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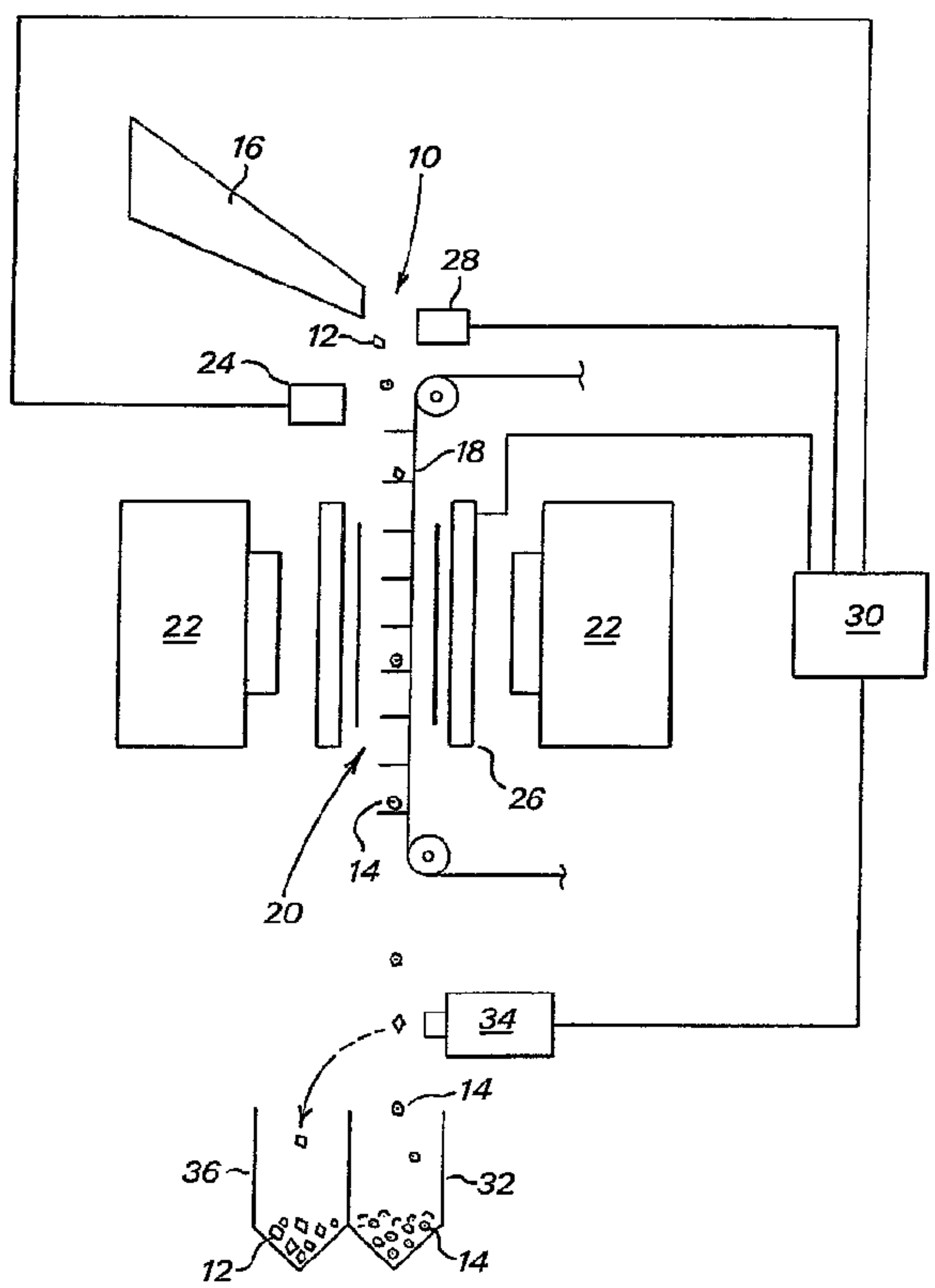


(57) Abrégé/Abstract:
The invention concerns a method of sorting particulate, diamondiferous material into a fraction rich in diamonds and a fraction rich in non-diamond particles according to ESR (electron spin resonance) response. In the method, the particles (12, 14) are located in a microwave cavity (20) and are subjected in the microwave cavity to a magnetic field. Microwave radiation is applied to the particles in the cavity in the presence of the magnetic field. The microwave spectrum transmitted by the cavity for each particle is detected and analysed. The particles are then sorted into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond.

