Dec. 24, 1968 D. J. RENNER 3,418,542

METHOD AND APPARATUS FOR DEMAGNETIZATION OF MULTIPOLE MAGNETIC DEVICES

Filed April 18, 1966 3 Sheets-Sheet 1

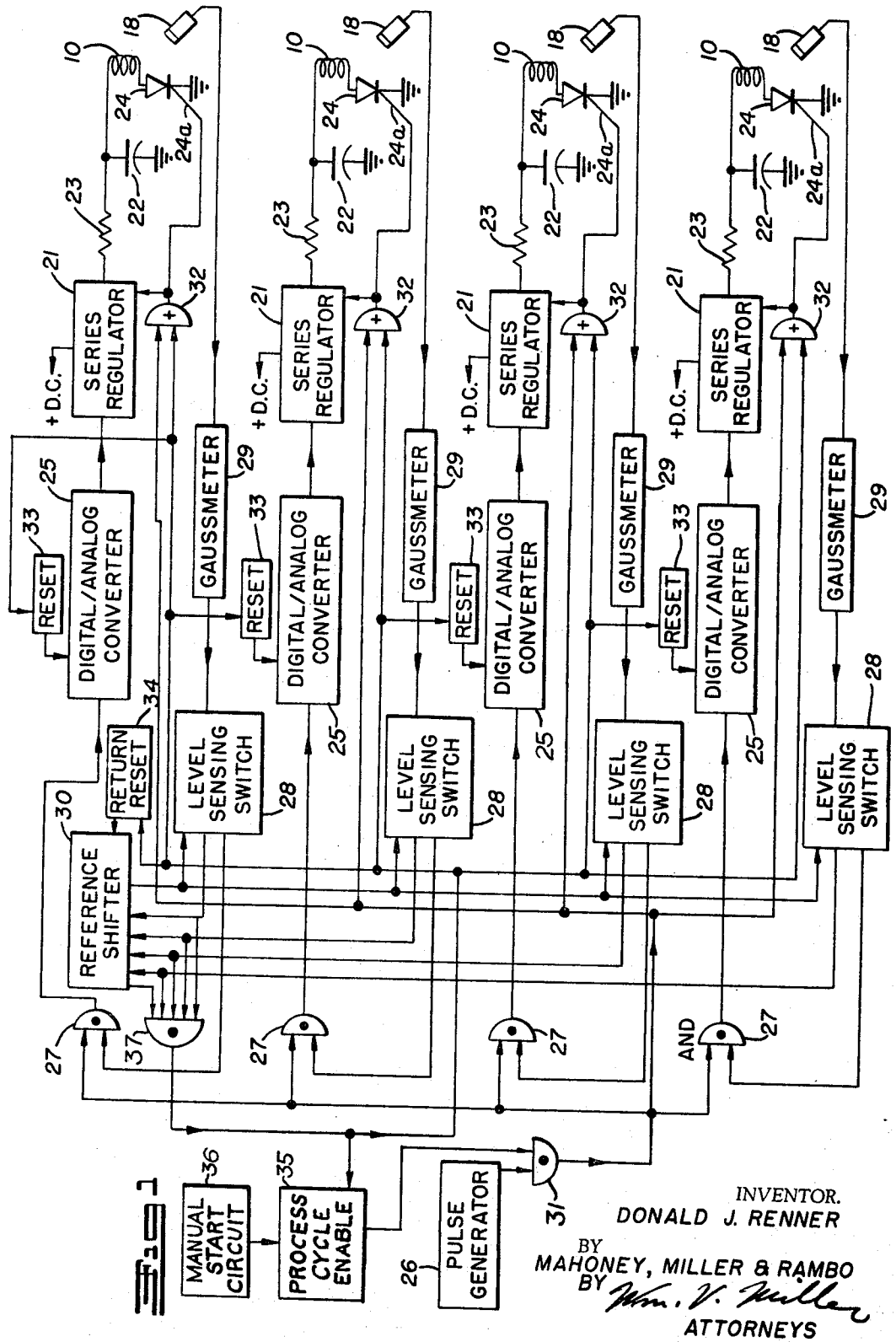


Fig. 1

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Filed April 18, 1966 3 Sheets-Sheet 2

