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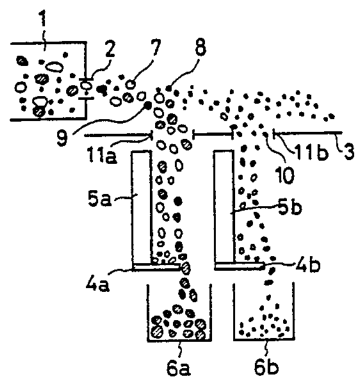
(54) Purification apparatus for superconductor fine particles.

(57) A purification apparatus for superconductor fine particles is provided which comprises a means for forming a flow of powder containing the superconductor fine particles, and a means for applying a magnetic field to the flow of the powder.

FIG.1



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Purification apparatus for superconductor fine particles

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an apparatus for classifying and purifying fine particles to obtain only the desired superconductor particles from among mixtures of fine particles of different particle diameters comprised of superconductors, normal conductors, insulators or the like having different critical temperatures, critical magnetic fields, etc.

Related Background Art

Recent years, it has been discovered that the sintering of ceramic materials with certain definite composition can give a sinter that exhibits superconductivity (or superconducting) at 77 K or more, or, in some instances, near room temperature. However, the crystal structure and the phase of these superconductors have not been sufficiently elucidated yet, and usually there coexist non-superconducting crystal phases.

In the instance where the non-superconducting crystal phases coexist, it is very difficult to separate them from the superconducting crystal phases. Moreover, no technique has been established that will form only the superconducting crystalline material by controlling heat-treatment conditions. In recently available ceramic superconductors, there also often coexist a plurality of superconducting crystal phases different in the critical temperature or critical magnetic field, and no method has been established to separate only the superconducting crystal phases having any desired critical temperature range and critical magnetic field range from among them.

In addition, the sinter having superconductivity usually comprises a mass or aggregate of fine crystals, and its superconductivity characteristics depend greatly on the state of crystal grain boundaries so that its crystal grain boundaries must be made uniform to obtain a sinter having stable characteristics.

A proposal has ever been made to obtain a superconducting sinter having uniform crystal grain boundaries by re-sintering superconductor fine particles having uniform particle diameter. However, any suitable method for classifying such superconductor fine particles having uniform particle diameters has not been discovered, and nothing has been available except for the method in which the generally practiced particle classification methods as described in Funtai Kogaku Handobukku (Particle Technology Handbook) (edited by Koichi Iitani, Asakura Publishing Co.) are applied in the superconductor fine particles.

Known as the conventional generally practiced particle classification methods are a screening method in which shieves having different openings are piled up in the order from those having larger opening diameter to carry out classification, a sedimentation method in which the terminal settling velocity of the particles settling in a fluid is utilized to carry out the classification, and the similar methods.

For example, however, in the screening method, it is impossible to prepare those having a screen opening of several micrometers or less, thus enabling no classification for particles of very small diameter. Moreover, it is often practiced to apply pressure loading to the fine particles to force them to pass through the screen openings, and in such an instance the problems occur such that the classification cannot be carried out in vacuo as a means for classification with higher precision. Also, in the sedimentation method, where the settling velocity depends not only on the diameter of particles but also the specific gravity thereof, no strict classification can be carried out. In instances where a liquid phase sedimentation method is used, it requires much labor to separate fine particles from liquid, and also the settling velocity is so low in general as to take much time for the classification. This method also involves the problems such that it cannot naturally be carried out in vacuo.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an apparatus for purifying superconductor fine particles that is capable of separating and purifying only the superconductor fine particles from among powder to be purified containing superconductor fine particles.

Another object of the present invention is to provide an apparatus for purifying superconductor fine particles that is capable of classifying and purifying only the superconductor fine particles having desired characteristics from among powder to be purified in which a plurality of superconductor fine particles having differences in the characteristics such as the particle diameter, critical temperature and critical magnetic field coexist.

The above objects can be achieved by the invention described below.

According to an aspect of the present invention, there is provided a purification apparatus for superconductor fine particles, comprising a means for forming a flow of powder containing the superconductor fine particles, and a means for applying a magnetic field to the flow of said powder.

According to another aspect of the present invention, there is provided a purification apparatus for superconductor fine particles, comprising a means for blowing powder containing the superconductor fine particles in a horizontal direction by use of a carrier gas to form a flow of said powder, a partition means horizontally provided, having a plurality of slits at different distances from said blowing means, and a means provided beneath said respective slits, for applying a magnetic field to the flow of said powder.

According to a still another aspect of the present invention, there is provided a purification apparatus for superconductor fine particles, comprising a means for floating powder containing the superconductor fine particles by use of a carrier gas to form a flow of said powder, a partition means vertically provided, having a plurality of slits at different heights from said floating means, and a means provided at the positions facing said respective slits for applying a magnetic field to the flow of said powder.

According to a further aspect of the present invention, there is provided a purification apparatus for superconductor fine particles, comprising a means for allowing powder containing the superconductor fine particles to fall, one or plural partition means horizontally provided in a falling path of said powder and provided with a slit at a certain part thereof, and a means for alternately applying with an appropriate period, magnetic fields having the magnetic inclinations in the two directions facing each other in the plane rectangular to the falling direction of said powder.

Still another embodiments of the present invention will become apparent from the following descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1, 4, 7, 12, 13, 14, 15, 16, 17, 20, 21, 22, 23, 26 and 27 each illustrate schematic constitution of an example for the purification apparatus for superconductor fine particles according to the present invention;

Fig. 2 is a graph showing an X-ray diffraction pattern of a superconductor containing impurities;

Fig. 3 is a graph showing an X-ray diffraction pattern of a purified superconductor;

Fig. 5 is a graph showing temperature dependency of the electric resistance of a superconductor;

Fig. 6 illustrates constitution of another example of a magnet and a partition panel part of the apparatus of the present invention;

Fig. 8 illustrates constitution of another example of a powder-feeding means in the apparatus of the present invention;

Figs. 9, 10 and 19 each illustrate constitution of another example of a means for applying magnetic field in the apparatus of the present invention;

Fig. 11 illustrates constitution of another example of a powder-collecting means in the apparatus of the present invention;

Fig. 18 illustrates constitution of another example of a partition means in the apparatus of the present invention;

Figs 24 and 25 respectively illustrate motion of super conductive fine particles in the power passage.

Figs. 28 and 29 respectively illustrate a block diagram and a time chart of a controlling system in the apparatus of the present invention;

Figs. 30 and 31 respectively illustrate a block diagram and a time chart of another controlling system in the apparatus of the present invention; and

Figs. 32 and 33 respectively illustrate a block diagram and a time chart of still another controlling system in the apparatus of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is based on the utilization of the Meissner effect which is attributable to magnetic properties inherent in superconductors.

The Meissner effect is meant to be the effect that the superconductor fine particles become perfectly diamagnetic when a magnetic field is applied to the fine particles at the temperature at which the superconductor fine particles exhibit superconductivity. More specifically, at the abovementioned temperature, application of a magnetic field by means of a magnet to the powder containing superconductor fine particles produces repulsion to the magnet owing to the Meissner effect with respect to those having a particle diameter of about 0.01 μm or more. On the other hand, no repulsion is produced since the Meissner effect is not brought about with respect to those having a particle diameter less than that and the fine particles of normal conductors or insulators.

According to this principle it is possible to separate and purify with a high precision only the superconductor fine particles from among the powder mixed with normal conductors or insulators.

For example, a flow of powder to be purified, mixed with normal conductors, insulators, etc. is formed, and a magnetic field with a strength by which the superconductivity can be effectively utilized is applied to the powder to be purified, under the temperature of the degree at which the superconductor fine particles in the powder to be purified exhibit the superconductivity, so that the repulsion produced as a result owing to the Meissner effect causes positional separation of the flow of the superconductor fine particles in the powder to be purified. from the flow of the particles other than the same. thus effecting the purification.

The locus of the flow of a superconductor-containing fine particle that shifts according to Meissner effect depends on the proportion of the superconductor contained in the fine particle. This is because the force by which the superconductor fine particle is moved is produced by Meissner effect. Namely, even if the superconductors have the same particle diameters, the repulsion becomes small when the proportion of the superconductors is small. In other words, the low purity thereof results in a small change in the locus of the flow of particles.

For example, in instances where a magnetic field having the distribution such that the magnetic flux density becomes smaller from a lower part toward an upper part is applied, the particles having a small proportion of superconductors may be given small Meissner effect, resulting in a small height of floating. On the contrary, the particles having a large proportion of superconductors can float higher. The floating height depends on the balance between the weight of particles and the greatness of the Meissner effect.

By selectively collecting portions at a certain height of the thus floated superconductor fine particles, it is possible to take out only the superconductor fine particles having desired purity, i.e., desired values for the proportion of superconductors.

Here may be used any means for forming the flow of powder in the apparatus of the present invention, including, for example, a means for directly blowing a carrier gas to the powder, and a means for naturally allowing the powder to fall in a fluid such as helium gas and liquid nitrogen.

The carrier gas used in the apparatus of the present invention may include, for example, helium gas. Also preferred is a gas that may not liquified even at a temperature sufficiently lower than the critical temperature of the superconductors.

The means for applying a magnetic field to the flow of the above powder include, for example, a permanent magnet and an electromagnet, which magnets may have any shape so long as there can be applied a magnetic field by which the superconductor fine particles can deflect their flying path. Accordingly, it may include plate-shaped, column-shaped or concave-shaped magnets, or those arranged with a plurality of these magnets. In instances where the flow of powder is formed by gravitational fall, the magnets may be shaped or positioned such that a magnetic field that deflects their falling orbital path can be applied.

In instances where a desired particle diameter or particle size distribution is to be obtained, various types of classifying means can also be used in combination according to the range of the desired particle diameter. However, since the Meissner effect for the effective purification can be obtained usually in respect of the superconductor fine particles having a particle diameter of 0.01 μm or more, the fine particles having a particle diameter of 0.01 μm or more and the fine particles having a less particle diameter can be readily classified, which have ever been classified not easily by conventional classification methods.

It is also possible to carry out classification of particles of the particle diameters other than that. More specifically, if powder having uniform specific gravity are treated in the apparatus of the present invention, the difference in flying distance or floating height of the particles owing to the carrier gas or the difference in terminal settling velocity, for example, depends on their particle diameter. Therefore, they may be collected selectively by zones, so that it becomes also possible to classify the superconductor fine particles included in a desired particle diameter range from among the superconductor fine particles having a particle diameter of 0.01 μm or more.

Superconductor fine particles having the same weight and different specific gravity, which have differences in their settling velocity, can also be separated according to the specific gravity by sedimentation in a liquid.

To carry out the powder classification with higher precision in the apparatus of the present invention, a partition means having one or plural slit(s) may preferably be provided additionally in the same apparatus.

In the apparatus of the present invention, superconductor fine particles having a desired critical temperature range or critical magnetic field range can also be obtained from among the powder in which a plurality of superconductor fine particles each different in the critical temperature (superconductive transition temperature) or critical magnetic field (superconductive transition magnetic field).

For example, in instances where the superconductor fine particles having a desired critical temperature range are to be obtained in the above purification apparatus, the above purification apparatus may be operated while appropriately selecting the temperatures of a powder storing vessel, a carrier gas, a powder flow path, etc. according to the desired critical temperature range.

Also in instances where the superconductor fine particles having a desired critical magnetic field range are to be obtained, the above purification apparatus may be operated while appropriately selecting the magnetic field applied to the powder to be purified, according to the desired critical magnetic field range.

In the apparatus of the present invention, it is further possible to obtain only the powder having a desired specific gravity, not to speak of the above purification and classification of the superconductor fine particles.

More specifically, if the powder have a uniform particle diameter, the difference in flying distance or floating height of the powder owing to the carrier gas, the difference in terminal settling velocity, and the degree of changes in the flow direction of superconductor fine particles owing to the application of a magnetic field depend on their specific gravity. Therefore, they may be selectively collected by zones, so that it becomes also possible to separate only the superconductor fine particles having a desired specific gravity.

The above purification apparatus for superconductor fine particles of the present invention will be described below by giving several preferred embodiments.

A first embodiment of the apparatus of the present invention is characterized by having a means for horizontally ejecting powder containing superconductor fine particles to form a flow of the powder, a partition means horizontally provided, having one or plural slit(s) at the position with a specified distance from an ejecting outlet, and a means provided beneath said respective slit(s), for applying a magnetic field in the vertical direction to the flow of said powder

According to the present embodiment, the powder to be purified containing superconductor fine particles maintained to a temperature at which their superconductivity can be sufficiently exhibited are horizontally ejected from a nozzle or the like together with a carrier gas, whereupon the powder particles larger in particle diameter and heavier among the powder to be purified begin to fall at a position near to the above nozzle, and the particles smaller in particle diameter and lighter among them begin to fall at a position far from the above nozzle, so that the groups of the falling powder particles form the particle size distribution in the horizontal direction. Classification can be carried out by selectively separating them by the partition means horizontally provided, having one or plural slit(s) at the position with an appropriate distance from the nozzle. Here, the various conditions such as the kind of the above-mentioned carrier gas, the flow rate, the flow quantity, the slit width may be appropriately selected according to the desired particle diameter range.

Only the superconductor fine particles can also be separated by providing a plate-shaped magnet beneath the above slit, having a width and shape sufficient for making purification under the above temperature, in a vertical state or a state slightly inclined than vertical, applying the magnetic field previously mentioned to the powder to be purified that have been classified and passed the slit as described above to let the powder fall in the vicinity of the plate-shaped magnet, under the temperature previously mentioned, to change the falling locus of the superconductor fine particles in the powder to be purified, and collecting them by use of a collecting means each provided at the falling position of the superconductor fine particles and at the falling position of the other fine particles. Thus, the apparatus of the present embodiment can carry out the purification and classification simultaneously.

In the above apparatus, the means for applying a magnetic field may be any of a permanent magnet and an electromagnet, without any particular limitation also in its shape. However, when, for example, a sheet of the above plate-like magnet is constituted of a plurality of electromagnets to give a means for applying magnetic fields that can repeat on-off in succession in the powder-falling direction and with a specified period, the falling locus of the superconductor fine particles can be changed with good efficiency to bring about the advantages such that the purification process can be simplified. To attempt to further simplify this purification process, a plate of non-magnetic material may be provided on the surface of the magnet and may be vibrated (as exemplified by an ultrasonic vibration plate), thus making it possible to smooth the flow of powder.

A second embodiment of the apparatus of the present invention is characterized by a means for floating the powder containing superconductor fine particles, in a carrier-gas flow path, a means for applying a magnetic field that may move the superconductor fine particles in the vertical direction to the carrier gas flow formed by the first-mentioned means, and a partition means vertically provided, having one or plural slit(s) at the position facing said magnetic field applying means.