ABSTRACT

The invention concerns a method of sorting particulate, diamondiferous material into a fraction rich in diamonds and a fraction rich in non-diamond particles according to ESR (electron spin resonance) response. In the method, the particles (12, 14) are located in a microwave cavity (20) and are subjected in the microwave cavity to a magnetic field. Microwave radiation is applied to the particles in the cavity in the presence of the magnetic field. The microwave spectrum transmitted by the cavity for each particle is detected and analysed. The particles are then sorted into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond.

BACKGROUND TO THE INVENTION

THIS invention relates to the sorting of diamonds.

It has already been proposed to sort diamonds from other particles by detecting the characteristic Raman response of diamonds when they are irradiated with laser radiation.

A problem with laser-Raman sorting of diamonds is the fact that it is necessary for the diamond particles to have an at least partially exposed, clean surface if a detectable response is to be obtained. In practice in diamond concentration operations, the diamond particles are usually associated with other matter which can obscure the surface of the diamond particles. In order to implement a laser-Raman diamond sorting technique effectively, it is accordingly necessary to clean the particles, typically by acidisation, before irradiation can take place.

SUMMARY OF THE INVENTION

According to one aspect of the invention there is provided a method of sorting particulate diamondiferous material, according to ESR response, into a fraction rich in diamonds and a fraction rich in non-diamond particles, the method comprising the steps of locating particles which are to be sorted in a microwave cavity, subjecting the particles in the microwave cavity to a magnetic field, applying microwave radiation to the particles in the cavity in the presence of the magnetic field, detecting and analysing the microwave spectrum transmitted by the cavity for each particle, and sorting the particles into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond.

The particles may be passed sequentially through the microwave cavity with microwave radiation applied in pulses to the cavity. Typically, first and second pulses of microwave radiation are applied sequentially to the microwave cavity with a particle therein, the time lapse between pulses being selected such that a non-diamond particle which is initially polarised by the first pulse has depolarised while a diamond particle initially polarised by the first pulse remains polarised.

Alternatively, the particles may be passed sequentially through the cavity with continuous wave microwave radiation applied to the cavity. In this case, the magnetic flux density is typically swept over a limited range.

Preferably, the microwave radiation has a frequency in the range 1GHz to 50GHz.

In the preferred embodiment, the microwave spectrum transmitted by the cavity for each particle is detected by detector means adjacent the cavity, the transmitted microwave spectra are analysed by means of a computer which determines, from the analyses, which of the transmitted spectra are indicative of ESR absorption characteristic of diamond, and the particles are sorted into fractions by separation means which are located downstream of the microwave cavity and which are controlled by the computer.

Further according to the method of the invention, the fraction rich in diamonds may be further sub-divided, according to the ESR absorption response of the particles, into sub-fractions rich in diamonds of different types.

According to another aspect of the invention there is provided apparatus for sorting particulate diamondiferous material, according to ESR response, into a fraction rich in diamonds and a fraction rich in non-diamond particles, the apparatus comprising a microwave cavity, a magnetic field generator for generating a magnetic field in which the microwave cavity is located, a microwave generator for applying microwave radiation to particles in the cavity in the presence of the magnetic field, detection means for detecting the microwave spectrum transmitted by the cavity for each particle, a computer for analysing the transmitted spectra and sorting means responsive to the computer for sorting the particles into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond. The apparatus may include particle feed means for passing the particles sequentially through the microwave cavity.

Other features of the preferred apparatus are set forth in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawing which diagrammatically illustrates an apparatus used to carry out the method of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The invention is based on the phenomenon known as electron spin resonance (ESR), otherwise known as electron paramagnetic resonance. This phenomenon relies on the presence of unpaired electrons in the atoms of samples undergoing analysis. In known ESR theory, unpaired electrons have two or more energy states in an applied magnetic field. When subjected to electromagnetic radiation at an appropriate frequency, energy can be absorbed from the incident radiation to cause the unpaired electrons to move to another energy state.

