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54 **Inductive heating apparatus and process.**

57 An inductive heating apparatus comprising an induction furnace (1) and induction heating coil (10) embedded within a refractory block (6) of cylindrical form and a metal susceptor sleeve (7) arranged with a clearance in the bore of the refractory block (6). The susceptor sleeve extends below the bottom of the refractory block (6) and is supported in a metal support collar (8). A cylindrical canister (4) is positioned inside the refractory block (6) and is supported on a movable lower refractory pressure pad (3) located on top of a water cooled hydraulic ram (5). An upper refractory pressure pad (2) is provided above the cylindrical canister (6) and serves as an abutment means when the lower refractory pressure pad (3) and cylindrical canister (4) thereon are moved upward. The induction heating coil (10) may also have a number of tapings (A, B, C) for progressively increasing the length of the heating zone.

INDUCTIVE HEATING APPARATUS & PROCESS

The present invention relates to an inductive heating apparatus and process for providing effective heat transfer between the induction coils of an induction furnace and an article or material to be heated thereby. The invention is especially applicable where it is desired to heat a metal canister of generally cylindrical form and including a bellows-like wall structure; in a heated condition, the canister is free-standing and undergoes uniaxial pressing in order to compact the contents of the canister.

By way of example only, the present invention will be described in relation to its application to an apparatus and process for immobilising high level radioactive nuclear waste material in a synthetic rock formed by sintering an intimate mixture of such a waste material and a synthetic rock-forming material at a high temperature. Such a process must be conducted in a active cell and not only must the process operate extremely reliably, but furthermore the process needs to have safeguards to permit any failure to be rectified using remote manipulators.

The applicants' pending European Patent Specification numbers 81303221.6 and 83304974.5 describe a process for forming synthetic rock containing high level nuclear waste, the process comprising pressing a cylindrical bellows-like

container in a vertical hydraulic press while maintaining heating with an induction furnace.

The invention is directed to new and useful developments which may be used in such a process or
5 any other similar process for other materials in which the process requires the application of high temperature to a material.

Accordingly, one aspect of the present invention provides an inductive heating process comprising the
10 steps of placing a metal canister (1) within an induction heating coil (10), the metal canister having a cylindrical wall which includes a bellows like structure, characterised by a metallic susceptor (7) of sleeve-like form being located at least partially
15 between the canister (1) to be heated and the induction heating coil (10), and operating the induction heating coil (10) to cause the canister and its contents to be heated.

One important embodiment of the invention is one
20 in which the canister contains radioactive nuclear waste and synthetic rock forming materials in particulate form intimately mixed with one another, and wherein the canister is supported in a hydraulic press and, after the canister and its contents have
25 been heated, the hydraulic press is operated over an extended period of time while heating is maintained in order to cause a hot uniaxial pressing of the canister and the formation of synthetic rock with the nuclear waste immobilised therein.

30 Use of the present invention can permit a controlled and substantially even heating effect to be applied to the bellows-like wall structure of the metal canister so that non-uniform undue thermal stressing at various points in the bellows-like wall
35 structure is avoided. Use of this invention permits a relatively thin wall structure to be employed.

Since heating to temperatures in the range

1150°C to 1200°C are typically required, it is necessary to take account of the relatively low strength of the best available steels at these temperatures. Use of the susceptor sleeve facilitates the application of heat and reduces the risk of any excessive deformation or failure of the bellows-like wall structure during the process as a result of uneven heating.

Furthermore, the susceptor sleeve preferably has sufficient strength to provide a safety shield effect in the event of a bellows rupture and thus may be used to confine the zone of spillage in the event of a failure.

Very advantageously, the process may be operated such that the susceptor sleeve co-operates with a shroud structure whereby, in the event of a bellows failure, any spilt material is contained within the shroud for subsequent clean-up.

Such a shroud structure when closed can be substantially gas tight so as to facilitate the provision of a hot gas purge flow through the shroud from an inlet to an outlet, whereby the exhaust gases can be readily filtered to remove any radioactive gases or particles that might otherwise escape. This arrangement can be especially useful where the bellows-like canister is not completely sealed but has a discharge duct to permit gas from the canister to escape during both pre-heating and compression steps. This gas is from the interstices of the particulate material and might also include volatile components from the material within the canister. Preferably the canister has a filter structure for preventing the discharge of particulate material with any gas escaping from the canister.