According to the present embodiment, the powder containing superconductor fine particles are floated by the floating means using a carrier gas, so that, if the powder have a uniform particle diameter, the powder having a smaller specific gravity float higher and the powder having a larger specific gravity float only up to a lower position. Accordingly, the purification and separation can be simultaneously carried out by applying a magnetic field to the floating powder, separating selectively to the outside of the carrier gas flow only the superconductor fine particles from among the powder by the repulsion owing to the Meissner effect, through means of a partition panel provided with one or plural slit(s) and according to the height of the slit(s), and collecting the particles using a collecting means provided at the outside of the carrier gas flow.

Here, the floating means may be any means so long as it is a means capable of blowing the powder by use of the carrier gas, and may include, for example, a means for directly blowing the carrier gas to the powder, a means for putting the powder in a container and introducing the carrier gas in that container, a means for allowing the powder to fall from a container and blowing the carrier gas to that falling powder, and a means for making suction from the direction of the magnetic field applying means.

The magnetic field applying means may also be any of a permanent magnet and an electromagnet also in the present embodiment, without any particular limitation in its shape. When the magnet comprises, for example, an electromagnet to give a means for applying a magnetic field that can repeat on-off synchronously with the powder floating means and with a specified period, the classification can be carried out more precisely.

In this instance, the respective sections can be synchronized by electrical control with use of a controlling system as shown in Fig. 28. In Fig. 28, the numeral 101 denotes a synchronizing computer; 102, a shutter to open and close an inlet (Position A exemplified in Fig. 14 and Fig. 15 of the apparatus of an Example described later) for injecting a carrier gas for blowing up the powder; 103, a shutter fitted to an inlet (Position B exemplified in Fig. 14 and Fig. 15 of the apparatus of an Example described later) for introducing the superconductor fine particles discharged from the carrier-gas flow path by the repulsion owing to the Meissner effect from among the given floated fine particles; 104, an electric source for the magnet; 105, the electromagnet (which is provided at Position M exemplified in Fig. 14 and Fig. 15 of the apparatus of an Example described later) that produces the magnetic field necessary for purifying the superconductor fine particles owing to the Meissner effect.

The above shutters and magnet are driven by being synchronized as shown in Fig. 29. In Fig. 29, the abscissas indicate the time, and the ordinates indicate the driving pulse in respect of the actuation of the shutters 102 and 103, and the electric current to be flowed in respect of the magnet 105. The shutters 102 and 103 turn "open" by the rise of the pulse and turn "close" by the decay of the pulse.

First, the shutter 102 turns "open" to bring the powder particles to float in the carrier-gas flow path together with the carrier gas. The shutter 103 turns "open" when the time t_1 lapses and the floating positions have been settled for each particle diameter, and at the same time the magnet turns "on". Thereafter, during the time t_2, the superconductor fine particles are discharged from the carrier-gas flow path through the introducing inlet. Thereafter the shutters 102 and 103 turn "close" and the magnet turns "off". After the time t_3 lapsed and the non-superconductor particles having remained in the carrier-gas flow path have fallen, the shutter 102 again turns "open", thus repeating the above operations.

In an instance where a means for collecting non-superconductors is provided (exemplified in Fig. 15 of the apparatus of an Example described later), equipped is a shutter 106 (at Position C in Fig. 15). A block diagram and a time chart in a controlling system for that instance are shown in Fig. 30 and Fig. 31, respectively. Operations are the same as described above. The shutter 106 turns "close" when the shutter 102 is "open", and the shutter 106 turns "open" when the shutter 102 is "close".

In the above apparatus, the various conditions such as the type of the above carrier gas, the flow rate, the flow quantity, the width of the slit may be suitably selected according to the desired particle diameter range.

A third embodiment of the apparatus of the present invention is a purification-classification apparatus for superconductor fine particles, comprising a container filled with a fluid such as helium gas or liquid nitrogen, a means for allowing the powder containing superconductor fine particles to fall in said container, a means for maintaining said fluid and said powder to a temperature not higher than the superconductive transition temperature of the desired superconductors, a partition means horizontally provided in singularity or in plurality in a path for allowing said powder to fall and provided with a slit at a certain part, and a means for alternately applying, with an appropriate period, magnetic fields having inclinations in the two directions facing each other in the plane rectangular to the falling direction of said powder, where said slit is suitablly disposed, and made to be opened or closed or moved so that only the superconductor fine particles having a particular settling velocity may be passed through the slit to be selectively taken out only the superconductor fine particles having the desired particle diameter.

According to the present embodiment, the powder to be purified, kept at a temperature not higher than the critical temperature Tc are allowed to fall in a fluid such as helium gas or liquid nitrogen, and, in a zone at which the fine particles having the desired particle diameter have reached the terminal settling velocity, the magnetic fields having the inclinations opposite directed each other are made to be alternately applied with an appropriate period to the fine powder that are settling in the above zone, so that only the fine powder existing in the superconducting state are made to generate a settling orbital path in a zigzag fashion by the repulsion caused by the Meissner effect. At the same time, an suitable number of partition panels are disposed in a suitable number in the above zone, and slits are provided at certain parts of the partition panels, which slits are suitably arranged or the slits are made open or close with an appropriate period so that only the superconductor fine particles having a particular settling velocity may be passed through them, thus carrying out the purification and classification simultaneously.

In the above apparatus, the magnetic field applying means may be any of a permanent magnet and an electromagnet, without any particular limitation also in its shape.

These opening and closing of the nozzle and the shutters for slits and the on-off of the electromagnets are electrically controlled and synchronized, for example, in the following manner.

Fig. 32 illustrates a block diagram of a controlling system (The illustrated example premises the apparatus exemplified in Fig. 17 and Fig. 18 described later). The numeral 107 denotes a controlling computer; 108, a shutter to open or close a nozzle (Position N in Fig. 17); 109, an electric source for the electromagnet; 110, an electromagnet to apply a first magnetic field (Position M_1 in Fig. 17); and 111, an electromagnet to apply a second magnetic field (Position M_2 in Fig. 17). In an instance where two paths exist for the fall of powder (the apparatus exemplified in Fig. 18), there are added a shutter 112 to open or close the slit belonging to a first path (Positions S_1, S_1' and S_1'') and a shutter 113 to open or close the slit belonging to a second path (Postions S_2, S_2' and S_2''.

The above shutters and electromagnets are driven, and synchronized as a whole, for example, according to the time chart as shown in Fig. 33. The abscissas indicate the time.

The driving pulse is indicated in respect of each shutter, which turns "open" by the rise of the pulse and turns "close" by the decay of the pulse. Electric currents are indicated in respect of the electromagnets.

The period T_o for driving the shutters and electromagnets has the following relationship with the terminal settling velocity V_f of the desired superconductor fine particles and the distance Q of the partition panels:

$$T_o = \frac{2\,\Omega}{V_f}$$

Provided that this relationship can be precisely established when the falling locus of the superconductor fine particles is not so much deviated from the straight line, thus actually somewhat requiring experiential correction.

The deviation T_d in the timing between the opening and closing of the shutter of the nozzle and the driving of other parts corresponds to the time by which the powder to be purified are released from the nozzle to reach the zone at which the purification is effected, or the time remaining when the time of integer times of T_o has been deducted from that time, and can be experientially found so that the quantity of the superconductor fine particles collected after purification may become maximum.

A fourth embodiment of the present invention is characterized by having a powder passage provided with a means comprising a non-magnetic material serving as a wall material, for smoothing the flow of powder by vibrating this wall material, a means for forming in said passage a flow of the powder containing superconductor fine particles, and a means for applying a magnetic field in the direction vertical to the flow of said powder.

According to the present embodiment, provided as the magnetic field applying means are, for example, magnets provided in a multi-stage fashion along the vibrating passage, in the order of from a magnet applying a weaker magnetic field to a magnet applying a stronger magnetic field. Thus the powder flowing in the passage and containing the superconductor fine particles are first applied with a weak magnetic field by means of the magnet applying a weak magnetic field. Thereby the superconductor fine particles in that flow of powder and having a larger particle diameter undergo a great deflection in their flying path. However, the superconductor fine particles having a smaller particle diameter are not deflected at all in their flying path or only a little deflected. This is because if the depth of penetration of the particles into the magnetic field is the same, the superconductor fine particles having a larger particle diameter suffer a larger repulsion owing to the Meissner effect. The superconductor fine particles that were not deflected or only a little deflected at that time are deflected in an applied magnetic field by a strong magnet provided at a downstream part of the passage, and thus can be classified and purified.

Deflecting in this manner the superconductor fine particles light in weight and small in particle diameter enables the classification and purification of the superconductor fine particles having a desired particle diameter range among the superconductor fine particles having a particle diameter of 0.2 μm or less.

In the above apparatus, the powder flow forming means may be any means so long as a flow of powder can be formed in the vibrating passage, and includes, for example, a means for directly blowing a carrier gas to the powder, and a means for allowing the powder to fall by gravity by making the vibrating passage upright or inclined. In the instance where the powder are allowed to fall by gravity, the vibrating passage may be filled with a suitable liquid to allow the powder to settle in the liquid.

There also is no particular limitation in the powder passage so long as it comprises a non-magnetic material that can be vibrated and serve as a wall material. The non-magnetic material may include, for example, glass, ceramics and aluminum. It can have a shape of a pipe, or various shapes such as an internally hollow V-shape, a box and a flat plate. The powder passage may also not necessarily be a hermetically closed passage, but may preferably be a hermetically closed passage when taking account of the purification and classification to be precisely carried out without being adversely affected by the outside wind, air flow or the like. As a preferred embodiment thereof, it may also include a vibrating passage equipped with collecting ducts on both sides, having a shape of an internally hollow V-shaped flat plate, and so provided that it is inclined with an inclination angle of 60° to 70°.

A vibration-generating means may be connected to such a passage to constitute the vibrating passage of the present embodiment. The vibration may not necessarily be required to be exerted to the whole passage, and may be exerted to the passage corresponding to the part at which the magnetic field is applied by the magnetic field applying means.

There is no particular limitation in the frequency of the vibration, but in general it may range approximately from 1 Hz to 20 kHz, and the vibration-generating means may be any of those that can give vibration to the passage, including a mechanical means employing a motor and a cam, or an ultrasonic vibrator employing a piezoelectric material (such as ZnO, AlN and PZT).

As described previously, the ultrasonic vibration plate that may be provided on the surface of the magnet in the first embodiment of the present invention is like the one as in the present embodiment.

As having described above, employment of the apparatus of the present invention makes it possible to simultaneously and readily carry out the purification, classification and separation of superconductor fine particles having the desired purity, particle diameter, critical temperature range and critical magnetic field range from among the powder to be purified, and the apparatus used in the process can be of small size and simple, with the course of the process capable of being visually observed. Moreover, the process can be carried out under a low pressure, and yet the above process is proceeded while forming the flow of the powder to be purified. Accordingly, a large quantity of powder can be purified in a high rate and high precision.

The apparatus of the present invention is also very useful in enhancing the purity of a superconductive sinter that contains impurities. More specifically, since the present invention can carry out the purification and classification in the order of a μm unit, the sinter can be very finely grounded and purified to the extent such that a superconductivity part and an impurity part may not coexist in its one fine particle. As a result, there can be obtained superconductive powder with high purity.

In the apparatus of the present invention, it is also further possible to obtain superconductor fine particles having uniform specific gravity, and thus possible to obtain superconductors with less intermixing of superconductors having different composition.

EXAMPLES

The present invention will be described below in greater detail by giving Examples and also with reference to the drawings.

Example 1

Fig. 1 illustrates an example of the apparatus of the present invention. The numeral 9 indicates superconductor fine particles having relatively large particle diameter; 10, superconductor fine particles having relatively small particle diameter of about 0.1 μm or less; and 7 and 8, superconductor fine particles having relatively large particle diameter and non-superconductor fine particles having relatively small particle diameter. In the present Example, the superconductive material to be classified and purified is $YBa_2Cu_3O_{7-\delta}$ ($0 \leq \delta \leq 0.5$). Y_2O_3, $BaCO_3$ and CuO were mixed in a ratio of Y : Ba : Cu = 1 : 2 : 3, and the mixture was treated by heating for 2 hours at 950°C in an atmosphere. The X-ray diffraction pattern obtained here is shown in Fig. 2. In Fig. 2, the peaks in the intended superconductor $YBa_2Cu_3O_{7-\delta}$ are indicated by "S". As will be clear from this figure, this sample contains a non-superconductor.

The mixture was ground in a mortar, and thereafter the settling velocity was measured in toluene to reveal that the settling velocity differs depending on the particle diameter, but the particles having the same particle diameter as a whole settled substantially in the same velocity. Accordingly, the superconductors and the impurity non-superconductors are considered to have substantially the same specific gravity.

First, powder containing superconductor fine particles and a carrier gas (as exemplified by He gas) having a temperature not higher than the critical emperature are mixed to make a mixed powder 1. This is ejected from an opening 2. The ejecting rate is selected depending on the specific gravity of powder or the particle diameter range as desired. The position of slits 11a and 11b of a partition panel 3 is made movable, and the width of the slits is selected by the particle diameter range as desired. Fine particles having a larger particle diameter are transported near the opening 2, and smaller fine particles having a smaller particle diameter, up to a distant place by the carrier gas. The powder having uniform particle diameter pass the slits and then fall by gravity, but at this time, because of a plate-shaped permanent magnet, the superconductor fine particles 9 having relatively large particle diameter become apart from the surface of the magnet to pass over a partition panel 4a to fall. However, it may not occur that normal conductors, i.e., the fine particles 7 of non-superconductor (including conductors, semiconductors and insulators) pass over the partition panel 4a. The superconductor fine particles passed over the partition panel 4a are collected by a collection receptacle 6a. Similarly, the superconductor fine particles 10 having relatively small particle diameter are also separated from the non-superconductor fine particles 8 by a permanent magnet 5b and a partition panel 4b, and collected in a collection receptacle 6b.

In the present Example, the classification and purification are carried out under the following conditions. In Fig. 1, the mixed powder 1 is ejected from the opening 2 at a flow rate of about 200 ml/min with use of the carrier gas comprising He gas. The He gas is beforehand cooled to a temperature of 70 K or less by use of a cooling unit (not shown). The slit 11a has a space of 3 mm, and the slit 11b, 4 mm. The distance from the opening 2 to the slit 11a is 50 cm, and that from the opening 2 to the slit 11b, 150 cm. The permanent magnets are all comprised of Sm-Co and cooled to a temperature of 77 K using a a cooling unit (not shown). The partition panels 4a and 4b protrude by 4 mm from the surface of the magnets 5a and 5b. Under the working conditions as described above, superconductors were able to be collected from about 5 g of raw material powder in the collection receptacle 6a in an amount of about 2.5 g, and in the collection receptacle 6b, about 2 g. The powder in this collection receptacle showed the X-ray diffraction pattern as shown in Fig. 3, resulting in disappearance of all the diffraction peaks of the non-superconductor fine particles in Fig. 2. Thus it was able to confirm that the present apparatus can make purification of superconductors. An electron microscope also revealed that superconductors of about 100 to 200 µm in particle diameter have been collected in the collection receptacle 6a, and those of about 10 to 50 µm in particle diameter, in the collection receptacle 6b, thus confirming the effect of classification.

