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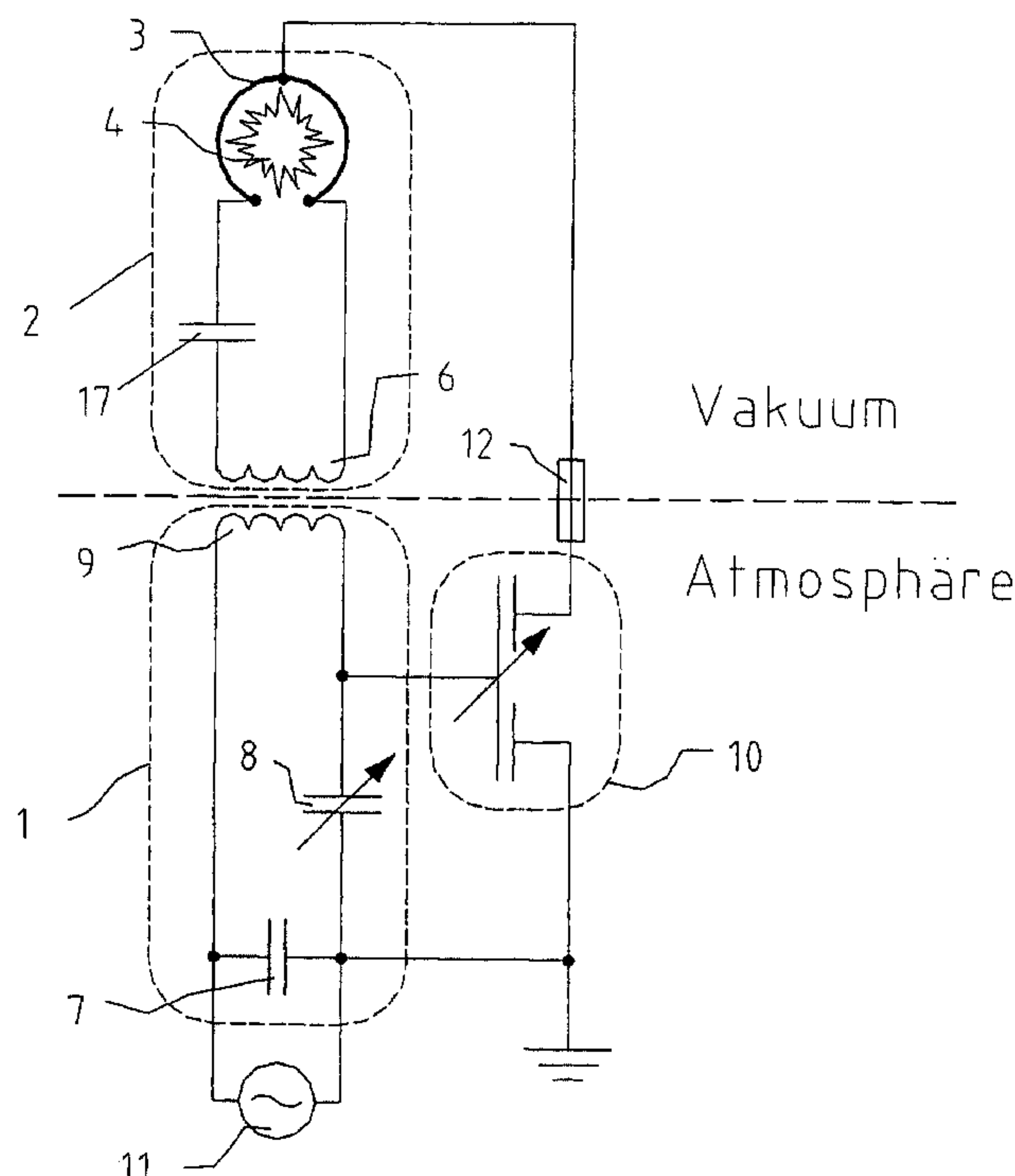
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(54) Title: HIGH-FREQUENCY MATCHING NETWORK



(57) Abrégé/Abstract:

The invention relates to a high-frequency matching network comprised of a primary switching circuit (1) provided with any type of capacitor (7) and with a variable capacitor (8), and of a high-frequency air-core coil (9). The high-frequency matching network is also comprised of a secondary switching circuit (2) provided with any type of capacitor (5, 17), of a high-frequency air-core coil (6) and of at least one excitation electrode (3), whereby the switching circuits (1, 2) are interconnected via the inductive flux of the high-frequency air-core coils (6, 9), and the primary circuit (1) and secondary circuit (2) are additionally coupled in a capacitive manner.



Abstract

The invention relates to a high-frequency matching network comprised of a primary switching circuit (1) provided with any type of capacitor (7) and with a variable capacitor (8), and of a high-frequency air-core coil (9). The high
5 frequency matching network is also comprised of a secondary switching circuit (2) provided with any type of capacitor (5, 17), of a high-frequency air-core coil (6) and of at least one excitation electrode (3), whereby the switching circuits (1,2) are interconnected via the inductive flux of the high-frequency air-core coils (6,9), and the primary circuit (1) and secondary circuit (2) are
10 additionally coupled in a capacitive manner.

High frequency matching network

The present invention is an apparatus, in the following referred to as high frequency matching network, to induce a high frequency electric alternating field into a low pressure gas discharge, in the following referred to as plasma, while simultaneously matching the load impedance to the interior resistance of a commercial high frequency generator.

Currently high frequency excited plasmas have applications in many technological areas, especially in the treatment of solid state surfaces. Thus high frequency plasmas are used for example for deposition of thin films or cleaning and etching of surfaces. When using high frequency plasmas the use of an impedance matching network is necessary as to tune the load impedance to the interior resistance of the utilized high frequency generator. Only if the load impedance is equal to the interior resistance of the generator the optimal transmittance of power from the generator to the load is possible. Generally, there is an impedance matching network between load and generator, which provides the matching of the two impedances.