An absorption spectrum obtained for the particle exhibits absorption peaks at the frequencies at which resonant absorption by unpaired electrons has taken place. In the case of diamonds, the ESR technique is dependent on the presence in diamond particles of nitrogen impurities and impurities due to other species which contain unpaired electrons. In practice, virtually every naturally occurring diamond contains nitrogen or other impurities giving rise to the presence of unpaired electrons.

The drawing diagrammatically illustrates an apparatus which employs the ESR phenomenon in on-line sorting of diamondiferous gravel in accordance with the present invention.

In a first embodiment of the invention gravel particles 10, composed of diamonds 12 and non-diamond particles 14, are fed under gravity from a feeder 16 onto a conveyor 18 which transports the particles sequentially through a waveguide forming a resonant cavity indicated generally with the numeral 20.

The resonant cavity 20 is located in a magnetic field of appropriate field strength, typically in the range 0.03 to 1.5 Tesla, generated by electromagnets 22 located alongside the cavity.

A microwave generator 24 is arranged to pass pulses of microwave radiation, typically at a frequency in the range 1GHz to 50GHz, into the cavity. The transmitted radiation is detected by a detector array 26. A position sensor 28 is arranged alongside the conveyor 18 to detect the presence of each particle 12, 14 as it enters the cavity 20. The output of the position sensor 28 is fed to a computer 30 which also controls the operation of the microwave generator 24. When a particle 12, 14 is at a position inside the cavity 20, the microwave generator 24 transmits a first pulse of microwave radiation into the cavity 20 under the control of the computer 30.

Prior to irradiation of each particle with the first microwave pulse, the electron spin of the particle is aligned with the direction of the applied magnetic field, i.e. the electron spin precesses about an axis parallel to the applied field. Irradiation of the particle with the first microwave pulse "flips" the electron spin out of alignment with the magnetic field, typically through 90°. In the case of minerals with which diamond is normally associated in nature, i.e. the non-diamond particles 14, this polarisation of the particles decays in a very short time, i.e. the spin-spin relaxation time constant T_2 is relatively short so the electron spins move back rapidly to a condition of parallel alignment with the applied field. The diamond particles, having a purer crystal structure, have longer spin-spin relaxation time constants T_2 and hence depolarise more slowly than the non-diamond particles. The time T_2 for diamond particles is typically of the order of milliseconds compared to microseconds for the non-diamond particles.

After a predetermined, short time delay the microwave generator transmits a second pulse of microwave radiation into the cavity under the control of the computer 30. The time delay is selected such that the non-diamond particles 14 have fully depolarised while the diamond particles retain their polarisation, i.e. the electron spins of the diamond particles remain out of alignment with the applied magnetic field.

The second microwave pulse "flips" the electron spins, typically through 180°. This reverses the direction of precession resulting in rematching of phases after a short time interval. As the spins come into phase a microwave absorption peak is discernible in the microwave spectrum detected by the detector array 26. Detection of this absorption peak at the relevant time is accordingly indicative of the presence of a diamond.

The detector array 26 directs signals corresponding to the detected microwave spectrum to the computer for analysis. From the output signals directed to it by the detector array, the computer derives an absorption spectrum for the particle. Using a pulse-echo technique and appropriate time-gating with predetermined time constants to isolate spectra attributable to non-diamond particles, the computer determines whether the spectrum contains an absorption peak which is indicative of the ESR absorption characteristic of a nitrogen or other impurity in diamond. In this regard it will be understood that due to the difference in T_2 times for diamond and non-diamond particles, and with suitable time-gating, only the diamond particles will display an absorption spectrum. This serves as the basis for the on-line sort described below.

After passing through the cavity 20, the particles fall freely from the conveyor 18 towards a tailings bin 32. An air blast ejector 34, controlled by the computer 30, is located alongside the free fall path of the particles. When the computer determines that the derived absorption spectrum for a particular particle contains an absorption peak indicative of a diamond associated nitrogen impurity, it causes the ejector, after the appropriate time delay, to issue a short duration blast of air at the falling stream of particles.

The air blast deflects the relevant particle out of the stream so that it falls into a bin 36, while the remaining, non-ejected particles, i.e. the particles 14, continue free-falling into the tailings bin 32. Diamonds and diamond-containing particles are therefore concentrated in the bin 36 while gangue or waste particles collect in the tailings bin 32.

