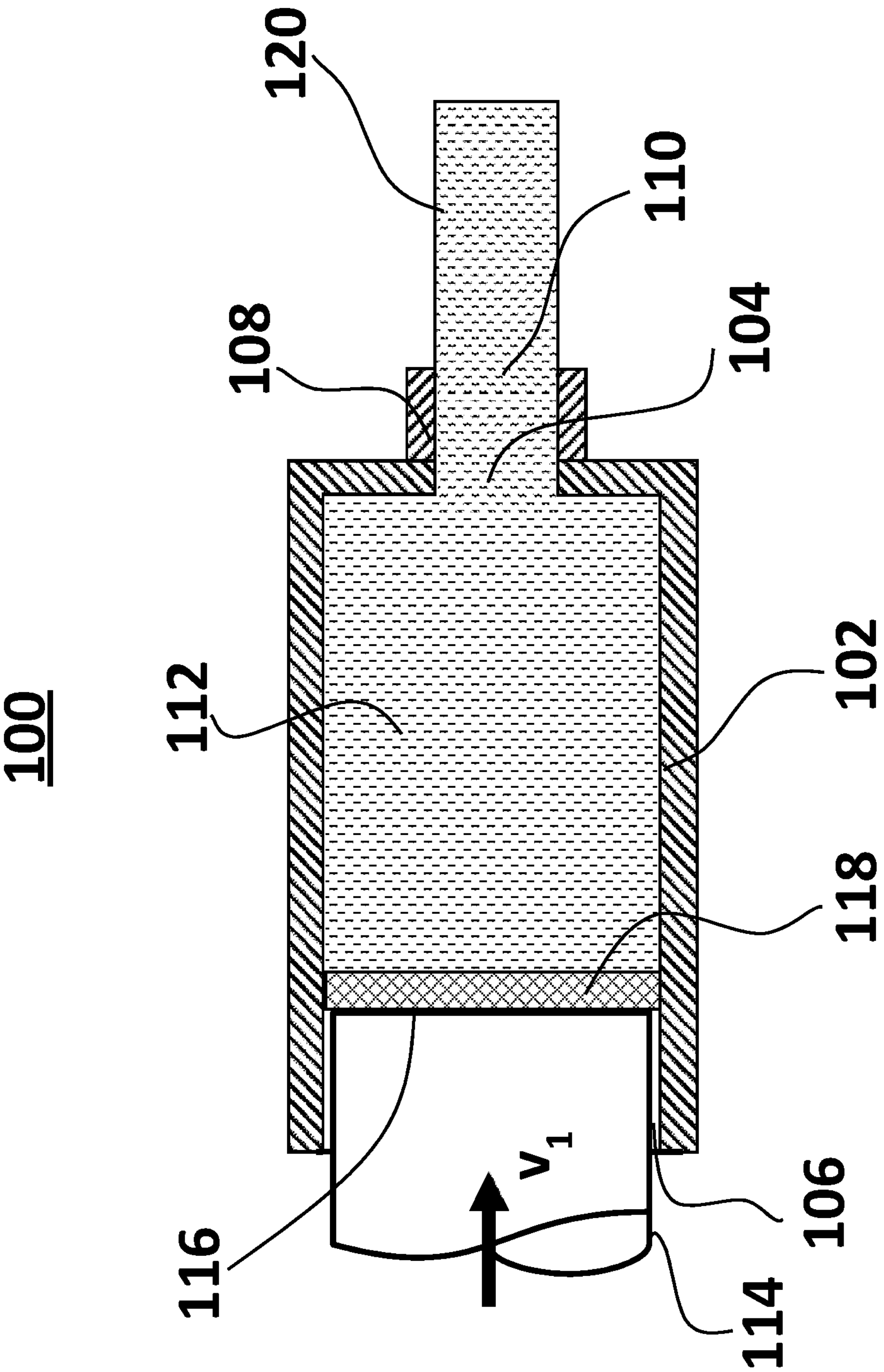

Figure 1a

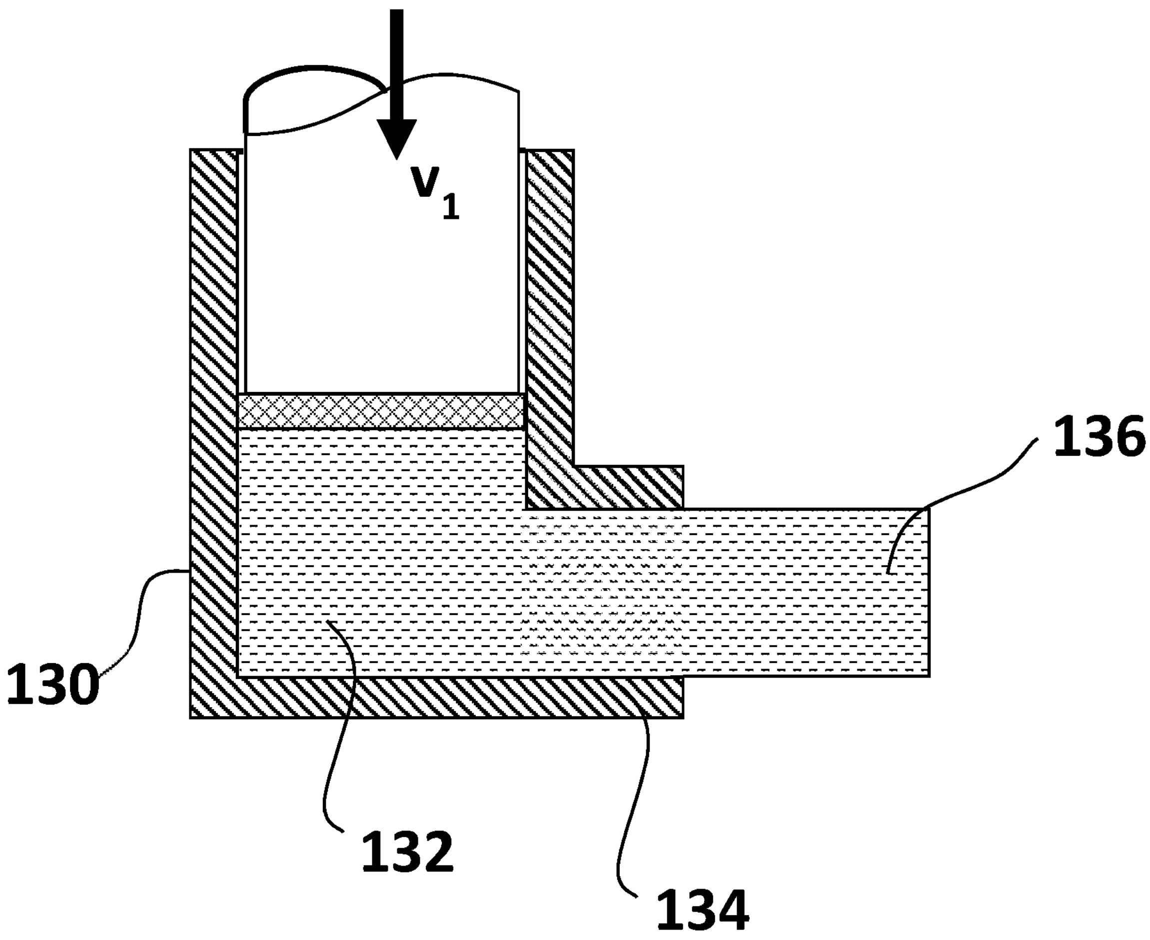

