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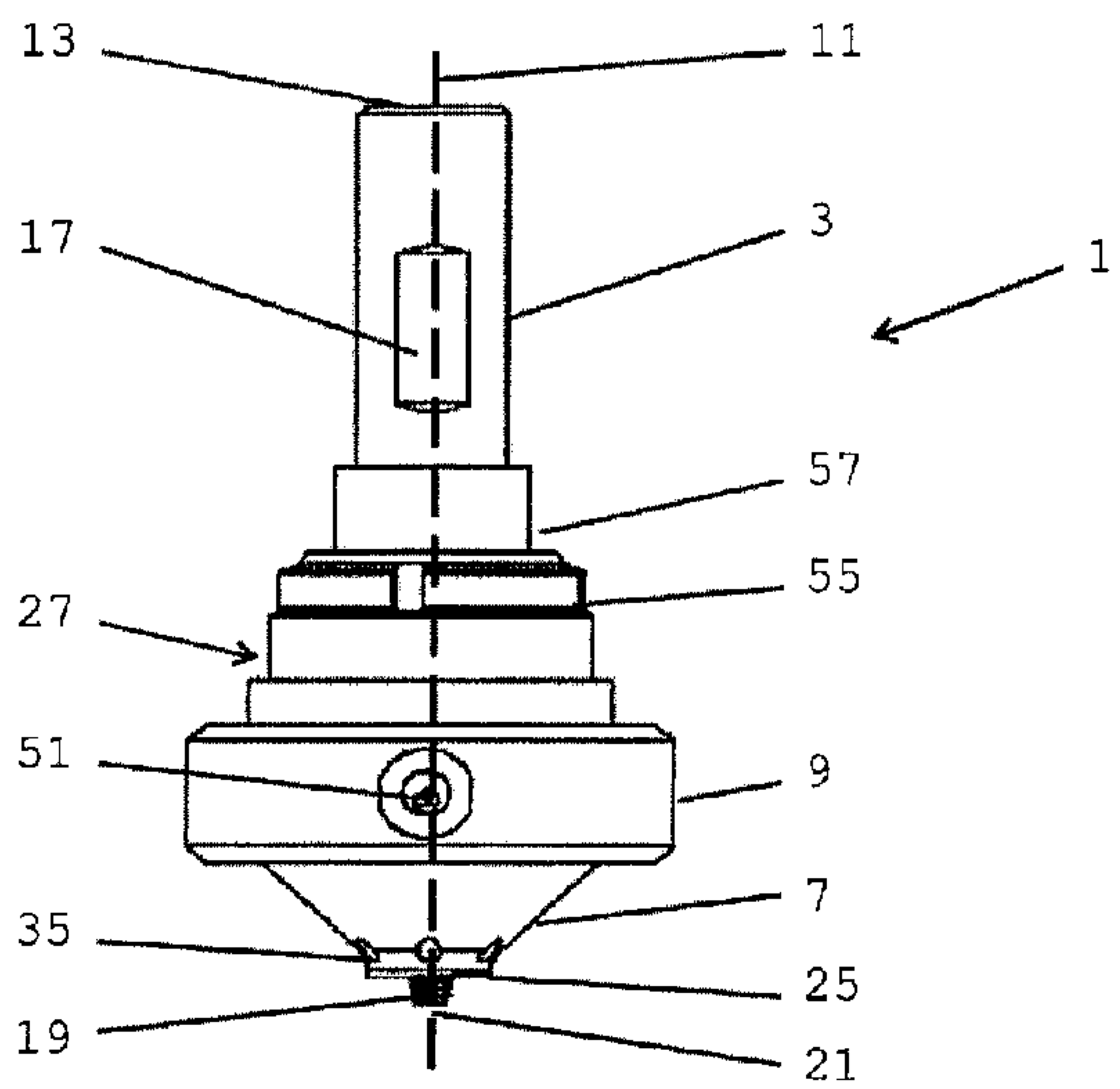
(54) Title: APPARATUS FOR FRICTION STIR WELDING WITH A SHOULDER COMPRISING FIRST AND SECOND THROUGH HOLES



(57) Abrégé/Abstract:
An apparatus for friction stir welding with a drive shaft, a probe, which has a first friction surface, and a shoulder element having a second friction surface. An annular cavity is formed between an inner surface of the shoulder element and the drive shaft and/or the probe. The shoulder element includes first and second through holes that are spaced apart in the longitudinal direction. An annular ring element is rotatable with respect to the shoulder element and is rotatably supported on the shoulder element by first and second support members between which an annular channel is formed. The annular channel is arranged such that the first through hole connects the annular channel with the annular cavity. The annular ring element radially outwardly delimits the annular channel and includes a through bore which extends to the annular channel.