Example 2

In the case when the powder containing superconductor fine particles have a large particle size distribution and at the same time contain large particles of about 100 µm or more in particle diameter, the opening 2 is made to have the shape of a nozzle, and powder flow is ejected from the nozzle-shaped opening 2 so that the ratio of the pressures of the carrier gas before and after passing the nozzle-like opening 2 may be 10 or more. This operation enables the classification of the superconductor fine particles with a high efficiency like in Example 1 even if the powder contains those having a particle diameter of about 100 µm or more.

Example 3

It may often occurs that superconductor phases having different critical temperatures coexist if ceramics having the composition such as $YBa_2Cu_3O_x$ (x = 6.00 to 7.00) or Bi_2 (Sr, Ca)$_3$ Cu_2O_{12-x} ($x > 0$) are sintered under the same conditions. In such an instance, used is an apparatus having functions as shown in Fig. 4.

In Fig. 4, the numeral 7a indicates non-superconductor fine particles having relatively large particle diameter; 8a, non-superconductor fine particles having relatively small particle diameter; and 9a, 9b, 10a and 10b each, superconductor fine particles, where 9 indicates a higher critical temperature than 10, and a indicates those having relatively large particle diameter, and b, those having relatively small particle diameter.

The temperature dependence on the electric resistance of the superconductors used as samples of the present invention is shown in Fig. 5. As will be seen from Fig. 5, there exists a crystal phase that exhibits superconductivity at 107 K or less.

In a mortar, about 10 g of raw material powder is ground, and this is ejected from an opening 2 of 5 mm in diameter at a flow rate of about 300 ml/min by using He gas cooled to about 60 K as a carrier gas. Sm-Co magnets 5a and 5b at the upper stage are beforehand cooled to 50 K by means of a cooler (not shown) and Sm-Co magnets 5c and 5d at the lower stage are similarly beforehand cooled to 90 K. The partition panels 4a and 4b at the upper stage protrude by 4 mm from the surface of the magnets and the partition panels 4c and 4d at the lower stage protrude by 3 mm. As a result, superconductors (critical temperature: 107 K) having a particle diameter of about 100 to 400 µm were collected in the one collection receptacle 6a and those having a particle diameter of about 30 to 50 µm were collected in the other collection receptacle 6b in an amount of about 0.05 g and 0.08 g, respectively. On the partition panels 4c and 4d, also collected were 3 g and 5 g, respectively, of superconductors haing a critical temperature of 80 K. Meanwhile, the slits 11a and 11b are both 5 mm in width, and the slit 11 is 70 cm distant and the slit 11b is 200 cm distant, from the opening 2.

Example 4

In Examples 1 to 3, the magnets and the partition panels at the bottom parts thereof, as exemplified by the magnets 5a and 5b and the partition panels 4a and 4b in Fig. 1 had the shapes of flat plates. The partition panels 4a and 4b are made to have the shapes having edges fitted on their both ends as shown in Fig. 6, and in some instances the partition panels are made continuously movable according to a belt conveyor system. This makes it possible to make separation of a large quantity of powder.

Example 5

In the instances where the powder containing superconductor fine particles have relatively uniform grain size and no further classification is required as in Examples 1 to 4, no carrier gas is required, and the superconductor fine particles can be separated by allowing the powder to fall on a magnet 5 as shown in Fig. 7.

More specifically, the powder is allowed to fall from a container 12 holding the powder containing superconductor fine particles, and the powder may be brought to slip down the surface of the magnet 5 by appropriately selecting the inclination of the magnet 5 from a vertical position according to the particle diameter of the powder, so that only the superconductors 9 kept apart from the magnet surface pass over the partition panel owing to the Meissner effect and are collected in a collection receptacle 6.

Example 6

As shown in Fig. 8, powder is allowed to fall from the container 12 holding the superconductors 9 to make the apparent shape of the powder falling on a slip board 13 to be of thin plate, to which a carrier gas is blown through a gas-introducing pipe 14. The classification of the superconductor fine particles can be carried out in the same manner as in Example 1 except for transporting the powder in this manner.

Example 7

In Examples 1 to 5, the means for applying the magnetic field is constituted of a plurality of electromagnets 5I, 5II, 5III, ... and 5n as shown in Fig. 9, so that the on-off of the above electromagnets may be repeated (in the order of 5I → 5II → 5III → ... 5n → 5I) by a means (not shown) for controlling the application of magnetic fields, in succession in the falling directions of from 5I to 5n and with an appropriate period. This makes it possible to attempt to simplify the purification process and separate a large quantity of powder.

The period of the on-off of the magnetic fields may be selected according to the velocity of the powder flow, and also the magnetic fields may be made stronger in succession from 5I toward 5n.

Example 8

In Examples 1 to 5 and 7, provided is a vibration plate that ultrasonically vibrates by use of an ultrasonic oscillator (not shown) as shown in Fig. 10. This makes it possible to prevent the powder to be purified from being deposited on the magnets, attempt to make efficient the purification process, and separate a large quantity of the powder.

Example 9

In instances where the powder containing superconductor fine particles have relatively a uniform particle diameter so that no further classification may be required, a collecting means as shown in Fig. 11, may be provided after the same classification and purification as in Example 1, so that the superconductor fine particles can be separated according to the difference in the specific gravity.

In Fig. 11, the numeral 19a denotes superconductor fine particles having relatively high specific gravity; 19, superconductor fine particles having relatively low specific gravity; and 7, non-superconductor fine particles, where all of these fine particles have substantially the same particle diameter.

The collecting means in the present embodiment comprises passages 18a and 18b and superconductors collection receptacles 6a and 6b, and is constituted such that the powder to be purified fall on the slant of a magnet 5, and the non-superconductor fine particles 7 in the powder continue to come into contact with the slant until they slip down in an impurities receptacle 17.

It is also constituted such that the superconductor fine particles 19b having relatively light specific gravity become greatly apart from the magnet 5 owing to the magnetic field applied, and the superconductor fine particles 19a having relatively heavy specific gravity are not so much apart from it so that the distribution of the flows according to the specific gravity can be formed.

It is also constituted such that each of the superconductor fine particles 19a and 19b in that distribution can be collected by superconductors collection receptacles 6a and 6b through the passages 18a and 18b.

The distance of the passages 18a and 18b from the magnet 5 in this apparatus and the inclination of the magnet 5 may be appropriately selected to find an optimum value according to the desired particle diameter and specific gravity. To carry out the classification and separation with further precise particle diameter and specific gravity, the passages 18a and 18b may be made to have a narrower width and the number of the passages may be increased.

Example 10

If the spacing of the slits become broader, it can be contemplated, for example, in Fig. 1 that the non-superconductors pass over the partition panels 4a and 4b to mix into the collection receptacle. In such an instance, a flow-deflecting device 1 (as exemplified by a baffle) may be provided, so that the precision of the classification and purification can be improved.

Example 11

The apparatus illustrated in Fig. 13 comprises a container 20, a diaphragm 21, a partition panel 3, a nozzle 1, and a funnel 23. The inside of the container is kept at about 70 K, and its lower part is filled with liquid nitrogen. The upper part thereof is filled with helium gas blown in from the nozzle together with sample powder.

The sample powder blown out from the nozzle falls from slits 11a, 11b and 11c corresponding to the respective superconductor to enter into the liquid nitrogen. Magnets 5a, 5b and 5c are provided in the vicinity of the powder-falling orbital path, and the superconductor fine particles are deflected in their orbital path by the repulsion owing to the Meissner effect and gathered in saucers 6a, 6b and 6c. The non-superconductor particles fall straight near the magnets and selected and separated from the superconductors.

In the present Example, the heat capacity of the liquid is larger by far than that of the gas so that the samples which fell into the liquid immediately come to have the same temperature as the liquid. Thus, this is characterized by having good precision for the temperature at the time of purification.

In the above Example, used magnets are all permanent magnets, but the magnetic fields may be applied to the powder by use of electromagnets to obtain quite the same effect. The slits are provided on the partition panels 3 at three points, but the slits may be made small in width and large in the number to effect precise classification of particle diameter. There are no particular limitations in the width and number of the slits. Alternatively, a vessel that can be moved by a belt conveyor or the like may be used in place of the slits, and this may, for example, be moved in the direction perpendicular to the paper surface of Fig. 13, and thereafter may be allowed to fall on the magnet areas.

Moreover, it is needless to say that the particle size distribution of the superconductor fine particles collected in the collection receptacle 6 may not be affected at all even if there is a great difference in the specific gravity between the superconductors and non-superconductors.

Example 12

Fig. 14 is a schematic view illustrating another example of the apparatus of the present invention. In Fig. 14, the numeral 38a denotes superconductor fine particles having relatively large particle diameter; 39a, superconductor fine particles having a particle diameter of about 0.1 µm or more but a relatively small particle diameter; and 37a and 37b, non-superconductor fine particles.

The floating means in this Example comprises a powder container 31, a opening 32 and a carrier gas ejector (not shown). The magnetic field applying means comprises a magnet 36.

This apparatus is so constituted that the powder to be purified contained in the powder container 31 can be floated by the carrier gas from the powder container 31 to a vertical passage 33 through the opening 32. The fine particles 37a and 38a having relatively large particle diameter among the powder floated in the vertical passage 33 float only up to a lower position, but the superconductor fine particles 37a and 38b having relatively small particle diameter float up to a higher position. In this Fig. 14. all the superconductor fine particles and non-superconductor fine particles are assumed to have substantially constant specific gravities. The ejection rate at this time may be selected according to the specific gravity of the powder or the desired particle diameter range. The position, width and number of the vertical passage 33 and horizontal passages 34a and 34b may also be selected according to the desired specific gravity and particle diameter.

The apparatus is further so constituted that once a magnetic field is applied by a magnet 36 to the powder inside the vertical passage 33 which have floated to different heights depending on the particle diameter, the respective superconductor fine particles 38a and 38b move to the respective horizontal passages 34a and 34b by the action of the repulsion caused by the Meissner effect, and are collected in the collection receptacles 35a and 35b for the respective superconductor fine particles.

It is also so constituted that the non-superconductor fine particles 37a and 37b staying inside the vertical passage 33 fall into the powder container 31 by stopping ejecting the carrier gas or by turning down the gas.

Employing this apparatus makes it possible to simultaneously and readily carry out the classification-separation according to the particle diameter and/or specific gravity by floating the powder with use of a carrier gas, and the purification by applying the magnetic field to the powder.

In regard to the flow rate of the carrier gas and the driving timing t_1, t_2 and t_3 previously mentioned. the flow rate is 300 ml/min; t_1, 20 seconds; t_2, 5 seconds; and t_3, 1 minute in instances where, for example, the superconductor fine particles to be classified contains even the fine particles of about 1 to 3 μm in particle diameter.

In instances where the particles having a relatively large particle diameter of about 10 to 30 μm are classified, the flow rate is 1 lit/min; t_1, 20 seconds: t_2, 5 seconds; and t_3, 20 seconds, in approximation, which are typical values.

Example 13

Fig. 15 is a schematic view illustrating an apparatus constituted by providing in the apparatus shown in Fig. 14 an impurities collection receptacle 39 and a closing flap 40, and arranging the opening 32 in the horizontal direction.

This apparatus is so constituted that when the non-superconductor fine particles 37 and 38 staying inside the vertical passage 33 are allowed to fall by stopping ejecting the carrier gas or by turning down the gas, they fall into the impurities collection receptacle 39 if the closing flap 40 is opened. Accordingly, the non-superconductor fine particles 37 and 38 may not return to the inside of the powder container 31 to enable the purification with good efficiency. Since moreover the direction of flow of the carrier gas containing the powder greatly changes, the powder tend to be uniformly distributed inside the vertical passage 33.

The flow rate of the carrier gas and the values for t_1, t_2 and t_3 are the same as in the case of Example 12.

Example 14

In the case when the powder containing superconductor fine particles have a large particle size distribution and at the same time contain large particles of about 100 μm or more in particle diameter, the opening 2 of the apparatus illustrated in Fig. 14 or Fig. 15 is made to have the shape of a nozzle, and powder flow is ejected from the nozzle-shaped opening 2 so that the ratio of the pressure of the carrier gas before and after passing the nozzle-like opening 2 may be 10 or more. This operation enables the classification of the superconductor fine particles with a good efficiency like in Example 1 even if the powder contain those having a particle diameter of about 100 μm or more.

Example 15

Fig. 16 illustrates an apparatus constituted by providing ultrasonic vibration plates 41a and 41b respectively at the bottom surfaces of the horizontal passages 34a and 34b of the apparatus illustrated in Fig. 14. or Fig. 15. In this apparatus, there is no friction resistance between the superconductor fine particles having moved from the vertical passage 33 to the horizontal passages 34a and 34b, and the bottom surfaces of the horizontal passages 34a and 34b, so that the superconductor fine particles can be efficiently transported to the collection receptacles 35a and 35b without stagnating on the way of the horizontal passages 34a and 34b.

Example 16

In the apparatus shown in Fig. 14, Fig. 15 and Fig. 16, the magnet 36 was made to comprise an electromagnet, and the electromagnet was so provided that it can repeat on-off with a certain period while being synchronized with the powder-floating means by using a means (not shown) for controlling the application of magnetic fields. More specifically, the magnet was so provided that the magnetic field may be applied after lapse of an appropriate time by which the particle size distribution of the powder formed in the vertical direction inside the vertical passage comes to a steady state after ejection of the carrier gas, and further that this operation may be repeated with a specified period.

Employment of such an apparatus further improves the precision in the classification of the superconductor fine particles.

Also, using the apparatus shown in Fig. 14, about 5 g of powder (showing the same X-ray diffraction pattern as in Fig. 2) containing the superconductor fine particles obtained in the same manner as in Example 1 were added to the flow of a carrier gas of a temperature not higher than the critical temperature (He gas; 70 K or less), and this was ejected from the opening 32 at a flow rate of about 200 ml/min. The horizontal passage 34a was made to be 4 mm in width, and the horizontal passage 34b, 3 mm in width. The horizontal passage 34a was also made 5 cm apart from the opening 32, and 10 cm apart from the horizontal passage 34b.

Used for the magnet 36 was a permanent magnet (Sm-Co), and the inside of the apparatus was cooled to 77 K by a cooling means (not shown) to carry out the process.

With respect to about 5 g of the raw material powder the process of the present invention was carried out. As a result, it was able to collect about 2.5 g of superconductor fine particles in the collection receptacle 5a, and about 1.3 g of superconductor fine particles in the collection receptacle 5b.