According to the current state of technology matching networks for plasma excitation permit only the inductive matching of the load impedance to the interior resistance of the generator, to minimize the reflected power and hence optimize the power induced into the plasma. An alternating electrical field is coupled into the plasma by an electrode in contact with the plasma or by irradiation of the field through a dielectric medium. For the excitation efficiency of the plasma it is of special significance whether the capacitive or inductive excitation prevails. A capacitive excitation of the plasma is characterized in that the electromagnetic wave is irradiated into the plasma through its boundary and is exposed to exponential damping when expanding towards the center of the plasma. An inductive excitation is characterized in that there is a coupling of the alternating electric field with an induced alternating magnetic field inside the plasma. Generally the excitation is a mixed excitation with a capacitive and inductive fraction. At a fixed supplied high frequency power the capacitive part of the plasma coupling is determined by the voltage amplitude and the inductive part of the plasma coupling by the current amplitude is determined by the current amplitude of the alternating electric field applied to the electrode.

Rayner, Cheetham and French described in J.Vac.Sci. Technol. A 14(4) (Jul/Aug 1996), pages 2048-2055 a high frequency matching network, which consists out of two electrical circuits, which are coupled by the inductive flux of high frequency air core inductive coils.

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The present invention provides a low loss high frequency matching network for plasma excitation, which allows the separate and free selection of current and voltage amplitude, simultaneously matching the load impedance to the interior resistance of a high frequency generator and thus the present invention allows
10 a continuous adjustment between capacitive and inductive excitation of the plasma.

A high frequency matching network according to the present invention consists of a primary electrical circuit with an arbitrary and a variable capacitor and a
15 high frequency air core inductive coil into which the power of a high frequency generator is induced, as well as a secondary electrical circuit with a fixed or a variable capacitor and a high frequency air core inductive coil and at least one excitation electrode for generation of the plasma, where the electrical circuits are coupled by the inductive flux of the high frequency air core inductive coils
20 and are additionally coupled capacitively. When using a variable capacitor a continuous selection between capacitive and inductive plasma coupling is possible.

The degree of the capacitive coupling between primary and secondary circuit
25 can be adjusted by one or more fixed capacitors or a variable capacitor. As capacitor can be used for example a high frequency air capacitor made of a non-noble metal with low electrical resistivity which is provided with a layer of gold or a platinum group metal, e.g. platinum, on the surface, as described in the German patent application "Hochfrequenz-Luftkondensator" with the
30 official application number 100 08 483.4 of the company CCR GmbH Beschichtungstechnologie. The high frequency air capacitor can be embodied as parallel plate capacitor, cylindrical capacitor or spherical capacitor. Preferably the capacitor is embodied in the shape of a trimmer, e.g. as differential air trimmer, especially with a multi linear characteristic curve, as
35 described in the German patent application "Differential-Luftplattentrimmer mit multi-linearer Kennlinie" with the application number 100 08 486.9 of the company CCR GmbH Beschichtungstechnologie.

Such a differential air trimmer, that enables improved matching of simple functional dependencies due to a multi linear characteristic curve (multi-linear differential air trimmer), shows contrary to linear air trimmers a combination of conventional and segmented stator discs and rotor discs. In conventional differential air trimmers stator discs and rotor discs, are similar to a 180° circle segment or a rectangular with the ratio of side lengths of 2:1, which will give the air trimmer only a linear characteristic curve. In contrast the preferred multi-linear differential air trimmer is additionally fitted with circle or rectangular segments with angles $< 180^\circ$. This gives this differential air trimmer a multi-linear characteristic curve, i.e. the characteristic curve is composed of two straight lines with different slopes. To exhibit a n-fold linear dependency additionally to the conventional trimmer discs additionally n-1 different segmented discs are needed. The necessary number of discs of the different segment types has to be matched to the required dependency. In general, the higher the number of different segment types the more exactly can the required dependency be approached. The characteristic curve of the preferred multi-linear differential air trimmer can thus be matched well to a simple functional dependency. Preferably the segmented rotor discs are only faced by one stator disc. The segmented stator discs do not have to face a stator side. The stator discs and/or rotor discs can be embodied as conventional 180° segments.

In case of a capacitive coupling the plasma potential with reference to ground potential can be varied by adjusting the high frequency amplitude which alters the voltage drop across the plasma sheath. Thus, with the variation of the high frequency amplitude the energy of the ions can be adjusted as the energy of the ions is determined by the plasma potential. If instead of a common trimmer the above mentioned multi-linear differential trimmer is used, a subsequent matching of the resonance circuit by variation of the capacitive coupling due to a variation of the plasma potential is not necessary any more. Thus the ion energy can be easily adjusted with only one single trimmer. If a continuously adjustable ion energy is not demanded, the differential trimmer can be replaced by fixed capacitors.

The resonance frequency of primary and secondary electrical circuit can be matched to the generator frequency by a primary as well as by a secondary trimmer and /or by variation of the inductive coupling between primary and secondary inductive coil, especially by the variation of the axial and radial

distance between the inductive coils. Additional fixed capacitors can be connected in parallel to the trimmers. Ideally the primary electrical circuit is dimensioned in such a way that high voltage amplitudes (voltage resonance) can be achieved and the secondary circuit in such a way that high current amplitudes (current resonance) can be achieved.

The high frequency air core inductive coils are in particular coolable high frequency air core inductive coils made from a non-noble material pipes with low electrical resistivity. On at least on their outer surface is a layer of gold or a platinum group metal, e.g. platinum, as described in the German patent application 100 08 484.2 of the company CCR GmbH Beschichtungs-technologie. The pipe can have an arbitrary cross section. The cross section does not necessarily have to be a circle, but can also be quadratic or rectangular. For cooling the high frequency air core inductive coil is flushed with a liquid medium, preferably water. The coil can be wound in screw or spiral form, and in latter case be also spherically arched. The diameter of the coils is preferably between 10 and 100 mm.

To generate a current resonance in the secondary electrical circuit the total induction of the circuit should be as low as possible. The secondary inductive coil is hence reduced to a minimum of windings, preferably only one winding. To generate the voltage resonance in the primary electrical circuit the inductivity of this circuit should be as large as possible. Hence the primary inductive coil consists of many, preferably 2 to 10 windings. The diameter of the coils should be between 10 and 100 mm.

The excitation electrode for plasma generation can be situated inside as well as outside the vacuum. If the excitation electrode is situated inside the vacuum, it can be connected with the part of the secondary circuit on the atmospheric side by a vacuum current feed-through. Also the complete secondary electrical circuit, consistent of trimmer, coil, excitation electrode and connecting elements may be situated inside the vacuum, where the secondary trimmer can be adjusted with a mechanical vacuum feed through. Between the two coupling coils a dielectric window of non-magnetic and magnetic permeable material can serve to separate the vacuum from atmosphere. Such a window can be made of plastics, e.g. Teflon, or glass, e.g. quartz or window glass, as well as ceramics or aluminum oxide.