Abstract of the Disclosure

An apparatus for friction stir welding with a drive shaft, a probe, which has a first friction surface, and a shoulder element having a second friction surface. An annular cavity is formed between an inner surface of the shoulder element and the drive shaft and/or the probe. The shoulder element includes first and second through holes that are spaced apart in the longitudinal direction. An annular ring element is rotatable with respect to the shoulder element and is rotatably supported on the shoulder element by first and second support members between which an annular channel is formed. The annular channel is arranged such that the first through hole connects the annular channel with the annular cavity. The annular ring element radially outwardly delimits the annular channel and includes a through bore which extends to the annular channel.

APPARATUS FOR FRICTION STIR WELDING WITH A SHOULDER COMPRISING FIRST AND SECOND THROUGH HOLES

The present invention relates to an apparatus for friction stir welding comprising a drive shaft extending along a longitudinal direction which coincides with an axis of rotation of the drive shaft, and having a drive end and a second end opposite the drive end, the drive end being adapted to be coupled to rotational drive means, a probe formed on the second end of the drive shaft, extending along the longitudinal direction, having a circumferential first friction surface extending along the longitudinal direction, and having a distal end remote from the drive shaft, and a shoulder element having a second annular friction surface extending away from the longitudinal direction and facing towards the free end, wherein the shoulder element is supported on the drive shaft and wherein an annular cavity is formed between the drive shaft and/or the probe on the one hand and an inner surface of the shoulder element on the other hand.

The principle of friction stir welding is described in WO 93/10935 and involves a rotationally driven tool to join together two abutting workpieces which are typically formed of metallic material. The two metal workpieces may be placed surface against surface (lap joint) or next to one another such that they are butted against each other with their narrow side surfaces (butt joint). The material of the two workpieces is initially plasticized and intermixed due to the frictional heat that results from the movement of the rotating friction stir welding tool in between the two surfaces. After some time the material at the interface of the two metal work pieces cools down and solidifies again such that the two metal work pieces are welded together.

The frictional heat that is generated due to the rotation of the friction stir welding tool in between the two facing work pieces does not only heat up the two abutting surfaces but is also transferred into the friction stir welding tool. The rotating probe and the shoulder element are particularly heated resulting in excessive process temperatures also in the region around the probe and thus in the shoulder element, which significantly reduces the life time of the entire friction stir welding tool.

Apparatuses for friction stir welding are already known from the prior art, such as for example WO 98/51441 or U.S. 6,199,745 B1. These apparatuses usually comprise a probe with an engagement portion for engaging with the two facing work pieces and a shoulder element for bearing against the surfaces of the two working pieces. The probe and the shoulder elements are driven in a rotating manner with a drive shaft.

The tool of WO 98/51441 further comprises a cooling mechanism. A cooling medium is transported into the interior of the friction stir welding tool via supply means. These supply means comprise one elongate conduit that extends through the tool facing directly the probe, which may be consequently cooled down during the welding process. The device described in U.S. 6,199,745 B1 also comprises conduits to supply parts of the interior of the welding tool with a cooling fluid, whereas these conduits do not cross the probe and the shoulder element.

Starting from the afore-mentioned prior art it is the object of the present invention to provide a friction stir welding tool with an improved cooling system.

This object is achieved with an afore-mentioned apparatus for friction stir welding, wherein the shoulder element comprises first and second through holes extending from an outer surface thereof to the inner surface, the first and the second through holes being spaced apart in the longitudinal direction, wherein an annular ring element is provided, which surrounds and is rotatable with respect to the shoulder element around an axis that coincides with the longitudinal direction, the annular ring element being rotatably supported on the shoulder element by first and second support members between which an annular channel is formed, the annular channel being arranged such that the first through hole connects the annular channel with the annular cavity, and wherein the annular ring element radially outwardly delimits the annular channel and comprises a through bore which extends to the annular channel.

In this way, a supply for cooling fluid can connected with the through bore in the annular ring element which is held stationary or at least does not rotate during the welding process. The cooling fluid can flow through the annular channel and the first through hole into the cavity delimited by the probe and the shoulder element. Finally, the cooling fluid can leave the cavity via the second through hole. Thus, the entire lower part of the apparatus for friction stir welding is cooled down during the friction welding process. In contrast to the afore-mentioned prior art, the annular cavity between the probe and the shoulder element is completely flushed with cooling fluid. This means, cooling fluid surrounds the entire probe and the inner surface of the shoulder element at the same time and a constant flow through the cavity can be obtained.

Thermal loading of the probe and the shoulder element is consequently reduced. Thus, a higher welding speed can be set, i.e., the apparatus can be moved forward through the material at a higher speed due to the lower temperature of both the probe and the shoulder element. This speed is even higher than in case of a rather selective cooling of the probe as shown in the prior art such that a more efficient welding process with a shorter duration is obtained. On the other hand the life time of the entire apparatus is significantly increased due to a reduced heat transfer into its interior.