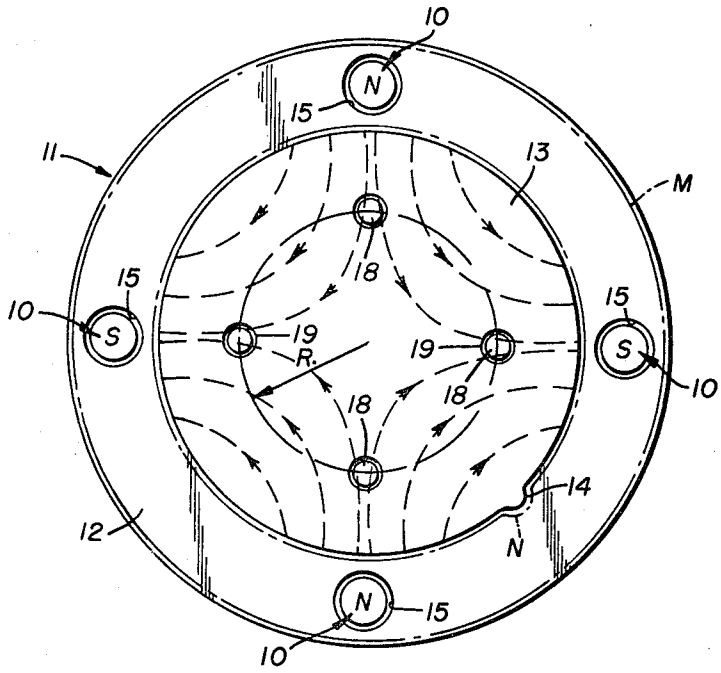


Fig 2

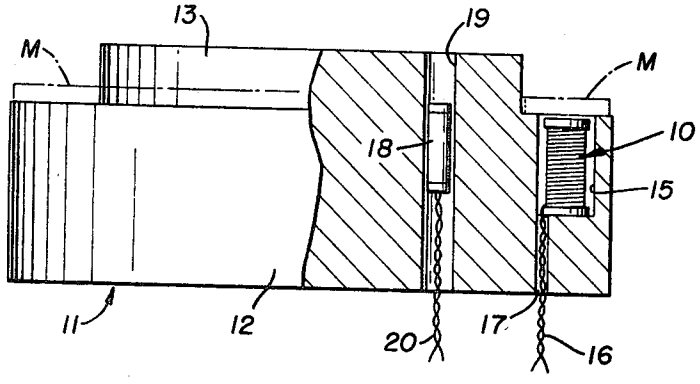


Fig 3

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METHOD AND APPARATUS FOR DEMAGNETIZATION OF MULTIPOLE MAGNETIC DEVICES

Filed April 18, 1966 3 Sheets-Sheet 3

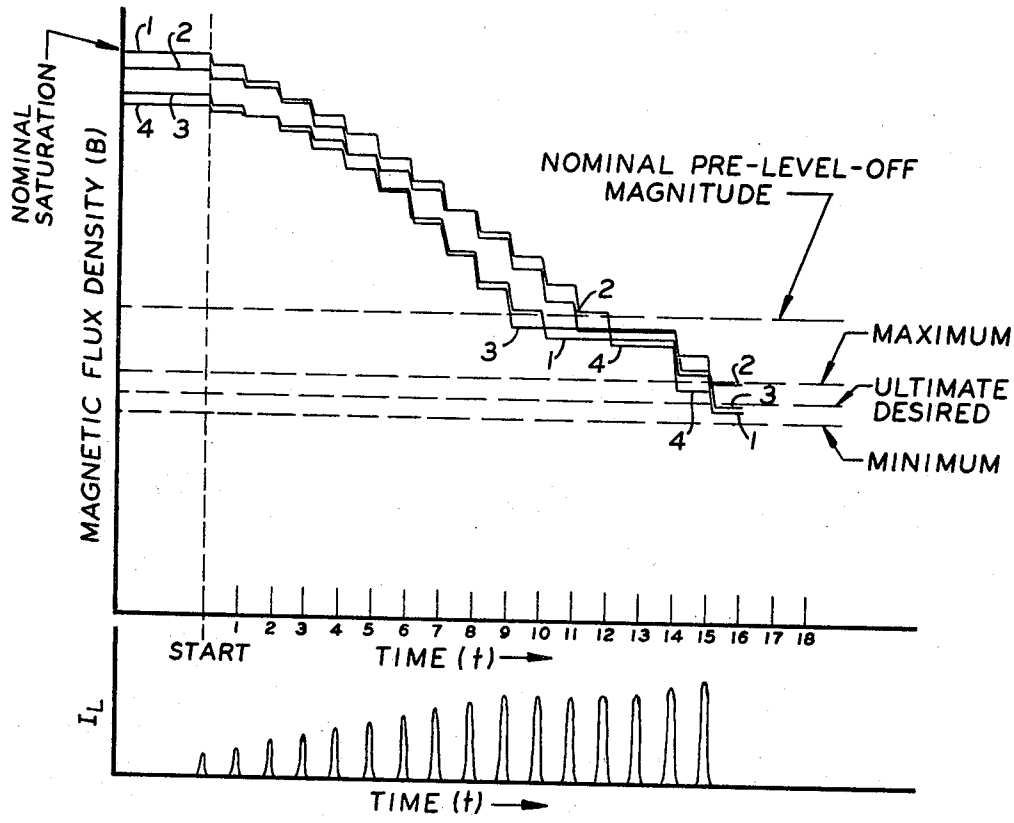


Fig 4

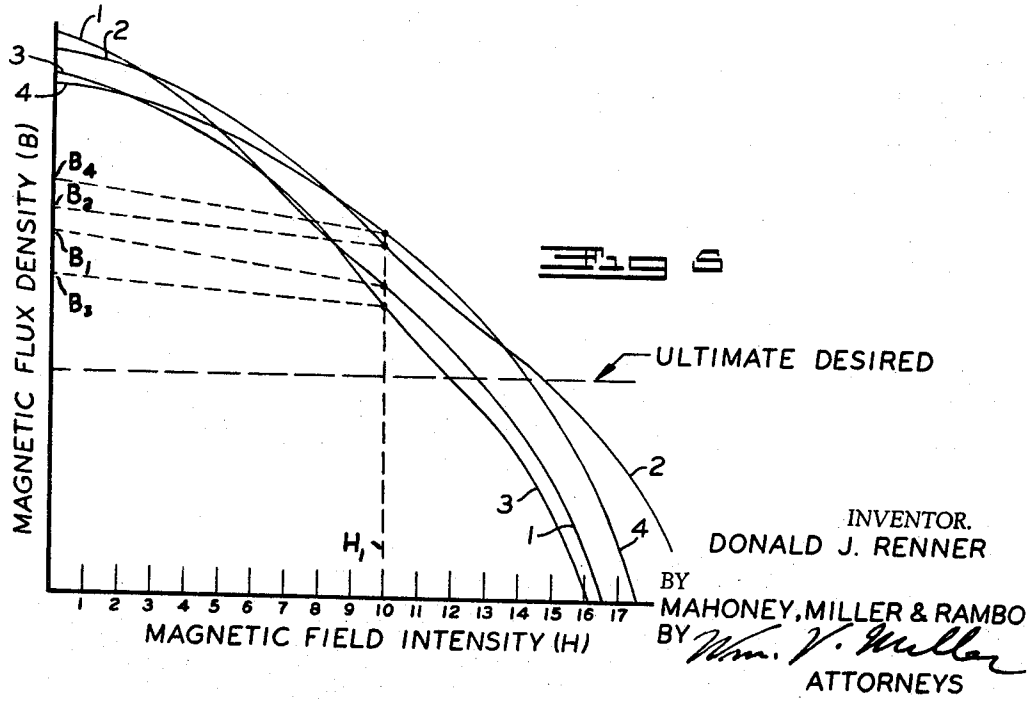


Fig 5

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METHOD AND APPARATUS FOR DEMAGNETIZATION OF MULTIPOLE MAGNETIC DEVICES