In accordance with a second aspect of the invention, there is provided an inductive heating apparatus comprising an induction coil (10) and

characterised in that it has a metallic susceptor (7) of sleeve like form which extends axially and at least partially within the coil (10) and which is arranged to receive therein a cylindrical canister (4) having a bellows-like wall structure and containing particulate matter which is to be heated and compressed, the metal canister (4) being supported in a press, and the susceptor (7) being arranged for heating the canister (4) and its contents by virtue of heat generated in the susceptor sleeve (7) upon operation of the induction coil (10).

This aspect of the invention extends to an apparatus comprising a vertical hydraulic press for receiving a metal canister having a cylindrical wall which includes a bellows-like structure, the press being arranged for uniaxial pressing of the metal canister and its particulate contents, and an induction coil surrounding the portion of the press in which the canister is to be located for the compression step, and the apparatus being characterised by a metallic susceptor sleeve arranged within and extending at least partially through the induction coil for substantially shielding the canister from the induction coil and for causing heating of the canister and its contents by virtue of heat generated in the susceptor sleeve upon operation of the induction coil.

In a preferred embodiment, the induction coil is embedded in a refractory material having a bore therein, the canister to be heated being positioned within a metallic susceptor sleeve located in the bore. Preferably, the susceptor sleeve is positioned on or adjacent the exposed refractory surface of the bore.

It is preferred that the susceptor sleeve is supported on a refractory support, the susceptor sleeve being removable from within the induction coil for

replacement should it be necessary to do so.

Advantageously, the induction furnace has two or more tappings for the inductive heating coil for progressively reducing or increasing the length of the heating zone.

By way of example only, sintering apparatus for immobilising high level radioactive nuclear waste material, incorporating embodiments of the invention will now be described with reference to the accompanying drawings of which:

Figure 1 is an elevation in partial section of a hot press incorporating an embodiment of the present invention during a pre-heating step and before the application of pressure to a canister in the press;

Figure 2 is a view corresponding to Figure 1 but showing the apparatus at the conclusion of the hot uniaxial pressing stage;

Figure 3 is a schematic view of a further embodiment of the invention illustrating the use of a shroud structure with the susceptor sleeve of the apparatus of Figures 1 and 2 and illustrating the loading and unloading configuration of the apparatus;

Figure 4 corresponds to Figure 3 and shows the apparatus during the closing (and opening) configuration; and

Figure 5 is a view corresponding to Figures 3 and 4 and illustrating the hot uniaxial pressing configuration of the apparatus.

In the embodiments described, an intimate mixture of high level radioactive waste and synthetic rock forming particles are loaded into a cylindrical canister having a bellows-like wall structure. In the embodiments shown in Figures 1 and 2 the canister is completely sealed whereas in the embodiment of Figures 3 to 5, the canister could be sealed but also it may have a gas bleed duct. The requirement is that the bellows-like canister and its contents be brought to a

reasonable uniform high temperature (about 1150°C) and then while heating is maintained pressure of up to 21 MPa is applied to cause hot uniaxial pressing. This process causes the contents of the canister to
5 form a synthetic rock safely immobilising the radioactive waste and the canister is compressed without gross radial outward deformation in a reliable manner.

Referring first to Figure 1, there is shown a
10 bellows canister 4 mounted in a vertical hydraulic press comprising a fixed upper refractory pressure pad 2 attached to a press frame element 2' and a lower refractory pressure pad 3 located on top of a water cooled hydraulic ram 5. The ram may be retracted
15 sufficiently below the level of the remainder of the structure to permit loading and unloading of bellows canisters 4 and the ram may be moved upwardly as illustrated in Figures 1 and 2.

The apparatus also includes an induction furnace
20 1 comprising an induction heating coil 10 embedded within a refractory block 6 of cylindrical form and a metal susceptor sleeve 7 arranged with a clearance in the bore of the block 6. The block 6 is fixed within the press by a mounting structure not shown in the
25 drawings and the coils are connected through electrical tappings to a power supply.

