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UK CL (Edition V) H3U

INT CL⁷ G01H, G11B, H03H

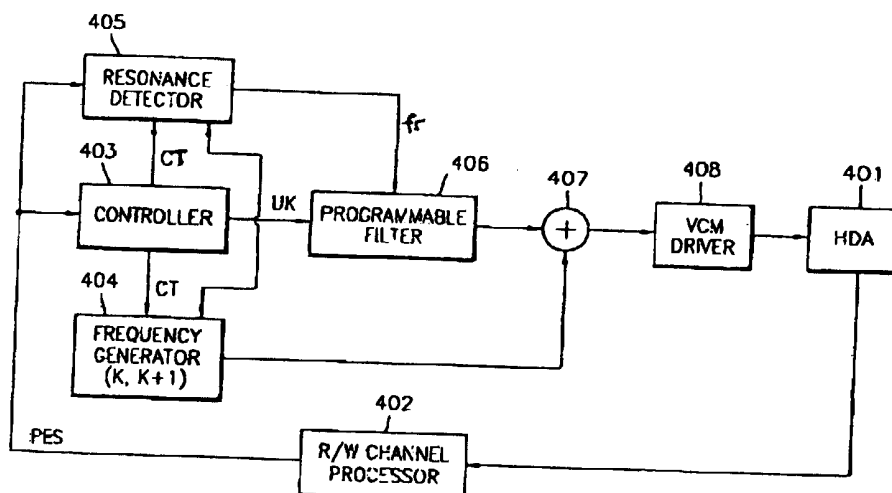
Other: Online: WPI, EPODOC, JAPIO

(54) Abstract Title

Apparatus and method for removing a resonant frequency

(57) An apparatus and a method for removing a resonant frequency of a system (e.g. a hard disk drive), in which resonant frequency occurring in a head stack assembly having a head for reading/writing data is identified and filtered to prevent mechanical damage caused by resonance. A frequency generator 404 generates a signal with which the system is artificially excited. A resonant frequency is identified from a head position error signal PES by a resonance detector 405, and then the system is adapted, such as by adapting a programmable filter 406, so that the identified resonance frequency is filtered. Thus, resonant frequency components above the Nyquist frequency of the system can be identified. Also, resonant frequencies can be identified very easily in the time domain without a complicated calculation process such as an additional frequency transformation process. Coefficients of the programmable filter are updated using the identified resonant frequency to prevent mechanical damage caused by resonance and improve a servo tracking performance and reliability of data.

FIG. 4



GB 2 381 973 A

FIG. 1 (PRIOR ART)