The impedance matching network according to this invention can be used in connection with all kind of and arbitrary excitation electrodes for plasma excitation. There are no restrictions regarding form, geometry, material, arrangement, number, etc. of the excitation electrode.

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To obtain a large current amplitude at a fixed high frequency power, all components of the matching network have to be constructed in such a way that ohmic power losses are minimized. Generally single or all high frequency conducting components of high frequency networks, especially connecting elements, conductor paths, high frequency air core inductive coils, capacitors, vacuum current feed-throughs and excitation electrodes are composed of a metal with a low electrical resistivity. For economic reasons in general non-noble metals, e.g. copper, iron, zinc, aluminum or their alloys as e.g. brass are chosen.

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At the expected frequencies of 1 to 50 MHz however, the current flows only in the surface of the conductors across a surface layer with a thickness of a few micro meters due to the skin effect. In conventional conducting materials, as e.g. copper, the surface of the conductor reacts due to the contact with oxygen or nitrogen of air to form an oxide or nitride layer, which reduces the conductivity at the surface of the conductor considerably and thus increases the ohmic loss of the high frequency power considerably. It should be ensured that the surface of the conducting materials remains highly conductive. This is ensured by depositing single or all high frequency conducting components at least on their outer surface with a layer of gold or a platinum group metal, e.g. platinum.

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If noble metals, for example gold or platinum, are deposited on non-noble metals, for example copper or brass, there is a danger that the noble metal diffuses into the non-noble metal or the non-noble metal diffuses into the noble metal. Subsequently the conductivity on the surface decreases due to the above mentioned reasons. The diffusion process can be prevented with the deposition of a diffusion barrier, for example a very thin layer of nickel, which is deposited onto the non-noble metal before deposition of the gold or platinum group metal. Thus the long time stability of the outer metal layer is ensured. Both layers can be deposited by plasma chemically or galvanically, preferably as a closed layer of a thickness of 10 nm to 10 μm , preferably 1 μm .

Both layers, i.e. the diffusion barrier and the deposited layer of gold or platinum group metal on top, are also described in detail in the German patent applications "Kühlbare Hochfrequenz-Luftspule" with the application number 100 08 484.2, as well as "Hochfrequenz-Luftkondensator" with the application number 100 08 483.4 of the company CCR GmbH Beschichtungstechnologie.

Single or all high frequency conducting components of the matching network can be cooled with a liquid medium, preferably water.

10 This invention of the matching network, which can be used for the generation of a quasi neutral plasma beam or ion beam, enables an optimization of the inductive coupling, which increases the excitation efficiency significantly. Also it enables the exploitation of special resonance excitations such as electron cyclotron wave resonance or Landau damping resonance.

15 The high frequency matching network described in this invention can for example be used in a high frequency plasma source or ion source as described in the German patent application "Hochfrequenz Plasmaquelle" with the application number 100 08 482.6 of the company CCR GmbH Beschichtungs-
20 technologie.

An exemplary embodiment is illustrated in the drawings and described in more detail below.

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- Figure 1 shows a possible design of the impedance matching network
- Figure 2 shows a variant of the impedance matching network
- Figure 3 shows a system to transmit the alternating electrical field into the vacuum
- Figure 4 shows a further variant of the impedance matching network
- Figure 5 shows the layers of the high frequency conducting components
- Figure 6 shows a segmented stator plate or rotor plate
- Figure 7 shows the schematic composition of a double-linear differential trimmer
- Figure 8 shows a comparison of linear and double linear characteristic curve
- Figure 9 shows a spiral wound high frequency air core inductive coil

Figure 10 shows a spiral wound and spherically arced high frequency air core inductive coil

The connection of the matching network in figure 1 consists of two coupled oscillating circuits, the primary circuit (1) and the secondary circuit (2). The power supplied by the high frequency generator (11) is induced into the primary circuit (1). Inside the vacuum there is an excitation electrode (3) to excite the plasma. The excitation electrode (3) is connected with the secondary circuit (2) by two vacuum current feed-throughs (12). The coupling of the two electrical circuits (1,2) takes place inductively by means of a transmitter consisting of two high frequency air core inductive coils (9,6), and capacitively by means of a differential trimmer (10). The primary electrical circuit (1) consists of a primary inductive coil (9), an arbitrary (7) and a variable capacitor (primary trimmer) (8). The capacitor (7) is connected in parallel to the exit of the high frequency generator; generally one pole of the high frequency generator (11) is connected to ground potential. Also parallel to the output of the high frequency generator (11) there is a serial connection of primary trimmer (8) and primary inductive coil (9), where the primary trimmer (8) is connected with the grounded pole of the high frequency generator (11). The secondary electrical circuit consists of a serial connection of the secondary inductive coil (6), a variable capacitor (secondary trimmer) (5) and the excitation electrode (3). The central pole of the differential trimmer is connected between the primary inductive coil (9) and the primary trimmer (8). The side poles of the differential trimmer (10) is held at ground potential, or connected with the central pole of the excitation electrode (3). If necessary, additional fixed capacitors can be connected in parallel to all trimmers.

Figure 2 shows a variation of the matching network illustrated in figure 1, in which the complete secondary circuit (2) is placed inside the vacuum. The boundary between vacuum and atmosphere is in between the two air core inductive coils (6,9), of the primary and secondary circuit which are coupled by the inductive flux. To separate vacuum and atmosphere a dielectric window (13) is used (figure 3), which does not discontinue the inductive flux between the two coupling inductive coils (6,9). Between the window (13) and the back wall of the plasma chamber (14) there is a vacuum gasket (15). The matching of the secondary circuit with the trimmer (5) is then enabled by means of a mechanical vacuum feed-through (16).

Figure 4 shows a further developed embodiment of the matching network, in which the secondary trimmer (5) was replaced by a fixed capacitor (17). In this case the matching of the resonant circuit is done by adjustment of the primary trimmer (8) and by adjustment of the inductive coupling between primary (9) and secondary inductive coil (6). For the latter the radial and axial distance between primary (9) and secondary coil (6) can be varied as the components of the atmospheric part of the matching network are mounted in bearings and hence movable. The movable and fixed components of the primary circuit are connected by flexible conductor paths or high frequency cables.