In summary, it can be stated that, with the apparatus for friction stir welding according to the invention, comprising a skilful arrangement of supply means for the cooling fluid, such as the annular channel within the annular ring element, the first and the second through holes for entering and exiting the cooling fluid that penetrates in longitudinal direction of the friction welding tool across the annular cavity, damage to the probe and the shoulder due to thermal loading is counteracted. A more efficient welding process due to reduced thermal loading is made possible and the life time of the apparatus is significantly increased.

In a preferred embodiment, the shoulder element comprises a bearing member for supporting the probe. This provides for a radial support of the rotating probe by the shoulder element. In this case, it is particularly preferred, if the bearing member is positioned with respect to the longitudinal direction between the first and the second through holes. This ensures that the bearing member is efficiently cooled by the cooling fluid passing through the cavity.

Further, it is preferred, if the support members for the annular ring element are formed as bearing assemblies. The use of bearing assemblies offers substantially friction-free mounting of the annular ring element.

In a further preferred embodiment, the shoulder element is rotatably supported on the drive shaft with respect to the longitudinal direction. In this case, it is particularly preferred if a bearing device is provided on the drive shaft for rotatably supporting the shoulder element. Such a configuration of the shoulder element achieves the effect that the shoulder element is freely rotatably about the axis of rotation and is not coupled with the probe.

In another preferred embodiment, the axial position of the shoulder element along the longitudinal direction is adjustable. In this case, it is particularly preferred if the shoulder element is slidably supported along the longitudinal direction on the drive shaft wherein a stop member is provided on that side of the shoulder element opposite the second friction surface, the position of the stop member along the longitudinal direction being adjustable. Thus, it is possible to adapt the axial position of the shoulder element with respect to the probe for adjusting the distance with which the distal end of the probe protrudes from the shoulder element. In this way, the length of the probe rubbing between the two workpieces and plasticizing them during the welding process can be set in a simple way to adapt the apparatus to workpieces of different thicknesses.

It is further preferred, if the shoulder element is fixedly mounted in the longitudinal direction on the bearing assembly for rotatably supporting the shoulder element on the drive shaft wherein the bearing assembly is slidably mounted on the drive shaft along the longitudinal direction and wherein the stop member abuts on the bearing assembly. Thus, the shoulder element is connected with the drive shaft by means of the bearing assembly. On the one hand, this guarantees the rotational movement of the shoulder element with respect to the drive shaft. On the other hand, the axial displacement of the shoulder element with respect to the axis of rotation is controlled by the stop member.

In a preferred embodiment, the stop member threadingly engages with the drive shaft. In this way, the position of the shoulder element is adjustable in the axial direction in a fast and simple way. The drive shaft comprises a thread and the shoulder element can be screwed in the area of the thread to adjust the length of the probe plasticizing the work pieces during the welding process.

Finally, in a preferred embodiment, the probe is formed as a separate element releasably coupled with the drive shaft. In this way, a replacement of the probe is possible in a simple way by removing the probe out of the drive shaft.

The present invention is explained on the basis of a drawing, which illustrates an exemplary embodiment and in which:

Figure 1 shows a side view of an exemplary embodiment of an apparatus for friction stir welding according to the invention and

Figure 2 shows a sectional view along the axis of rotation of the exemplary embodiment of Figure 1.

In the figures, an exemplary embodiment of an apparatus 1 for friction stir welding according to the invention is shown. The apparatus 1 for friction stir welding comprises a drive shaft 3, a probe 5, a shoulder element 7 and an annular ring element 9.

The drive shaft 3 has a substantially cylindrical form and can be driven in a rotating manner with respect to an axis of rotation 11 which coincides with the longitudinal direction of the apparatus. The drive shaft 3 has a drive end 13 and a second end 15, opposite from the drive end 13 in the longitudinal direction or the axis of rotation 11. A rotating drive such as a drive spindle can be coupled with the drive end 13. Between the drive end 13 and the second end 15 the drive shaft 3 comprises a recess 17 such that the drive shaft 3 can be secured in a rotationally fixed manner to a drive shaft.

The probe 5 also has a cylindrical form and is formed on the second end 15 of the drive shaft. The probe 5 extends in the longitudinal direction with respect to the axis of rotation 11 having a circumferential first friction surface 19 with a distal end 21 that is remote from the drive shaft 3 to generate greater friction during the engagement with the material of the work pieces.

As can be seen from Figure 2, the second end 15 of the drive shaft 3 comprises a cylindrical cavity 23 with an inner diameter that corresponds to the diameter of the probe 5 in the present exemplary embodiment. That means the probe 5 is formed as a separate element releasably coupled with the drive shaft 3. In another embodiment, that is not shown, the probe 5 can be formed with the drive shaft 3 in one piece.