Figure 1b

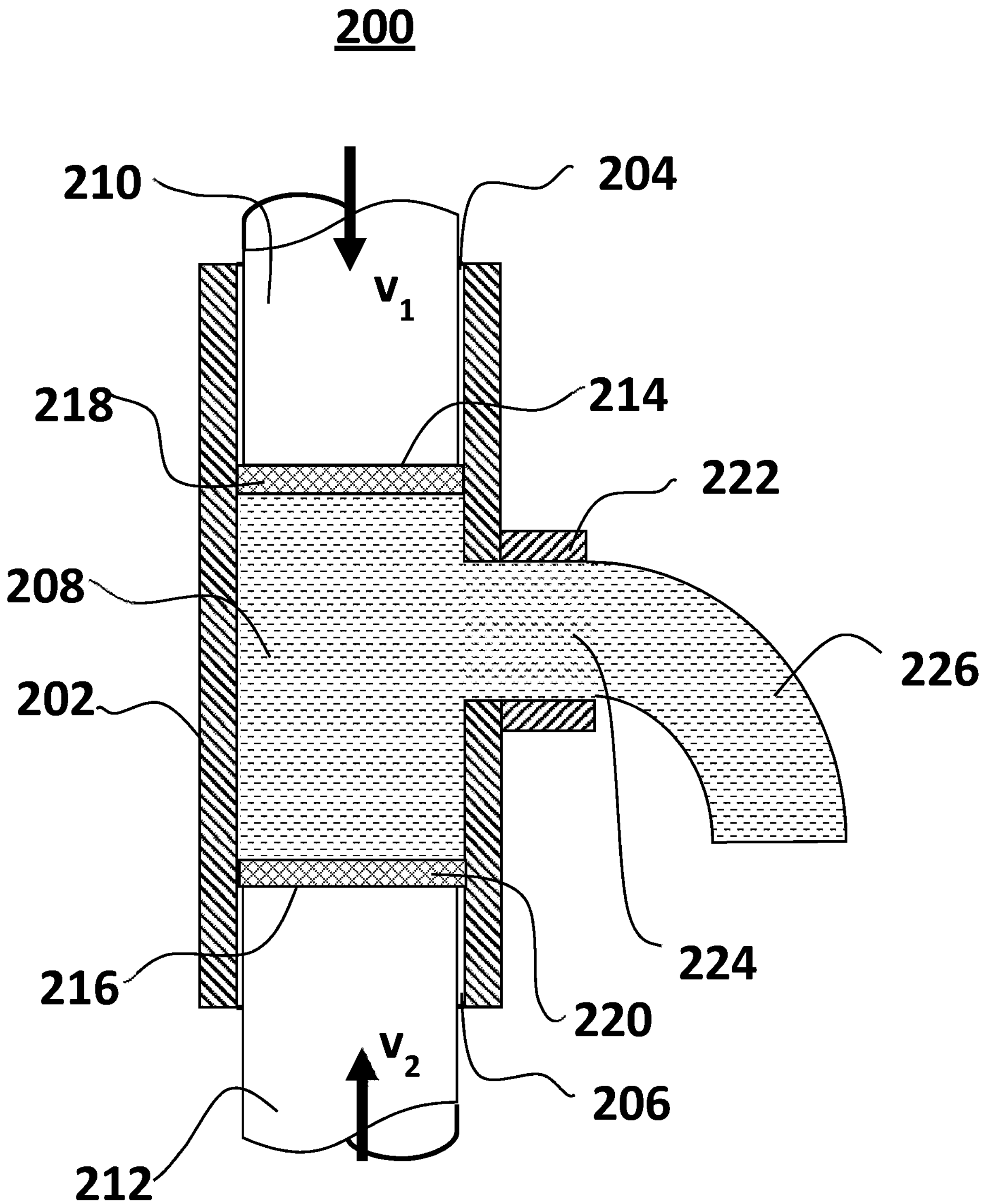