The susceptor sleeve 7 extends below the bottom of the refractory block 6 and is supported in its metal support collar 8.

30 In operation of the process the hydraulic ram 5 is loaded with a canister 4 which is moved up to the position shown in Figure 1 for pre-heating. The induction coil is energized through its full length through suitable electrical tappings to provide a
35 substantially uniform heating effect whereby the canister and its contents is brought up to a suitable temperature typically around 1150°C. After

gas such as an inert gas or gas mixture at a pressure slightly above the pressure prevailing in the active cell. This gas becomes hot within the envelope of the
susceptor sleeve 7 and thus tends to act as a blanket
5 filling the zone within the susceptor sleeve and causing a purge flow as indicated by arrows 12 to escape into the active cell during the loading and unloading stages.

The apparatus also comprises a lower shroud 13
10 comprising a cap-like member 14 having an outwardly flanged collar 15 for mating with the flanged collar 8 at the lower end of the susceptor sleeve 7. The lower shroud also includes an annular disc 16 fixed to the
hydraulic ram 5 below the pressure pad 3 and having a
15 cylindrical depending skirt 17 over which an interior rim 18 of the cap is a sliding fit. The cap 14 is suspended by helical extension springs 19 from the periphery of the disc 16.

The drawings also show schematically in dotted
20 line water cooling hoses 20 for the hydraulic ram 5.

As shown in Figure 3, at the loading/unloading station the bellows canister 4 is adapted to be placed by a suitable manipulator 22 onto the head of the ram pressure pad 3. The ram 5 is then raised and, as
25 shown Figure 4, the bellows canister 4 is inserted into the furnace and the flanged collars 15 and 8 approach one another. When these collars contact, a seal is effected and continued upward motion of the ram 5 causes the springs 19 to extend until the top of the bellows canister abuts the top pressure pad 2.
30 After initial pre-heating, high pressure is exerted by ram 5 to compress the bellows canister to the configuration shown in Figure 5 and during this stage imposes maximum extension of the springs 19. The ram
35 5 is then lowered and the compressed bellows canister 4 can be removed.

As illustrated in Figure 5, an option is to

sufficient time has elapsed to cause a sufficiently uniformed temperature to exist, high pressure is applied through the hydraulic ram 5 and over a period of hours densification and the formation of synthetic rock in the canister occurs. As the hydraulic ram 5 and its pressure pad 3 move progressively upwardly, at intervals the tappings of the induction coil can be switched from the lowest tapping A, through to the second tapping B, and finally to the upper tapping C. This causes the heating effect to be limited to the location where it is required and avoids unnecessary and indeed potentially deleterious heating to occur at the hydraulic ram 5. Excessive heating of the ram 5 could cause distortion, failure and indeed damage to seals. It is very desirable to provide an apparatus which can work reliably and with minimal maintenance for a very long period of time.

In the embodiment described above in relation to Figs. 1 and 2, the synthetic rock, which is generally known as SYNROC, is formed by sintering an intimate mixture of high level radioactive nuclear waste material and synthetic rock-forming material which form three titanate minerals, namely, Hollandite $\text{BaAl}_2\text{Ti}_6\text{O}_{16}$, Zirconolite $\text{CaZrTi}_2\text{O}_7$ and Perovskite CaTiO_3 , plus rutile titanium oxide TiO_2 and a small amount of metal alloy. However, any other suitable rock-forming material may be used.

Referring now to Figures 3 to 5, like parts have been given like reference numerals and only the additional features over and above Figures 1 and 2 will be described in detail.

The apparatus in this embodiment has the susceptor sleeve 7 formed as a first shroud element which, as shown schematically, is fixed in a substantial gas seal connection with the top frame member 2' and in its upper region the susceptor sleeve has an inlet pipe 11 for admitting a flow of suitable

configure the flanged collars 15 and 8 to define an exhaust duct 23 which can be connected to a suitable extraction and gas filtration system. Thus, if a bleed duct is provided in the bellows canister 4, gases (including any volatile radioactive gases) can be collected and reprocessed.