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9 Claims. (Cl. 317—157.5)

This invention relates, in general, to demagnetization of magnetized materials or devices such as permanent magnets. It relates, more specifically, to a method and apparatus for effecting the simultaneous, uniform demagnetization of a device having a multiplicity of poles.

In accordance with prior art methods and apparatus for producing magnetized devices or magnets, the devices or magnets are first magnetized to the saturation level of the particular material and then subjected to a demagnetization process in which the residual magnetic flux density is reduced to a predetermined, desired level. This is a conventional procedure for not only producing magnetic devices with a desired strength but for improving the stability of the magnetic device. Demagnetization of a conventional dipole magnetic device is effectively accomplished by positioning the device adjacent a magnetic field-producing, inductive device which is selectively energized to produce a relatively negative magnetic field intensity which opposes and reduces the residual magnetic flux density. The magnitude of the negative magnetic field intensity applied to the device determines the degree of reduction of the magnetic flux density and the magnetic field intensity for demagnetizing is sequentially increased in incremental steps to decrease the magnetic flux density of the device to the desired level.

Prior art apparatus and methods for demagnetization have only been found effective for demagnetization of the well known dipolar magnetic devices, such as the ordinary permanent magnet, and have not been found capable of effectively or efficiently demagnetizing devices having a multiplicity of poles, such as four or more. In such multi-pole magnetic devices, the demagnetization of any one specific pole will have an effect on the magnetic flux density of adjacent poles and localized variations in the magnetic characteristics of a multipole magnetic device at the several poles make it necessary to use correspondingly different magnetic field intensities at each of the poles in an attempt to obtain uniformity as to the resultant magnetic flux density of the several poles. Consequently, the application of prior art dipolar demagnetization apparatus and methods to the demagnetization of such multi-pole magnetic devices has required the utilization of trial and error techniques in attempting to reduce the magnetic flux density of each of several poles to a substantially identical level. Such trial and error techniques that have been utilized in the application of conventional, dipolar demagnetizing methods and apparatus to multi-pole magnetic devices often result in the production of multi-pole magnetic devices having substantial nonuniformity of flux density as between the several poles. These prior art techniques also require a relatively large amount of time to provide the necessary degree of demagnetization and must be manually controlled and closely monitored. Even with such close monitoring and control, a relatively large percentage of a production run may be found to be unsatisfactory in that the level of magnetic flux density of each of several poles may differ from the desired value or relative to each other as to present a variation which exceeds the maximum acceptable deviation from a desired value for the particular magnetic devices.

It is, therefore, the primary object of this invention to provide an apparatus and method for demagnetization of multi-pole magnetic devices.

It is a further object of this invention to provide a demagnetization apparatus and method for demagnetizing multi-pole magnetic devices which effects the simultaneous demagnetization of all poles to a predetermined, magnetic flux density within the limits of an accepted tolerance or predetermined deviation.

It is another object of this invention to provide demagnetization apparatus and method for demagnetizing multi-pole magnetic devices through automatically controlled apparatus and capable of effecting the simultaneous demagnetization of all poles to a predetermined magnetic flux density.

It is also an object of this invention to provide a method of demagnetization for multi-pole magnetic devices in which the demagnetization of all poles is effected simultaneously in two steps with the magnetic flux density of each pole being independently reduced to a predetermined value slightly greater than the ultimate desired value in a first step and simultaneously reducing the magnetic flux density to the ultimate desired value in a second step.

These and other objects and advantages of this invention will be readily apparent from the following detailed description of an embodiment thereof and the accompanying drawings.

In the drawings.

FIGURE 1 is a schematic diagram of the electrical circuitry of a demagnetizing apparatus embodying this invention for demagnetizing a four-pole magnetic device.

FIGURE 2 is a top plan view of a magnetic device holder showing the relative location of the demagnetizing magnetic field devices and the magnetic field detectors responsive to the magnetic field of the device.

FIGURE 3 is an elevational view of the magnetic device holder of FIGURE 2 partially sectioned to further illustrate the relative location of the demagnetizing field producing device, the magnetic field detectors and the magnetic device.

FIGURE 4 is a graphic representation of the demagnetization process of the four-pole magnetic device as demagnetized by the apparatus illustrated in FIGURES 1, 2 and 3.

FIGURE 5 is a graphic representation of the demagnetization characteristics of the several poles of the multipole magnetic device.

Having reference to FIGURES 2 and 3 of the drawings, a magnetic device M with which the apparatus of this invention may be utilized in the application of the method of demagnetization is seen to comprise a circular ring or annularly-shaped disc having a multiplicity of magnetic poles. This particular magnetic device M is formed with four magnetic poles and is illustrated for example only and is not to be considered as a limitation on the application of the apparatus and method of this invention. The poles are angularly displaced relative to each other at about 90° with each of the poles being effectively concentrated for illustrative purposes at the indicated north (N) and south (S) positions of FIGURE 2. The north and south pole indications of FIGURE 2 relates to the demagnetizing, magnetic field-producing devices of the apparatus and are disposed to coincide with the effective concentrated magnetic poles of the device to be subjected to a demagnetizing operation. In FIGURE 2, the broken arcuate lines are representative of the magnetic field produced by the magnetic device M and are not representative of the magnetic field produced by each of the demagnetizing devices **10**.