The shoulder element 7, mainly arranged concentrically around the probe 5 with respect to the axis of rotation 11, has in the present exemplary embodiment a substantially conical shape with a cone tapering with a free end towards the distal end 21 of the probe 5. Furthermore, the shoulder element 7 has a second annular friction surface 25, which is arranged perpendicularly to the axis of rotation 11 and is directed to the distal end 21 of the probe 5.

The substantially conical shape of the shoulder element 7 proved to be advantageous for allowing the heat produced by friction between a workpiece surface and the second annular friction surface 25 during a linear movement of the apparatus to be absorbed as much as possible and dissipated.

The shoulder element 7 is supported on the drive shaft 3, wherein the shoulder element 7 is rotatably connected to the drive shaft 3 with respect to the longitudinal direction. For that purpose, a bearing device 27 is provided on the drive shaft, wherein this bearing device 27 comprises a first section 29 with a first diameter and a second section 31 with a second diameter that is smaller than the first diameter, so that the first and second sections 29, 31 are arranged to form a step. The second section 31 of the bearing device 27 serves to support the shoulder element 7.

The shoulder element 7 further comprises first and second through holes 33, 35 extending perpendicularly to the axis of rotation 11 from the outer surface of the shoulder element 7 to the inner surface, wherein the first and second through holes 33, 35 are spaced apart in the longitudinal direction of the shoulder element 7. The distance between the first through holes 33 and the second annular friction surface 25 of the shoulder element 7 is larger than the distance of the second through holes 35 and the second annular friction surface 25 of the shoulder element 7 in the longitudinal direction.

The shoulder element 7 further comprises a bearing member 37 for supporting the probe 5, which is preferentially positioned with respect to its longitudinal direction between the first and second through holes 33, 35. The bearing member 37 surrounds the probe 5 and the axis of rotation 11 and is formed in the exemplary embodiment by means of a ball bearing. This ball bearing is intended for radially supporting the probe 5 by the shoulder element 7.

Between the bearing member 37 and an end of the shoulder element 7 that is opposite to its free end in the longitudinal direction, the shoulder element 7 has a cylindrical section 39 with side walls extending parallel to the axis of rotation 11. The cylindrical section 39 of the shoulder element 7 is surrounded by the annular ring element 9, which is rotatable with respect to the shoulder element 7 around an axis that coincides with the longitudinal direction. The annular ring element 9 has a first and a second internal surface 41, 43, which are parallel to each other and parallel to the axis of rotation 11. The annular ring element 9 is rotatably supported on the shoulder element 7 by first and second support members 45, 47, which are spaced apart from each other in the axial direction and are parallel to each other with respect to the axis of rotation 11 so that they abut against the internal surfaces 41, 43 of the annular ring element 9. In the present exemplary embodiment of the apparatus 1 for friction stir welding the first and second support members 45, 47 are formed as bearing assemblies.

An annular channel 49 is consequently formed inside the annular ring element 9 between the first and second support members 45, 47. Thus, the annular ring element 9 radially outwardly delimits the annular channel 49, and it comprises a through bore 51 which extends to the annular channel 49 perpendicularly to the axis of rotation 11. The annular channel 49 is arranged around the cylindrical section 39 of the shoulder element 7 such that the first through hole 33 of the shoulder element 7 connects the annular channel 49 with an annular cavity 53. This annular cavity 53 is formed between an inner surface of the shoulder element 7 and the drive shaft 3 and the probe 5.

The axial position of the shoulder element 7 along the longitudinal direction is adjustable with respect to the probe 5 in the present invention. For this purpose, the shoulder element 7 is slidably supported along the longitudinal direction on the drive shaft 3, which is provided with a stop member 55 that is located on that side of the shoulder element 7 opposite the second annular friction surface 25 and abuts on the bearing device 27 on the drive shaft. In a preferred embodiment, the stop member 55 is formed as a nut and the drive shaft 3 is further provided with a thread 57 extending in an area between the bearing device 27 and the drive end 13. The stop member 55 then threadingly engages with the drive shaft 3 and is adjustable along the longitudinal direction. Since the shoulder element 7 is fixedly mounted with the bearing assembly, which in turn is slidably mounted on the drive shaft 3 along the longitudinal direction, the shoulder element 7 can axially be adjusted in the axial direction of the axis of rotation 11 by turning the nut and the length with which the probe 5 protrudes from the second annular friction surface 25 in longitudinal direction is consequently adjusted, too.

The apparatus 1 for friction stir welding according to the present invention operates as follows.

At the beginning, two substantially flat workpieces, for example metallic plates or sheets, are placed against each other with those surfaces that are intended to be welded together (not represented). In this case, the two metallic workpieces are placed against one another along their end faces, i.e., generally the narrower sides, such that they are joined at these surfaces (butt joint). The apparatus 1 for friction stir welding of the invention is then moved with the probe 5 along these surfaces to be joined, wherein the probe 5 rotates in relation to the shoulder element 7 and the second annular friction surface 25 of the shoulder element 7 linearly bears against the two workpieces. The axis of rotation 11 and the probe 5 run in this case parallel to the plane that is defined by the surfaces lying against one another.