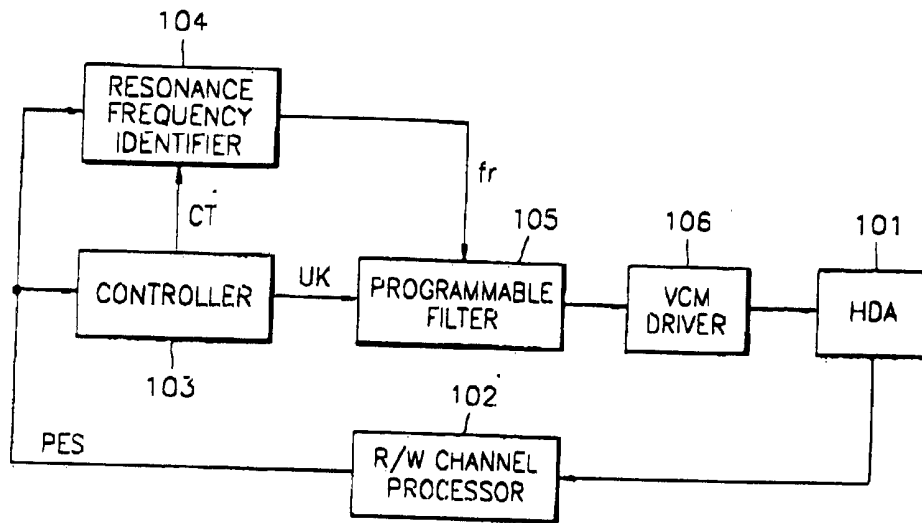


FIG. 2

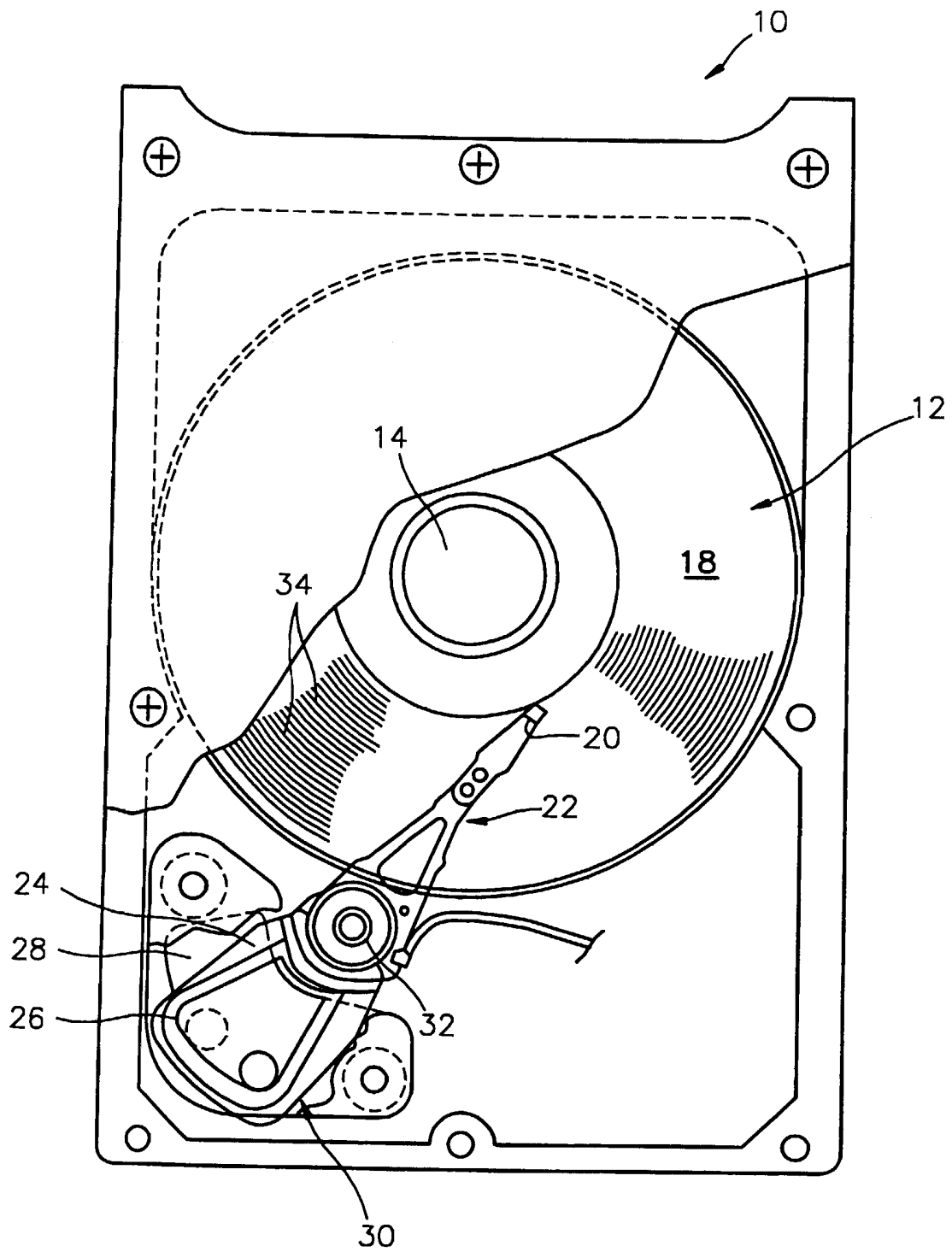


FIG. 3

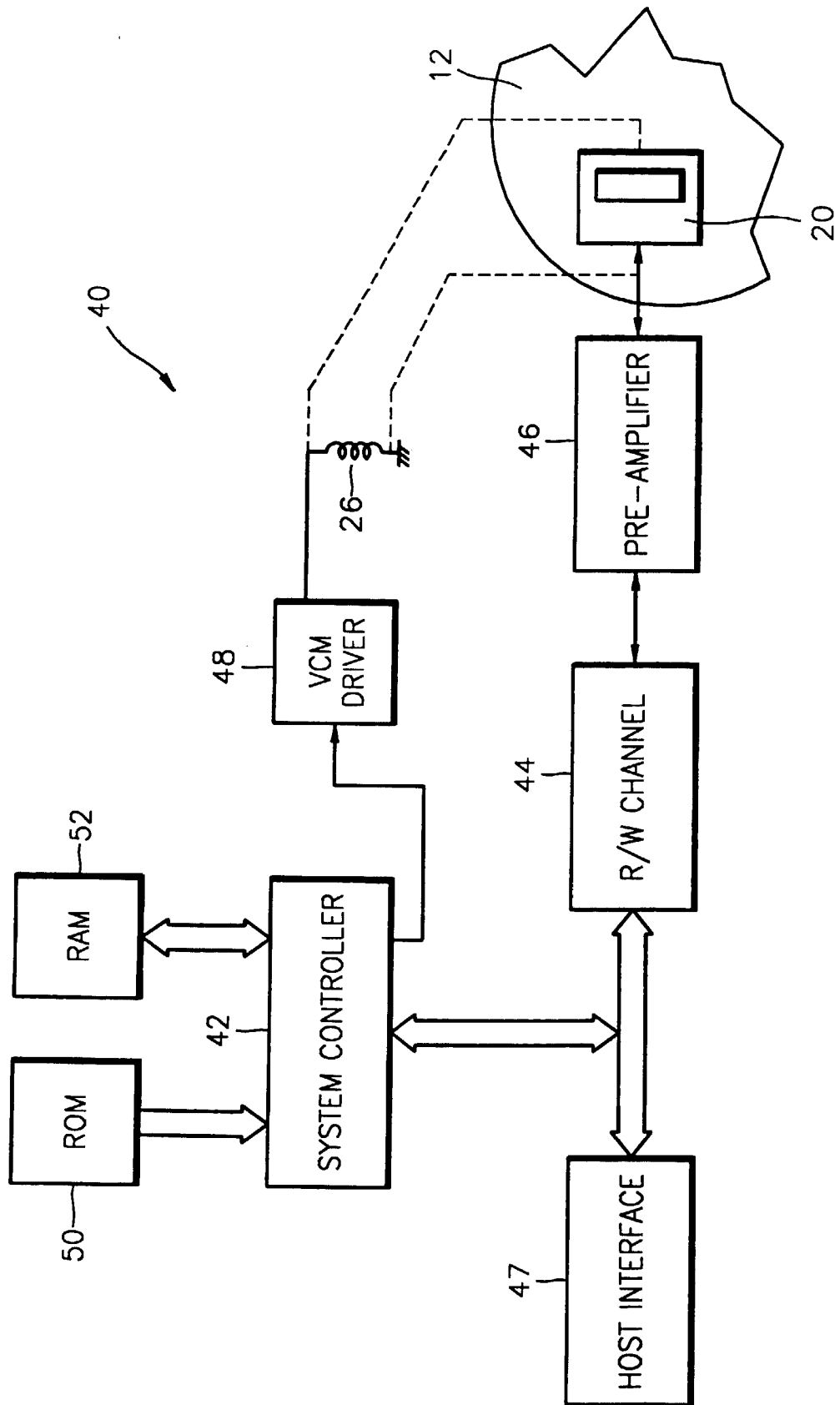