Figure 2

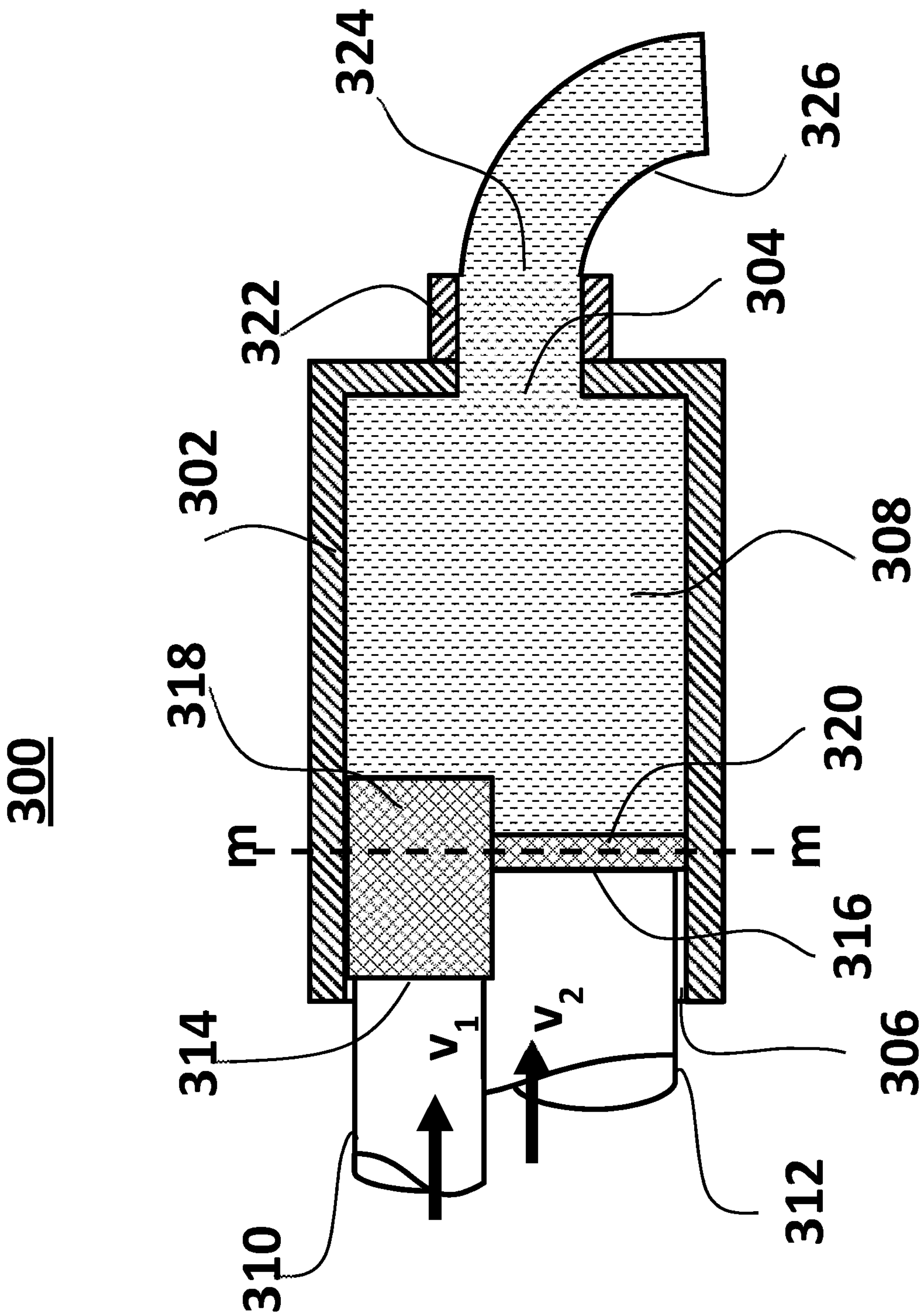

Figure 3a