In another case, parts of the two workpieces may also overlap, wherein the respectively overlapping surfaces are to be joint (lap joint). The axis of rotation 11 then runs perpendicularly to the bearing plane and the apparatus 1 for friction stir welding may be moved along the entire contact surface of the workpieces or is introduced specifically at individual locations.

The length of the circumferential first friction surface 19 of the rotating probe 5 that protrudes beyond the second annular friction surface 25 of the shoulder element 7 and is necessary for the respective welding process can be manually adjusted in a simple manner. The stop member 55, which is preferentially formed as a nut and abuts on the bearing device 27 between the drive shaft 3 and the shoulder element

7, is turned around the thread 57 such that the nut is offset in the longitudinal direction towards or away from the free end of the drive shaft 3. Consequently, the position of the bearing device 27 and the shoulder element 7 is also adjusted in the axial direction towards or away from the free end of the drive shaft 3 relative to the fixed position of the probe 5 in the longitudinal direction. The length of the circumferential first friction surface 19 of the probe 5 is finally increased or reduced.

During the welding process the second annular friction surface 25 contacts the workpieces. Consequently, the probe 5 and the second shoulder element 7 are heated due to the frictional heat that is generated by the movement of the probe 5 of the friction stir welding tool in between the workpieces. The thermal loading of the probe 5 and the shoulder element 7 is reduced due to a skilled cooling system described in the following.

With the improved cooling system of the present invention, the entire lower part of the apparatus 1 for friction stir welding, i.e., the shoulder element 7 and the probe 5, is cooled down during the friction welding process. The cooling fluid enters the annular ring element 9 from an outside cooling fluid source (not shown) across the through bore 51 and penetrates the annular channel 49, wherein the annular channel 49 is completely filled with the cooling fluid. Within the cylindrical section 39 of the shoulder element 7 the cooling fluid further penetrates across the first through hole 33 into the annular cavity 53 that is defined in the direction perpendicular to the axis of rotation 11 between the inner surface of the shoulder element 7 and the drive shaft 3 and the probe 5. In the longitudinal direction this annular cavity 53 extends between the first and second through holes 33, 35, which represent entrance and exit means of the cooling fluid, respectively.

With such a configuration, the annular cavity 53 is completely flooded with cooling fluid thus cooling the probe 5 circumferentially and the shoulder element 7 along its entire inner surface in the longitudinal direction. The probe 5 and the shoulder element 7 are effectively cooled during the welding process and their respective life time is significantly increased.

Claims:

1. An apparatus for friction stir welding comprising:

a drive shaft extending along a longitudinal direction which coincides with an axis of rotation of the drive shaft, and having a drive end and a second end opposite the drive end, the drive end being adapted to be coupled to rotational drive means,

a probe formed on the second end of the drive shaft, extending along the longitudinal direction, having a circumferential first friction surface extending along the longitudinal direction, and having a distal end remote from the drive shaft, and

a shoulder element having a second annular friction surface extending away from the longitudinal direction and facing towards the free end,

wherein the shoulder element is supported on the drive shaft,

wherein an annular cavity is formed between an inner surface of the shoulder element and at least one of the drive shaft and the probe,

wherein the shoulder element comprises first and second through holes extending from an outer surface thereof to the inner surface, the first and the second through holes being spaced apart in the longitudinal direction, and

wherein the annular cavity extends in the longitudinal direction between the first and second through holes,

wherein an annular ring element is provided which surrounds and is rotatable with respect to the shoulder element around an axis that coincides with the longitudinal direction, the annular ring element being rotatably supported on the shoulder element by first and second support members between which an annular channel is formed,

wherein the annular channel being arranged such that the first through hole connects the annular channel with the annular cavity,

wherein the annular ring element radially outwardly delimits the annular channel and comprises a through bore which extends to the annular channel; and

wherein a bearing member is mounted to the shoulder element, the bearing member supporting the probe and being positioned with respect to the longitudinal direction between the first through hole and the second through hole.

2. The apparatus of claim 1, wherein the support members are formed as bearing assemblies.

3. The apparatus of claim 1, wherein the shoulder element is rotatably supported on the drive shaft with respect to the longitudinal direction.

4. The apparatus of claim 3, wherein a bearing device is provided on the drive shaft for rotatably supporting the shoulder element.

5. The apparatus of claim 1, wherein the axial position of the shoulder element along the longitudinal direction is adjustable.

6. The apparatus according to claim 5, wherein

the shoulder element is slidably supported along the longitudinal direction on the drive shaft and

wherein a stop member is provided on that side of the shoulder element opposite the second friction surface, the position of the stop member along the longitudinal direction being adjustable.