A holder **11** for supporting the demagnetizing devices **10** in the desired relationship for the particular magnetic device M comprises a cylindrical body **12** having a relatively smaller diameter, coaxially disposed cylinder **13** formed on one end face thus providing an annular surface for the

support and positioning of the magnetic device M. The smaller diameter cylinder **13** is adapted to project through the center opening of the annularly shaped magnetic device M and forms an orientating means for properly positioning the magnetic device M on the holder **11**. The magnetic device M may be provided with an indexing notch N for facilitating the location of the poles formed on the device. For cooperation with the indexing notch N, a mating indexing projection **14** may also be formed on the cylindrical surface of the smaller diameter cylinder **13**. This projection **14** will assist in locating the magnetic device M in the desired predetermined relationship to the holder and thus locate the several magnetic poles of the device M in predetermined relationship to the demagnetizing devices **10** carried by the holder **11**. The illustrated holder **11** is preferably formed from a nonmagnetic material to avoid interference with the magnetic field produced by the magnetic device M.

Each of the demagnetizing magnetic field-producing devices **10** comprises a suitably formed coil which is adapted to be positioned in a socket **15** formed in the cylindrical body **12**. Each device **10** is disposed in a similar socket **15** at the desired angular displacement with the axis of the magnetic field produced by the devices **10** being substantially normal to the surface of the cylindrical body **12** on which the magnetic device M is positioned. This arrangement will thus provide a magnetic field which is most effective in demagnetizing the magnetic device M. The conductors **16** connecting with the coil or demagnetizing device **10** extend through an aperture **17** opening at the opposite face of the cylindrical body **12** for convenience in connection with the apparatus of this invention. If desired, the socket **15** may be filled with a suitable insulating compound to secure the demagnetizing device **10** in the socket and provide the necessary insulation.

During the course of the demagnetizing operation, it is necessary that the magnitude of the magnetic flux density of the device M be ascertained to assure control of the demagnetization operation in accordance with the method of this invention. A determination of the magnetic flux density may be readily accomplished by means of a magnetic field-responsive device, such as a Hall-effect device **18**. Each Hall-effect device **18** is mounted in a suitable protecting structure and is positioned in the holder **11** adjacent a respective one of the demagnetizing devices **10** and the associated pole of the magnetic device M. As best shown in FIGURE 3, each Hall-effect device is disposed in a cylindrical bore **19** extending axially through the cylindrical body **12** and smaller cylinder **13** of the holder. The several conductors **20** connected with the Hall-effect device extend outwardly from the cylindrical body **12** for connection with the apparatus. The bore **19** may also be filled with a suitable electrical insulating compound to securely position the Hall-effect devices **18** in the desired position and provide the necessary protection for the conductors **20**. All of the Hall-effect devices **18** are placed equidistantly from the center of the cylinder **13** and, therefore, are spaced equidistantly from the effective concentrated pole of the magnetic device M. Thus, the Hall-effect devices **18** will be primarily responsive to the magnetic field emanating from the respective pole and, in a uniform magnetic field condition wherein all poles have a magnetic flux density of equal magnitude, will provide an indication which is substantially identical.

Having reference, specifically, to FIGURE 1, the demagnetizing magnetic field-producing devices or coils **10** are shown connected in circuit with a suitable power source which is capable of providing the necessary energy. This power source may include a series regulator **21** which is connected to a source of direct current power and is operable to control the demagnetization. Connected in shunt relationship with each of the coils **10** is a suitable capacitor **22** capable of being charged and of storing sufficient electrical energy to energize the coils **10** upon discharge of the capacitor through the coil for effecting a demagnetization of a magnetic device. A series charging resistor **23** is connected between the capacitor **22** and the series regulator **21** to limit the charging current to an acceptable value. Connected in series with each of the coils **10** is a respective switching device **24** which is operable to control the flow of current through the coil **10** and the formation of the respective demagnetizing magnetic field. In the illustrated embodiment, this switching device **24** may comprise a silicon controlled rectifier which may be triggered from a non-conducting state to a conducting state by the application of a gating voltage to the gating terminal **24*a***.

The operation of this basic demagnetizing circuit consists of the alternate charging of the capacitor **22** and subsequent discharging of the capacitor through the coil **10** to produce the demagnetizing magnetic field. The resultant magnetic field intensities may be varied as desired through appropriate adjustment of the series regulator **21** to charge the capacitor **22** to a predetermined voltage. During the capacitor-charging portion of a cycle, the switching device **24** will be in a non-current conducting state and no current will flow through the coil **10**. After the capacitor **22** has been charged to a predetermined voltage, a trigger voltage is applied to the gating terminal **24*a*** of switching device **24** resulting in current conduction through the coil **10** and discharge of the capacitor **22**. Current conduction through the coil **10** will continue until the capacitor **22** has been discharged and the voltage reduced to the cut-off point of the switching device **24**. When the voltage has been reduced to the cut-off point or substantially zero, the switching device **24** will return to a nonconducting state and prevent further current conduction through the coil **10**. At this time, the capacitor **22** may again be charged for a subsequent discharge cycle through the coil **10**. As in accordance with conventional demagnetizing operations, the electrical energy stored by the capacitor, as determined by the voltage, is sequentially increased in predetermined increments for each subsequent and succeeding cycle for increased energy transfer to the magnetic field producing devices for a stepwise increase in the demagnetization. This process is continued until attainment of the desired magnetic flux density in the magnetic device.