In another embodiment of the invention, using the same apparatus, the microwave generator 24 is configured to deliver continuous wave microwave radiation to the microwave cavity 20. In this embodiment, the magnetic field is scanned, i.e. swept, over a range of a few hundred gauss within a few milliseconds with the particles in the cavity. Once again, the detector array 26 detects the radiation absorption spectrum. As a result of the different T_2 times for diamond and non-diamond particles, characteristic absorptions by nitrogen and other impurities in the diamond particles are once again discernible in the detected spectrum with suitable pulse-echo and time-gating procedures.

An advantage of the methods described above is that the ESR response and analysis thereof is extremely rapid, enabling rapid on-line sorting of large quantities of diamondiferous feed material to take place.

The method is not dependent on the size of the particles presented for analysis, so accurate pre-sizing is not required. Also, since the spectral response of the diamonds is not surface dependent, pre-cleaning of the particles prior to analysis is not required.

A further advantage arises from the fact that the absorption peak obtained for a diamond-associated nitrogen or other impurity is characteristic of the nature of the impurity and diamond crystal in question. Thus it is also possible in a refinement of the method to sort the diamond particles into different classes according to the absorption peaks which are detected. This further step may be carried out at the time of the main sort or subsequently.

In another refinement of the method as described above the particles 12, 14 may be irradiated with gamma radiation or X-radiation so as to enhance the ESR signal which is obtained for the diamond particles.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of sorting particulate diamondiferous material, according to ESR response, into a fraction rich in diamonds and a fraction rich in non-diamond particles, the method comprising the steps of locating particles which are to be sorted in a microwave cavity, subjecting the particles in the microwave cavity to a magnetic field, applying microwave radiation to the particles in the cavity in the presence of the magnetic field, detecting and analysing the microwave spectrum transmitted by the cavity for each particle, and sorting the particles into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond.

2. A method according to claim 1 wherein the particles are passed sequentially through the microwave cavity and microwave radiation is applied in pulses to the cavity.

3. A method according to claim 2 wherein first and second pulses of microwave radiation are applied sequentially to the microwave cavity with a particle therein, the time lapse between pulses being selected such that a non-diamond particle which is initially polarised by the first pulse has depolarised while a diamond particle initially polarised by the first pulse remains polarised.

4. A method according to claim 2 or claim 3 wherein the strength of the magnetic field is in the range 0.03 to 1.5 Tesla.

5. A method according to claim 1 wherein the particles are passed sequentially through the cavity and continuous wave microwave radiation is applied to the cavity.

6. A method according to any one of claims 1 to 5 wherein the microwave radiation has a frequency in the range 1GHz to 50GHz.

7. A method according to any one of claims 1 to 6 wherein the microwave spectrum transmitted by the cavity for each particle is detected by detector means adjacent the cavity, the transmitted microwave spectra are analysed by means of a computer which determines, from the analyses, which of the transmitted spectra are indicative of ESR absorption characteristic of diamond, and the particles are sorted into fractions by separation means which are located downstream of the microwave cavity and which are controlled by the computer.

8. A method according to any one of claims 1 to 7 wherein the fraction rich in diamonds is further sub-divided, according to the ESR absorption response of the particles, into sub-fractions rich in diamonds of different types.

9. An apparatus for sorting particulate diamondiferous material, according to ESR response, into a fraction rich in diamonds and a fraction rich in non-diamond particles, the apparatus comprising a microwave cavity, a magnetic field generator for generating a magnetic field in which the microwave cavity is located, a microwave generator for applying microwave radiation to particles in the cavity in the presence of the magnetic field, detection means for detecting the microwave spectrum transmitted by the cavity for each particle, a computer for analysing the transmitted spectra and sorting means responsive to the computer for sorting the particles into fractions according to whether or not the detected microwave spectra are indicative of ESR absorption by diamond.

10. An apparatus according to claim 9 comprising particle feed means for passing the particles sequentially through the microwave cavity.

11. An apparatus according to either on of claims 9 or 10 wherein the microwave generator is arranged to apply microwave radiation to the cavity in pulses.