The X-ray diffraction pattern of the superconductor fine particles in the collection receptacles 35a and 35b resulted in the same as in Fig. 3.

From these results, it was able to confirm that the apparatus of the present invention can make purification of superconductors in good precision.

Observation of the superconductor fine particles in the collection receptacles 35a and 35b using an electron microscope also revealed that the fine particles in the collection receptacle 35a had a particle diameter of about 100 to 200 µm, and the fine particles in the collection receptacle 35b, about 10 to 50 µm. From these results it was able to confirm that the apparatus of the present invention can make classification of superconductors having a very small particle diameter.

Example 17

Fig. 17 is a cross section to explain the principle of another example of the apparatus of the present invention. In this Fig. 17, a helium gas chamber 41 is filled in its inside with helium gas maintained at a temperature not higher than Tc with an appropriate pressure. At an upper part of the helium gas chamber 41, a powder tank 42 equipped with a nozzle 43 at its lower end is provided, and powder to be purified and kept at a temperature not higher than Tc are held in the powder tank 42. The nozzle 43 opens or closes in agreement with the on-off period of a magnet described later. Inside the helium gas tank 41, partition panels 44 are disposed in plural stages that are spaced above and below, and a saucer 47 is provided at a lower part of a lowermost partition panel 44. In each of partition panels 44, slits 44a, 44b, 44c, etc. are formed at alternately shifted positions. At both outsides of the helium gas tank 41, a first magnet 45 and a second magnet 46 are provided facing each other.

In Fig. 17, the powder to be purified, contained in the powder tank 42 are allowed to fall from the nozzle 43 that opens or closes in agreement with the on-off period of the first and second magnets 45 and 46. When the powder fall inside the helium gas tank 41, its velocity reaches the terminal settling velocity which depends on the particle diameter. Thereafter the powder approaches the partition panels 44 having the slits in an alternate fashion. Here, the first magnet is excited, and the superconductor fine particles are subject to the repulsion owing to the Meissner effect to suffer deflection of the falling orbital path and pass the first slit 44a. Naturally, the powder that are not in a superconducting state can not pass the slit. Subsequently, after the magnetic intensity of the first magnet was lowered, the second magnet 46 is excited and the superconductor fine particles are deflected to opposite side to pass the next slit 44b. At this time, only the powder having a specific settling velocity can pass successively the slits 44a, 44b, 44c, etc. by appropriately selecting the on-off periods of both the magnets 45 and 46 by using a means (not shown) for controlling the application of magnetic fields. As to the particles in which the superconductor phases and impurity phases coexist, even though having the same settling velocity, the repulsion owing to the Meissner effect is so small as compared with its mass that the moving distance to the lateral direction becomes small. For this reason, the postions of the slits 44a, 44b, 44c, etc. may be suitably selected to enable removal of such powder.

In this manner, the superconductor fine particles having been purified and classified are finally collected in the saucer 47.

In the present Example, the part that must be mechanically driven is only the nozzle 43 for allowing the powder to fall, and thus what are aimed can be achieved by a very simple mechanism.

As to the distance between the partition panels and the values for T_o and T_d in instances where, for example, the superconductor fine particles of 5 µm in particle diameter are to be obtained, T_o was 4.5 seconds and T_d was 1.3 seconds when the distance is 5 cm.

Example 18

Fig. 18 illustrates an apparatus constituted by modifying the partition panel 44 in the apparatus of the present invention shown in Fig. 17, wherein a shutter 48 is provided on every two slits 44p and 44q provided on each partition panel 44. Making this shutter 48 appropriately open and close makes it possible to pass both the powder passing through a settling path 49 and the powder passing through another settling path 50. In the apparatus of Fig. 17, it was possible to open the nozzle only once with respect to one on-off period of the magnets 45 and 46, but, it is possible according to this embodiment to open it twice, making double the treatment capacity.

The distance of the partition panels and the values for T_o and T_d are the same as those in Example 17.

Example 19

Fig. 19 illustrates an apparatus same as in Examples 17 and 18 but comprising a disc-like barrier 44 having one opening 44a, and a permanent magnet 51 mounted in place of the electromagnet, both of which are rotated on a common rotating shaft with an appropriate period. In this instance, the powder can be continuously allowed to fall to carry out the purification and classification.

Example 20

The present Example operates like Example 17. The inside of the apparatus is maintained at about 70 K, whose upper half is filled with helium gas, and lower half, with liquid nitrogen. The sample placed in a powder tank 42 falls in the liquid nitrogen when a nozzle 43 is opened, and settles at a terminal settling velocity according to the particle diameter of each particle. Magnetic fields having the inclination opposite each other may be alternately applied to this settling particles with an appropriate period, so that only the superconductor fine particles having the desired particle diameter can be allowed to pass slits 44a, 44b and 44c provided on partition panels 44 and gathered on a saucer 47.

As compared with the case when only the liquid is used, what is characteristic are that the apparatus can be made small in size and there can be used even the powder having relatively large particle diameter.

Example 21

Fig. 21 is a perspective and side elevation illustrating still another embodiment of the apparatus of the present invention, Fig. 22 is a cross section along the line A - A thereof, and Fig. 23 is a cross section along the line B - B thereof.

In the apparatus of the present embodiment, the vibrating passage comprises a V-shaped frame 64 so provided as to be inclined with an angle of 60° to 70°, and an ultrasonic vibrator 63 connected thereto. The magnetic field applying means also comprises a magnet 65 set on the way of the frame 64.

An example of operational procedures for the apparatus in the present Example will be described below.

First, powder (particle diameter: about 0.1 µm or more) containing superconductor fine particles are transported from a storing vessel (not shown) to the frame 64 through a transporting pipe 61 by means of a feed pump 72.

The frame 64 is ultrasonically vibrated by the ultrasonic vibrator 63, and thus the powder transported into the frame 64 fall as shown in Fig. 25 almost without suffering the frictional resistance with the inner wall of the frame 64.

When the powder approaches the area of the magnet 65 set on the way of the frame 64, a magnetic field is applied to the powder to deflect the falling path of only the superconductor fine particles 67 as shown in Fig. 23, which particles are guided in a duct 66 as shown in Fig. 21 and collected there.

Fig. 24 shows a state in which the superconductor fine particles 67 with its weight of mg are deflected along the magnet 65 set to have an inclination θ and with a gravity acceleration of $g \bullet \cos\theta$ (g: gravity acceleration degree). This applies to the case when the frame 64 was stood upright.

Impurity fine particles 71 other than the superconductor fine particles 67 are not deflected even when the magnetic field is applied, and thus fall in a impurities store vessel 70 as shown in Fig. 21 and collected there.

Operating in the above manner, it becomes possible to purify the superconductor fine particles by using the apparatus of the present Example.

In the present Example, the classification of superconductor fine particles having the desired particle diameter can also be carried out by using an electromagnet as the magnet 75 and controlling the strength of the applied magnetic field according to the desired particle diameter.

Using this apparatus and under the following conditions, it was able to purify superconductors in a good state from powder obtained after grinding a sinter of Y-Ba-Cu-O system.
Frame size: 100 mm x 300 mm; applied magnetic field: 1,500 Gauss; powder flow density: 1 cc/min; distance between flat plates: 3 mm; and under a liquid nitrogen temperature.

Example 22

Fig. 26 diagramatically illustrates an example where a plurality of magnets are provided in the apparatus of Example 21, and Fig. 27 is a cross section along the line C - C thereof.

In the apparatus of the present Example, the vibrating passage comprises a flat plate frame 64 and an ultrasonic vibrator 63 connected thereto. The magnetic field applying means also comprises three magnets 65a, 65b and 65c set on the way of the frame 64. The three magnets have the strength of applied magnetic fields in the order of 65a < 65b < 65c.

An example of operational procedures for the apparatus in the present Example will be described below.

First, in the same manner as the apparatus of Example 21, powder (particle diameter: about 0.1 μm or more) containing superconductor fine particles are transported to the frame 64 through a transporting pipe 61.

The frame 64 is ultrasonically vibrated by the ultrasonic vibrator 63, and thus the powder transported into the frame 64 fall almost without suffering the frictional resistance with the inner wall of the frame 64.

When the powder approaches the area of the magnet 65a set on the way of the frame 64, a weak magnetic field is applied to the powder to deflect the falling orbital path of only the superconductor fine particles 67a having relatively large particle diameter, and collected. Subsequently, similarly the superconductor fine particles 67b and 67c having the particle diameter corresponding to the magnitude of the applied magnetic fields of the magnets 65b, and 65c are successively deflected, and collected.

Fine particles 71 other than the superconductor fine particles 67a, 67b and 67c are not deflected even when the magnetic field is applied, and thus fall in an impurities store vessel 70, and collected there.

Operating in the above manner, it becomes possible to classify the superconductor fine particles by using the apparatus of the present Example.

Claims

1. A purification apparatus for superconductor fine particles, comprising a means for forming a flow of powder containing the superconductor fine particles, and a means for applying a magnetic field to the flow of said powder.

2. A purification apparatus for superconductor fine particles, comprising a means for blowing powder containing the superconductor fine particles in a horizontal direction by use of a carrier gas to form a flow of said powder, a partition means horizontally provided, having a plurality of slits at different distances from said blowing means, and a means provided beneath said respective slits, for applying a magnetic field to the flow of said powder.

3. A purification apparatus for superconductor fine particles, comprising a means for floating powder containing the superconductor fine particles by use of a carrier gas to form a flow of said powder, a partition means vertically provided, having a plurality of slits at different heights from said floating means, and a means provided at the positions facing said respective slits for applying a magnetic field to the flow of said powder.

4. A purification apparatus for superconductor fine particles, comprising a means for allowing powder containing the superconductor fine particles to fall, one or plural partition means horizontally provided in a falling path of said powder and provided with a slit at a certain part thereof, and a means for alternately applying with an appropriate period, magnetic fields having the magnetic inclinations in the two directions facing each other in the plane rectangular to the falling direction of said powder.

5. A purification apparatus for superconductor fine particles, comprising a powder passage provided with a means comprising a non-magnetic material serving as a wall material, for smoothing

the flow of powder by vibrating this wall material, a means for forming in said passage a flow of the powder containing superconductor fine particles, and a means for applying a magnetic field to the flow of said powder.

6. A purification apparatus for superconductor fine particles, comprising a means of forming a flow of powder containing the superconductor fine particles, a partition means provided in a flow path of said powder and having one of plural slit(s), and a means for applying a magnetic field to the flow of said powder.

7. A purification apparatus for superconductor fine particles, comprising a means for forming a flow of powder containing the superconductor fine particles. and a means for forming along said flow of the powder a plurality of magnetic fields having different strengths.

8. The apparatus of any preceding claim, wherein said means for applying a magnetic field comprises a permanent magnet.

9. The apparatus of any of claims 1 to 8, wherein said means for applying a magnetic field comprises an electromagnet.

10. The apparatus of Claim 1, 2, 5 or 6, wherein said means for applying a magnetic field is provided in plurality along the flow of the powder.

11. The apparatus of Claim 1, 5, 6 or 7, wherein said means for forming a flow of powder is a means for directly blowing a carrier gas to the powder.

12. The apparatus of Claim 11, wherein said carrier gas serves as a coolant for said powder.

13. The apparatus of Claim 1, 5, 6 or 7, wherein said means for forming a flow of powder is a means for allowing the powder to fall.

14. The apparatus of Claim 1, wherein a partition means having one or plural slit(s) is provided in said flow of the powder.

15. The apparatus of Claim 1, 2, 3 or 6, wherein said means for applying a magnetic field and said means for forming a flow of powder are all governed by an electrical control, and the application of the magnetic field is synchronized with the flow of the powder by means of said electrical control.

16. The apparatus of Claim 1, 2, 3, 4, 6 or 7, wherein there is provided one or plural collecting means for collecting said superconductor fine particles in a flow path deflected by said means for applying the magnetic field.

17. The apparatus of Claim 1, 2, 3 or 5, wherein there is provided one or plural collecting means for collecting said superconductor fine particles in a flow path defected by said means for applying the magnetic field, and one or plural collecting means for collecting fine particles in another flow path not deflected by said means for applying the magnetic field.

18. The apparatus of Claim 1, 3, 4, 6 or 7, wherein said flow of the powder is formed in a gaseous coolant and/or a liquid coolant.

19. The apparatus of Claim 2, wherein the carrier gas serves as a coolant for the powder.

20. The apparatus of Claim 3, wherein said means for forming a flow of powder, and said means for collecting the superconductor fine particles in a flow path deflected by said means for applying the magnetic field, and said means for collecting fine particles in another flow path not deflected are all governed by an electrical control.

21. The apparatus of Claim 20, wherein said carrier gas serves as a coolant for said powder.

22. A purification apparatus for superconductor fine particles, comprising means for containing a powder containing the superconductor fine particles and means for applying a magnetic field to said powder.

23. A purification apparatus for superconductor fine particles comprising a means for forming a flow of powder containing the superconductor fine particles and means for applying a field to the flow of powder.

24. A method of purifying a moving mixture containing superconductor fine particles which comprises applying a field to the moving mixture so that the superconductor fine particles take a different path or paths from other components of the mixture.