FIG. 4

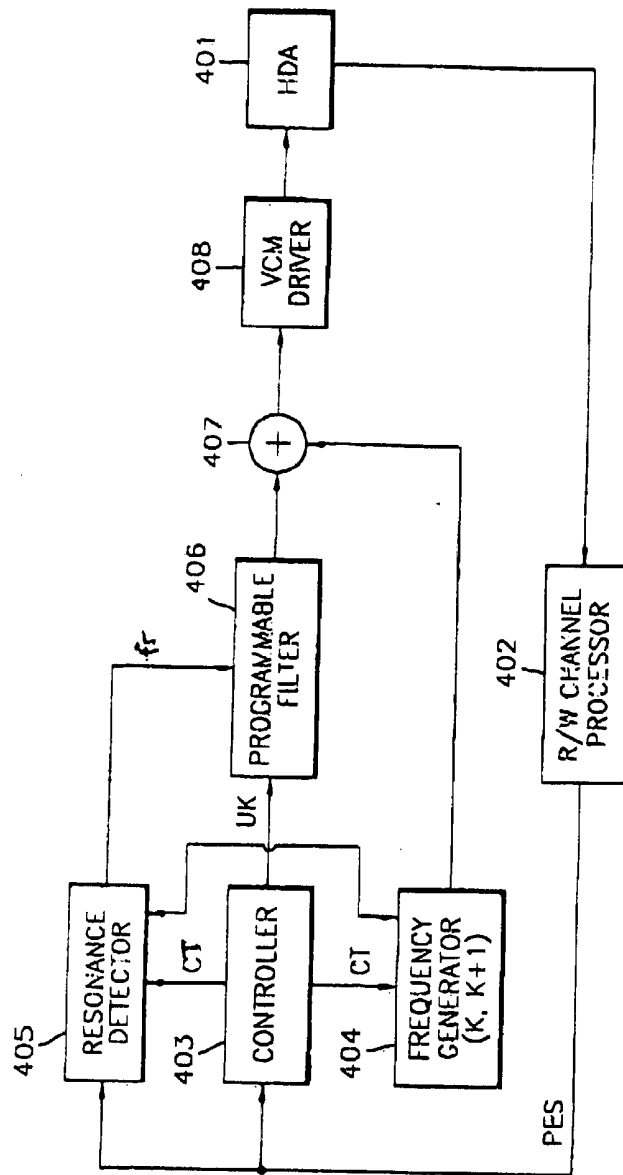


FIG. 5

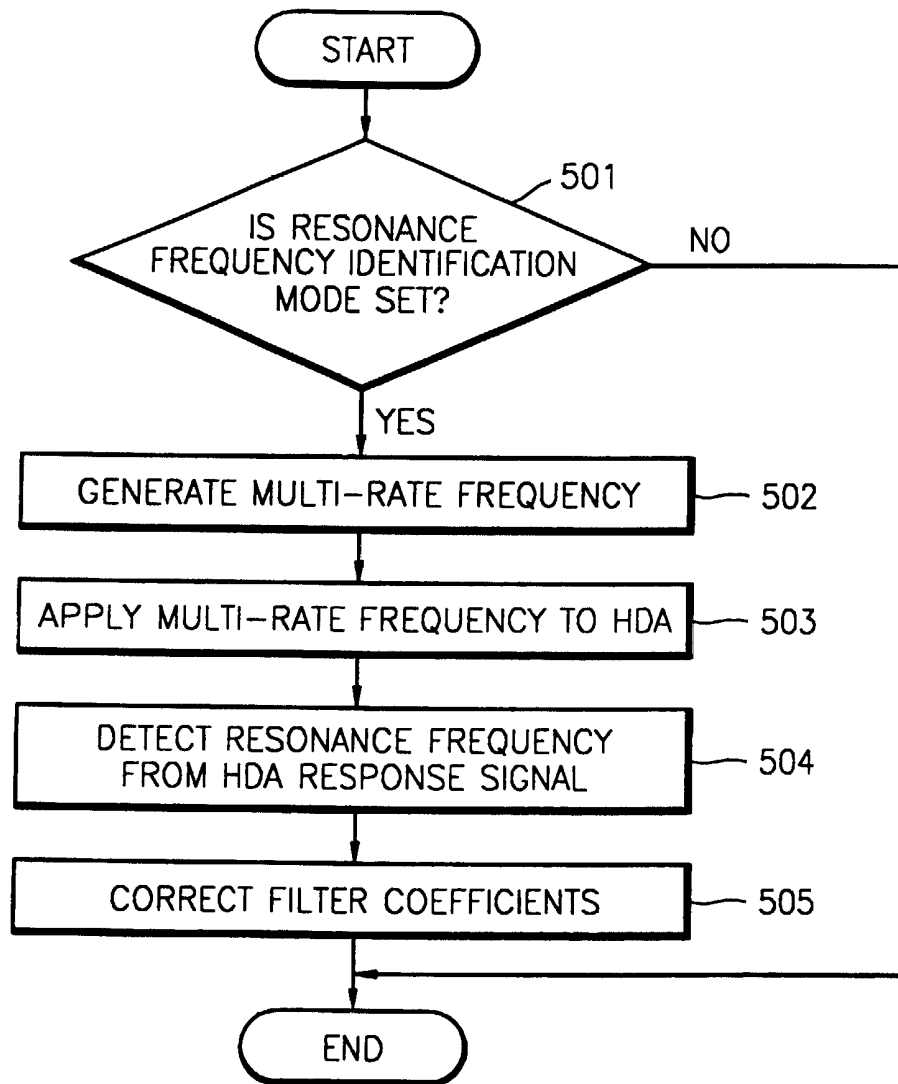


FIG. 6