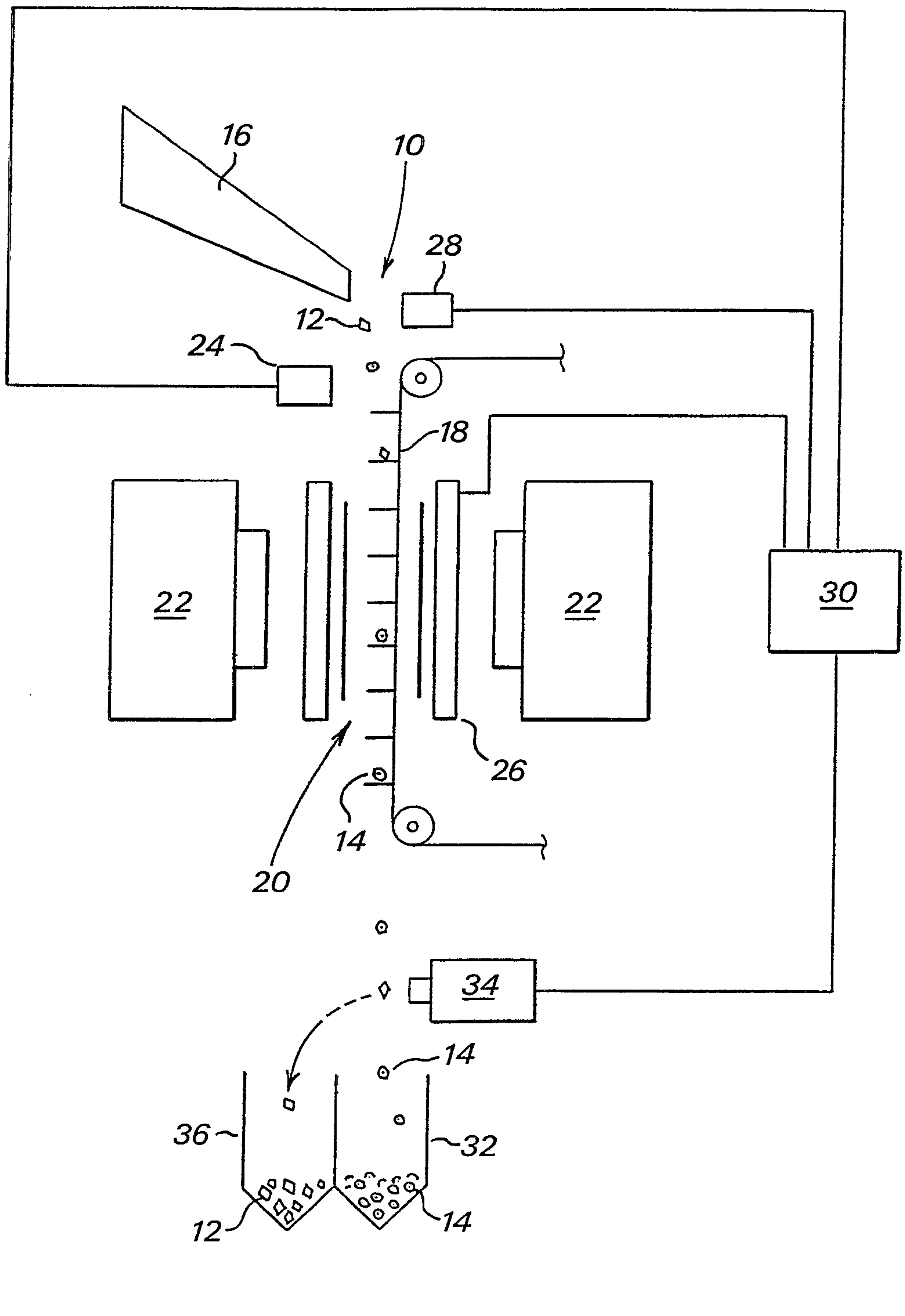
12. An apparatus according to claim 11 wherein the microwave generator is arranged to apply first and second pulses of microwave radiation sequentially to the microwave cavity under the control of the computer, the time lapse between pulses being selected such that a non-diamond particle initially polarised by the first pulse has depolarised while a diamond particle initially polarised by the first pulse remains polarised.

13. An apparatus according to claim 11 wherein the magnetic field generator is arranged to generate a magnetic field having a strength in the range 0.03 to 1.5 Tesla.

14. An apparatus according to claim 9 or claim 10 wherein the microwave generator is arranged to apply continuous wave microwave radiation to the cavity.