FIG.1

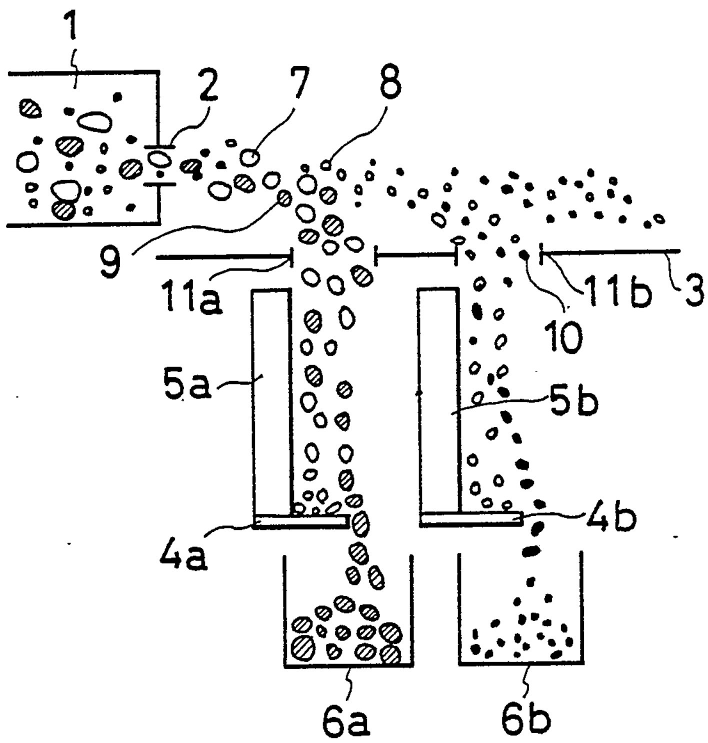


FIG.2

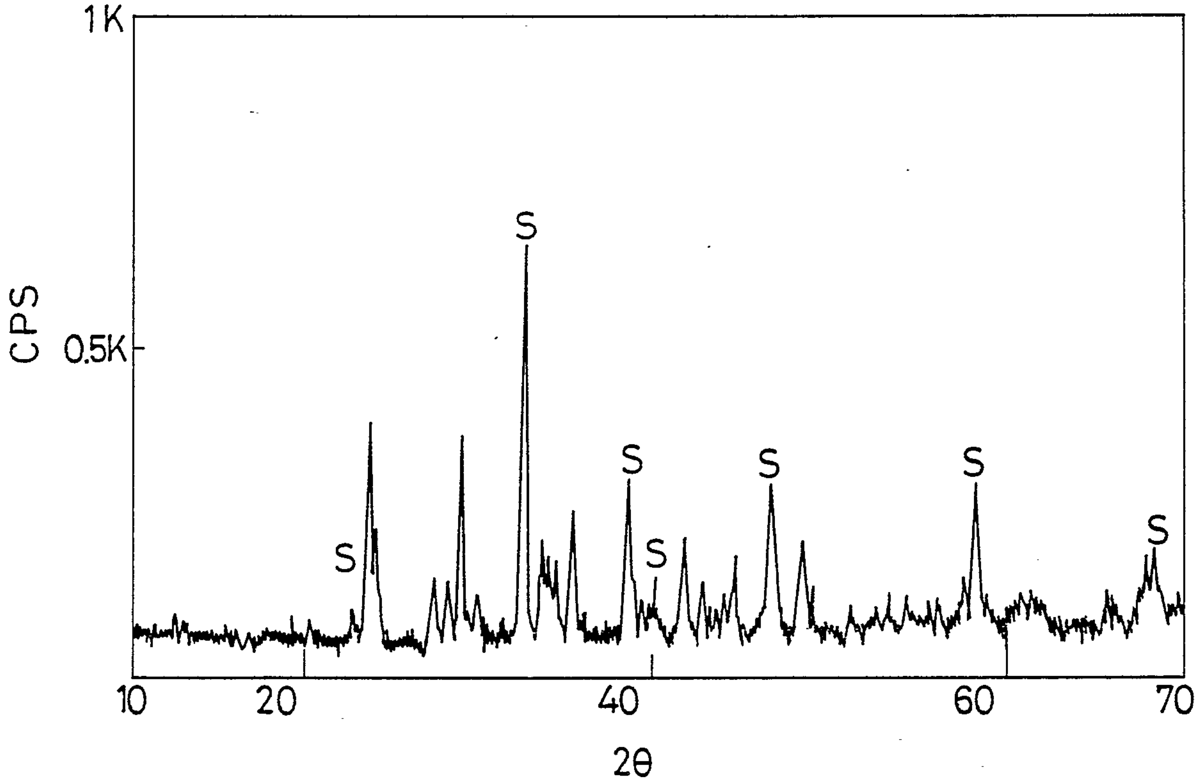


FIG.3

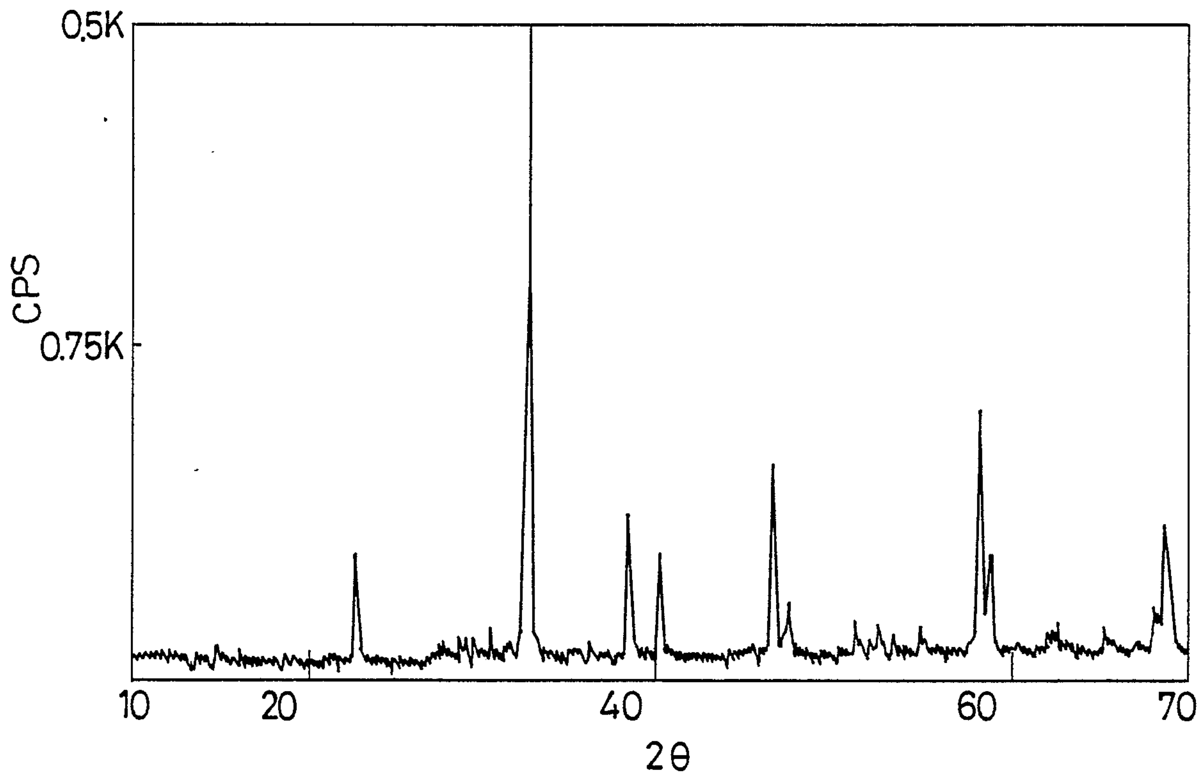


FIG.4

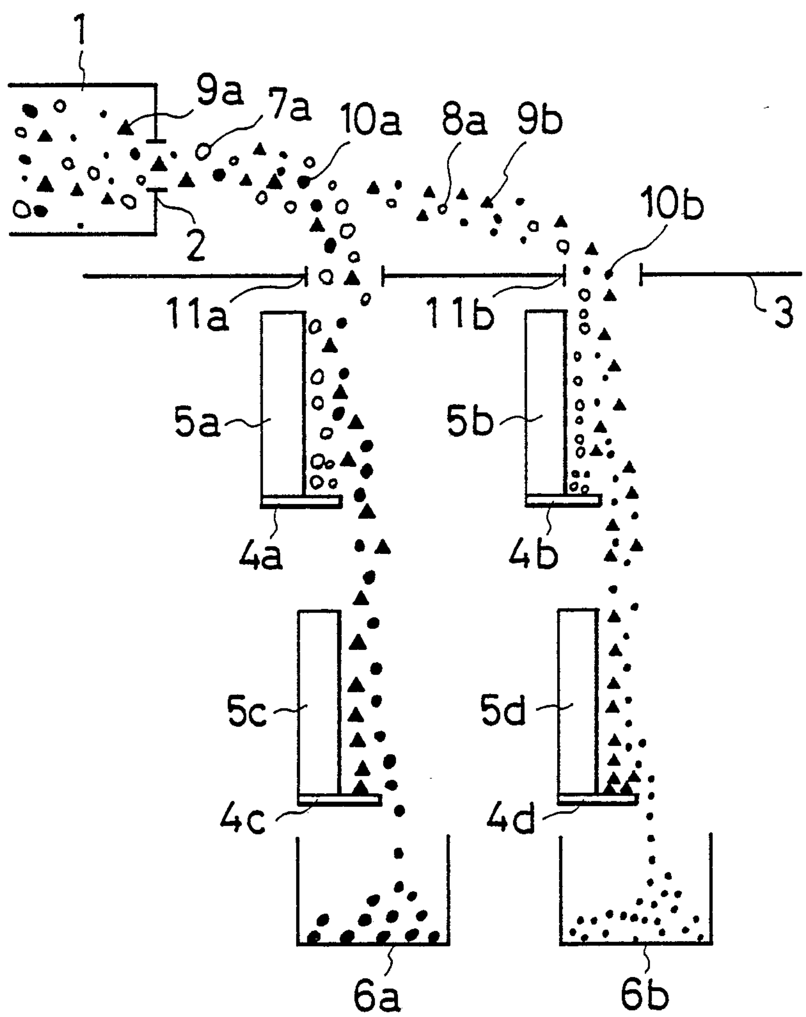


FIG.5

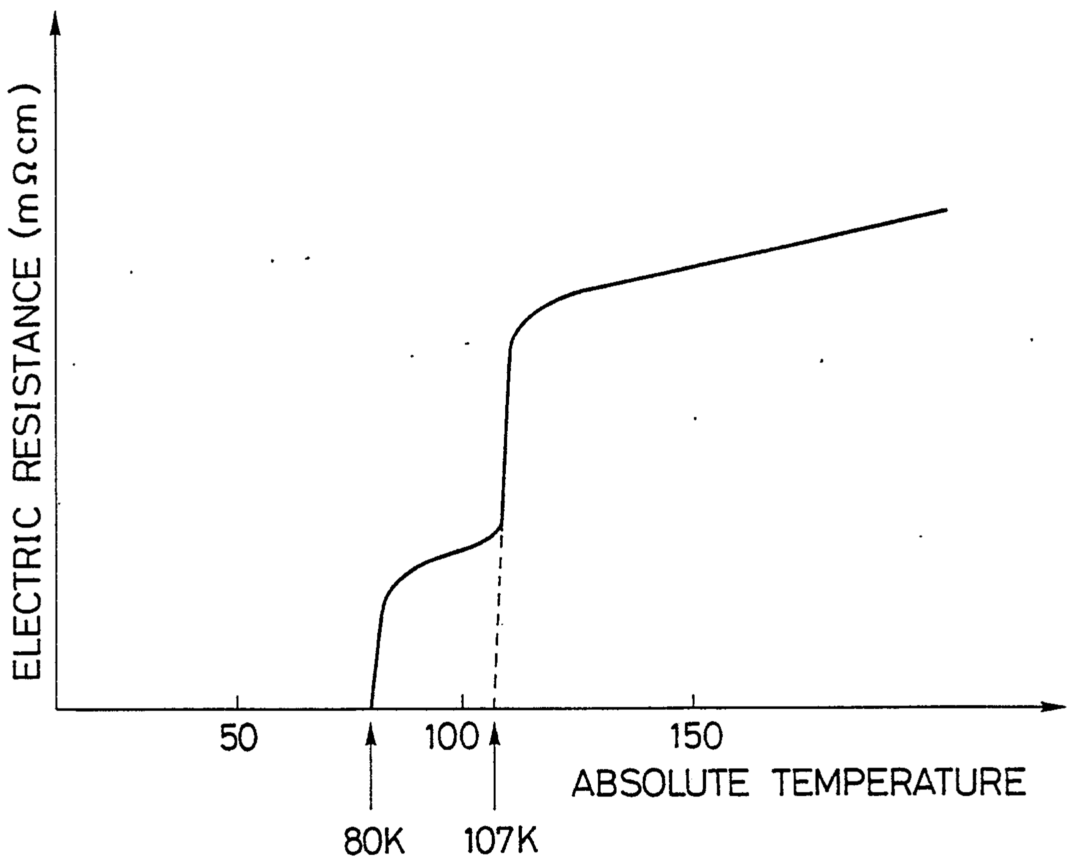

ELECTRIC RESISTANCE (mΩcm)
50
100
150
ABSOLUTE TEMPERATURE
80K
107K

FIG.7

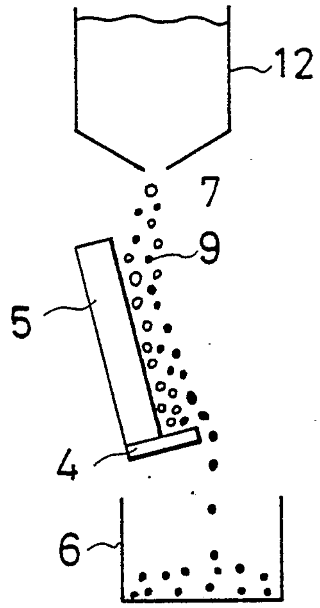


FIG.6

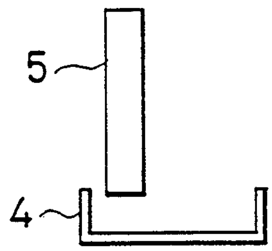


FIG.9

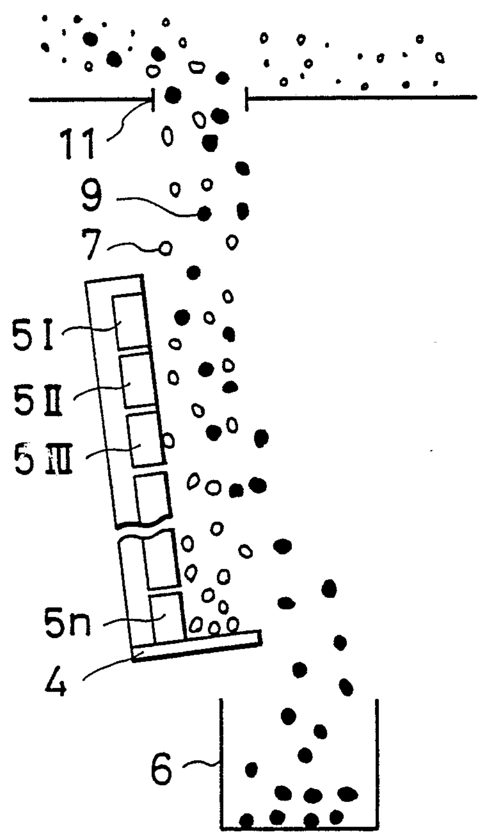


FIG.8

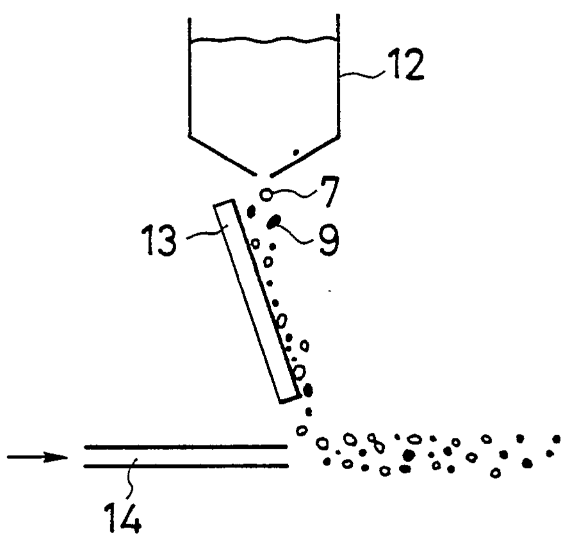


FIG.10

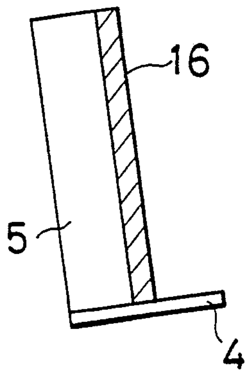


FIG.11