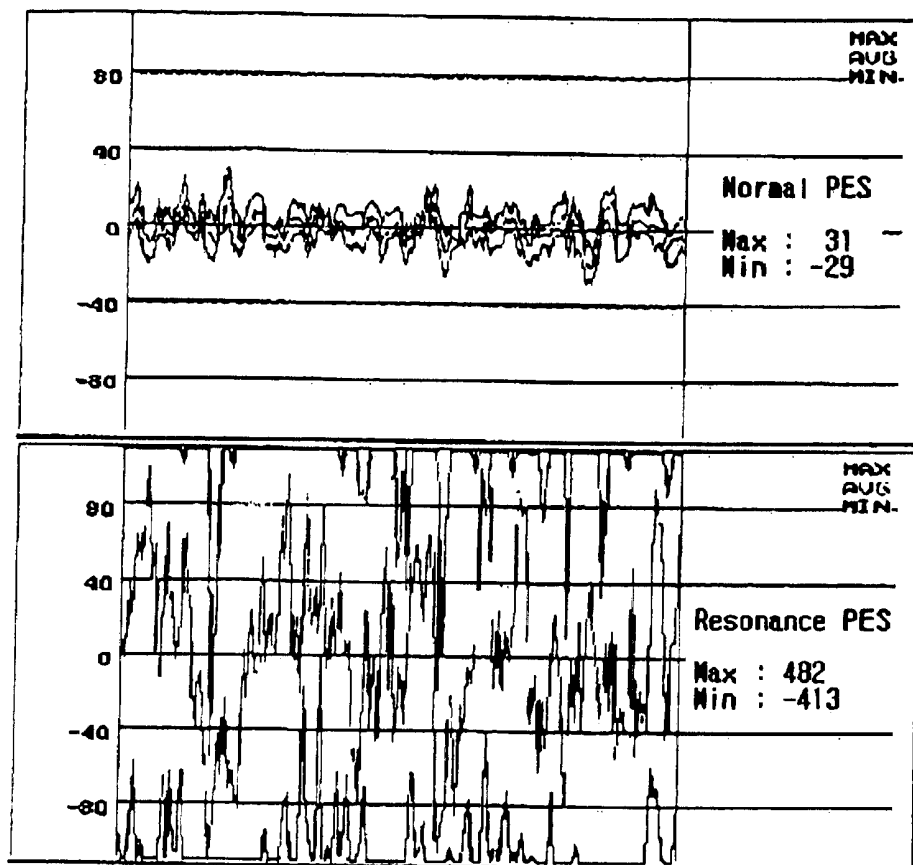


FIG. 7

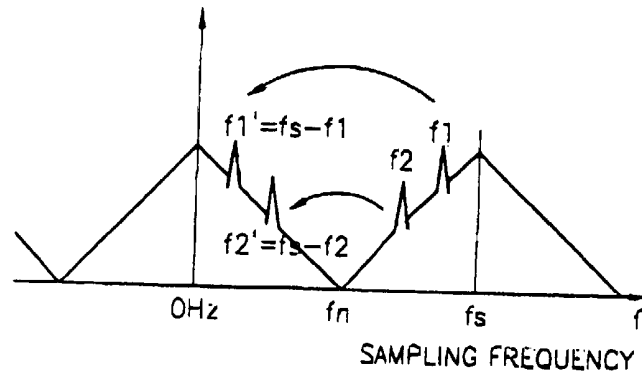
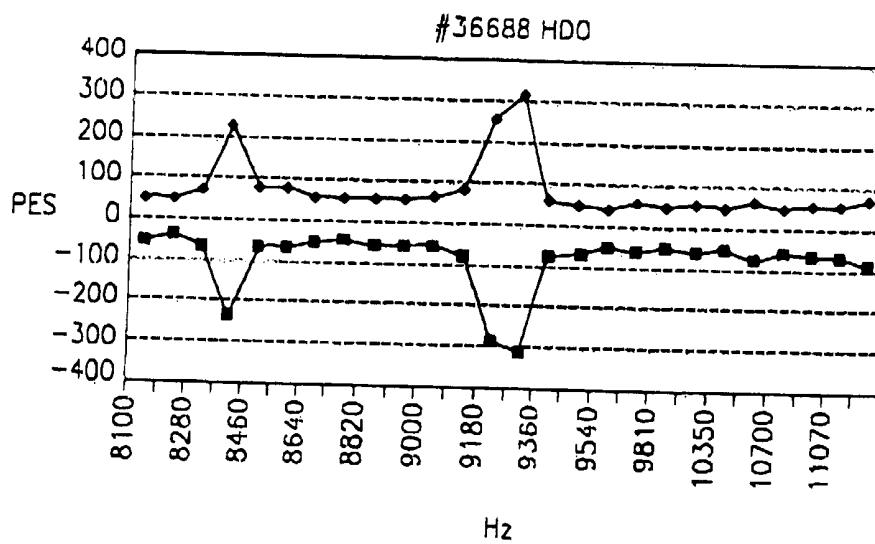