Use of the susceptor sleeve provides convenient and effective heating of the bellows canister but furthermore the shroud arrangement shown in Figures 3 to 5 can provide enhanced safety and, in the unlikely event of any failure of a bellows canister, there is a surrounding structure which can collect spilt particulate material which is capable of being cleaned up from the confined zone in question and the apparatus can continue to operate.

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CLAIMS

1. An inductive heating process comprising the steps of placing a metal canister (1) within an induction heating coil (10), the metal canister having
5 a cylindrical wall which includes a bellows-like structure, characterised by a metallic susceptor (7) of sleeve-like form being located at least partially between the canister (1) to be heated and the
10 induction heating coil (10), and operating the induction heating coil (10) to cause the canister and its contents to be heated.

2. An inductive heating process as claimed in claim 1, characterised in that the induction heating coil (10) has a plurality of tappings (A,B,C), and the
15 method includes switching power supply between the tappings (A,B,C) to vary the length of the heating zone.

3. An inductive heating process as claimed in claim 1 or claim 2, characterised in that it includes
20 the step of supporting the canister (1) on an hydraulic press (5) within the inductive heating coil (10) and uniaxially pressing the canister (4) while its contents are heated.

4. An inductive heating process as claimed in claim 1, characterised in that the canister (4)
25 contains radioactive nuclear waste and synthetic rock forming materials in particulate form intimately mixed with one another and the heating and uniaxial pressing of the canister and its contents results in the
30 formation of synthetic rock with nuclear waste immobilised therein.

5. An inductive heating process according to any one of the preceding claims, characterised in that the bellows like structure extends substantially over
35 the full length of the cylindrical wall which is relatively thin material, and the susceptor sleeve (7) acts as a shroud extending around the cylindrical wall

for substantially all of its length.

5 6. An inductive heating process according to claim 1, characterised in that the induction coil (10) is operated for an extended period to bring the contents of the canister (1) to a temperature of substantially 1150°C.

10 7. An inductive heating apparatus comprising an induction coil (10) and characterised in that it has a metallic susceptor (7) of sleeve like form which extends axially and at least partially within the coil (10) and which is arranged to receive therein a cylindrical canister (4) having a bellows-like wall structure and containing particulate matter which is to be heated and compressed, the metal canister (4) being supported in a press, and the susceptor (7) being arranged for heating the canister (4) and its contents by virtue of heat generated in the susceptor sleeve (7) upon operation of the induction coil (10).

15 8. An inductive heating apparatus according to claim 7, characterised in that the induction coil (10) is embedded in a refractory material (6) having a bore therein, the canister (4) to be heated being positioned within the susceptor sleeve (7) located in the bore.

20 9. An inductive heating apparatus according to claim 7 or 8, characterised in that the susceptor sleeve (7) is supported on a refractory support (3) and is removable from within the induction coil (10) for replacement when required.

25 10. An inductive heating apparatus according to any one of claims 7 to 9, characterised in that the induction coil (10) has two or more tappings (A,B,C) for progressively reducing or increasing the length of the heating zone.

30 11. An inductive heating apparatus according to any one of claims 7 to 9, characterised in that the bellows like structure extends substantially over the

full length of the cylindrical wall which is of a relatively thin material, and the susceptor sleeve (7) acts a shroud extending around the cylindrical wall for substantially all of its length.

5 12. An inductive heating apparatus according to claim 11, characterised in that the susceptor sleeve (7) forms part of a substantially gas tight shroud within which the cylindrical canister (4) is isolatable from the outside environment.

10 13. An inductive heating apparatus according to claim 12, characterised in that the shroud is provided with an inlet (not shown) and outlet (23) to facilitate the provision of hot gas purge flow and a filter (not shown) is provided whereby exhaust gases
15 are filtered to remove radioactive gases or particles.