15. An apparatus according to any one of claims 9 to 14 wherein the microwave generator is arranged to apply microwave radiation at a frequency in the range 1 GHz to 50GHz to the microwave cavity.

16. An apparatus according to any one of claims 9 to 15 wherein the sorting means is arranged to sort the fraction which is rich in diamond into sub-fractions rich in diamonds of different types according to the ESR absorption response of the particles.



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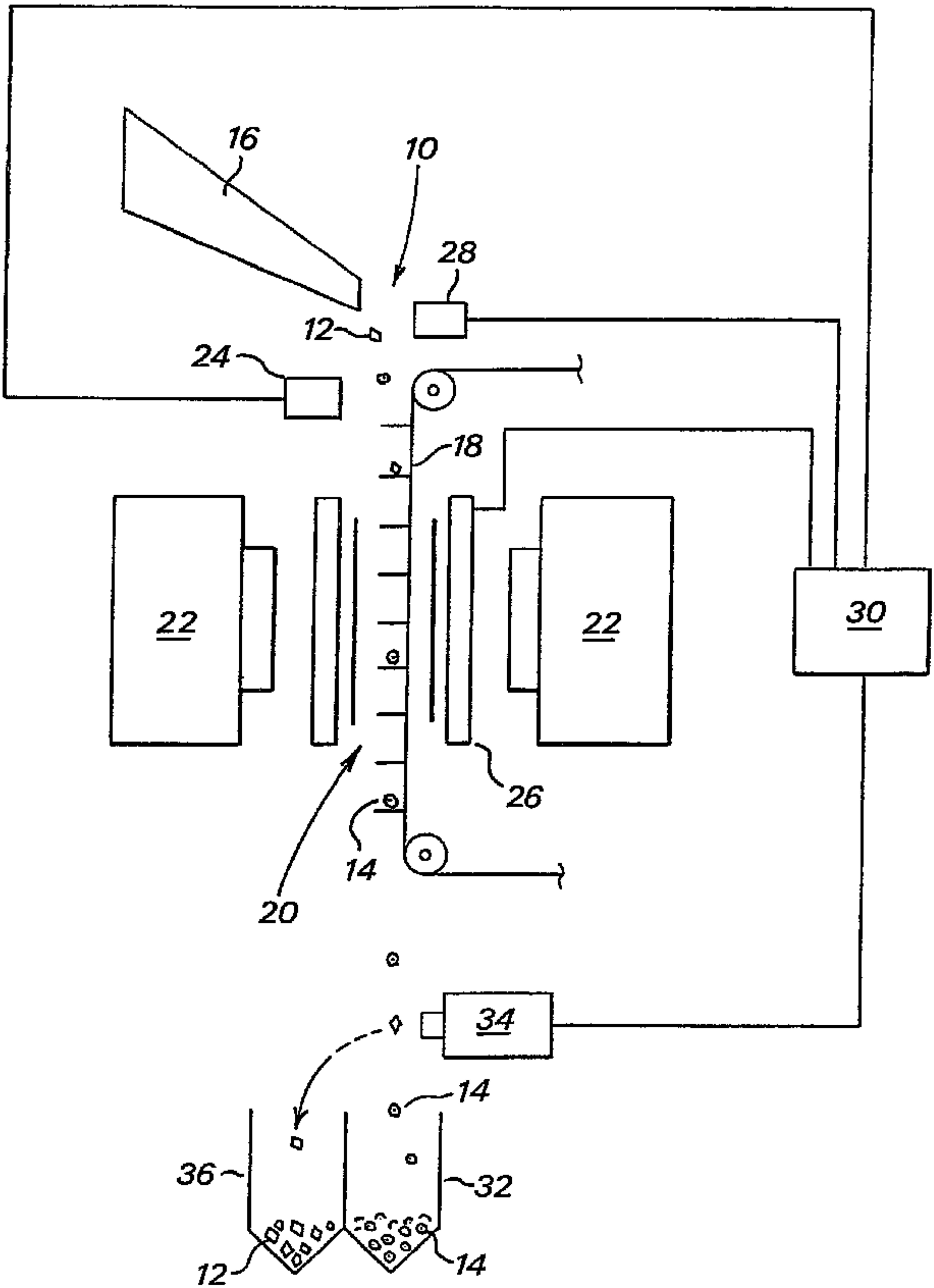
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