FIG. 8



APPARATUS AND METHOD OF REMOVING RESONANCE
FREQUENCY IN SYSTEM

The present invention relates to an apparatus and a
5 method for removing resonance frequency of a system, and
more particularly, to an apparatus and a method for
removing resonance frequency of a system in which
unnecessary resonance frequency occurring in a head stack
assembly (HSA) having a head for reading/writing data is
10 identified and filtered to prevent mechanical damage
caused by resonance.

In general, a hard disk drive (HDD) which is a data
storage system is composed of a head disk assembly (HDA)
15 consisting of instrumental parts and an electric circuit.
Harmful resonance generated from a head stack assembly
(HSA) constituting the HDA directly appears in a position
error signal (PES), which deteriorates the stability of a
servo tracking control of a hard disk drive.

20

To address this problem, a conventional method
analyses a resonance frequency, which has a bad effect on
the hard disk drive, from a frequency of the PES of the
HSA and filters or screen the resonance frequency to
25 remove the resonance frequency. Filters used for removing
the analyzed resonance frequency were designed based on
resonance frequency components, which are identified in
PES of a predetermined number of HDDs, in an early
development stage and applied to the HDDs.

30

However, resonance frequency is changed by
characteristics of parts constituting the HSA and
characteristics of assembling of the parts. The change in

resonance frequency between HSAs having such different characteristics cannot be solved by fixed filter coefficients which are applied to the HDDs.

5 A method of removing resonance frequency of HSAs using an adaptive filter has been developed to solve this problem. This method comprises identifying a resonance frequency in a frequency domain after a PES undergoes a frequency transformation process such as discrete fourier
10 transformation (DFT), fast fourier transformation (FFT), wavelet transformation, and the like, and filtering the resonance frequency using a programmable filter.

 In other words, as shown in Figure 1, a known
15 apparatus for removing resonance frequency of a HDD according to the improved prior art includes a HDA 101, a read/write (R/W) channel processor 102, a controller 103, a resonance frequency identifier 104, a programmable filter 105, and a voice coil motor (VCM) driver 106.
20 Here, the R/W channel processor 102 includes a pre-amplifier.

 The R/W channel processor 102 amplifies signals read from a transducer of a HSA constituting the HDA 101.
25 Burst signals corresponding to servo information are separated from the amplified signals and are subject to a servo control algorithm to generate a PES.

 The controller 103 applies a control signal CT for
30 analyzing resonance frequency to the resonance frequency identifier 104 if a command for carrying out a process of identifying resonance frequency of the HSA of the whole process of manufacturing the HDD is input. Also, the

controller 103 generates a control output signal UK for driving a VCM based on a speed error signal and a acceleration error signal which are analyzed by the PES and the servo control algorithm.

5

The resonance frequency identifier 104 performs frequency transformation to the PES and identifies resonance frequency fr in a frequency domain if the resonance frequency identifier 104 receives the control
10 signal CT.

The programmable filter 105 resets coefficients thereof, filters the control output signal UK, outputs the filtered control output signal UK to the VCM driver 106,
15 and drives the VCM in order to remove the identified resonance frequency fr .

However, the resonance frequency identifier 104 limits frequency bandwidth which can be identified from the PES
20 due to a servo sampling ratio of a HDD.

In other words, a frequency identified by a process of frequency transformation to the PES is limited within a Nyquist frequency that is half of a servo sampling
25 frequency. If an aliasing phenomenon occurs due to a sampling effect and resonance frequency components $fr1$ and $fr2$ within a range of a Nyquist frequency and a sampling frequency, then the resonance frequency components $fr1$ and $fr2$ are identified as resonant frequencies $fr1'$ and $fr2'$
30 which exist within a Nyquist frequency fn , due to a mirroring phenomenon as shown in Figure 7. The programmable filter 105 cannot accurately remove resonance occurring in the HSA if coefficients of the programmable

filter 105 are set so as to correspond to the misidentified resonant frequencies $fr1'$ and $fr2'$.

To address the above-described problems, it is an aim
5 of the present invention to provide a method and apparatus
for accurately identifying resonance frequency beyond a
Nyquist frequency bandwidth, in a time domain. Another
aim is to provide a method and apparatus for removing a
resonance frequency.