7. The apparatus of claim 6, wherein the stop member threadingly engages with the drive shaft.

8. The apparatus of claim 1, wherein the probe is formed as a separate element releasably coupled with the drive shaft.

9. The apparatus of claim 6, wherein the shoulder element is rotatably supported on the drive shaft with respect to the longitudinal direction.

10. The apparatus of claim 9, wherein a bearing device is provided on the drive shaft for rotatably supporting the shoulder element.

11. The apparatus of claim 10, wherein

the shoulder element is fixedly mounted on the bearing assembly in the longitudinal direction,

wherein the bearing device is slidably mounted on the drive shaft along the longitudinal direction, and

wherein the stop member abuts on the shoulder element.

12. An apparatus for friction stir welding comprising:

a drive shaft extending along a longitudinal direction which coincides with an axis of rotation of the drive shaft, and having a drive end and a second end opposite the drive end, the drive end being adapted to be coupled to rotational drive means,

a probe formed on the second end of the drive shaft, extending along the longitudinal direction, having a circumferential first friction surface extending along the longitudinal direction, and having a distal end remote from the drive shaft, the probe being formed as a separate element that is releasably coupled with the drive shaft, and

a shoulder element having a second annular friction surface extending away from the longitudinal direction and facing towards the free end, the shoulder element being supported on the drive shaft and defining first and second through holes extending from an outer surface thereof to the inner surface, the first and the second through holes being spaced apart in the longitudinal direction,

wherein a bearing member mounted to the shoulder element supports the probe, the bearing member being positioned with respect to the longitudinal direction between the first and the second through holes,

a stop member abutted against a side of the shoulder element opposite the second friction surface, the stop member being threadably enaged with the drive shaft such that the position of the stop member along the longitudinal direction is adjustable, a bearing device provided on the drive shaft for rotatably supporting the shoulder element,

wherein the shoulder element is fixedly mounted on the bearing device in the longitudinal direction, and

wherein the bearing device is slidably mounted on the drive shaft along the longitudinal direction, and an annular ring element is provided which surrounds and is rotatable with respect to the shoulder element around an axis that coincides with the longitudinal direction, the annular ring element being rotatably supported on the shoulder element by first and second bearing assemblies between which an annular channel is formed,

wherein an annular cavity is formed between an inner surface of the shoulder element and at least one of the drive shaft and the probe,

wherein the annular cavity extends in the longitudinal direction between the first and second through holes,

wherein the annular channel is arranged such that the first through hole connects the annular channel with the annular cavity, and

wherein the annular ring element radially outwardly delimits the annular channel and comprises a through bore which extends to the annular channel.

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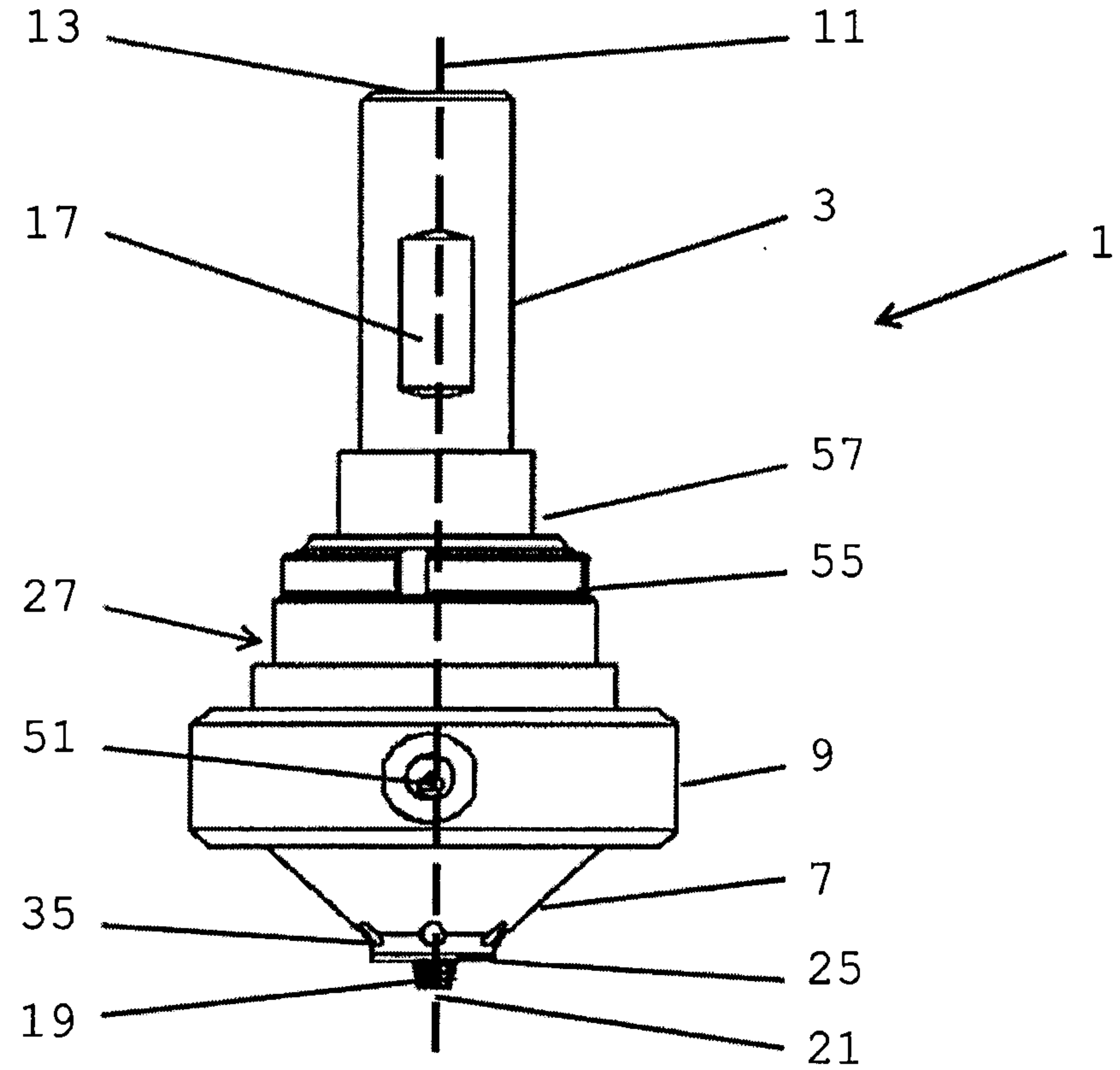
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FIG. 1