The series regulator **21** is a device employing well known circuitry which provides an output voltage which is dependent on an input signal. The input signal to the series regualtor **21** will thus limit the output voltage of the series regulator to a proportional value of the voltage of the D.C. power source. Through appropriate adjustment of the input signal to the series regulator, the output voltage may be sequentially increased in predetermined increments to provide stepwise increases in the magnetic field intensity for demagnetization of the magnetic device M. The control of this input signal for the series regulator **21** may be provided by manually operated apparatus and circuitry or, as in the case of the present invention illustrated herein, through circuitry providing automatic sequential control. Each channel of the apparatus associated with a demagnetizing device **10** may thus be independently controlled to perform a demagnetizing operation with respect to a specific pole of the magnetic device M.

In accordance with prior art techniques and methods, the demagnetizing operation is initiated after the magnetic device has been first magnetized to saturation and is continued until the desired magnetic flux density is obtained. This technique is satisfactory in the instances where a single dipole type magnetic device is being processed; however, where a multi-pole magnetic device must be processed in this manner, the inter-relationship and interaction of each of the poles of the device and the localized variations in magnetic properties of the material will prevent such a simple process from producing a multi-pole magnetic device having a satisfactory field pattern with each pole having the desired magnetic flux density. Accordingly, it is necessary to continuously monitor the magnetic flux density of each of the poles and independently control the demagnetization of the respective

poles to obtain the optimum uniform magnetic flux density. Such manual monitoring and control of the demagnetization process substantially increases the cost of production and thus the production of multi-pole magnetic devices in accordance with prior art procedures has utilized only the minimum control necessary to approximately obtain an ultimate, desired magnetic flux density for the several poles which may deviate from the ultimate, desired flux density to a relatively large extent. Demagnetization in accordance with prior art practices is also incapable of consistently producing multi-pole magnets wherein the interpole deviation is within prescribed limits. Consequently, the rejection rate of such magnetic devices demagnetized in accordance with prior art practice on production runs has been relatively high which further increases the per unit cost of production.

One of the characteristics of a magnetic device which has prevented the application of prior art, simple dipolar demagnetization apparatus and methods to multi-pole demagnetization is the variation of demagnetization characteristics occurring in localized areas of a magnetic material. In multi-pole magnetic devices, the demagnetization characteristics of the material forming each of the poles of a particular magnetic device may be so substantially different as to prevent the utilization of a common control in performing the demagnetization operation. Each of the poles may be demagnetized at a relatively different rate for a particular demagnetizing magnetic field intensity. This effect is diagrammatically illustrated in FIGURE 5 wherein it can be seen that subjection of each pole of a four-pole magnetic device having the four respective demagnetization characteristics to a specific magnetic field intensity will result in a substantial deviation in the relative magnetic flux density for each of the poles. In addition to dissimilarities in the demagnetization characteristics, the saturation level of magnetization for each of the poles may be dissimilar. This is also illustrated in FIGURE 5 wherein each of the poles is seen to have a different magnetic flux density for the application of a zero magnetic field intensity to the magnetic device. Thus, it will be readily seen that the application of a specific demagnetizing or relatively negative magnetic field intensity H_1 to each of the poles will produce the respective resultant magnetic flux densities B_1 through B_4. It will be noted that the magnetic flux densities of the respective poles increase slightly from the value attained by the application of the magnetic field intensity H_1 to the indicated densities B_1 through B_4 after removal of the field as a consequence of the minor hysteresis effect. These magnetic flux densities of the respective poles are widely varied and may further exceed the differences noted at the saturation level for a zero magnetic field intensity. An increase or decrease of the applied magnetic field intensity from the illustrated magnetic field intensity H_1 will also result in differences in the relative magnetic flux density of the respective magnetic poles.

The nonlinearity of the demagnetization characteristics of each of the respective poles of a multi-pole magnetic device prevents the application of a single step type method and a simple multi-pole or multi-channel demagnetization apparatus with only the most simple control system for continuous demagnetization from the saturation level to the desired magnetic flux density. It will be obvious from FIGURE 5 that simultaneous demagnetization by subjection of all poles to the same magnetic field intensity will result in dissimilar magnetic flux densities for the respective poles as determined by the specific demagnetization characteristics of the material forming each pole of a particular magnetic device.

The effect of such dissimilar demagnetization characteristics on the simultaneous demagnetization of a multi-pole magnetic device is obviated by the apparatus and the method of this invention for performing the demagnetization operation. This method is graphically illustrated in FIGURE 4 and, in general, consists of performing the demagnetization operation in two steps by subjecting each pole to a pulse-form magnetic field intensity with successive pulses being incrementally increased in magnitude. The pulse-form current I_1 graphically illustrated in FIGURE 4 is the current through the demagnetization coil **10** and is, therefore, representative of the applied magnetic field intensity. Demagnetization of the magnetic poles is most effectively accomplished through increasing the magnitude of the current pulses through the demagnetization coil **10** and the resultant demagnetizing magnetic field intensity in successive, relatively small incremental steps over a predetermined time interval. Thus, the demagnetization will appear as a step-type wave form on a time basis. In the first step, each of the poles is demagnetized to a nominal predetermined magnetic flux density which is only slightly greater than the ultimate desired flux density. The control of the demagnetization of each pole is independent of each other pole and is continued only until the magnetic flux density of the respective pole has been reduced to the nominal predetermined value or prelevel off-flux density. As each pole attains the prelevel-off magnetic flux density, further decreases in the magnetic flux density are delayed until all of the poles have reached this nominal prelevel-off flux density. As the magnetic flux density of a pole reaches the prelevel-off magnitude, the magnetic field intensity is continued to be applied but is not further increased until all poles have attained the prelevel-off magnetic flux density. Only the demagnetization current for pole number **3** is illustrated in FIGURE 4 and illustrates the discontinuance of further demagnetization when the magnetic flux density of this pole reaches the nominal prelevel-off magnitude. During this interval, the magnitude of demagnetizing current pulses will be maintained at the last attained level until initiation of the second step of the demagnetization operation. The poles first to reach this prelevel-off flux density will remain at substantially this value until all of the poles have been demagnetized to the prelevel-off magnetic flux density. Continued application of demagnetizing pulses of the same magnetic field intensity will substantially prevent the magnetic flux density of an adjacent pole from affecting the flux density of a pole which first reaches a predetermined value.