10

According to a first aspect of the present invention
there is provided an apparatus for removing resonance
frequency of a system. The apparatus includes a frequency
generator, a resonance detector, and a programmable
15 filter. The frequency generator generates an excitation
signal for exciting the system and applies the excitation
signal to the system. The resonance detector detects
resonance frequency from a signal responding to the
excitation signal in the system. The programmable filter
20 removes the resonance frequency detected in the resonance
detector.

Preferably, the excitation signal generated in the
frequency generator has frequency components up to a servo
25 sampling frequency bandwidth of the system.

Preferably, the frequency generator generates an
excitation signal having a servo sampling cycle of the
system and an excitation signal having half of the servo
30 sampling cycle using a multi-rate method.

Preferably, the frequency generator increases
frequency of the excitation signal at predetermined

intervals from a bandwidth within Nyquist frequency to a sampling frequency bandwidth.

Preferably, the signal responding to the excitation
5 signal in the system is a position error signal of a hard disk drive.

Preferably, the resonance detector determines a frequency of the excitation signal at a time when a
10 magnitude of the signal responding in the system exceeds a critical value in a time domain without a frequency transformation as a resonance frequency.

According to a second aspect of the present invention
15 there is provided a method of removing resonance frequency of a system. An excitation signal for exciting the system is generated. The excitation signal is applied to the system. Resonance frequency is detected from a signal responding to the excitation signal in the system. Then,
20 the resonance frequency is removed.

Preferably, removal of the resonance frequency is performed by a programmable filter which is adapted to remove the detected resonance frequency.
25

For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:
30

Figure 1 is a configuration diagram of an apparatus for removing resonance frequency of a HDD according to the prior art;

Figure 2 is a plan view of a HDD according to the present invention;

5 Figure 3 is a circuit diagram of an electric system for controlling a HDD;

Figure 4 is a configuration diagram of an apparatus for removing resonance frequency of a system according to
10 a preferred embodiment of the present invention;

Figure 5 is a flowchart of a method of removing resonance frequency of a system according to a preferred
15 embodiment of the present invention;

Figure 6 is a waveform diagram of a PES depending on whether or not resonance occurs;

Figure 7 is a graph explaining a mirroring effect; and
20

Figure 8 is a graph showing changes in a PES according to changes in excitation frequency.

Figure 2 is a plan view of a hard disk drive 10, including at least one magnetic disk 12 which is rotated by a spindle motor 14, and a transducer (not shown) which is located adjacent to a disk surface 18. The transducer can sense and magnetize a magnetic field to read or record data in the rotating magnetic disk 12. This transducer
25 is described as a single transducer, but it is understood that the transducer comprises a writing transducer for magnetizing the magnetic disk 12 and a reading transducer which is separated from the writing transducer, for
30

sensing the magnetic field of the magnetic disk 12. The reading transducer is constituted from a magneto-resistive (MR) device.

5 The transducer may be integrated into a head 20. The head 20 generates an air bearing between the transducer and the disk surface 18. The head 20 is combined into a head stack assembly (HSA) 22. The HSA 22 is attached to an actuator arm 24 having a voice coil 26. The voice coil
10 26 is adjacent to a magnetic assembly 28 including a voice coil motor (VCM) 30. Current supplied to the voice coil 26 generates torque which rotates the actuator arm 24 with respect to a bearing assembly 32. The rotation of the actuator arm 24 moves the transducer across the disk
15 surface 18.

Information is generally stored in annular tracks of the magnetic disk 12. As shown in Figure 2, each track 34 generally includes a plurality of sectors. Each sector
20 includes data fields and identification fields. The identification field includes a gray code for identifying a sector and a track (cylinder). The transducer moves across the disk surface 18 to read or write information on each track.

25

Figure 3 shows an electric system 40 which is capable of controlling the hard disk drive 10. The electric system 40 includes a system controller 42 which is connected to a head 20 via a read/write (R/W) channel
30 circuit 44 and a pre-amplifier circuit 46. The system controller 42 may be a digital signal processor (DSP), a microprocessor, a microcontroller, and the like. The system controller 42 supplies a control signal to the R/W

channel circuit 44 to read information from the disk 12 or write information on the disk 12. Information is generally transmitted from the R/W channel circuit 44 to a host interface circuit 47. The host interface circuit 47
5 includes a buffer memory and a control circuit which permits a disk drive to interface with a system such as a personal computer.

The system controller 42 is connected to a voice coil
10 motor (VCM) driver 48 which supplies driving current to the voice coil 26. The system controller 42 supplies a control signal to the VCM driver 48 to control the excitation of the VCM driver 48 and the motion of the transducer.

15

The system controller 42 is connected to nonvolatile memory such as a read only memory (ROM) or flash memory device 50, and a random access memory (RAM) device 52. The memory devices 50 and 52 include commands and data
20 used by the system controller 42 to execute a software routine. The software routine includes a seek routine which moves the transducer from one track to another track. The seek routine includes a servo control routine for determining accurate movement of the transducer to a
25 desired track. For example, the memory device 50 includes acceleration, velocity, and position trajectory equations.

Figure 4 is a schematic diagram of apparatus for removing resonance frequency of a system of components of
30 a HDD, according to a preferred embodiment of the present invention. As shown in Figure 4, the apparatus includes a head disk assembly (HDA) 401, a read/write (R/W) channel processor 402, a controller 403, a frequency generator

404, a resonance detector 405, a programmable filter 406, a mixer 407, and a VCM driver 408.