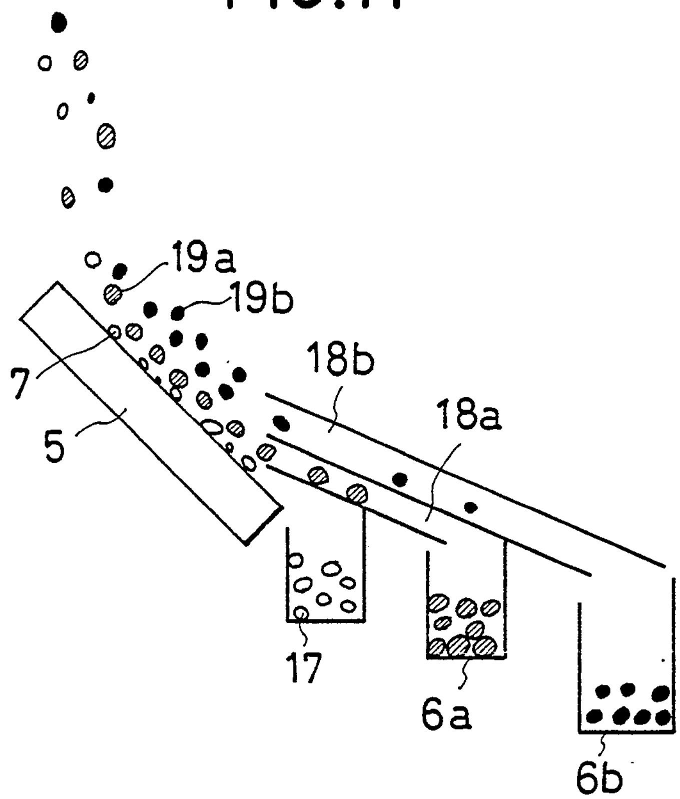


FIG.12

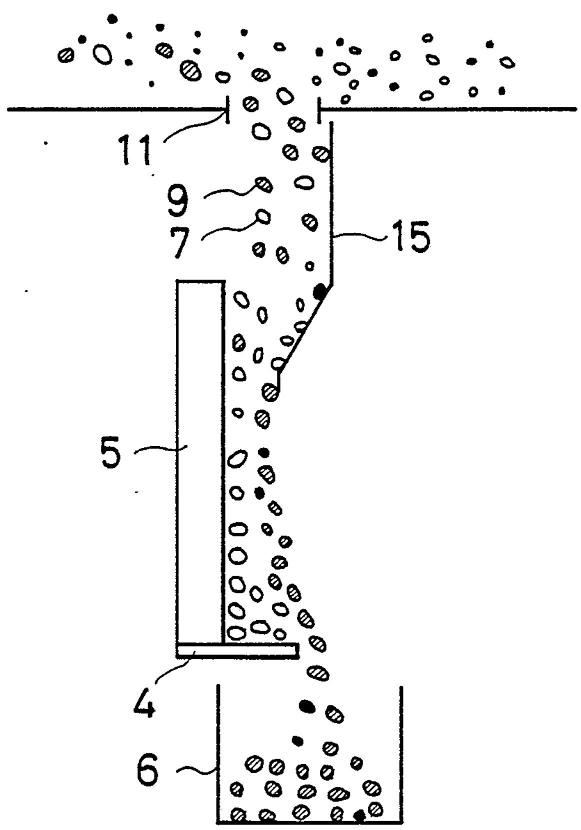


FIG.13

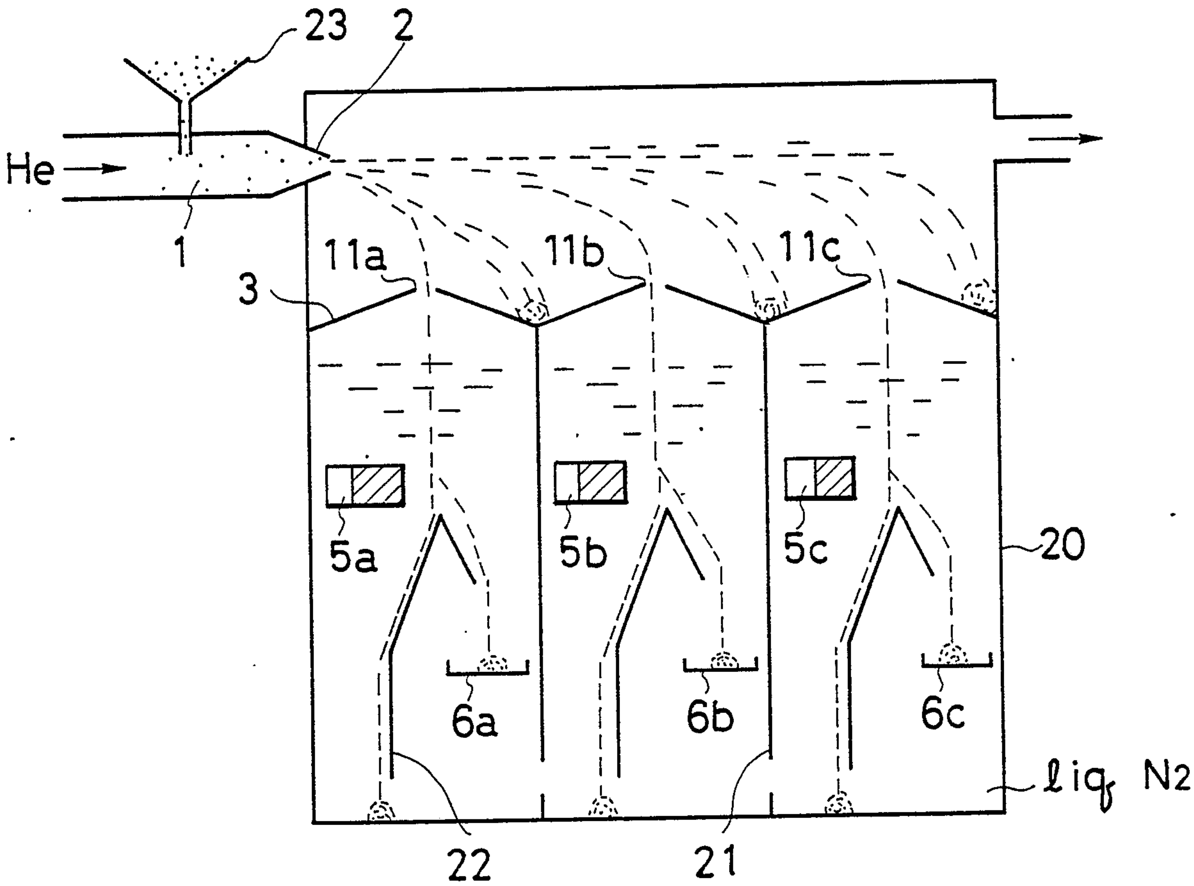


FIG.14

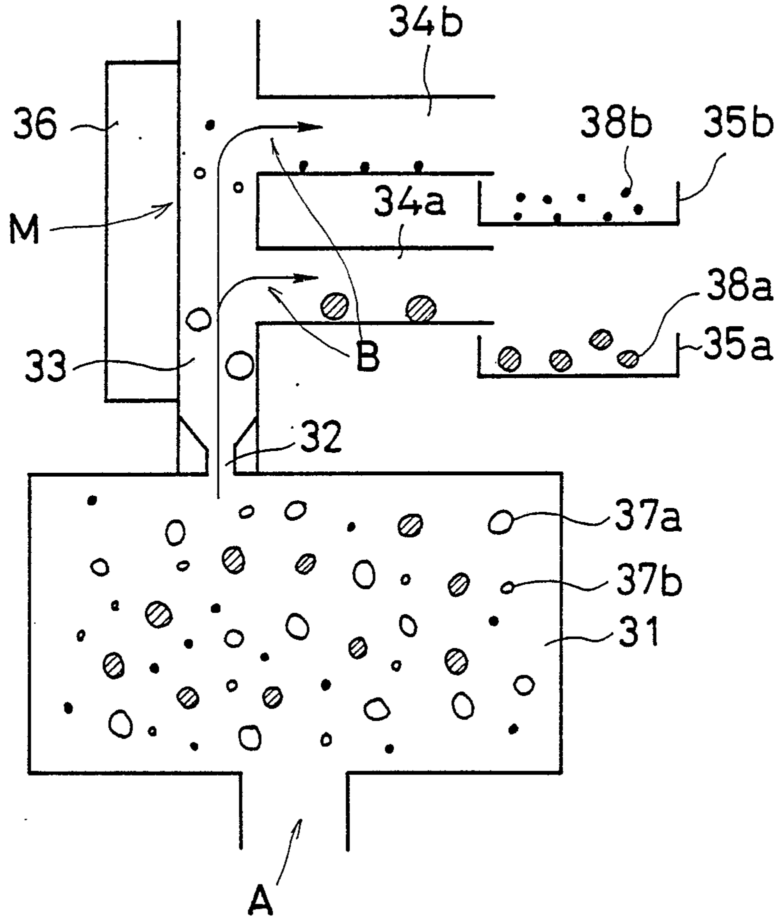


FIG.15

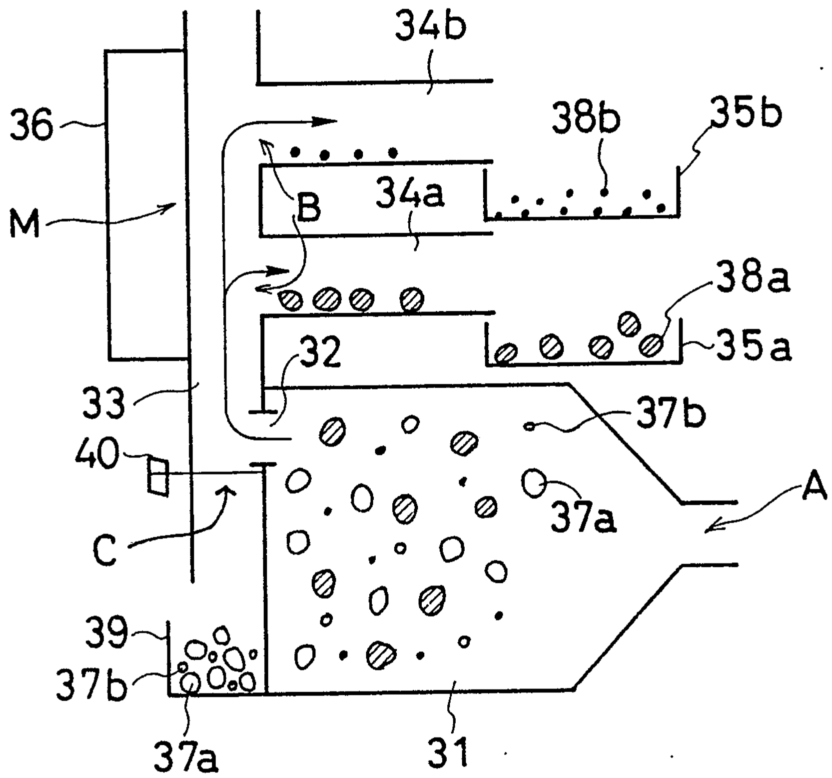

34b
36
38b
35b
B
34a
M
38a
35a
32
33
37b
40
37a
A
C
39
37b
37a
31

FIG.16

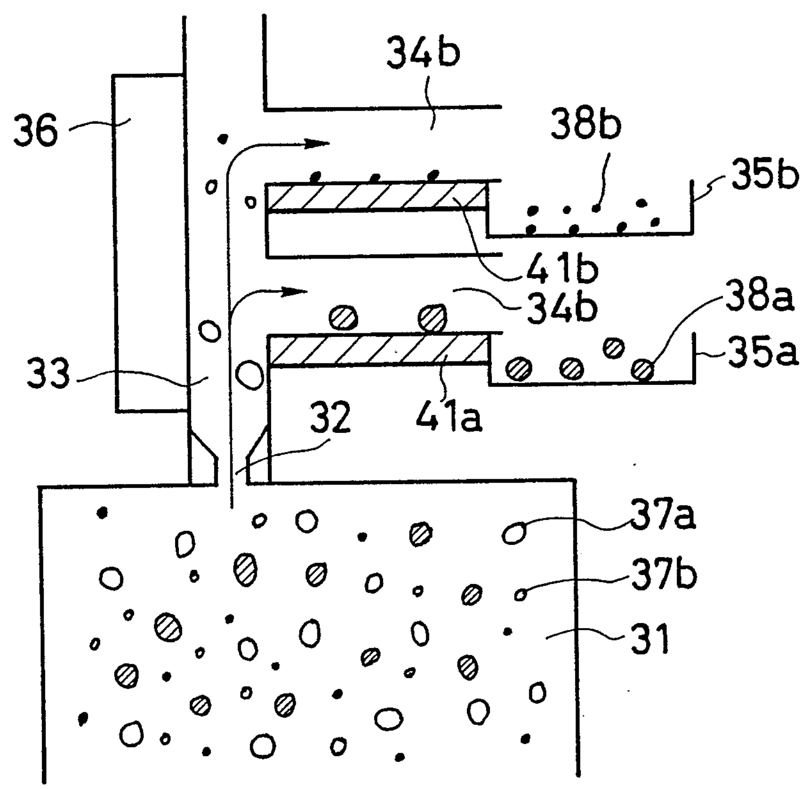

34b
36
38b
35b
41b
34b
38a
35a
33
32
41a
37a
37b
31

FIG.17

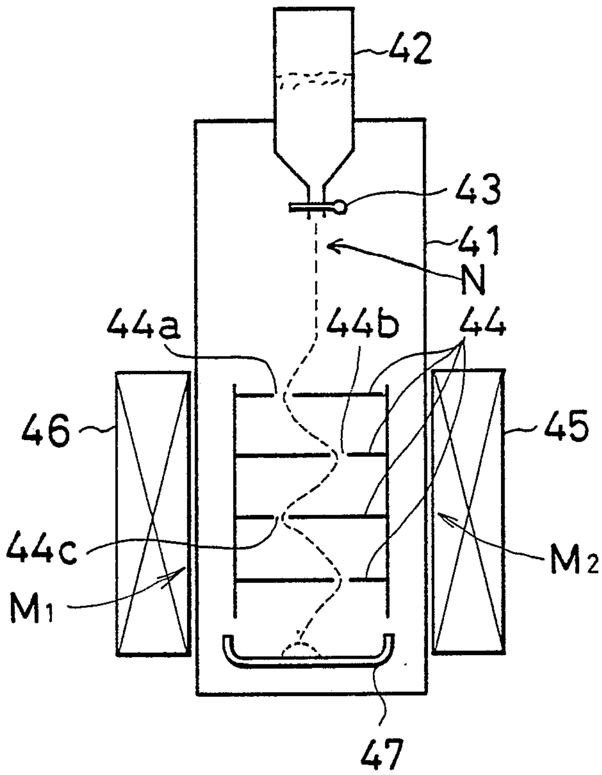


FIG.18

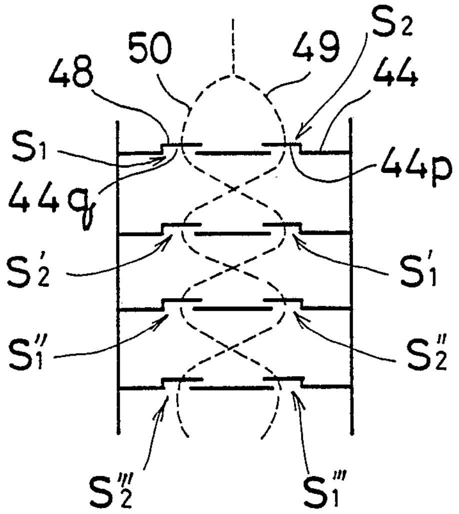


FIG.19

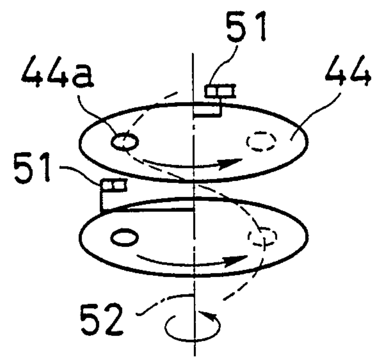


FIG.20

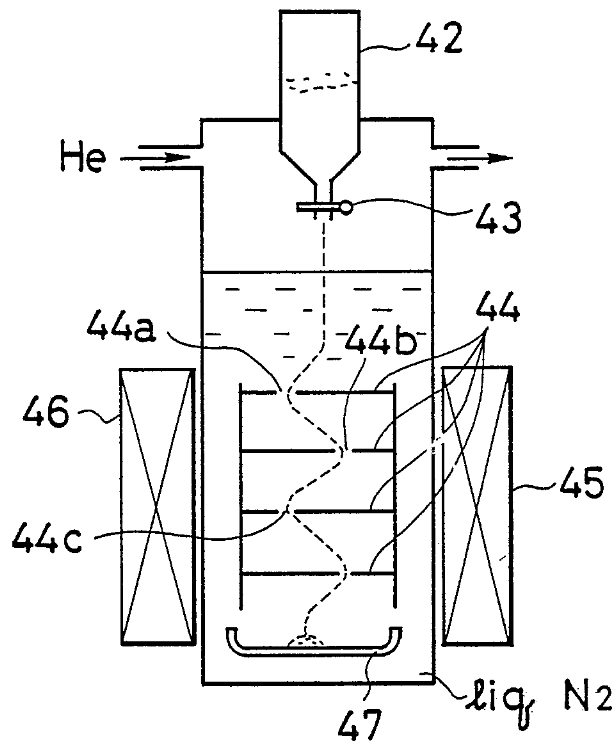