 14. An inductive heating apparatus according to any one of claims 11 to 13, characterised in that the cylindrical canister (4) is adapted to be placed by a manipulator (22) onto a pressure pad (3) located on
20 top of an hydraulic ram (5), the susceptor sleeve (7) having a flanged collar (8) at its lower end which is adapted to mate with a flanged collar (15) of a lower shroud (13) fixed to the hydraulic ram (5) when the hydraulic ram (5) is raised, in use the flanged
25 collars (8,15) contacting to form a seal during the upward motion of the hydraulic ram (5) and after contact is effected the hydraulic ram (5) proceeding upward against the restraining force of at least one compression spring (24) connected between the
30 hydraulic ram (5) and the lower shroud (13) to effect a hot pressing of the canister (4).

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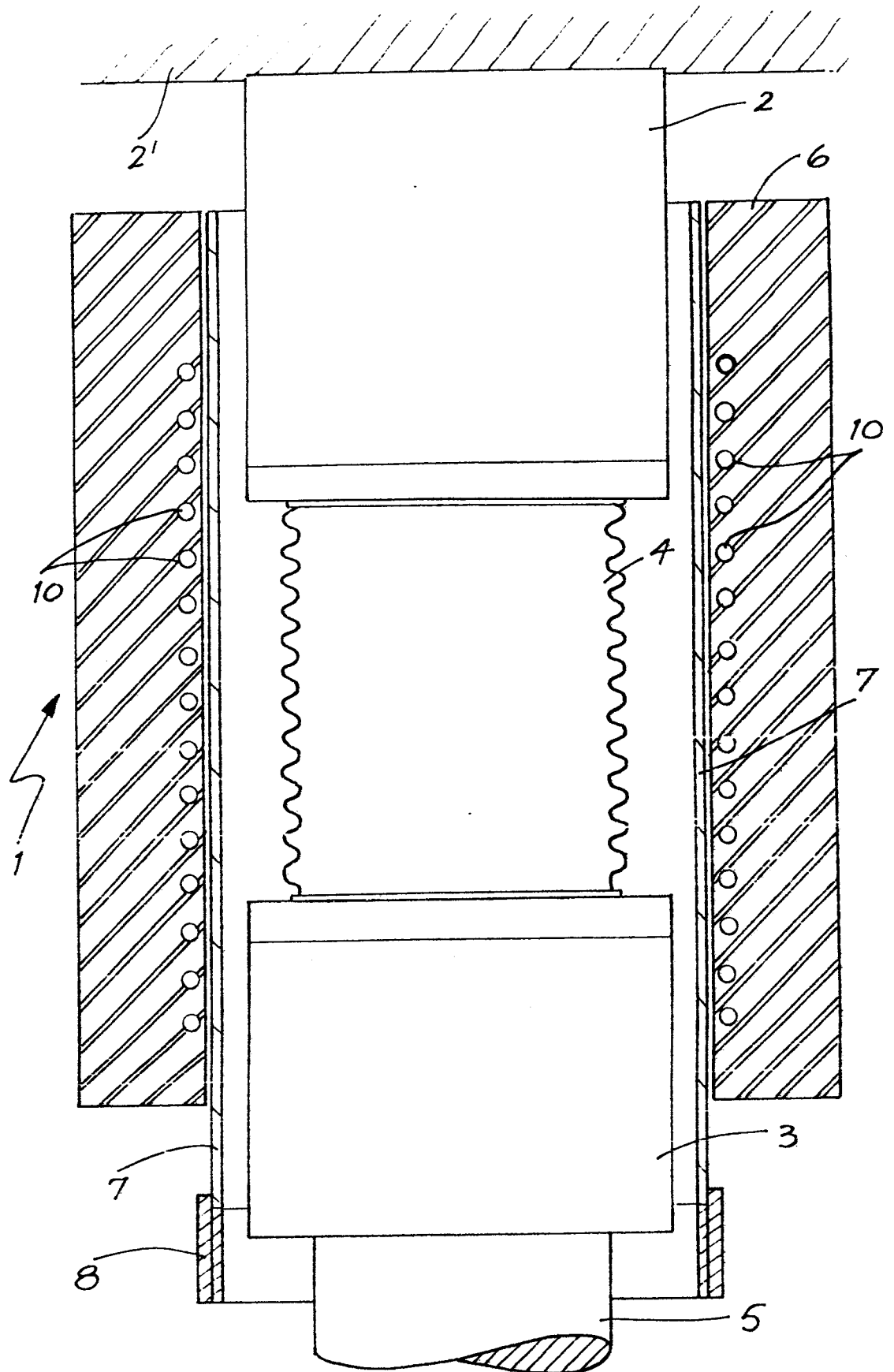