Figure 5 shows layers of high frequency conducting components of the matching network. The basis material of the components (26) is covered with a closed layer of nickel (25) which acts as diffusion barrier. On top of the nickel layer a layer of gold (24) is deposited.

Figure 6 shows a selection of segmented trimmer discs of a differential air trimmer with a multi linear characteristic curve. The illustrated 135° segments (18,19), 90° segments (20,21) and 45° segments (22,23) are, additionally to the conventional trimmer discs, necessary to obtain a multi-linear dependency.

Figure 7 shows a double linear differential trimmer as exemplary embodiment of a multi linear differential air trimmer. It consists of a revolving axle (28), to which a rotor is attached. The rotor consists of five conventional 180° circle segments (27) as well as of ten 90° segments (20). The stator side C1 consists of five conventional stator discs, which are mounted on a stator mount (29). The stator side C2 consists of fifteen conventional stator discs, which are attached to the second stator mount (30). The 90° rotor segments (20) are arranged in such a way that they pass only the stator discs on the stator side C2. By analogy to obtain a multi-linear characteristic curve of a trimmer the stator discs can also be designed as part segments.

In figure 8 the characteristic curve of a double linear differential air trimmer, i.e. the stator side C1 in dependency of stator side C2 is illustrated. The characteristic curve is composed of two lines with different slopes. With this double linear differential trimmer the illustrated non-linear dependency can be approached with increased accuracy, as compared to conventional trimmers with a linear characteristic curve.

Figures 9 and 10 show possible embodiments of high frequency air core inductive coils of this invention. They consist preferably of a metal pipe which is wound into a spiral (figure 9). This axis of this spiral can additionally be
5 bend to form an arch (Figure 10).

Legend

	1	Primary electrical circuit of the impedance matching network
	2	Secondary electrical circuit of the impedance matching network
5	3	Excitation electrode
	4	Plasma
	5	Variable capacitor (trimmer)
	6	High frequency air core inductive coil
	7	Capacitor
10	8	Variable capacitor (trimmer)
	9	High frequency air core inductive coil
	10	Differential trimmer
	11	High frequency generator
	12	Vacuum current feed-through
15	13	Dielectric window
	14	Back wall of plasma chamber
	15	Vacuum gasket
	16	Mechanical vacuum feed-through
	17	Fixed capacitor
20	18	Segmented Trimmer Plate (135° circle segment)
	19	Segmented Trimmer Plate (135° rectangular segment)
	20	Segmented Trimmer Plate (90° circle segment)
	21	Segmented Trimmer Plate (90° rectangular segment)
	22	Segmented Trimmer Plate (45° circle segment)
25	23	Segmented Trimmer Plate (45° rectangular segment)
	24	Gold layer
	25	Diffusion barrier of nickel
	26	Base material of high frequency conducting component
	27	Conventional rotor plate (180° circle segment)
30	28	Revolving axle
	29	Stator mount
	30	Stator mount

Claims

1. High frequency matching network consisting of
 - a primary electrical circuit (1) with an arbitrary (7) and a variable (8) capacitor and a high frequency air core inductive coil (9) and
 - a secondary electrical circuit (2) with an arbitrary capacitor (5, 17), a high frequency air core inductive coil (6) and at least one excitation electrode (3),where the electrical circuits (1,2) are coupled by the inductive flux of the high frequency air core conductive coils (6,9), characterized in that primary circuit (1) and secondary circuit (2) are additionally coupled capacitively.
2. High frequency matching network according to claim 1, characterized in that between capacitive and inductive coupling can be chosen.
3. High frequency matching network according to claim 1 or 2, characterized in that the choice between capacitive and inductive coupling is continuously.
4. High frequency matching network according to claim 1 to 3, characterized in that the capacitive coupling is by one or more fixed capacitors.
5. High frequency matching network according to claim 1 to 4, characterized in that the capacitive coupling is by a variable capacitor.
6. High frequency matching network according to claim 1 to 5, characterized in that the capacitive coupling is by a differential trimmer (10).
7. High frequency matching network according to claim 6, characterized in that a differential air trimmer, which shows a combination of common and segmented stator and/or rotor discs to obtain a multi-linear characteristic curve, is used as the differential trimmer (10).
8. High frequency matching network according to claims 1 to 7, characterized in that the resonance frequency of primary electrical circuit (1) and secondary electrical circuit (2) can be matched to the generator frequency by a primary trimmer (8) as well as by a secondary trimmer (5).

9. High frequency matching network according to claims 1 to 8, characterized in that additionally fixed capacitors can be connected in parallel to the trimmers (5,8).
- 5 10. High frequency matching network according to claims 1 to 9, characterized in that the primary electrical circuit (1) is dimensioned in such a way that large voltage amplitudes can be obtained, and the secondary electrical circuit (2) in such a way that large current amplitudes can be achieved.
- 10 11. High frequency matching network according to claims 1 to 10, characterized in that the primary inductive coil (9) consists of many, preferably 2 to 10 windings.
12. High frequency matching network according to claims 1 to 11, characterized in that the secondary inductive coil (6) consists of less than 2 windings, preferably only one winding;
- 15 13. High frequency matching network according to claims 1 to 12, characterized in that the diameter of the inductive coils (6, 9) is between 10 and 100 mm.
- 20 14. High frequency matching network according to claims 1 to 13, characterized in that the excitation electrode (3) is situated inside the vacuum.
15. High frequency matching network according to claims 1 to 14, characterized in that the excitation electrode (3) is connected to the atmospheric part of the secondary circuit (2) with a vacuum current feed-through (12).
- 25 16. High frequency matching network according to claims 1 to 15, characterized in that all of the secondary circuit (2) consisting of trimmer (5), inductive coil (6), excitation electrode (3) as well as connecting elements, is situated inside the vacuum.
- 30 17. High frequency matching network according to claim 16, characterized in that there is a dielectric window (13) in between the two coupling coils (6,9).