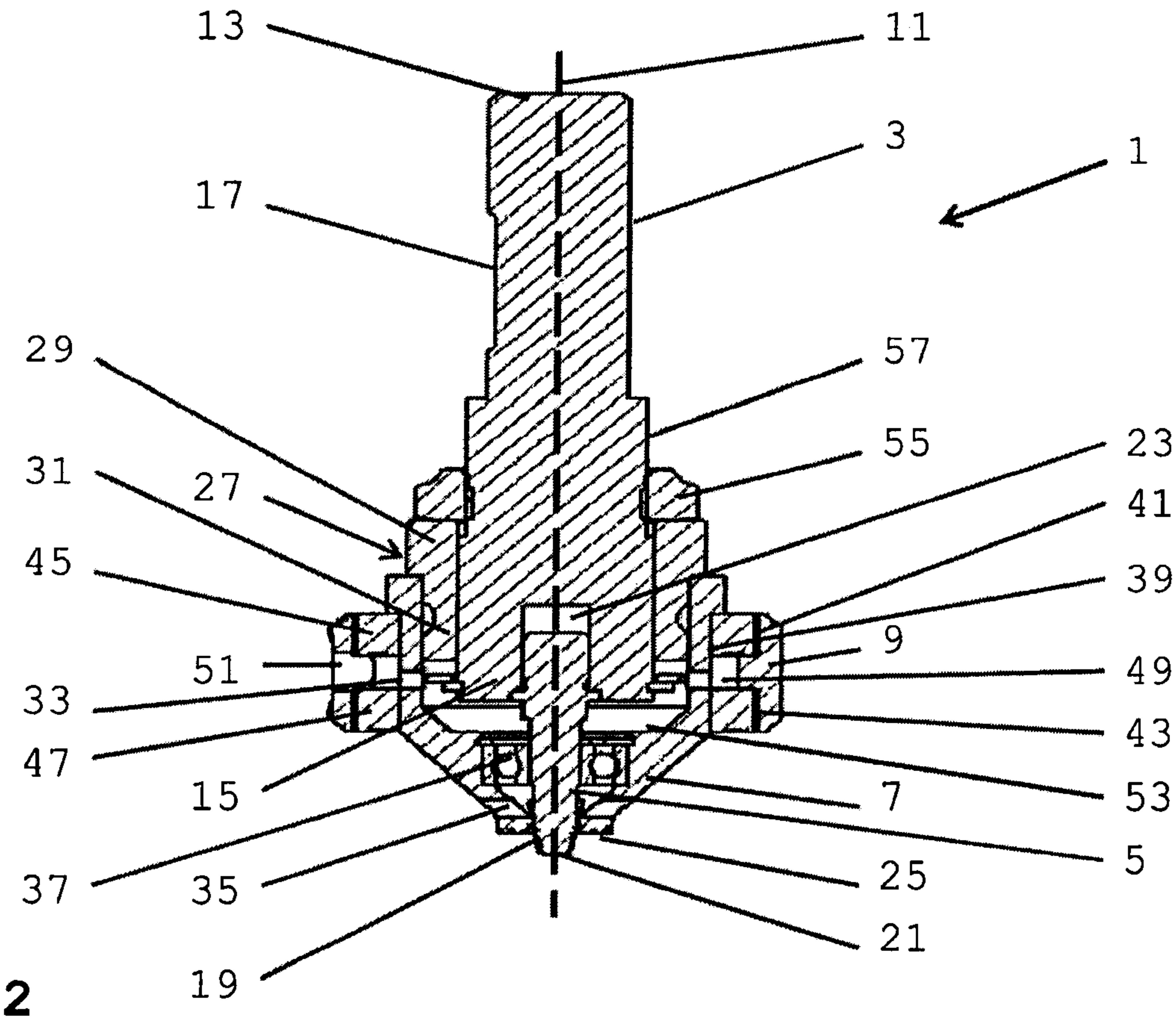
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