FIG.21

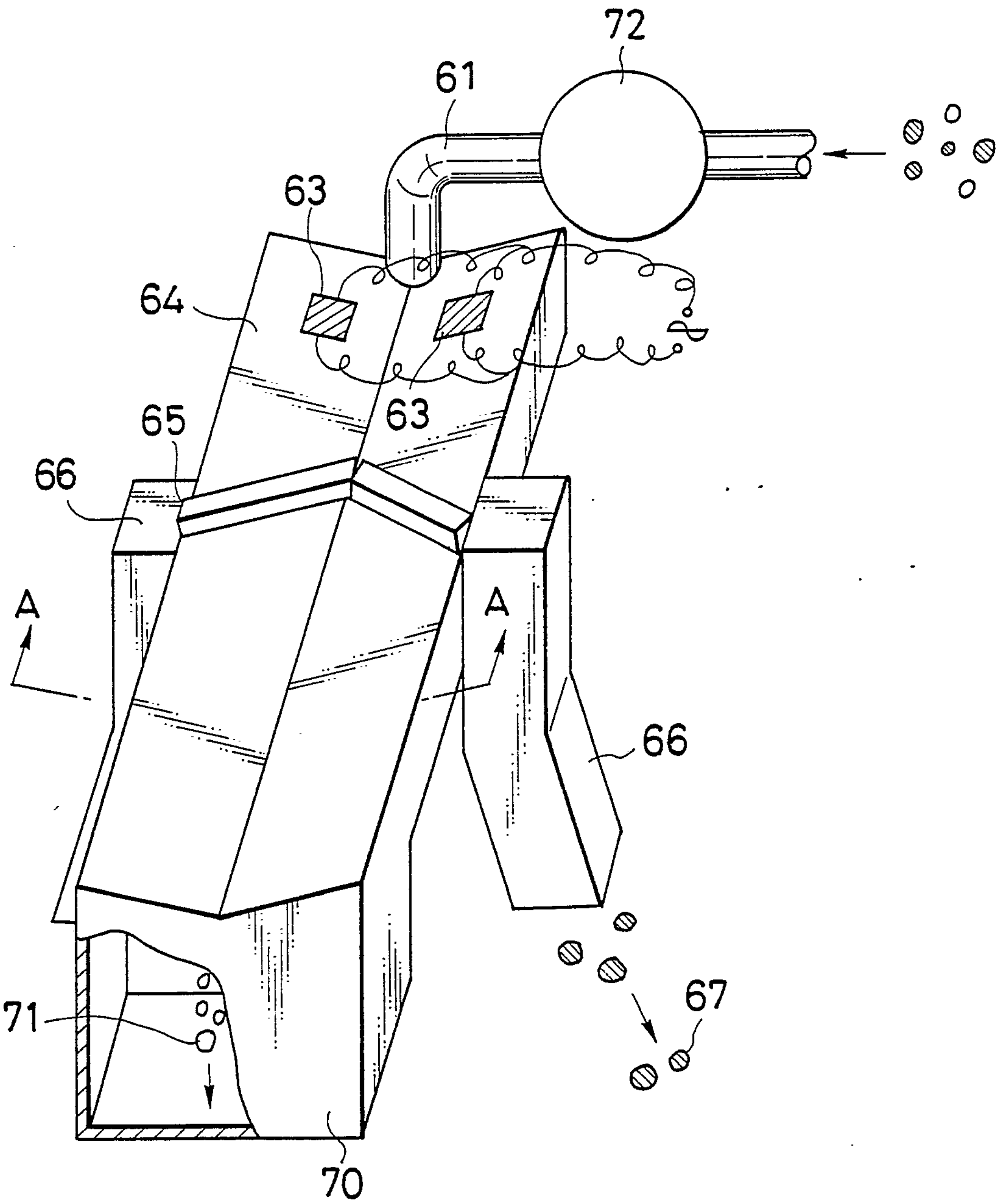


FIG.22

CROSS-SECTION A-A

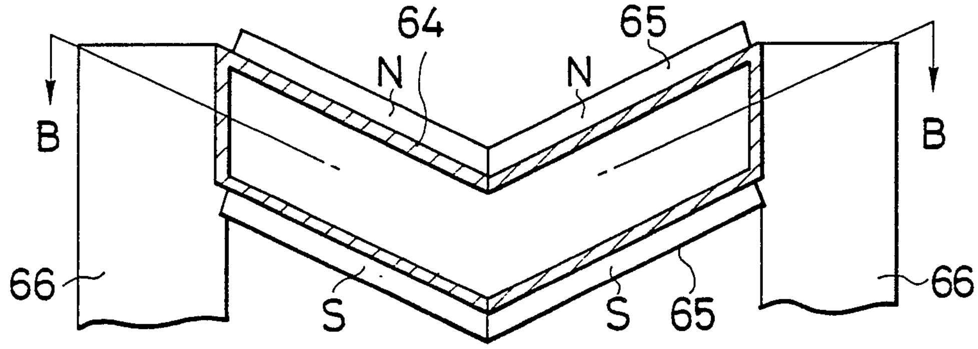


FIG.23

CROSS-SECTION B-B

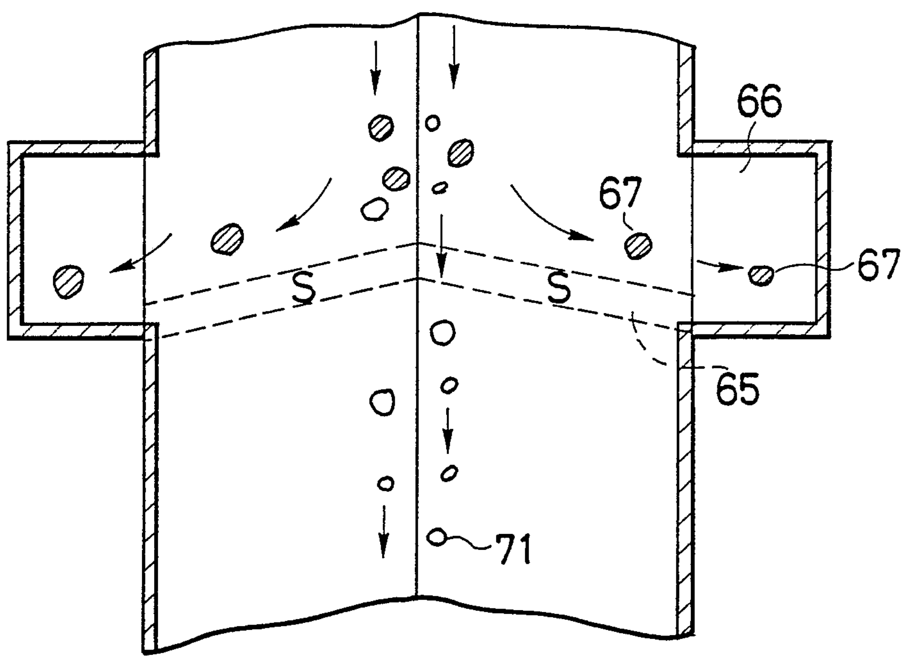


FIG.24

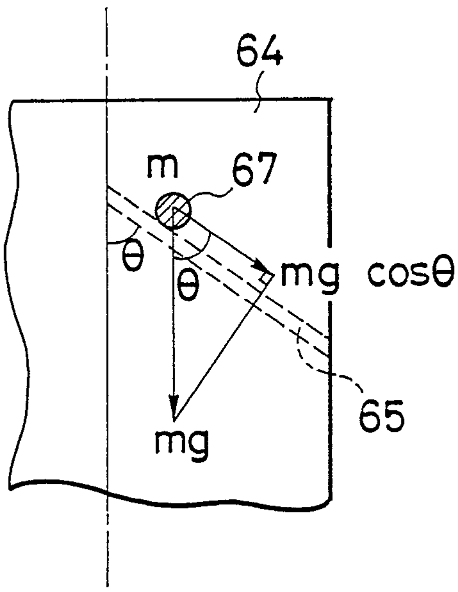


FIG.25

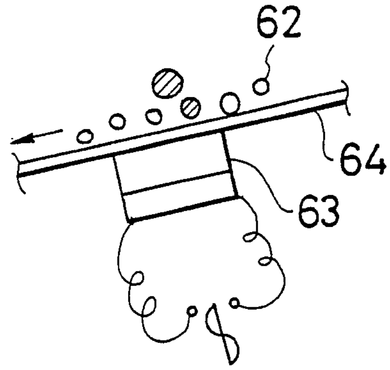


FIG.26

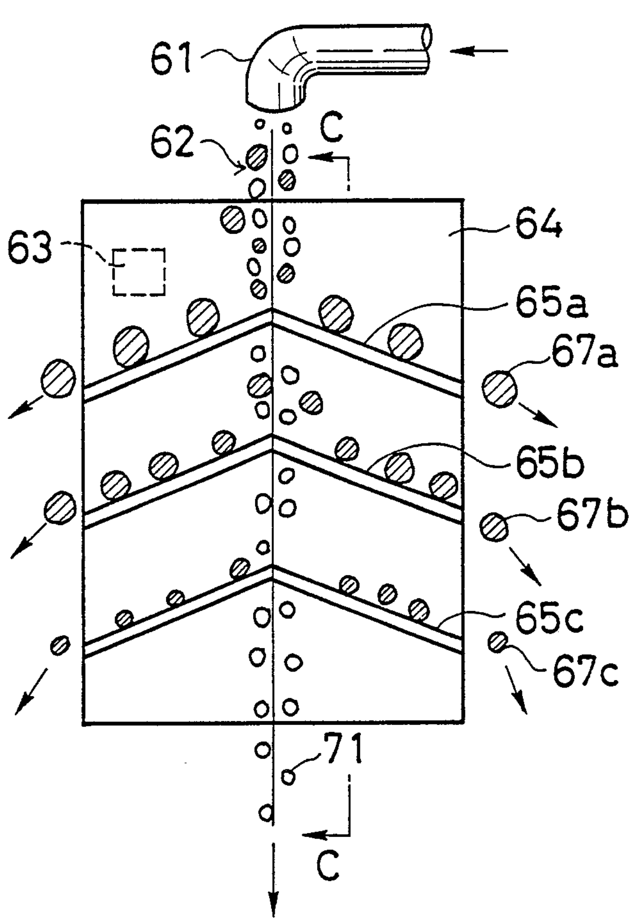


FIG.27

CROSS-SECTION C-C

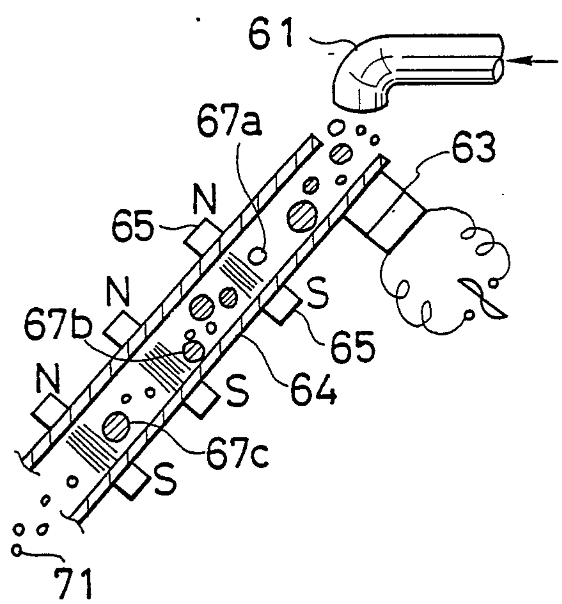


FIG.28

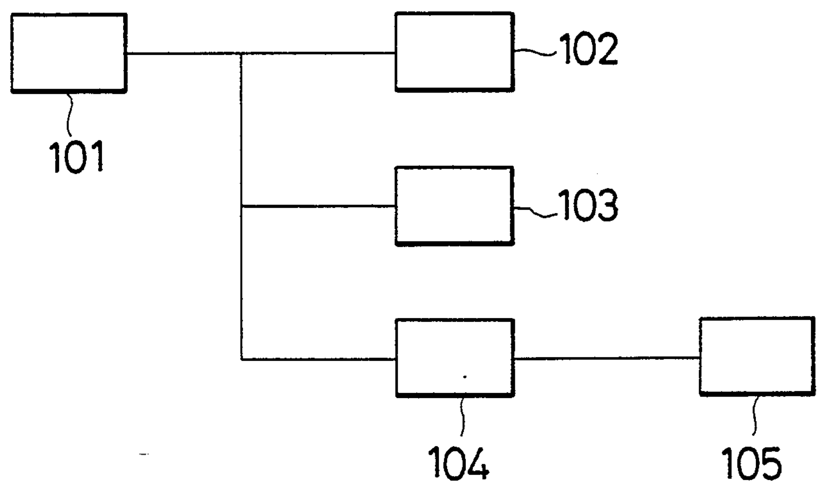

102
101
103
104
105

FIG.29

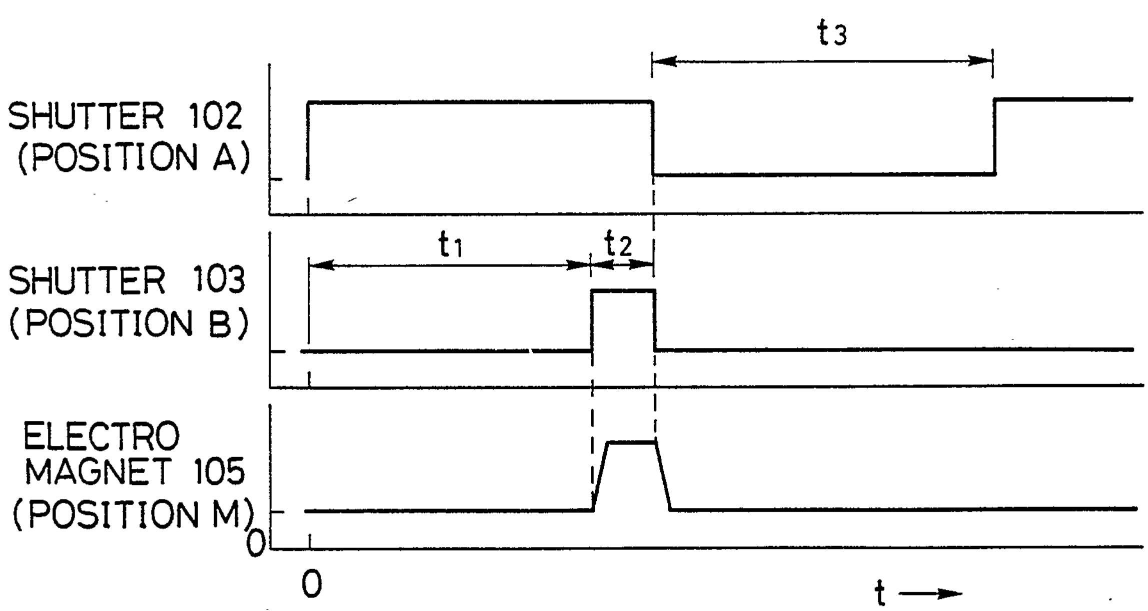

t3
SHUTTER 102
(POSITION A)
t1
t2