18. High frequency matching network according to claim 16 or 17, characterized in that the dielectric window (13) consists of a non-magnetic and magnetic permeable material.
- 5 19. High frequency matching network according to claims 16 to 18, characterized in that the dielectric window (13) consists of quartz glass or aluminum oxide.
20. High frequency matching network according to claims 1 to 19, characterized in that the secondary trimmer (5) is adjustable by a mechanical vacuum feed-through (16).
- 10 21. High frequency matching network according to claims 1 to 20, characterized in that the secondary circuit (2) consists at least of one fixed capacitor (17), one high frequency air core inductive coil (6) and an excitation electrode (3).
- 15 22. High frequency matching network according to claims 1 to 21, characterized in that the resonance circuit is matchable by varying the coupling between primary inductive coil (9) and secondary inductive coil (6) and/or by adjusting the primary trimmer (8).
- 20 23. High frequency matching network according to claims 1 to 22, characterized in that the coupling is adjustable by varying the axial and radial distance of primary coil (9) and secondary coil (6).
- 25 24. High frequency matching network according to claims 1 to 23, characterized in that single or all high frequency conducting components of the matching network, especially connecting elements, conductive paths, air core conductive coils, capacitors, vacuum current feed-throughs, excitation coils, consist of a non-noble metal with a low electric resistivity and are provided with a layer of gold or a platinum group metal on their outer surface.
- 30 25. High frequency matching network according to claims 1 to 24, characterized in that between the non-noble metal of the high frequency conducting elements and the layer of gold or a platinum group metal there is deposited a diffusion barrier (30) as a closed layer.

26. High frequency matching network according to claims 1 to 25, characterized in that single or all high frequency conducting components of the impedance matching network are cooled with a liquid medium, preferably water.
- 5 27. Application of the high frequency matching network according to one of the claims 1 to 26 to generate a quasi neutral plasma beam.
28. Application of the high frequency matching network according to one of the claims 1 to 26 to generate an ion beam.

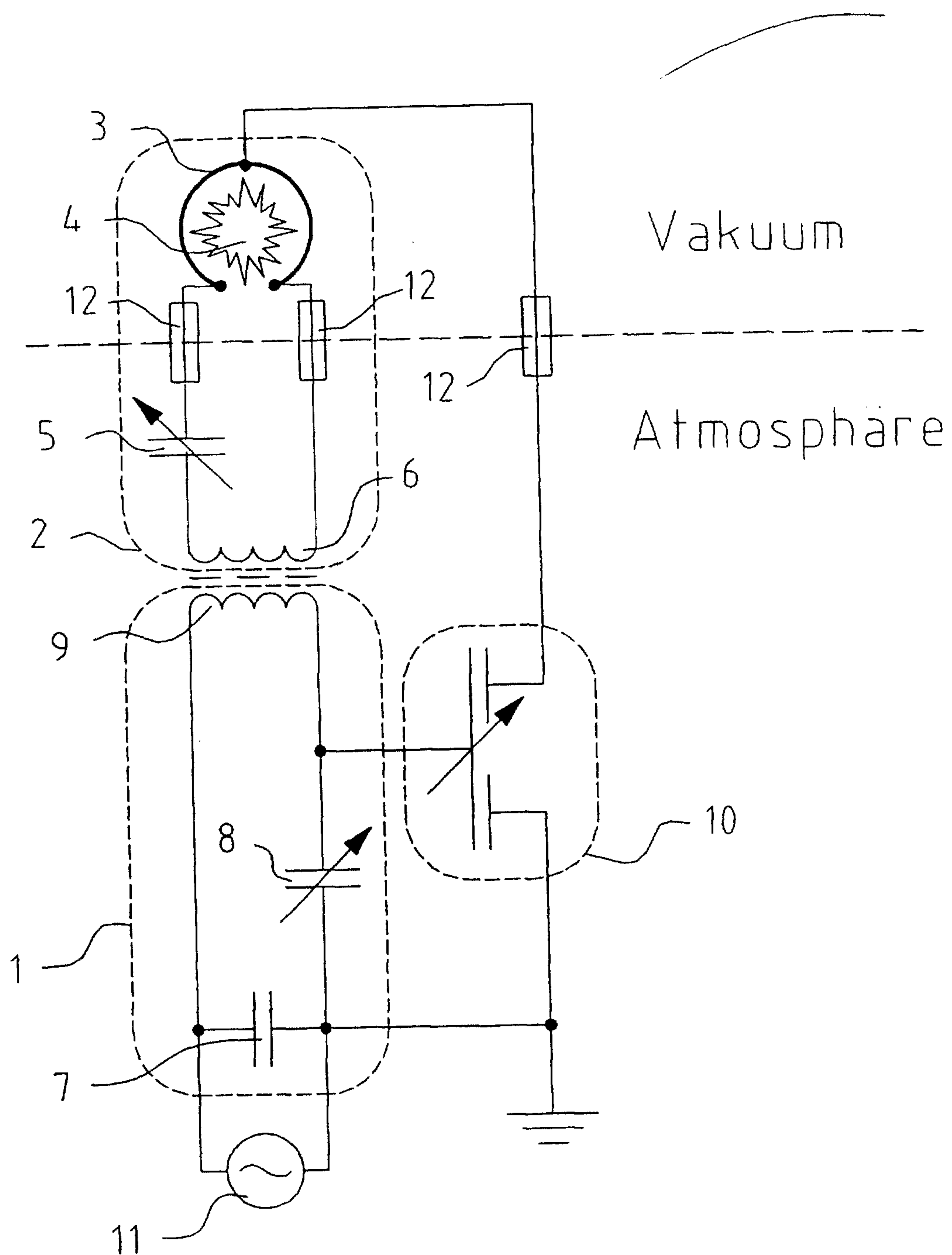
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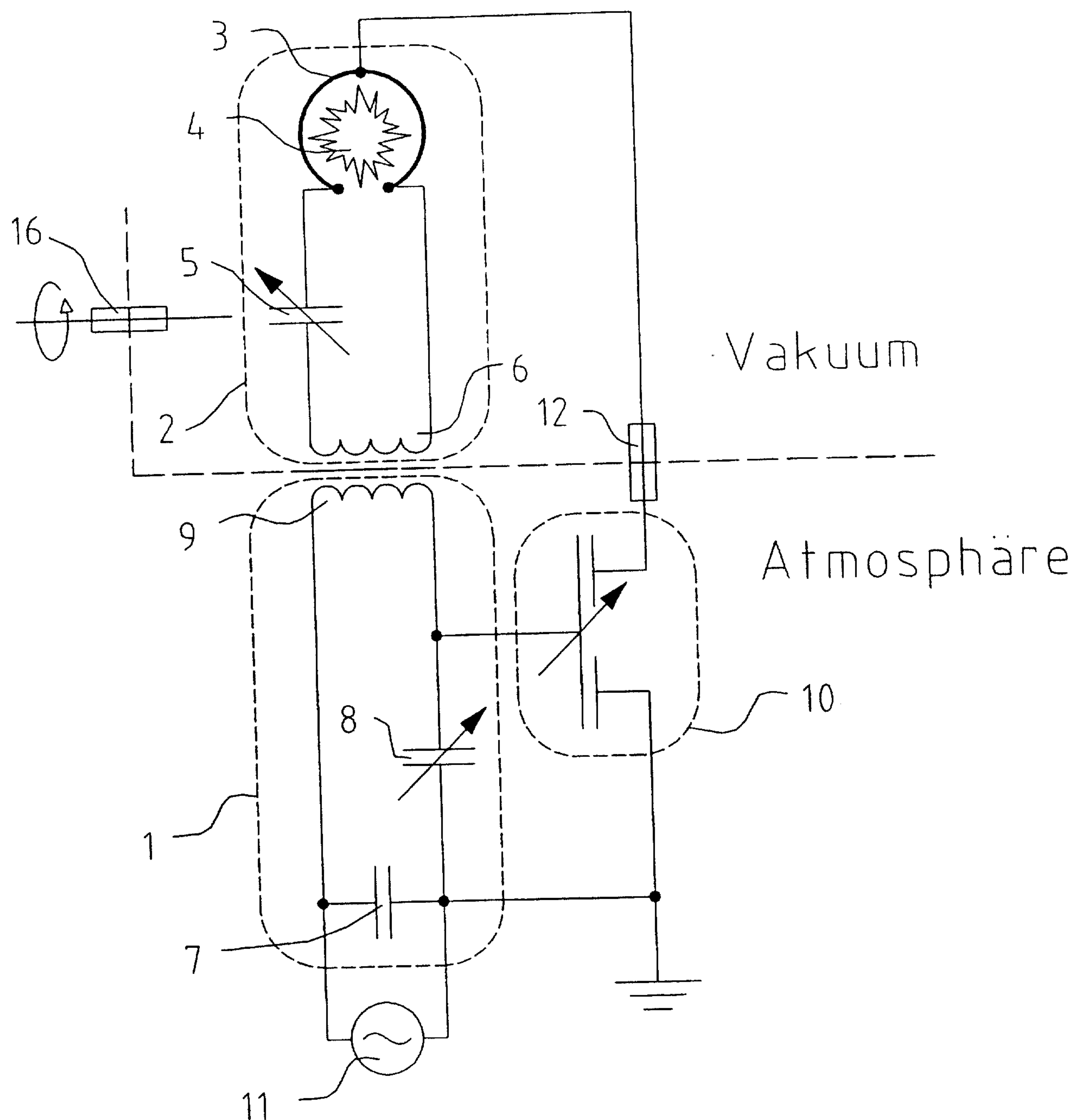
Figures: 5, 6, 7, 8