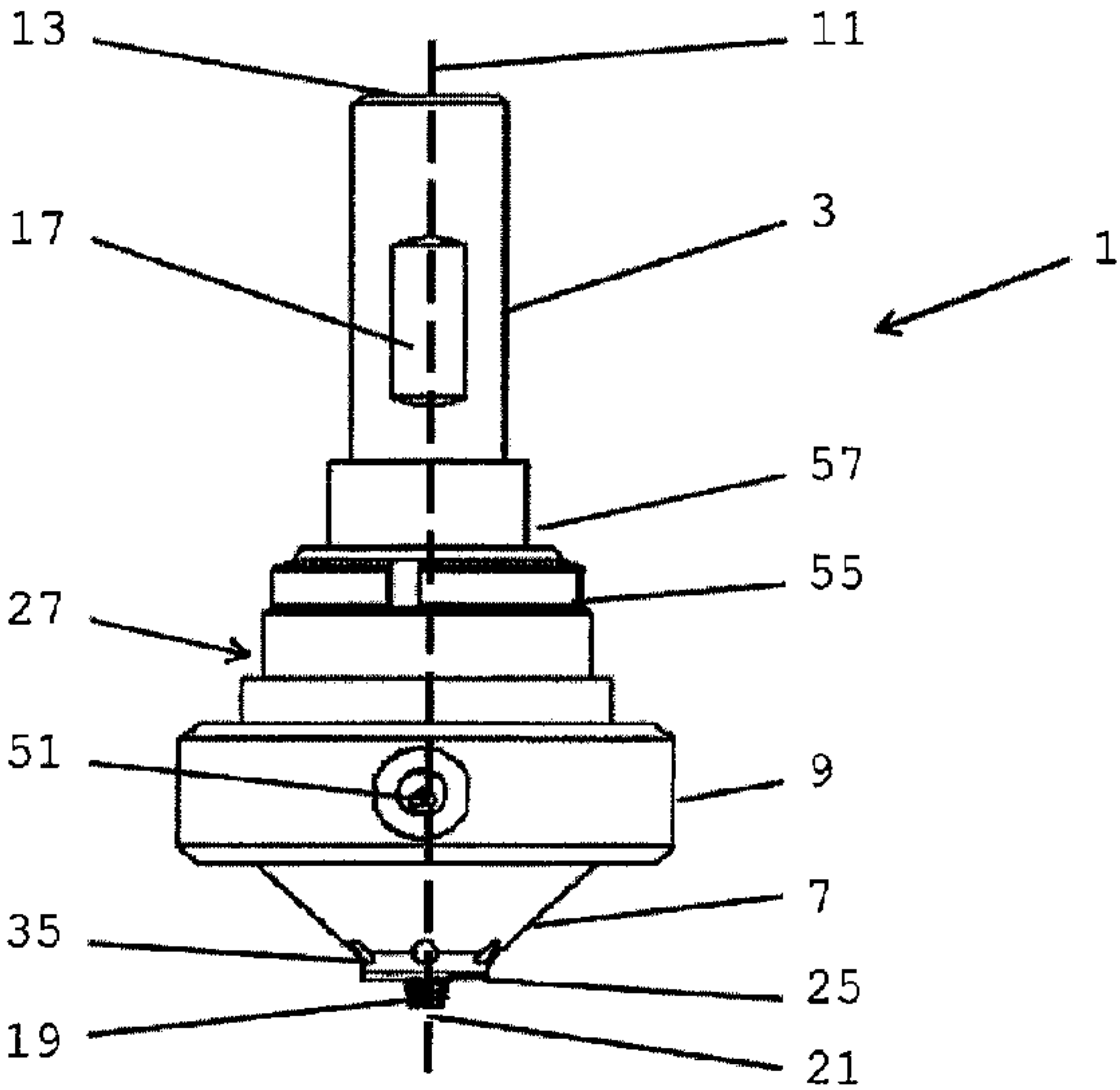
FIG. 2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