SHUTTER 103
(POSITION B)
ELECTRO
MAGNET 105
(POSITION M)
0
0
t

FIG.30

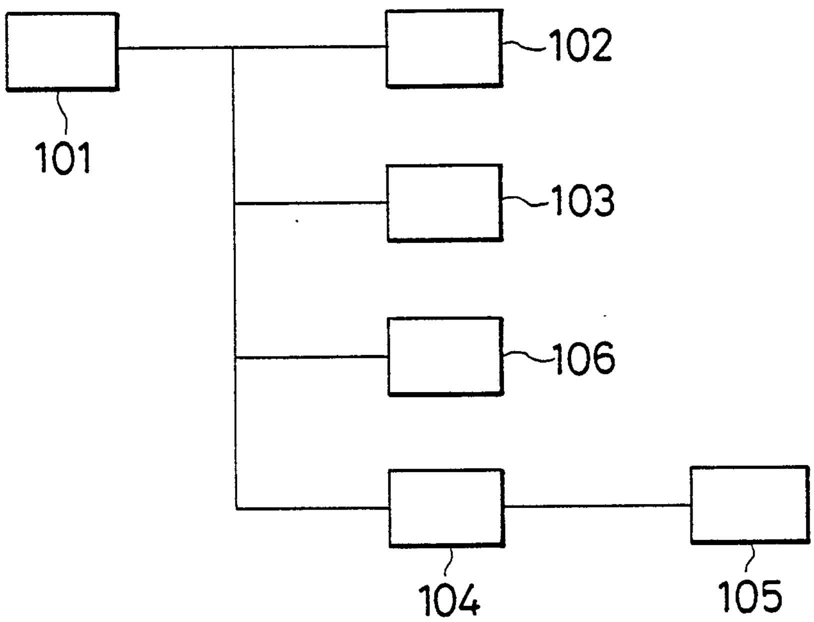

101
102
103
106
104
105

FIG.31

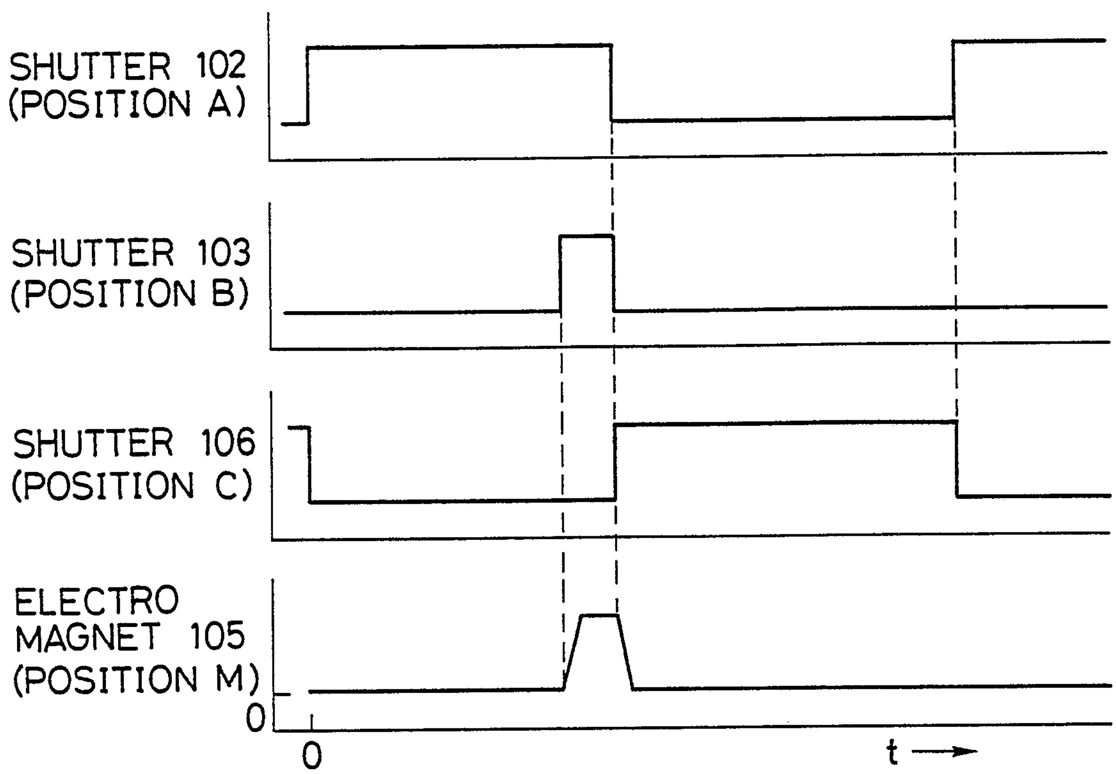

SHUTTER 102
(POSITION A)
SHUTTER 103
(POSITION B)
SHUTTER 106
(POSITION C)
ELECTRO
MAGNET 105
(POSITION M)
0
0
t

FIG.32

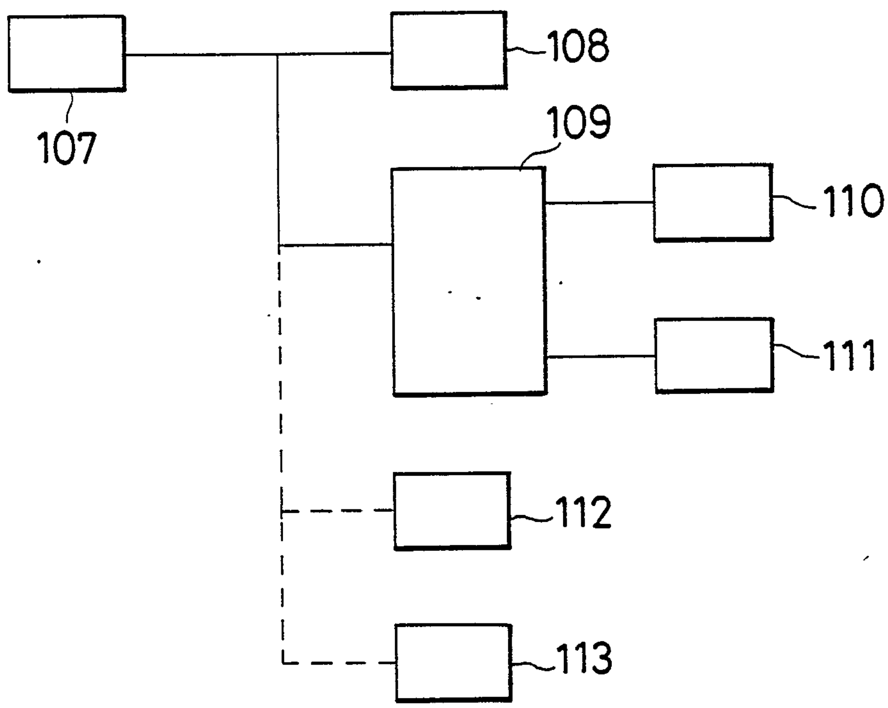
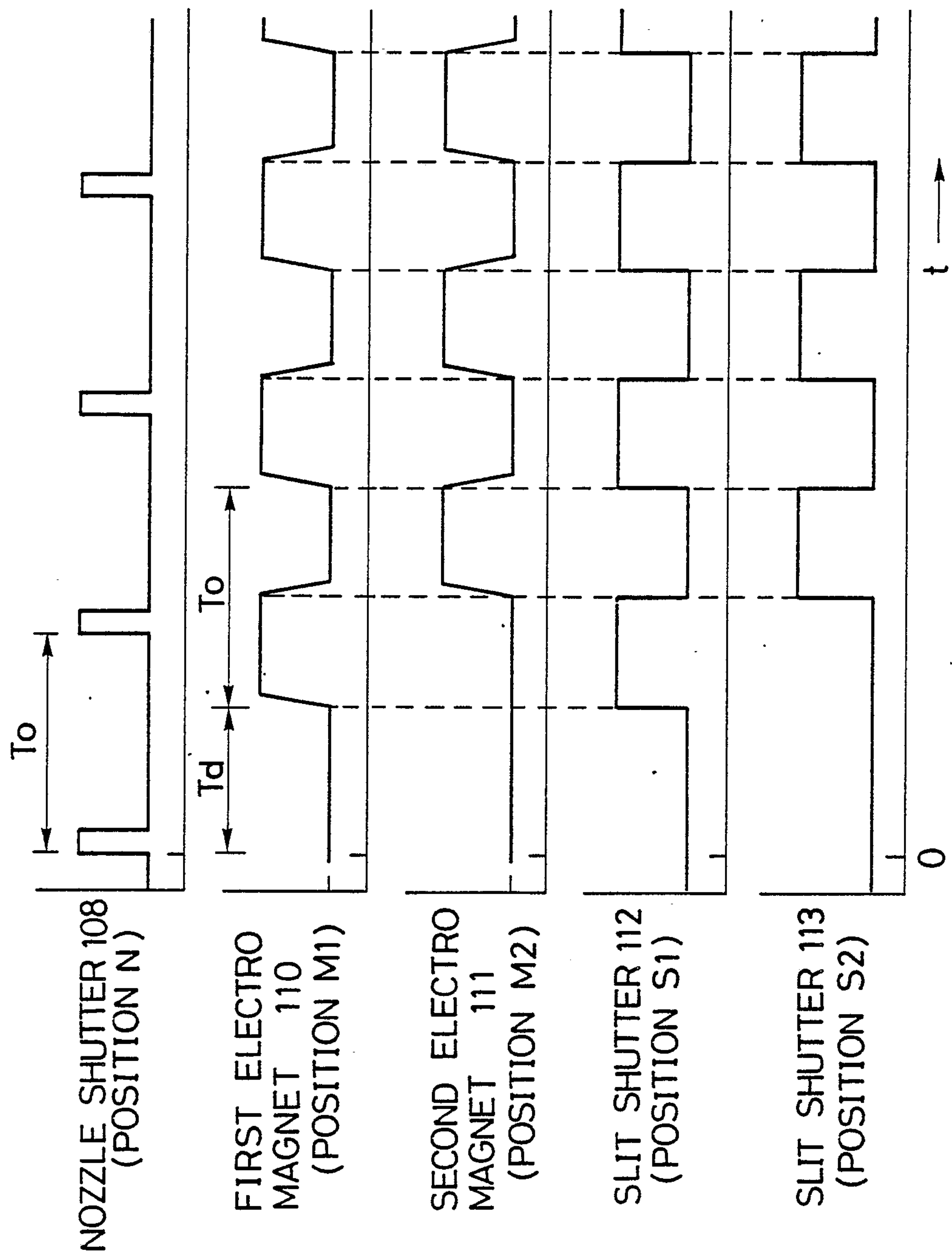


FIG. 33


NOZZLE SHUTTER 108 (POSITION N)
FIRST ELECTRO MAGNET 110 (POSITION M1)
SECOND ELECTRO MAGNET 111 (POSITION M2)
SLIT SHUTTER 112 (POSITION S1)
SLIT SHUTTER 113 (POSITION S2)
To
Td
To
0
t