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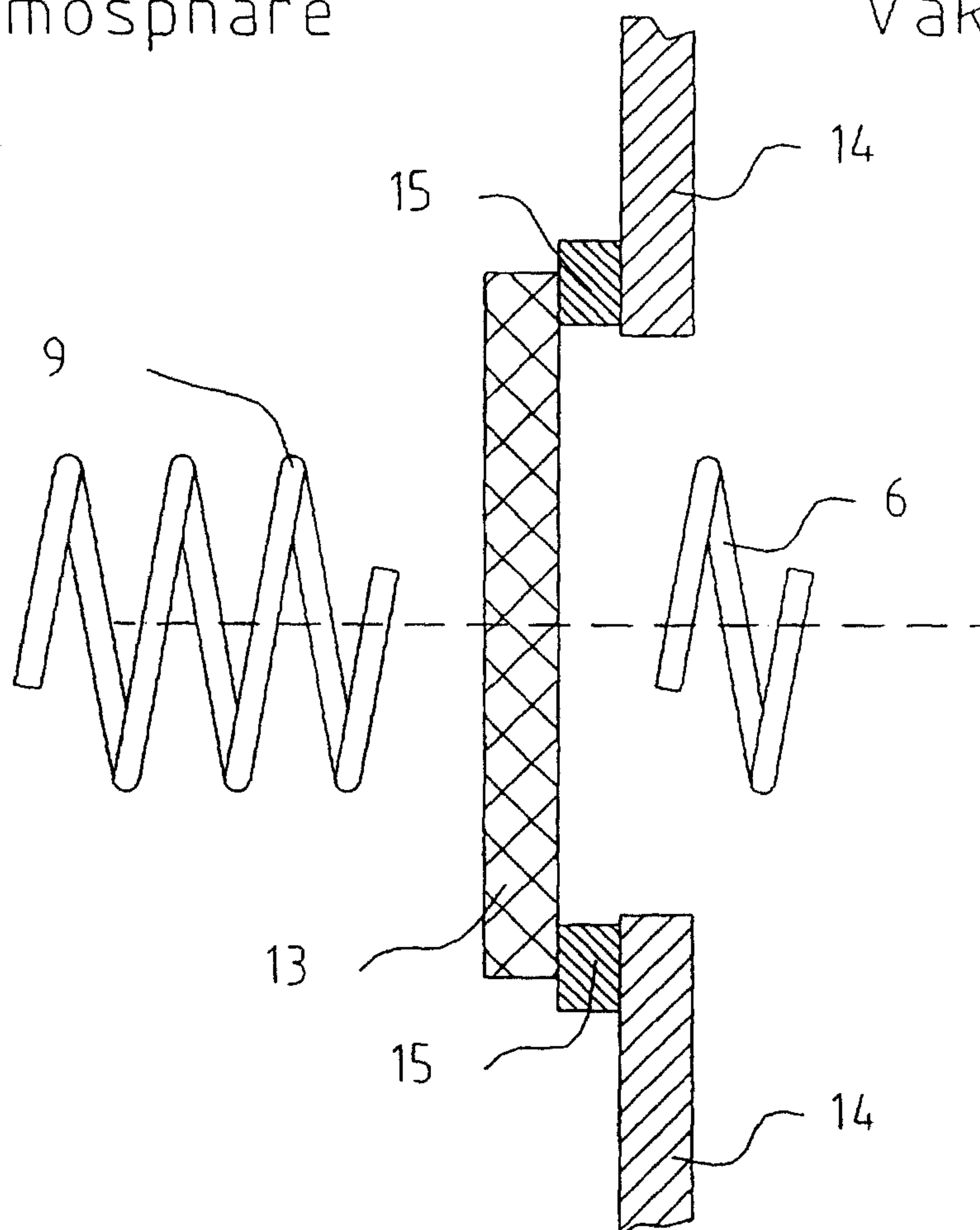
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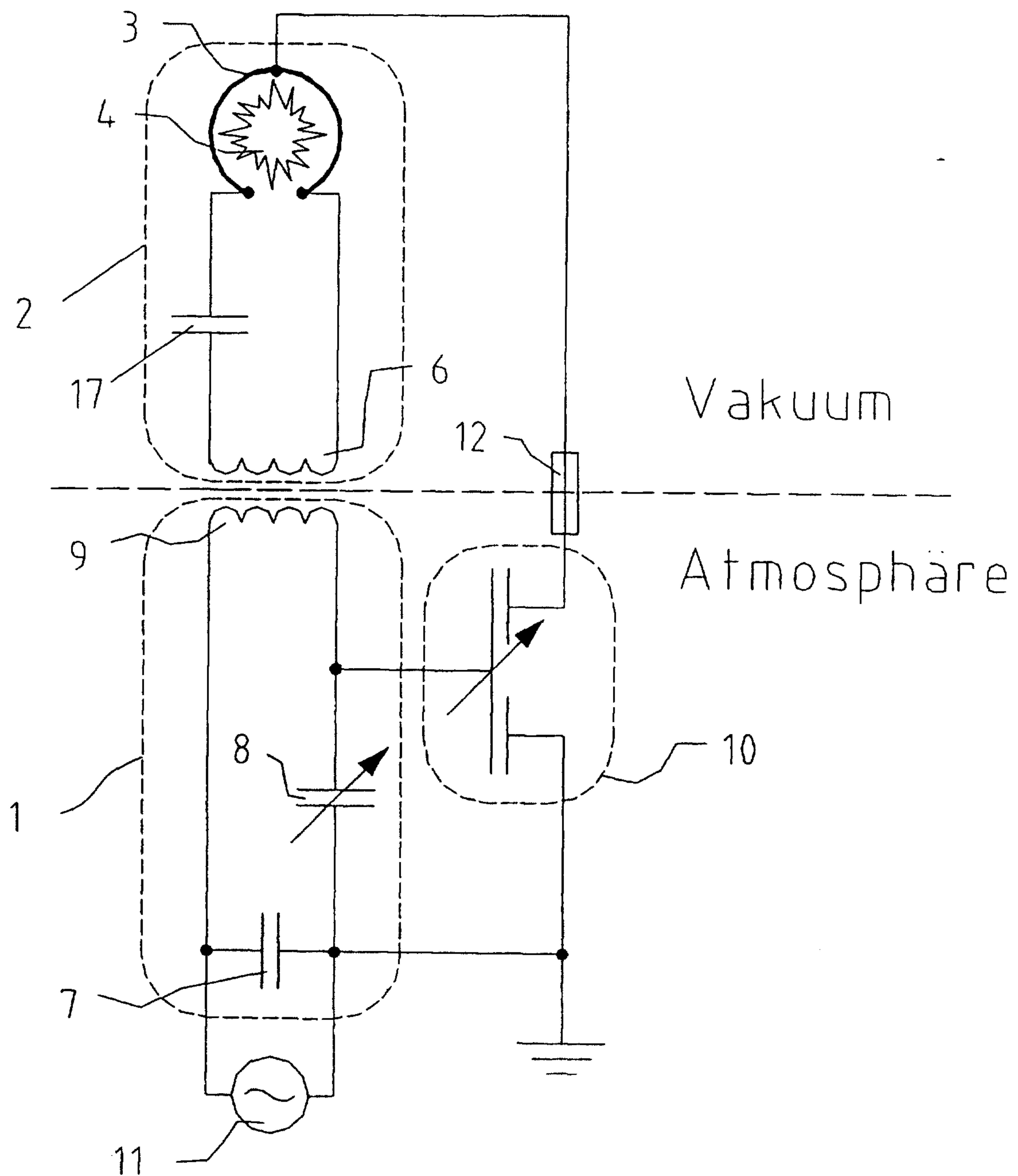
**Figur 1**