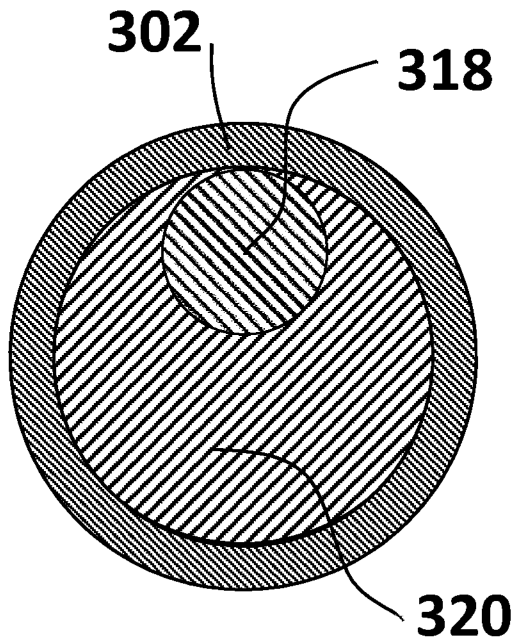

Figure 3b

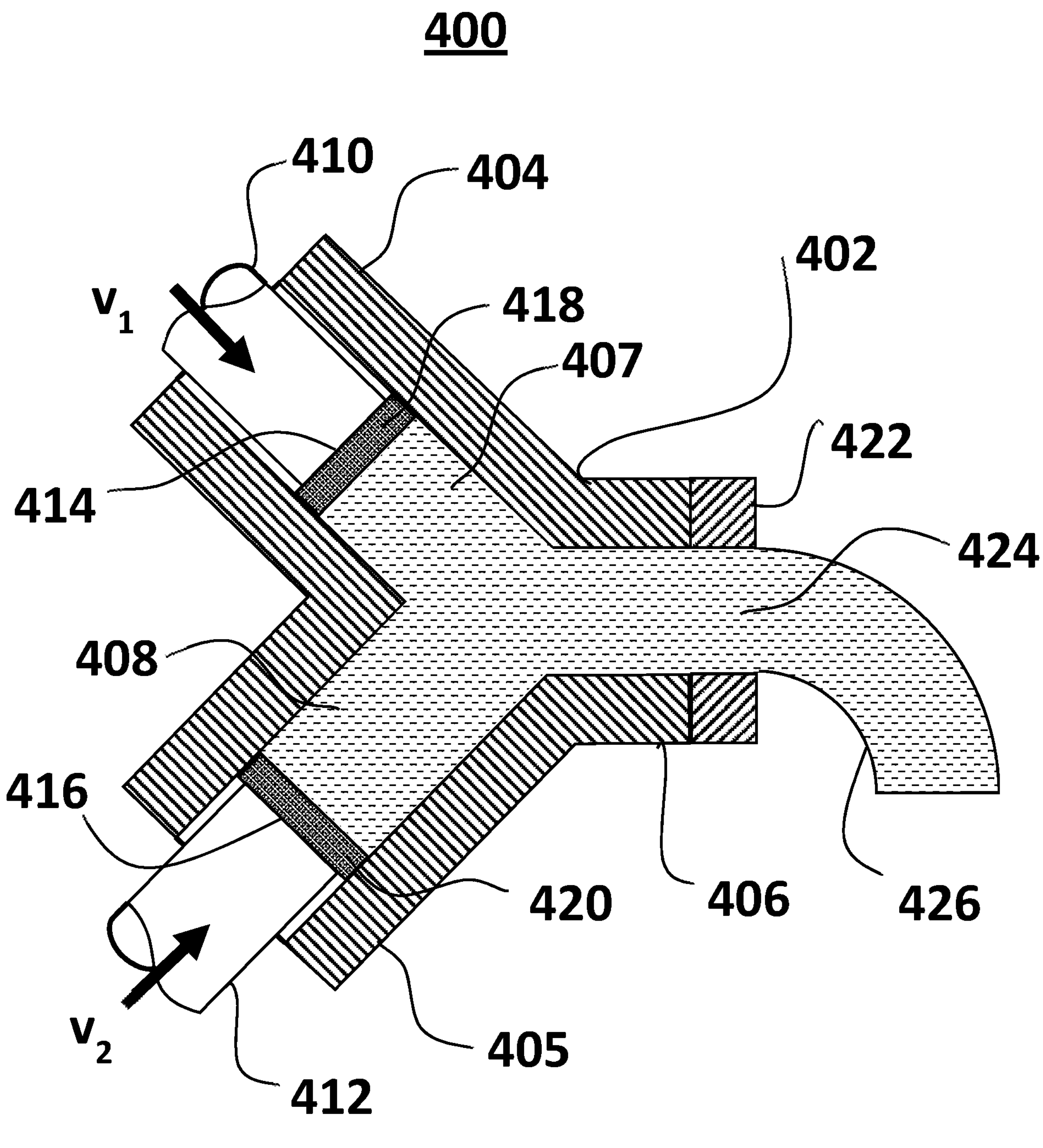
400
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Figure 4