The second step of the demagnetization operation is initiated when all of the poles have been demagnetized to a magnetic flux density equal to or less than the nominal prelevel-off value. During the second step each of the poles is again subjected to pulse-form magnetic field intensities which are successively increased in predetermined increments. The demagnetization process continues with respect to each pole until that pole has been demagnetized to the desired magnetic flux density. All of the poles will reach the desired flux density at approximately the same time regardless of dissimilarities in the respective demagnetization characteristics as the second step of the demagnetization results in operation on only a relatively small portion of the demagnetization characteristic. By appropriately selecting the nominal prelevel-off magnetic flux density to be only slightly greater than the ultimate desired magnetic flux density, the effect of differences in the demagnetization characteristics of the materials forming each of the specific poles may be minimized as a result of minimizing the total change in magnetic field intensity required to effect the second step of the demagnetization operation.

As a practical matter, achievement of the ultimate desired magnetic flux density is difficult, if not impossible, and flux densities which deviate slightly from the desired are determined to be acceptable. Acceptable deviations, either above or below the desired, are defined by appropriate production standards or specific criteria for the particular magnetic device and are indicated in FIGURE 4 as maximum and minimum limits. The pulse-form magnetic field intensity is preferably increased by increments which are effective in decreasing the flux

density of each of the poles, at each pulse, by an amount which is slightly less than the difference between the maximum and minimum allowable flux densities. Thus, if a particular magnetic field intensity applied to a pole results in a decrease of the magnetic flux density to a magnitude slightly above the maximum allowable, a succeeding pulse having an incrementally greater value is applied and thereby decreases the magnetic flux density to a magnitude within the prescribed maximum and minimum limits. Irrespective of the magnitude of the magnetic flux density at the point immediately preceding the last pulse of applied magnetic field intensity, the applied magnetic field intensity for the last pulse will be effective in decreasing the flux density to a value between the maximum and minimum allowable limits but will not decrease the flux density to a value below the minimum allowable flux density.

Greater precision in demagnetization may be readily achieved by the method of this invention through decreasing the difference between the nominal prelevel-off flux density and the ultimate desired flux density and decreasing the incremental increase in magnetic field intensity. A decrease in the incremental increase in magnetic field intensity will permit reduction of the allowable deviation as determined by the maximum and minimum limits provided that the relative relationship of the nominal prelevel-off magnetic flux density to the desired flux density is also decreased proportionally.

The multi-pole demagnetization apparatus for effecting the demagnetization of a multi-pole magnetic device in accordance with the method of this invention is illustrated in FIGURE 1. The illustrated apparatus includes four separate channels for independent control and operation of the demagnetizing magnetic field-producing devices **10** for each of the poles. All of the channels are of identical construction and the following description as it relates to a single channel is equally applicable to the other channels. This apparatus also continuously monitors the magnetic flux density of each of the poles of a magnetic device undergoing demagnetization and provides an appropriate, related control signal for automatic operation of the demagnetization process. This process is automatically performed as briefly outlined in the preceding paragraphs.

A signal for control of the series regulator **21** is provided by a digital-to-analog converter **25** responsive to a timing pulse to provide a specific control signal to the series regulator at a predetermined time resulting in charging of the regulator at a predetermined time resulting in charging of the capacitor **22**. In addition to the provision of the control signal at a predetermined time, the signal from the converter **25** is effective to control the output of the series regulator **21** by increasing the output thereof in uniform increments for each timing pulse received by the converter. The sequential, incremental increases in the output voltage of the series regulator **21** produce step increases in the current I_1 through the respective demagnetizing device **10** and a consequent increase in the pulse-form magnetic field intensity applied to the magnetic device.

The timed operation of the digital/analog converter **25** is controlled by a pulse generator **26** which provides a continuous series of timing pulses. The timing pulses from the pulse generator **26** control the converter **25** through a logic circuit **27** of the AND type having a first input connected with the pulse generator **26**.

A second input to each AND circuit **27** is provided by a level sensing switch **28** connected to a gaussmeter **29** which has a respective one of the Hall-effect devices **18** forming the probe thereof. The level sensing switch **28** is operative to provide an output to one of the inputs of the AND circuit **27** whenever the level of magnetic flux density of the magnetic device as determined by the gaussmeter is above a predetermined value. Since there are two steps in the operation of this apparatus in accordance with the method of this invention to effect the demagnetization, the level sensing switch is designed to provide an output to the AND circuit **27** at either of the two states; that is, the switch **28** will provide an output when the magnetic flux density of the specific pole is greater than the nominal prelevel-off magnetic flux density in its first state of operation and will provide an output when the magnetic flux density is greater than the ultimate desired magnetic flux density. A change in the state of operation of the level sensing switch **28** is effected by a reference shifter circuit **30**. The operation is such that the switch **28** will provide an output during the time that the magnetic flux density as determined by the gaussmeter **29** is above the nominal prelevel-off magnetic flux density and will cease to provide the output once this magnitude of flux density is reached. No further output will be provided by the switch **28** until its reference is shifted by operation of the reference shifter **30** to the second state of operation wherein an output will again be provided for as long as the magnetic flux density of the specific pole of the magnetic device, as determined by the gaussmeter **29**, will be above the ultimate desired magnetic flux density.