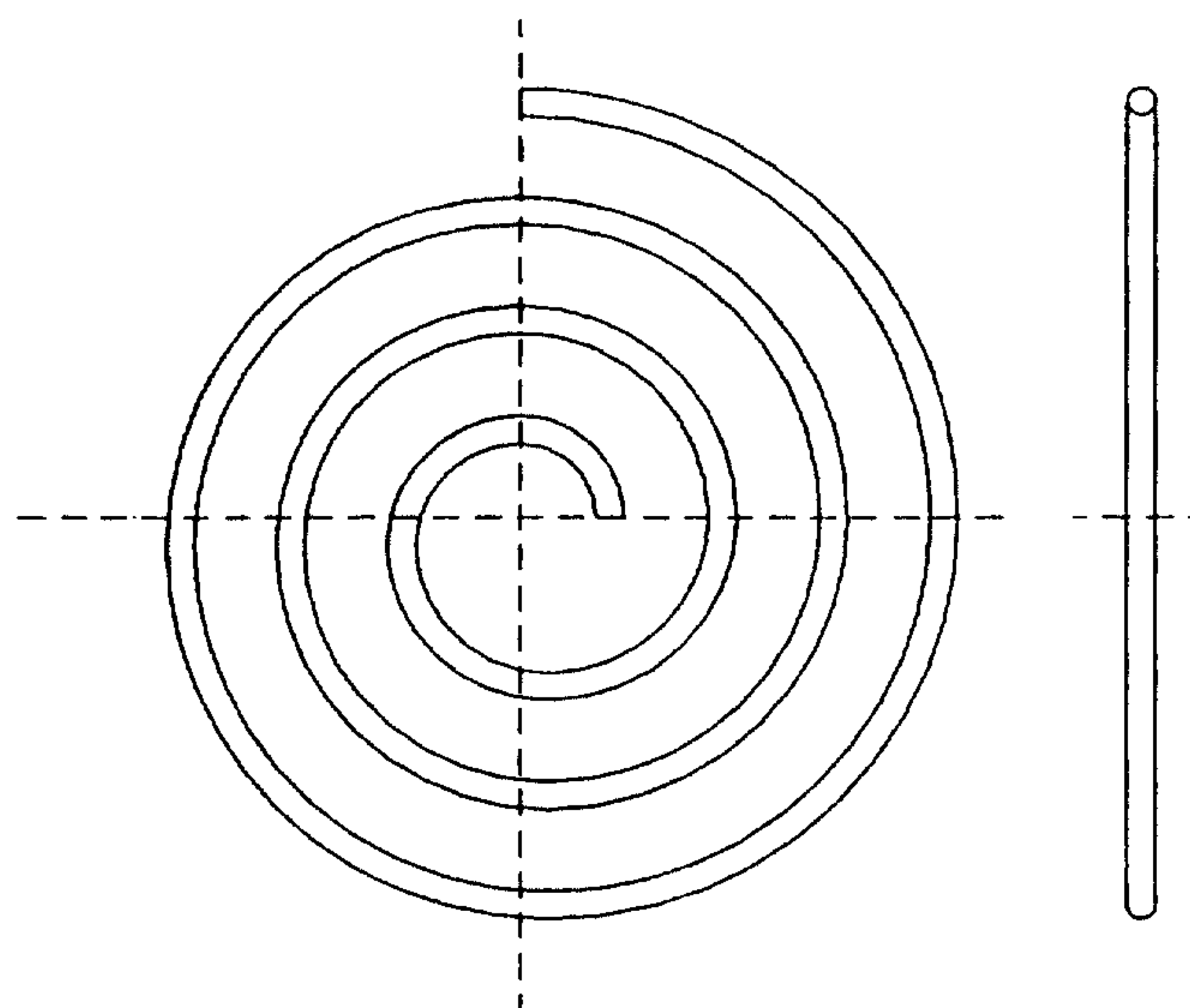
**Figur 2**

Atmosphäre

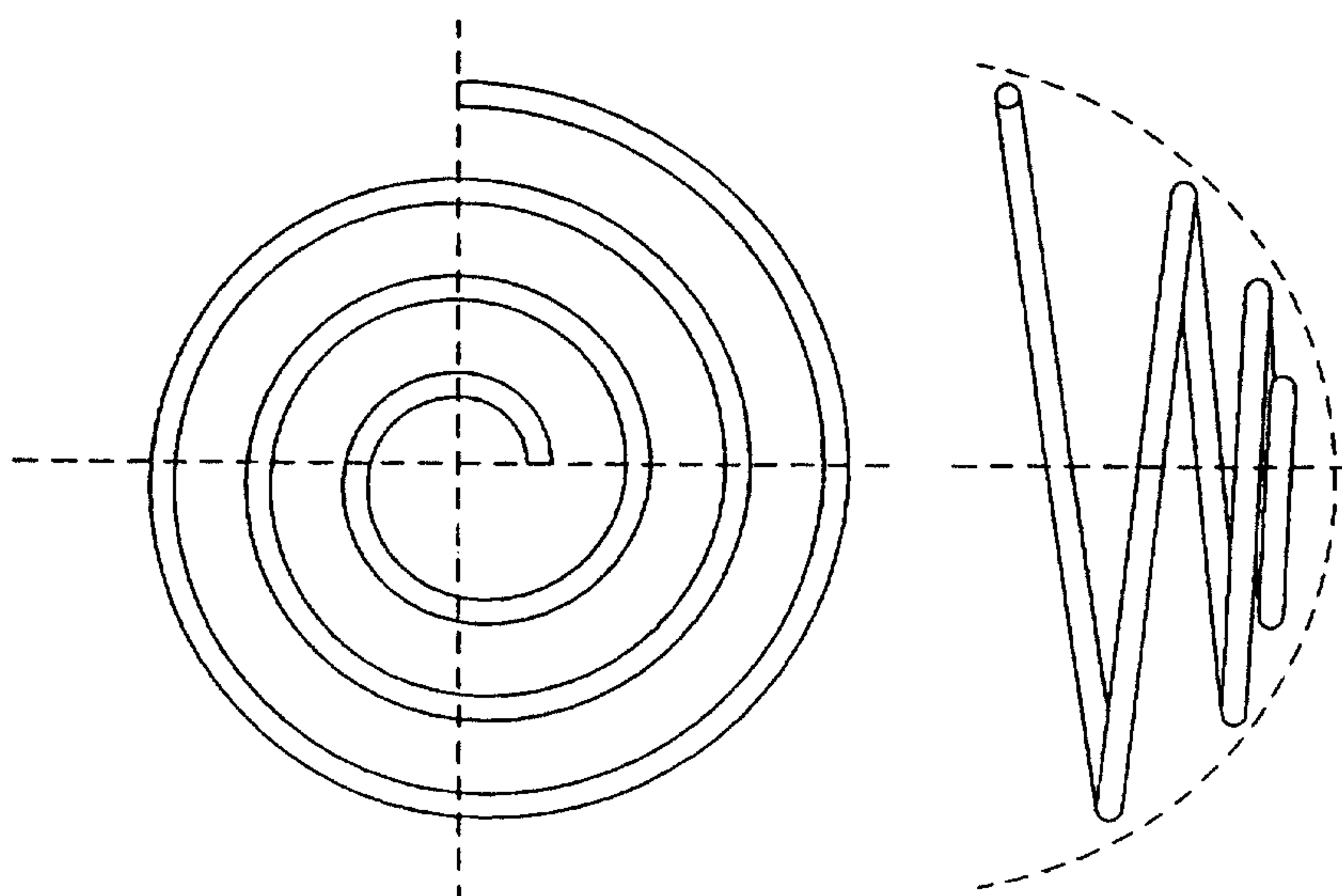
Vakuum

**Figur 3**

**Figur 4**



Figur 9



Figur 10