FIG. 1

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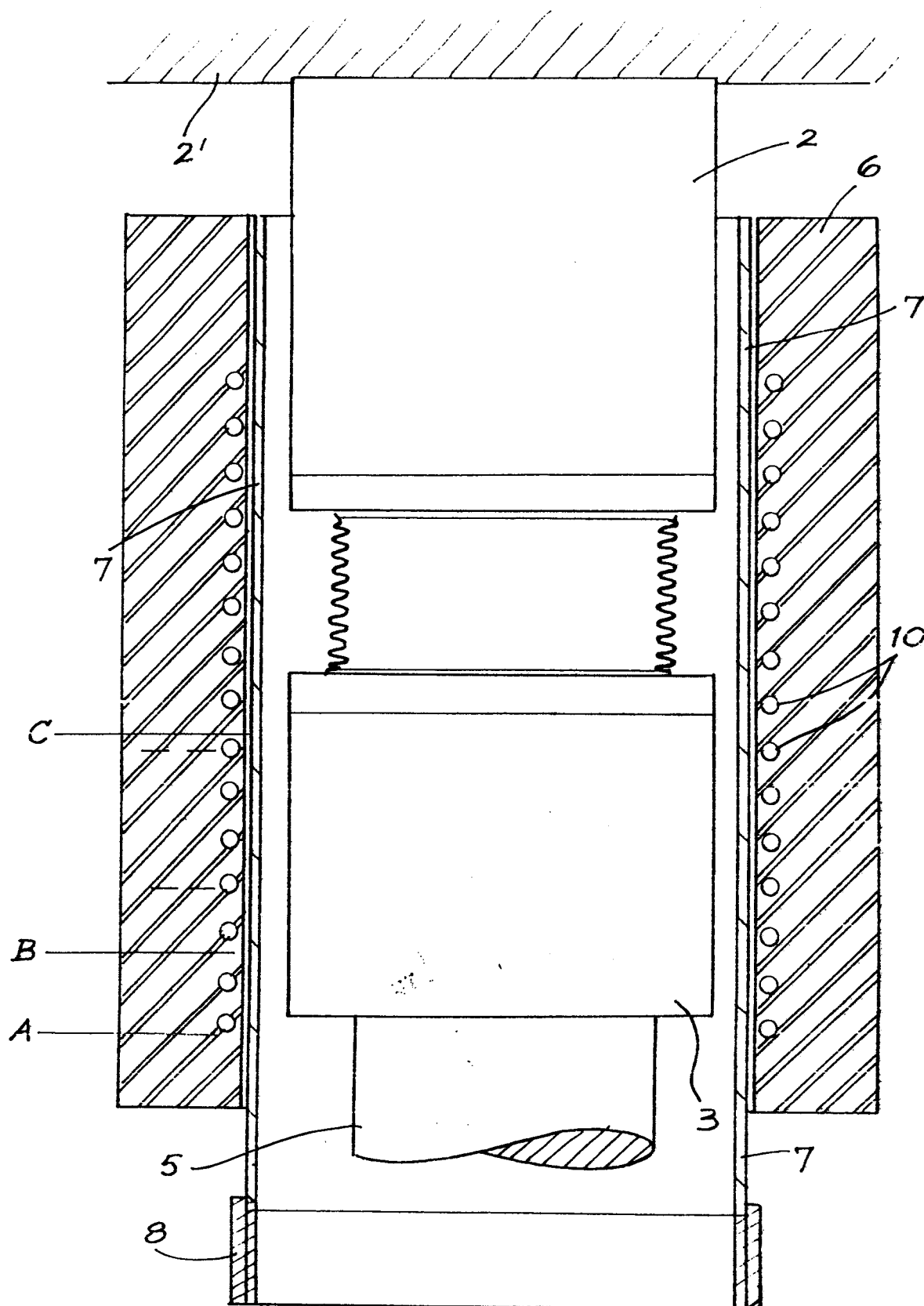