A timing pulse from the pulse generator **26** and an output signal from the level sensing switch **28** must be concurrently applied to the AND logic circuit **27** to provide a timing pulse to the digital/analog converter **25**. Upon receipt of each succeeding pulse, the control signal from the digital/analog converter **25** will be sequentially stepped to a higher value in successive increments and transmitted to the series regulator **21** to sequentially increase the output thereof.

As previously described, the output of the series regulator **21** is utilized in charging the capacitor **22** to a value as determined by the operation of the digital/analog converter **25** before subsequent discharge through the coil **10** to produce the demagnetization field. Discharge of the capacitor **22** is controlled by the SCR switching device **24** which may be triggered to a current conducting state by the application of a suitable trigger signal to the gating terminal **24***a*. This trigger signal is also provided by the pulse generator **26** which is connected to the gating terminal **24***a* through an AND logic circuit **31** and an OR logic circuit **32**. A demagnetization cycle is terminated by sufficiently discharging the capacitor **22** whereby a sustaining current is no longer supplied the SCR switching device **24** and the SCR will return to a nonconducting state. In order to obtain the necessary discharge of the capacitor **22**, it is necessary to interrupt the charging operation of the series regulator for the discharge time interval. Interruption is readily obtained through inclusion of a gating circuit in the series regulator **21** which operates to open the output circuit of the regulator. This gating circuit may be of the type which is normally closed but becomes open circuited for a predetermined time interval on receipt of a suitable signal. In this circuit, this signal is the trigger signal applied to the gating terminal **24***a* and is applied to the gating circuit by interconnection of the series regulator **21** with the output of the OR logic circuit **32**.

When the magnetic flux density of the magnetic device reaches the prelevel-off magnitude, the level sensing switch **28** will be operative to prevent transmission of a gating signal to the AND circuit **27** thereby suspending further operation of the digital/analog converter **25** as to continued, sequential increasing demagnetization. It is desirable that the poles of the magnetic device which first attain the nominal prelevel-off magnetic flux density be continued to be pulsed with a demagnetizing magnetic field intensity of the last attained value to further assure a substantially uniform magnetic flux density for all of the poles at the initiation of the second step of the demagnetizing operation. The series regulator **21** and the digital/analog converter **25** are operable to continue charging of the capacitor **22** to the last attained voltage

value and the coil **10** will thus be enabled to continue producing the demagnetizing field on discharge of the capacitor. Triggering pulses will continue to be applied to the gating terminals for cyclic energization of the respective coils **10**.

An output signal from each level sensing switch **28** is also applied to the reference shifter **30**. The reference shifter **30**, which may also be a logic circuit, is responsive to the simultaneous application of a signal from each of the channels to provide an output signal. Each level sensing switch **28** is adapted to provide a signal for operation of the reference shifter when the magnetic flux density of the respective pole reaches the nominal prelevel-off magnetic flux density. When such a signal is received simultaneously from each of the level sensing switches **28**, a reference shifting signal will be provided by the reference shifter **30** for triggering the respective level sensing switches **28** to the second state of operation. In this second state of operation, the level sensing switches **28** will again provide a signal to the AND circuit **27** resulting in continued operation of the digital/analog converter **25** to permit further increase in the magnitude of the demagnetization pulses applied to the respective magnetic poles. This second state of operation will then continue until the magnetic flux density of the respective pole attains the ultimate desired magnetic flux density. Attainment of the ultimate desired magnetic flux density will again result in elimination of the output signal from each of the level sensing switches **28** to the respective AND circuit **27** and prevent the transmission of further timing pulses to the digital/analog converter **25** which would further increase the magnitude of the demagnetization field.

A demagnetization operation for a particular magnetic device M is concluded when all level sensing switches **28** reach the second level of operation. At this time, the demagnetization operation is terminated and the circuit may be returned to its initial state through appropriate resetting of the several circuit elements and removal of the magnetic device M from the holder **11**. As each level sensing switch **28** reaches the second level of operation, a signal is transmitted to the reference shifter **30** to terminate the demagnetization operation and initiate resetting of the several circuit elements to their initial state. Each of the digital/analog converters **25** must be reset to a predetermined starting point for a subsequent demagnetization operation. Also, the reference shifter **30** must be reset and the capacitors **22** must be discharged prior to removal of the demagnetized magnetic device M from or placement of a succeeding magnetic device on the holder **11**.

Initiation and termination of a demagnetization operation is effected by operation of the AND circuit **31** through which the timing pulses from the pulse generator **26** must pass for operation of the digital/analog converters **25** and triggering of the SCR switching devices **24**. The necessary second input signal to the AND circuit **31** is provided by a process cycle enable circuit **35**. This circuit is designed to provide a second input signal for a predetermined interval of time which is adequate for completion of demagnetization operation. In the illustrated embodiment of the invention, a manual start circuit **36** connected with an input of the process cycle enable circuit **35** may be selectively actuated to provide a signal for initiation of the operation of the latter. The process cycle enable circuit **35** is also designed to be controlled upon reception of a second input signal to terminate a demagnetization operation through elimination of the second input signal to the AND circuit **31**. This second input signal for termination of a demagnetization operation is provided by an AND logic circuit **37** having five input circuits. Four of these input circuits are connected to respective input circuits to the reference shifter **30** and receive the signals from the respective level sensing switches **28**. The fifth input signal for the AND circuit **37** is provided by the reference shifter **30** when the latter has received a signal from each of the level sensing switches **28** indicating conclusion of the first stage of the demagnetization operation. The signal from the reference shifter **30** to the AND circuit **37** is not applied until after the signal from the level sensing switches **28** has terminated and a termination signal is not transmitted to the process cycle enable circuit **35** at this time. A termination signal will only be transmitted at the conclusion of the second stage of the demagnetization operation and the AND circuit **37** has again received a signal from each of the level sensing switches **28** in addition to the signal from the reference shifter **30**.