Here, the R/W channel processor 402 represents the R/W
5 channel circuit 44 having the pre-amplifier 46 shown in Figure 3, and the controller 403 and the programmable filter 406 represent circuits included in the system controller 42 shown in Figure 4.

10 The R/W channel processor 402 amplifies signals read from a transducer of a head stack assembly (HSA) constituting the HDA 401. Burst signals corresponding to servo information are separated from the amplified signals and are subject to a servo control algorithm to generate a
15 position error signal (PES).

The controller 403 generates a control signal CT output to the frequency generator 404 if a resonance frequency identification mode is set by receiving an input
20 command. Also, the controller 403 generates a control output signal UK for driving the VCM based on a speed error signal and an acceleration error signal which are analysed by the PES and the servo control algorithm.

25 The frequency generator 404 generates an excitation signal which has frequency components up to a sampling frequency of the system, for exciting the system artificially. The excitation signal may use any one of a sine wave, a cosine wave, or a combination of the sine
30 wave and the cosine wave. The strength of the excitation signal is set to a strength sufficient for causing resonance when exciting the system. Also, the strength of the excitation signal is determined within a range

sufficient for performing servo seeking and following operations and normally obtaining the PES from a signal output from the system.

5 Signal sampling two times or more the number of servo sampling is necessary for generating a signal having frequency components up to the sampling frequency bandwidth when the frequency generator 404 generates the excitation signal. In the present invention, the signal
10 is generated by a multi-rate method. The multi-rate method is a signal generation method by which a signal for driving an actuator is mixed with a signal synchronized by a servo sampling cycle and a signal output as half of the servo sampling cycle, and output.

15 In other words, the frequency generator 404 may generate a Nyquist frequency as the maximum excitation frequency if the excitation signal is input to the system every servo sampling cycle T . The excitation signal may
20 be generated up to the sampling frequency bandwidth if the excitation signal is input to the system for half ($T/2$) of the servo sampling cycle using the multi-rate method. The frequency generator 404 increases the frequency of the excitation signal at specified intervals within possible
25 limits for generating resonance.

 The excitation signal generated in the frequency generator 404 is input to the mixer 407 and mixed with the control signal UK output from the controller 403 via the
30 programmable filter 406. The mixed signal is applied to the VCM driver 408 and a driving current of the VCM which is transformed into a current signal in the VCM driver 408 is applied to the VCM of the HDA 401. As a result, the

actuator is driven by the driving current applied to the VCM and vibrated by the frequency generated in the frequency generator 404.

5 The PES has a magnitude three times more than a normal PES if resonance occurs and increases in proportion to the strength of the excitation signal which serves as an excitation source.

10 As a result, the excitation signal applied to the HDA 401 is reflected in the PES and output. The PES sharply increases in the form as shown in Figure 6 if the excitation signal generates resonance.

15 The resonance detector 405 determines whether or not resonance occurs in the HDA 401 due to the excitation signal, using the magnitude of the PES. In other words, the magnitude of the PES becomes 482 mV (94.1% of track pitch) at its maximum as shown in Figure 6 if resonance
20 occurs and otherwise, becomes 31 mV (6% of track pitch) at its maximum. As a result, it is seen that the magnitude of the PES varies depending on whether or not resonance occurs. Thus, the resonance detector 405 determines that resonance occurs if the magnitude of the PES is over a
25 reference value for detecting resonance. Here, the resonance detector 405 senses the frequency f_r of the excitation signal generated in the frequency generator 404 as resonance frequency of the HSA to output the resonance frequency of the HSA to the programmable filter 406. The
30 reference value for determining the resonance frequency in the resonance detector 405 may be determined by an experiment.

Figure 8 shows the magnitude of a PES based on changes in frequency of an excitation signal, where resonance occurs at frequencies of 8.3 and 9.3 KHz.

5 The programmable filter 406 updates coefficients thereof which are set as default values as coefficients for removing detected resonance frequency fr. The programmable filter 406 designs bandwidth, which can be filtered, beyond a resolving power of the frequency
10 generator 404 in consideration of a gain margin and a phase margin of the system.

A method of removing resonance frequency of a system according to the present invention will now be described
15 in detail with reference to Figure 5.

The controller 403 determines whether or not a command for setting a resonance frequency identification mode of the HSA is input via the host interface in step 501. The
20 resonance frequency identification mode is generally set in a process of manufacturing a HDD, but a user can directly set the resonance frequency identification mode if necessary.

25 The controller 403 controls generation of an excitation signal for carrying out the resonance frequency identification mode if the controller 403 receives the command for setting the resonance frequency identification mode. Here, the excitation signal is generated by a
30 multi-rate method by which a signal for driving an actuator is mixed with a signal synchronized by a servo sampling cycle and a signal output as half of the servo sampling cycle, and then output. In other words, the

maximum frequency of an excitation signal generated every servo sampling cycle T is a Nyquist frequency. The maximum frequency of an excitation signal generated every half of the servo sampling cycle $T/2$ includes a sampling frequency bandwidth. Also, the generated excitation signal increases frequency at specified intervals within possible limits for generating resonance in step 502.

The excitation signal generated by the multi-rate method is applied to the HDA 401 in step 503. A method of mixing VCM driving current with the excitation signal is an example of the method of applying the excitation signal to the HDA 401.