FIG. 2

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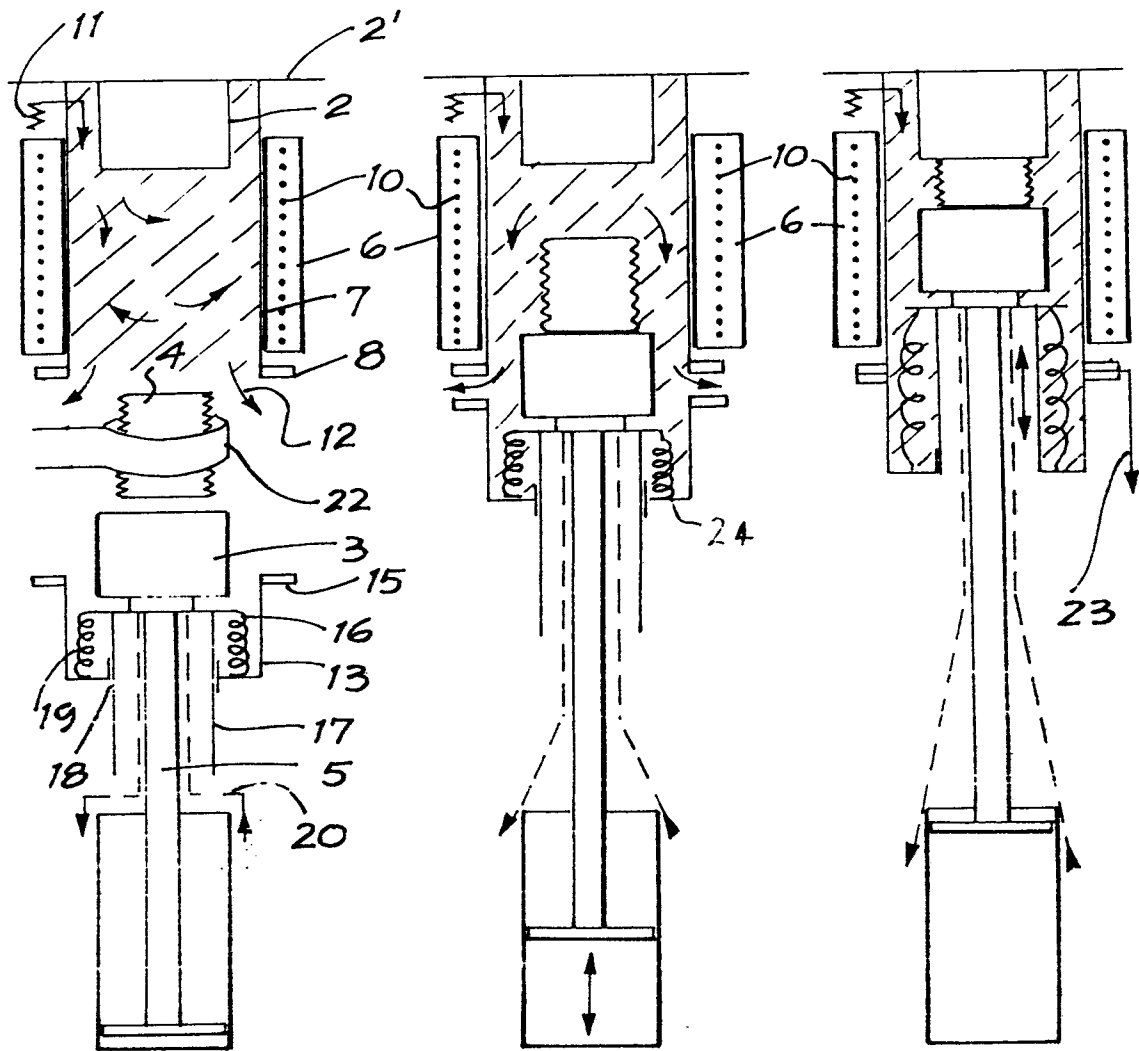


FIG. 3

FIG. 4

FIG. 5