The termination signal from the AND circuit **37** is also transmitted to a reset circuit **33** operatively connected with each of respective digital/analog converters **25** and to a return reset circuit **34** connected with the reference shifter **30**. Each of the reset circuits is operative to return the respective circuit to its initial state of operation. Simultaneously, the termination signal is utilized to trigger the SCR switching devices **24** to a conducting state and discharge the capacitors **22**. This trigger signal is applied through the OR circuits **32** which are also connected with the AND circuit **37**. No further demagnetization will occur after discharge of the capacitors **22** since the continuous train of trigger pulses supplied by the pulse generator **26** has been interrupted by elimination of the second input signal to the AND circuit **31**. At this time, the magnetic device M may be removed from the holder **11** without disruption of the level of magnetization attained through the demagnetization operation. A subsequent demagnetization operation may be initiated at this time through actuation of the manual start circuit **36**.

The several electrical circuit components of this apparatus are only illustrated by representative block diagrams as the components are of a construction well known to those skilled in the art. The specific circuits of these components, being well known, may also be readily interconnected as indicated in the assembly of a demagnetizing apparatus embodying this invention. Details of construction and operating criteria for demagnetization of a particular magnetic device are within the comprehension of those skilled in the art and further specific description is omitted.

It is readily apparent from the foregoing detailed description that this invention provides a method and apparatus for effecting the demagnetization of a multipole magnetic device. The method permits simultaneous demagnetization of a multiplicity of poles on a particular magnetic device and is capable of demagnetizing each pole to a desired value with all of the poles having substantially the same resultant value. Performance of the demagnetization operation in two steps results in a relatively high degree of precision with production of relatively few magnetic devices which do not meet the desired specifications. The apparatus is automatically operable in performance of a demagnetization operation and is operable to minimize the time required for a demagnetization operation.

According to the provisions of the patent statutes, the principles of this invention have been explained and have been illustrated and described in what is now considered to represent the best embodiment. However, it is to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

Having thus described this invention, what is claimed is:

1. The method of decreasing the magnetic flux density of a multi-pole magnetic device consisting of subjecting each pole to a respective, independently controllable, relatively negative magnetic field intensity which is applied until the magnetic flux density of the specific pole is reduced to a predetermined nominal magnitude which is greater than an ultimate desired magnetic flux density,

and again subjecting each pole to a respective, independently controllable, relatively negative magnetic field intensity after the magnetic flux density of all poles has been reduced to the predetermined nominal value to reduce the magnetic flux density of each of the poles to substantially the ultimate desired value.

2. The method of decreasing the magnetic flux density of a multi-pole magnetic device according to claim 1 with the negative magnetic field intensity for reducing the magnetic flux density of a particular pole to the predetermined nominal magnitude continued to be applied until the magnetic flux density of each of the poles has been reduced to this magnitude.

3. The method of decreasing the magnetic flux density of a multi-pole magnetic device according to claim 1 with the magnetic field intensity being applied in sequential pulses with each pulse being of an incrementally greater magnitude.

4. The method of decreasing the magnetic flux density of a multi-pole magnetic device according to claim 3 wherein the incremental increases in magnetic field intensity are of a magnitude to effect a decrease in magnetic flux density which is slightly less than the magnitude of the difference between a maximum and a minimum ultimate desired magnetic flux density determined to be acceptable.

5. Apparatus for decreasing the magnetic flux density of a multi-pole magnetic device to an ultimate desired magnitude comprising independently operable demagnetization means adapted to be operatively associated with a respective pole of the magnetic device for subjecting the respective pole to a relatively negative magnetic field intensity, magnetic-flux-density-responsive means for providing a signal related to the magnetic flux of each of the poles, and circuit means connected with each of said demagnetization means and a respective one of said flux-density-responsive means to control the magnitude of the magnetic field intensity in accordance with said signal, said circuit means being operable to increase the magnetic field intensity applied to a particular pole to effect a reduction of the magnetic flux density of the respective pole to a predetermined nominal magnitude which is greater than the ultimate desired in a first step and to further decrease the magnetic flux density to the ultimate desired after the magnetic flux density of each of the poles has been first reduced to the nominal magnitude.

6. Apparatus according to claim 5 wherein each said demagnetization means comprises an electromagnetic inductive device adapted to be positioned in inductively coupled relationship to a respective pole of the magnetic device.

7. Apparatus according to claim 5 wherein said circuit means is operable to apply a magnetic field intensity to a specific pole in sequential pulses with each pulse being of an incrementally greater magnitude.

8. Apparatus according to claim 7 wherein said circuit means is operable, on reduction of the magnetic flux density of a specific pole to the predetermined nominal magnitude, to continue the application of pulses of magnetic field intensity to the specific pole at the last attained magnitude until the magnetic flux density of all of the poles has been reduced to the predetermined nominal value.

9. Apparatus according to claim 5 wherein said circuit means includes a selectively adjustable power source connected in circuit with said demagnetization means for the energization thereof to provide a relatively negative magnetic field intensity, a first circuit connected with said power source to control the magnitude of each pulse of magnetic field intensity applied to the magnetic device in sequentially increasing each successive pulse by a predetermined increment, and a second circuit connected with said first circuit and said magnetic-flux-density-responsive means operable to prevent further incremental increase of successive pulses of magnetic flux intensity when the magnetic flux density of the specific pole reaches the predetermined nominal magnitude or the ultimate desired magnitude, said second circuit being connected with each other magnetic-flux-density-responsive means and operable to permit further incremental increase of successive pulses of magnetic flux intensity applied to a specific pole when the magnetic flux density of each pole of the magnetic device is reduced to the predetermined nominal magnitude.

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