The HSA constituting the HDA 401 is driven by the current applied to the VCM and vibrated by frequency generated in the frequency generator 404.

A signal responding to the excitation signal is detected from the HDA. A PES is used as the response signal. Thus, the resonance detector 405 determines whether or not resonance occurs due to the excitation signal using the PES and detects frequency of the excitation signal at a point of time when resonance occurs as a resonance frequency in step 504.

The coefficients of the programmable filter 406 of the HDD are updated to filter the detected resonance frequency in step 505.

As described above, according to the present invention, a system is artificially excited to identify potential resonance frequency of the system. Then, the

system is adapted so that the identified resonance frequency is filtered. Thus, resonance frequency components over a Nyquist frequency bandwidth of the system can also be identified. Also, resonance frequency
5 can very easily be identified in a time domain without a complicated calculation process such as an additional frequency transformation process. Coefficients of a programmable filter are updated using the identified resonance frequency to prevent mechanical damage caused by
10 resonance and improve a servo tracking performance and reliability of data.

The present invention can be executed as a method, an apparatus, or a system and the like. In one embodiment,
15 the elements of the present invention are code segments which execute necessary tasks if the present invention is executed as software. Programs or code segments may be stored in a processor-readable medium or may be transmitted by a computer data signal combined with a
20 carrier wave over a transmission medium or communication network. The processor readable medium may include any medium which is capable of storing or transmitting information. The processor readable medium includes an electronic circuit, a semiconductor memory device, a ROM,
25 a flash memory, an erasable ROM (EROM), a floppy disk, an optical disk, a hard disk, an optical fiber medium, a radio frequency (RF) net, and the like. The computer data signal includes any signal which may be transmitted over a transmission medium such as an electronic network channel,
30 an optical fiber, air, electromagnetic field, a RF network, and the like.

Specific embodiments described with reference to the attached drawings should be understood only as examples of the present invention and should not be interpreted as limiting the scope of the present invention. The present invention can be modified into various other forms in the art without departing from the scope of the invention as defined by the appended claims. Therefore, it is apparent that the present invention is not limited to the example specific structure and arrangement shown and described above.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any
5 accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. An apparatus for removing resonance frequency of a system, the apparatus comprising:

5

a frequency generator for generating an excitation signal for exciting the system and applying the excitation signal to the system;

10

a resonance detector for detecting resonance frequency from a signal responding to the excitation signal in the system; and

a programmable filter for removing the resonance
15 frequency detected in the resonance detector.

2. The apparatus of claim 1, wherein the excitation signal generated in the frequency generator has frequency components up to a servo sampling frequency bandwidth of
20 the system.

3. The apparatus of claim 1 or 2, wherein the frequency generator generates an excitation signal having a servo sampling cycle of the system and an excitation
25 signal having half of the servo sampling cycle using a multi-rate method.

4. The apparatus of claim 1, 2 or 3 wherein the frequency generator increases frequency of the excitation
30 signal at predetermined intervals from a bandwidth within Nyquist frequency to a sampling frequency bandwidth.

5. The apparatus of claim 1, 2, 3 or 4 wherein the signal responding to the excitation signal in the system is a position error signal of a hard disk drive.

5 6. The apparatus of claim 1, 2, 3, 4 or 5, wherein the resonance detector determines a frequency of the excitation signal at a time when a magnitude of the signal responding in the system exceeds a critical value in a time domain without a frequency transformation as a
10 resonance frequency.

7. A method of removing resonance frequency of a system, the method comprising:

15 (a) generating an excitation signal for exciting the system;

(b) applying the excitation signal to the system;

20 (c) detecting a resonance frequency from a signal responding to the excitation signal in the system; and

(d) removing the resonance frequency detected in step (c).

25

8. The method of claim 7, wherein step (d) is performed by a programmable filter which is designed to remove the detected resonance frequency.

30 9. The method of claim 7 or 8, wherein the excitation signal has frequency components up to a servo sampling frequency bandwidth of the system.

10. The method of claim 7, 8 or 9, wherein the excitation signal is generated by a multi-rate method by which an excitation signal having a servo sampling cycle and an excitation signal having half of the servo sampling
5 cycle are generated.

11. The method of any of claims 7 to 10, wherein the response signal of the system is a position error signal of a hard disk drive.

10

12. The method of any of claims 7 to 11, wherein in step (c), a frequency of the excitation signal at a time when a magnitude of the response signal of the system exceeds a critical value in a time domain without a
15 frequency transformation is determined as a resonance frequency.

13. The method of any of claims 7 to 12, wherein the excitation signal is a signal, whose frequency increases
20 at predetermined intervals from a bandwidth within Nyquist frequency of the system to a sampling frequency bandwidth.

14. An apparatus for removing resonance frequency of a system, substantially as hereinbefore described with
25 reference to Figure 4 of the accompanying drawings.

15. A method for removing resonance frequency of a system, substantially as hereinbefore described with reference to Figure 5 of the accompanying drawings.

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Application No: GB 0212120.0
Claims searched: 1 to 15

Examiner: A J Oldershaw
Date of search: 27 February 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1,7 at least	US 6219196 B1 (IBM)
X	"	US 5369345 (SEAGATE)
X	"	JP 050313751 (FUJITSU)
X	"	JP 050109217 (FUJITSU)

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The following online and other databases have been used in the preparation of this search report :

Online: WPI, EPODOC, JAPIO