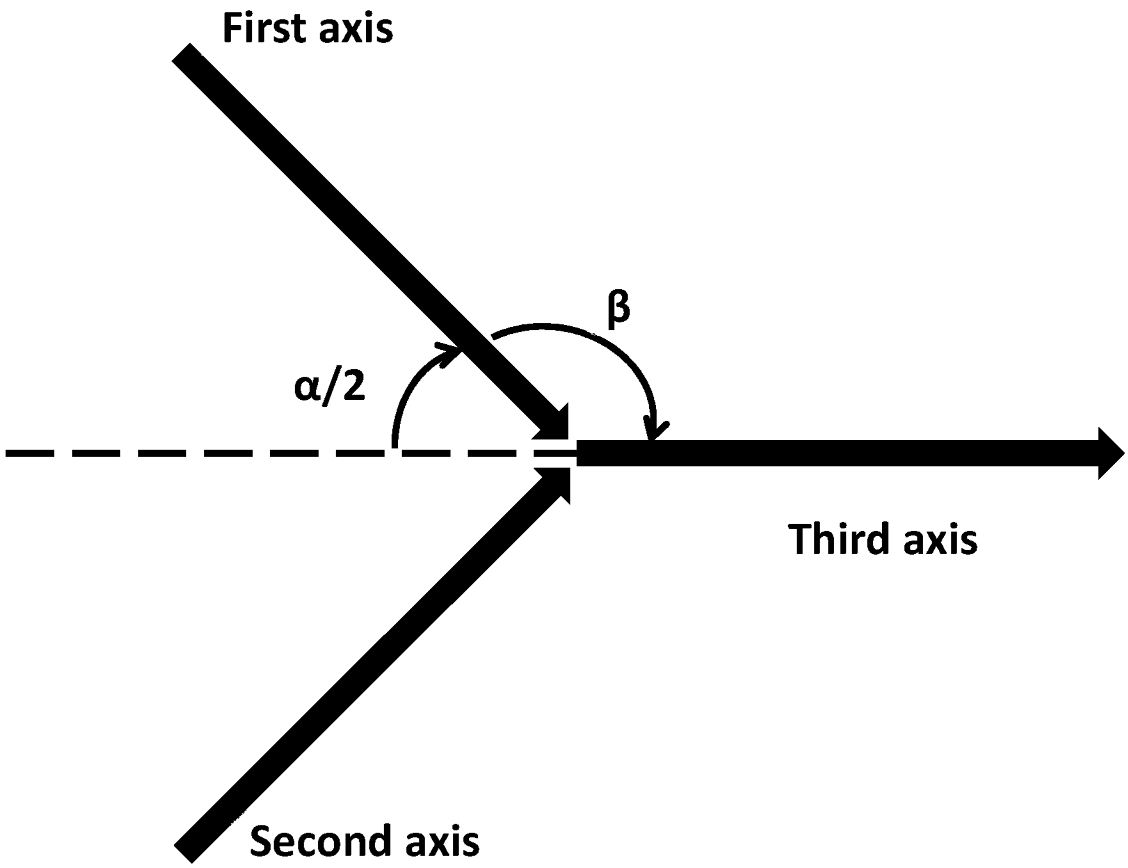

Figure 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/051260

A. CLASSIFICATION OF SUBJECT MATTER
INV. B21C23/00 B21C23/12 B29C47/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B21C B29C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/074275 A1 (JIN IN-TAI [KR]) 22 April 2004 (2004-04-22)	1-5, 8-10,13, 15,19, 21-26, 29-31, 34,36, 39,41-43
Y	paragraphs [0005] - [0008]; figures	14,16, 35,37
X	SU 837 435 A1 (ZAOCH MASHINOSTR INST [SU]) 15 June 1981 (1981-06-15) column 1 - column 3; figures	1-3, 5-13,15, 22-24, 26-34,36

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 July 2018	08/08/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Charvet, Pierre

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/051260

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 368 314 A (JAMES A. WHITNEY) 16 August 1887 (1887-08-16) page 1, line 57 - page 2, line 5; figures	1-3,5, 8-10, 13-15, 17,18, 20-24, 26, 29-31, 34-36, 38,40-43
Y	US 2016/114367 A1 (ROBBINS PAUL HENRY [CA]) 28 April 2016 (2016-04-28) paragraph [0004]	14,35
Y	GB 1 442 786 A (GRAENGES ESSEM PLAST AS) 14 July 1976 (1976-07-14) figures	16,37

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International application No
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